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Administration

# Strengthening Operational Agrometeorological Services at the National Level

Proceedings of the Inter-Regional Workshop  
March 22-26, 2004, Manila, Philippines



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### ***Editors***

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## **Foreword**

The agricultural sector is weather dependent and variations in weather/climate as well as their interaction with agricultural operations, from planting to harvesting, determine a significant portion of the yield variations. The growing interest in the possible impact of natural- and human-induced climate variability and long-term climate change on agriculture and forestry have created new demands for information and assessments from agrometeorologists. Also, the increasing demands for food and concerns with the need for achieving greater efficiency in natural resource use while protecting the environment require that much greater emphasis be placed on understanding and exploiting climatic resources for the benefit of agriculture and forestry. Hence, there is now a growing recognition of the importance of operational agrometeorological services for the agricultural, livestock, forestry, and fishery sectors. The series includes:

- Services to help reduce the impact of natural disasters, including pests and diseases;
- Early warning and monitoring systems;
- Short- and medium-range weather forecasts;
- Climate prediction/forecasting; and,
- Services to help reduce the contributions of agricultural production to global warming.

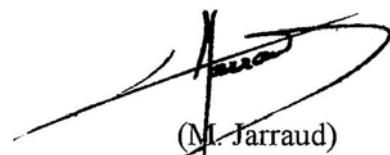
Several of these needs are echoed in documents such as Agenda 21, the World Food Summit Plan of Action, and the United Nations Convention to Combat Desertification (UNCCD). While data are the fundamental building blocks necessary to establish a sound foundation for the provision of operational agrometeorological services, it is the informational products that are the framework for any knowledge-based decision process. The ability to integrate the information from interdisciplinary sources utilizing new computer-based technologies and telecommunications creates a great opportunity to enhance the role of agrometeorologists in many decision-making processes. Information may be in the form of advisories to farmers regarding planting or decisions on spraying. Information may be used in crop management systems that extension services provide to the agricultural community. It may also be incorporated into early warning alerts related to food security or market implications.

Agrometeorological information plays a valuable part not only in making daily and seasonal farm management decisions but also in risk management and early warning systems. Weather and climate information can be used with new technological tools and database infrastructures to assess risk and to quantify probabilities associated with weather and climate variability. The implications are enormous not only for agricultural extension services, which are providing the linkage between new research results and operational applications, but also for policy-level decision makers who are responsible for food security and marketing decisions for agricultural products. Such early-warning information allows improved long-term planning opportunities that will benefit agriculture.

The Thirteenth Session of the Commission for Agricultural Meteorology (CAgM-XIII) of the World Meteorological Organization, held in October 2002 in Slovenia, considered the need to improve agrometeorological services to increase agricultural production and to conserve the environment. They identified this aspect as one of three priority areas to be addressed during the 2004-2007 period. CAgM-XIII recommended that an Inter-Regional Workshop on Strengthening Operational Agrometeorological Services at the National Level be organized.

Accordingly, the World Meteorological Organization (WMO), the United States Department of Agriculture (USDA), and the Food and Agriculture Organization (FAO) organized this Inter-Regional Workshop from March 22-26, 2004, in Manila, Philippines, at the kind invitation of the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). Twenty-eight participants from 19 countries, including the Philippines, attended the Workshop.

I am pleased to note that 21 invited papers from different regions were presented at the Workshop dealing with various aspects on strengthening operational agrometeorological services. I hope that these papers as well as the recommendations for strengthening operational agrometeorological services developed during the discussions at the Workshop and presented in this volume will serve as a very valuable source of information for all the National Meteorological and Hydrological Services (NMHSs) and other agencies involved in the provision of operational agrometeorological services at the national level.



(M. Jarraud)  
Secretary-General  
World Meteorological Organization

## **Executive Summary**

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World Agricultural Outlook Board, Office of the Chief Economist  
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Washington, D.C.

The World Meteorological Organization (WMO), the Food and Agriculture Organization (FAO), and the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) sponsored an Inter-Regional Workshop on Strengthening Operational Agrometeorological Services in Manila, Philippines, on March 22-26, 2004. The workshop objectives were: to evaluate how the National Meteorological and Hydrological Services (NMHSs) provide operational agrometeorological services to the various user communities at the national levels; to identify shortcomings and limitations in data, analytical tools, and the methods of provision of operational agrometeorological services; to assess how the organizational structures of the National Services and their links with other government agencies can be adopted in the most cost-effective manner to serve the needs of the customers; to review methods and tools to improve operational agrometeorological services and their delivery to decision makers at all levels in a timely fashion; and, to formulate an effective strategy to build the capacity of the NMHSs in the different WMO regions and strengthen their operational agrometeorological services.

The workshop program consisted of 21 papers. The first two papers focus on operational agrometeorological services from the national perspective. The Philippines is an agricultural country where dramatic increases or decreases in agricultural output have been, in most cases, associated with occurrence of severe weather events and changes in the climate system. Typhoons with its associated strong winds and rains and the global phenomenon, called El Niño, have contributed significantly to the large annual variability of the country's agricultural production. A system for assessing the danger of vegetation fires in Cuban regions is described in the second paper. The early warnings alert is a result of the agrometeorological conditions system that influences the content of soil humidity, living vegetation, and dead biomass. The early alert system was designed to operate at different temporal scales at the national and provincial levels. This system has allowed the country to strengthen preventive activity and to achieve operative efficiency during the high-danger forest fire occurrence in Cuba.

The following seven papers present perspectives from each of the six Regional Associations plus one additional example that focused on an emergency situation from Afghanistan. In RA-I, a questionnaire was prepared. The questionnaire was sent via fax and e-mail to 51 countries and centers. Fifteen countries responded. In RA-I, the flow of information is limited and methodologies have room for improvement. Technology is in high demand, and the density of the observational network is low in many countries. Some countries have only one or two agrometeorological stations, limiting agrometeorological activities. Agrometeorological units are also hampered by lack of trained personnel and limited budgets. Certainly, efforts are needed to assist these countries. The flow of data to users continues to be a high requirement.

Users, especially the farming community, usually request information on the onset of effective rains (to know when to plant) and length of the cropping season (to decide what to plant). They

also request information on the behavior of the dry and wet spells within the cropping season and want to know how likely it is that an extreme event will occur. Governments and farmers are both greatly interested in knowing how much grain yields and crop production are expected by the end of the rain/crop season. This knowledge helps strategic planning. Genuine efforts are, therefore, needed to improve agrometeorological services and make their products accessible to users.

From Regional Association II, a number of recommendations were made to strengthen operational agrometeorological services in the region. These include: developing agrometeorological forecasting centers; developing forest meteorology, predicting yield/biomass before planting; studying sand movement or desertification elements; measuring evapotranspiration; establishing the domestic infrastructure of a flux measurement network; developing agrometeorological models for crop growth; developing and evaluating agrometeorological environments using the agrometeorological advice model AMBER; integrating agrometeorological information services; collaborating with the World Agrometeorological Information System (WAMIS); cooperating with the International Society of Agricultural Meteorology (INSAM); strengthening agrometeorology networks including station density, fine equipment, and capacity building; providing more detailed agrometeorology information; and, developing the infrastructure of the information network to transfer agrometeorological information to farmers more easily and faster.

Regarding an agrometeorological service required under emergency situations, a paper was presented describing the Afghanistan example. In this paper, all the requirements were presented for a fully operational agrometeorological service installed in Afghanistan. This ranged from the installation of stations to data transmission, including personal experience to help educate users with archiving, data control, treatments, results, and products issued. Capacity-building through intensive, on-the-job training and courses was also given in Kabul. The use of very sophisticated agrometeorological tools was taught by the staff of the agrometeorological services. Database and information systems and the need for statistical analyses were reviewed. All of these tools are necessary to respond to any question emanating from decision makers in the country and/or Food and Agriculture Organization-Famine Early Warning System Information Network (FEWS-NET), Ministry of Rural Rehabilitation and Development (MRRD), World Food Program (WFP), Irrigation Department, and food security, in general. All of these tools, equipment, and means are presently being used in Afghanistan.

From Regional Association III, in most of the national meteorological services, the agrometeorological activity is at a disadvantage with respect to other areas of national meteorology. These disadvantages are directly related to the budget, training, and prioritization in the development of their corresponding services. Most of the services issue bulletins, agrometeorological warnings, and agrometeorological and weather forecasts; carry out agrometeorological studies and research; and some of them study the impacts caused by extreme weather events. Seventy percent of the services acknowledge that they have limitations and deficiencies in obtaining data and analytical tools. Eighty-percent of the services estimate that they have deficiencies and limitations in delivering agrometeorological services. Some major recommendations of Regional Association III include: improving spatial resolution and adapting global models; investing in the dissemination of meteorological tools applied to agriculture for the small and medium farmer; carrying out strategic associations with institutions to increase the agrometeorological stations networks, maintaining the existing ones, and developing competitive agrometeorological products; implementing a regional training program for climate modeling,

geographical information systems, and handling of agrometeorological data base and analytical tools; standardizing products, services, methods, and regional climatic and agroclimatic procedures; conducting a program of regional exchange of methodologies and knowledge of the professionals of the different services, by means of seminars, workshops, or hands-on training; and carrying out studies on climate variability and climate change and its impact on agriculture at a regional level.

The questionnaire was sent by Regional Association IV for a survey of operational agrometeorological services in the region, including recommendations for regional improvement. The summary of results included: introduce or improve agrometeorological monitoring services and early warnings and alerts to help reduce the agricultural impact of extreme events; improve observation networks and agrometeorological services technical staff and the extension-related agricultural sector; improve computer tools used to analyze agrometeorological data, meteorological, hydrological, and agricultural drought, and potential forest fire danger; use agrometeorological models to evaluate existing and expected conditions on different agricultural sectors; create capacity and apply operational Geographic Information System (GIS) technology; use high-resolution satellite images [vegetal cover, Normalized Difference Vegetation Index (NDVI), soil humidity, etc.] in the operational agrometeorological services; create capacity in the agricultural meteorology specialty, either National Meteorology and Hydrology Services (NMHS) or agrometeorological information users, identify funding sources and promote financial support to national agrometeorological services with users who guarantee to keep the agrometeorological services; and, create a National Technical Committee that promotes agrometeorological applications that meet the needs of the agricultural sector and coordinates this work among institutions and disciplines.

A questionnaire containing nine questions was circulated in the Regional Association V. Responses were received from four countries: Fiji, Indonesia, Malaysia, and Philippines. Based on the responses, it was revealed that Fiji has no independent agrometeorological services unit, while in Indonesia such a unit was developed in 2003. The main customers of the NMHS in the four countries are government agencies, in particular the Ministry of Agriculture. In Fiji and the Philippines, the industrial companies are also the customers. The services, which are provided in the form of bulletins, assist in conducting strategic studies, provide early warnings, and help with impact assessments. The main constraints for strengthening the operational agrometeorological services in the four countries are lack of human resources, analytical tools such as simulation modeling, and data. Therefore, recommendations given by the countries for strengthening the operational agrometeorological services include training activities on the use of remote sensing technology and simulation modeling for yield monitoring, forecasting, improvement of climate observation networks, and dissemination systems. The use of agriculture simulation modeling for operational agrometeorological services in developed countries such as Australia has already been adopted. In developing countries, such an approach is still in the research stage. There is a need to influence policy makers into making decisions and farmers into deciding crop management strategies. The problems include finding effective ways to disseminate or to communicate such knowledge and information to policy makers and farmers and helping local staff in the use of such an approach.

Regional Association VI consists of 49 countries from a broad region. A questionnaire was circulated to the members. In evaluating the submitted responses, it was very difficult to find any common lesson. It was concluded that the application of agrometeorological information, advice, and support issued by the meteorological community for the agricultural, horticultural,

forestry, and fishery users depends on the traditions and economic environment. The biggest problem for the agrometeorological community is the lack of feedback from the real users because there is an information gap between the producers and users. The general opinion was that the improvement of operational agrometeorological services requires better technology and business policy. To organize/reorganize or simply improve the agrometeorological service, two basic positions are held. First, the users of a service could be various groups with different needs, so there should be the opportunity to prepare various kinds of services. (In this case, it is more appropriate to talk about agrometeorological information systems). Secondly, the service evokes the idea of a printed document in a traditional approach, but we see that in many cases, it is necessary to use other means such as radio broadcasting or television to reach the targeted group. The best solutions seem to be the Internet or direct information transmission such as fax or short message service (sms). In the first position, passive information transmission refers to the absence of influence on the part of the user. In the second position, active information transmission means transferring the information to the user's contact point, and then the user choosing the information for their daily working practice.

In the next section, three papers focus on international perspectives of operational agrometeorological services. The first paper reviews the requirements for agrometeorological services that go well beyond the basic inherent needs of sustaining agricultural productivity. Agrometeorology is a complex multidisciplinary science, and, the services provided by the operational agrometeorologists are growing rapidly.

The current status of agricultural production and increasing concerns with related environmental issues call for improved agrometeorological services for enhancing and sustaining agricultural productivity around the world. The requirements for agrometeorological services were described in the light of emerging issues related to environment, climate change, biodiversity, drought and desertification, food security, and sustainable development. Agenda 21, International Conventions, including the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification (UNCCD), the World Food Summit Plan of Action, and the World Summit on Sustainable Development, have implications for strengthening operational agrometeorological services, which have been highlighted in this paper. Hydrometeorological disasters around the world have been increasing in the recent past and operational agrometeorological services could help the farming community with better preparedness and mitigation strategies. Perspectives from remote sensing and GIS for improved agrometeorological services were described. The WAMIS initiated by WMO could help strengthen operational agrometeorological services around the world.

The next paper presents the activities of the FAO in the field of the “food security information and early warning systems” (FSIEWS) with particular reference to their agrometeorological component. Starting in 1978, FAO has provided technical assistance with multilateral and bilateral financing to more than 50 projects for the establishment of regional and national FSIEWS around the world, to monitor all aspects of food availability, stability of supply, accessibility, and biological utilization. Focusing on the present and future availability of food, the agrometeorological component looks mainly at crop monitoring and yield forecasting, embracing an activity usually carried out by Agricultural Extension Services and National Agrometeorological Services.

The second part of the paper concentrates on FAO's approach in the development of methods and tools (e.g., software, databases, training, publications, and advisory services to farmers) for the agrometeorological user community of FSIEWS. Agrometeorology is an important component of the FSIEWS that monitors the availability of food by evaluating the impact of weather and climate on crop development. The main activities of the FAO Agrometeorology Unit include the development of tools and methods for crop monitoring and yield forecasting, starting with the rehabilitation and/or strengthening of the agrometeorological networks, and all aspects linked to the data transmission, collection, archiving, analysis, and dissemination. The basic philosophy is a total synergy with national and regional institutions and the development of integrated toolboxes, such as AgroMetShell, involving agrometeorology, remote sensing, and GIS tools for data collection, spatialization, and analysis.

The third paper in this section discusses the European Commission Joint Research Centre Monitoring Agriculture with Remote Sensing (MARS) project. The MARS project started in the Joint Research Centre with the main objective to provide to the European Commission decision makers, mainly in the Directorates General Agriculture and Eurostat, early, independent, and objective estimates of the main crop production in Europe (MARS-STAT). Technical support was also provided to the Common Agricultural Policy in several fields including the control of EU subsidies by remote sensing and the establishment of national land parcel identification systems (LPIS). This part of the activities is called MARS-PAC. More recently in 2001, a new activity of support to the European policy for Food Security and Food Aid was initiated (MARS-FOOD). Finally, in 2004, the spectrum of the activities was enlarged to the European fisheries policy and the unit name changed from MARS to AGRIFISH. The paper concentrated on MARS-STAT and MARS-FOOD activities. MARS-STAT is an operational crop yield forecasting and crop acreage estimation for European main field crops. MARS-FOOD main focus is to develop and operate improved methods for crop forecasting in regions outside of Europe, in particular in regions stricken by recurring food shortages.

The next section deals with a critical review of significant shortcomings and limitations in data, analytical tools, and the dissemination of agrometeorological information. In the first paper in this section, a lengthy review of the problems was presented, and recommendations were made for improvements. Some of the major recommendations include: data sets must have a minimum metadata base, standard format, standard quality control procedures and adequate continuity of records; personnel must be trained to recognize inconsistencies of data and establish appropriate patch-point methods to maintain continuity; software must be compatible with both temporal and spatial data sets to allow for the integration of point source data with geo-referenced digital data sets, modeling technology, and remotely sensed data; new technology in telecommunications should be used to bridge the gap between automated data collection systems and web-based information systems; GIS metadata are required for appropriate coordinate systems, projections, etc.; guidelines are needed to report national crop yields including sub-national trends and geo-spatial time trends; an industry, international standard for agroclimatic data, particularly crop data, should be developed; more telecommunication research that develops new applications using web-based technologies and automated observations should be supported; current measures of standardization are considered mature for meteorological data, poor for crop data, and emerging for soils data; and, spatial interpolation methods for specific applications should be recommended.

The second paper in this section notes the shortcomings with analytical tools and methods of operational agrometeorological services. Improvements in communication technology and in the

understanding of the physical components of the plant/earth/atmosphere interface have combined to increase the quality, sophistication, and potential utility of agrometeorological services provided to the agricultural industry. Regardless, many problems and shortcomings in analytical techniques and in the way in which the products are provided remain. These include long-term issues, such as the spatial analysis of agrometeorological variables and concerns about the economic challenges facing many elements of the agricultural industry worldwide. Recent advances in the development of spatial analytical techniques such as GIS offer some solutions to these difficulties. To become more effective, agrometeorologists need to demonstrate the utility of their products, including potential economic benefits. Finally, in order to provide the best quality agrometeorological information in the future, greater collaboration is needed between the major information participants and the information provision system: farmers, agricultural meteorologists, and agricultural extension services.

The final paper in this section deals with the extremely important topic of dissemination of agrometeorological information. Much climate data are available that can only be utilized if there is a flow of information to agri-business and farmers. As dissemination is the distribution of information, two-way communication channels are a necessity. The content of the message must be relevant to the decisions of the client. The process should involve the identification of climate sensitive decisions, interactions between the climatologists and the role players to develop technological products that should be evaluated prior to introduction at an operational level. Dissemination of agrometeorological information is illustrated with examples from the Florida Consortium, FARMSACPES in Australia, seasonal forecasts in Burkina Faso, and irrigation scheduling in Mexico. Critical factors for successful dissemination include good communication channels preferably based on a relationship between the agrometeorologists and the role players in the agricultural industry, and the collaborative development of products that can bridge the gaps and be relevant to climate-sensitive decision making in agriculture. The way forward is to form good relationships so that new agrometeorological applications can be developed as a cooperative and collaborative learning process to bridge the identified gaps in the knowledge chain and thus enable meteorological science to contribute to the economic benefit of the agricultural industry.

The last section presents six papers that discuss needs and linkages between agrometeorological services and the agricultural sector. The first paper discussed a global overview of the agricultural demand point of view. Agriculture, which provides our basic needs and is one of the biggest employers, is one of the most weather dependent sectors. A crucial role of the National Meteorological Service (NMS) is timely provision of accurate information on agrometeorology. With few NMS under the agriculture portfolio, priorities rarely focus on serving agriculture. Even those with observation networks do not always provide services, often due to the shortcoming in their analytical capability. Along with staff and budget constraints, the service suffers from poor understanding of the diverse agricultural users and their requirements.

Information requirements vary with different farming practices, while research and education require more detailed information with different emphasis. Among the variables with strong effects on crop growth and farm management are daily temperature, precipitation, solar radiation, and wind speed. More general information is required in advance by agricultural policy makers, planners, and institutional support systems for better planning. With challenges in climate change, desertification, and biodiversity, many NMS can play a crucial role in improving understanding and finding ways to mitigate and adapt. The NMS can take advantage of advances in computer and communication technology to improve analytical capability and

service delivery. With limited resources available, an effective way to benefit from the progress is through cooperation among countries within a region. By putting together the best resources and expertise, the limited resources can be more efficiently utilized. Presently, many climate institutions provide near real-time global observations of the ocean and atmosphere and periodically post the analytical results of their implications on regional climate. NMS can also accept feedback for the improvement of the service.

The next paper discusses the need for linkages between weather services and the agricultural sector. From the National Weather Service (NWS), adequate funding is essential for the maintenance of a modernized observational network that includes data needed for agricultural analysis. Cooperating agencies must provide recognition and support for the urgency of NWS to improve both short-term forecasts and long-range outlooks. While the accuracy of these forecasts has improved in recent years, natural disaster reduction and mitigation of extreme events in agriculture will be enhanced by further improvements. Agricultural agencies are tasked with helping the people protect soil, water, and wildlife as well as sustain agricultural growth and development. As advances in information and biological technologies move forward, fundamental changes will likely occur through the agricultural sector in the 21<sup>st</sup> Century. The demand for weather and climate information will likely continue to expand for a wide spectrum of agricultural applications. In government, the information will be used for crop, forest, pasture and livestock conditions, irrigation reserves, crop yield potentials, and marketing outlooks. In research, the information will be used to develop model simulations (yield, physiology, pest, and irrigation management), weather-based generators, and scenario analyses in operational applications. In farming and agribusiness, the information will be used for advisories, daily farm management decisions, and long-term agricultural planning. Finally, more coordinated and integrated national policy on natural disaster reduction and mitigation of extreme events on agriculture will necessitate linkage of operational services with communities affected by these events. Achieving all of these goals requires proactive leadership and cooperation among agricultural weather and weather service providers at the national, regional, and state levels, and with the agricultural user community at all levels.

The next paper focuses on a climate information application in Indonesia. At present, the use of climate (forecast) information is very low. At Indramayu, a vulnerable district to El Niño-Southern Oscillation (ENSO) events, farmers are always suffering from drought and flood whenever El Niño and La Niña occur. Some of the reasons are that end-users (farmers) have difficulty in understanding climate forecast information that contains probability, and there is no effective dissemination system of climate forecast information to end-users. Farmers are also not aware of the economic value of climate forecast information. As a consequence, the level of farmers' adoption to climate forecast information is low and they have no capacity to tailor their cropping strategy to climate forecasts. To increase farmers' adoption to climate forecast information, their knowledge of climate and its application should be improved. A process called Climate Field School (CFS) is introduced to increase farmers' knowledge on climate information application. The basic concept of CFS is to disseminate climate information applications to end users by translating the information from scientific language into field language and then translating field language into farmers' language through field school. Based on the result of the evaluation, it was indicated that the CFS might be an effective way to educate farmers (end-users) on climate information application. The main challenge in the implementation of CFS is the development of modules. Integrated efforts between universities, research agencies, and related government agencies are required.

The fourth paper emphasizes the importance of extension services and the supportive role of agricultural research. The climatic and environmental resource base of crops plays a dominant role in their survival, growth, and development. Therefore, weather and climate, crops, other parts of the resource base, and crop weather and crop/climate relations need the continuous attention of applied research. This helps not only to protect the resource base and sustain the quality and quantity of crop yields, but it also is a basis for the farmers' income. However, to make sense, the products of science as well as forecasts and advisories must increasingly be made available to assist the farmers through operational agrometeorological services, which range from agroclimatological characterization to management of natural resources. To explain the actual scarcity of agrometeorological services, particularly in developing countries, the author developed a diagnostic and conceptual framework that pictures the generation and transfer of agrometeorological information from the existing support systems to its adaptation, dispersion, and teaching at the farm level. This framework lessens the confusion between the goals and means in generating agrometeorological services. Diagnosis of current agrometeorology practices shows a need for agrometeorology to arrive at on-farm agrometeorological services. This is illustrated with ample examples from an earlier defined list of such services. It is concluded that agrometeorological in-service education of extension intermediaries is essential to train farmers in field classes, improve their income, and protect the agricultural production environment from degradation. This ultimately materializes in down-to-earth agrometeorological services in well-defined farming systems.

The next paper reviews the tools and methods for agrometeorological monitoring in the West African Sahel. Agrometeorological monitoring in the Sahelian countries consists of collecting, processing, and analyzing various data and information that can affect the outcome of the agricultural season. It combines observational data from national meteorological, hydrological, agricultural extension, plant protection, and livestock breeding offices, as well as satellite data provided by the AGRHYMET Center. From May until the end of October, multidisciplinary working groups (MWGs) in each country publish decadal and monthly bulletins. At the regional level in the AGRHYMET Center, data and information coming from the national components are combined with satellite data to elaborate regional syntheses that are published at different times. In these publications, the current situation is analyzed and compared with that of the previous period, the previous year, and the average. Forecasts of seasonal rainfall and crop yields, which are refined from month to month, are also given. Color maps illustrate the amounts of rainfall, sowing dates, crop water requirements, satisfaction indices, yield estimates, zones with particular pests, and the advance of the vegetation front. Hard copies and electronic versions of these publications are mailed to subscribers. They are also posted on the Center's website: [www.agrhymet.ne](http://www.agrhymet.ne).

The final paper in this section presents a summary of sugarcane advisory services in Colombia using an automated data network. The application of meteorological and climatological information obtained through the Colombian sugarcane industry's automated weather network is discussed. A primary concern is to minimize the number of cases when the ash and smoke from sugarcane burning causes annoyances to the residents of population centers of the Cauca Valley in Colombia. The most important topics related to this agricultural practice include: the technology; different types of information required; climatological and statistical data on the wind's behavior; procedures to obtain all this information; and, steps to apply it. The application of meteorological information for monitoring sugarcane burns makes it possible to decide whether to burn or not, depending upon whether the prevailing conditions in the place at the time

foreseen for the burning so permit, without affecting the areas that are to be protected from ash fallout or smoke presence.

Following the workshop presentations, there were several brainstorming sessions focusing on strengthening services. The group prioritizes their conclusions and recommendations. The following is a list of the workshop recommendations to strengthen operational agricultural meteorological services. There is a need:

- To improve the spatial resolution of the application of agrometeorological products, and strengthen the density of agrometeorological station networks;
- For the NHMS to accord recognition to the agrometeorological stations established and maintained by other national, regional, and international institutions focusing on agricultural, forestry, fisheries, and rangelands issues and assist, support, and collaborate with them;
- For routine interactions between agrometeorologists, agricultural extension services, and other intermediaries to provide better services to farmers;
- For a comprehensive strategy for capacity building at the national and regional level including short- and long-term education and training, roving seminars, workshops, and conferences that will build on synergies among institutions and organizations responsible for capacity building;
- For sharing of data, tools, methodologies, and experiences through the exchanges of experts among member countries and regional centers;
- For promoting the generation and application of climate information by increasing the awareness and understanding of policy makers of its importance for sustainable development from national to the local levels;
- To involve communication experts in the process of disseminating agrometeorological information;
- To implement the training programs for enhancing the capacity of farmers in using climate information for supporting farm activities;
- For coordinated and integrated national agricultural weather policy to ensure that operational services to agriculture and food security are met;
- To involve users in the identification of specific climate-sensitive issues in order to facilitate their operational decisions;
- For modern tools, such as remote sensing and GIS, that may help reduce the impact of traditional limitations such as data scarcity;
- To actively publicize the efforts and successful endeavors, including an assessment of economic benefits, if possible;
- For the development and provision of agrometeorological products that should involve active interaction with farmers and/or the agricultural industry;
- For an international standard for reporting crop data along with minimum requirements for metadata, database formats, and database content that should be accepted by industry, international centers, and academia;
- For promoting the use of participatory research in the establishment and implementation of projects involving agrometeorology in sustainable development; to apply efforts in order to establish and/or improve phonological observations on a regular basis, due to their fundamental role in agrometeorology;
- To obtain financial resources for agrometeorological activities, to present to different national and international agencies well-supported and completed projects for their consideration; and,

- For taking into account the day-to-day increasing advantages of new technologies, to try to enrich the users of agrometeorological products with more precise, timely, and local information and easier to use information. This means developing a framework fitting the concepts of “precision agriculture” and “per-specific application.”

These proceedings represent a formulation of ideas from diverse perspectives on ways and means to strengthen operational agrometeorological services at the national level. The editors thank all of the authors for their outstanding contributions.

# *Operational Agrometeorological Services: National Perspectives*

## **Operational Agrometeorological Services in the Philippines**

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### **Abstract**

The Philippines is an agricultural country. Almost half of the country's total land area is devoted to various agricultural crops, which makes the agriculture sector a major contributor to economic development. However, there are times that agricultural production falters to meet the population's food requirement thus affecting the country's economic condition. Dramatic increases or decreases in agricultural output have been, in most cases, associated with occurrence of severe weather events and changes in the climate system. Typhoons with its associated strong winds and rains and the global phenomenon, called El Niño, have contributed significantly to the large annual variability of the country's agricultural production.

### **Introduction**

The increasing need for better weather and climate information, e.g., weather forecasts, climate outlooks, drought advisories, typhoon bulletins, and other agrometeorological services that serve as a valuable tool in decision-making processes has made the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) an indispensable partner of the agricultural community.

## Southeast Asia



Figure 1. Location map of the Philippine archipelago.

The Philippine archipelago is geographically located between latitude  $4^{\circ}23'N$  and  $21^{\circ}25'N$  and longitude  $116^{\circ}E$  and  $127^{\circ}E$  (Figure 1). The total land area of the Philippines is 300 thousand square kilometers or 30 million hectares and is composed of 7,107 islands and islets. It constitutes two percent of the total land area of the world and ranks 57th among the 146 countries of the world in terms of physical size.

Three prominent bodies of water surround the archipelago: the Pacific Ocean on the east, the South China Sea on the west and north, and the Celebes Sea on the south. This position accounts for much of the variations in geographic, climatic, and vegetative conditions in the country.

Alluvial plains, narrow valleys, rolling hills, and high mountains characterize the topography of the bigger islands, particularly Luzon and Mindanao. The highest mountains are found in Mindanao and Luzon, with the altitudes varying from 1,790 to 3,144 meters. Most of the smaller islands are mountainous in the interior, surrounded by narrow strips of discontinuous flat lowlands, which constitute the coastal rims. The shorelines of both large and small islands are irregular.

### **Socio-Economic Profile**

As of 2000, the Philippines is home to around 76 million people and is one of the most populous countries in Asia and the world. While most of the population still resides in the rural areas, urban migration has increased steadily. In 1996, total urban population constituted 55 percent of the total national population. Metro Manila with its continued influx of rural migrants makes it a very densely populated place; more crowded than Metro Tokyo or Metro Paris according to studies. About 13 percent of the country's population resides in Manila's limited land area, representing a mere 0.2 percent of the country's total land area.

The country is divided geopolitically into 17 regions, Regions I-XIII, the National Capital Region (NCR), the Cordillera Administrative Region (CAR), the Autonomous Region of Muslim Mindanao (ARMM), and the Caraga Region. There are 73 provinces and 60 cities across the archipelago with Manila as the capital. From 1991 to 1996, economic indicators reflected national growth. In 1996, GNP grew to 6.9 percent and GDP to 5.7 percent.

Its principal products are: textiles, pharmaceuticals, chemicals, food processing, and electronics assembly. The natural resources include: forests, crude oil, and metallic and non-metallic minerals.

### **Philippine Climate**

The country's climate is tropical and maritime and is influenced by large-scale atmospheric patterns that bring in substantial amounts of rain almost all year round. It is characterized by a relatively high temperature, high humidity, and abundant rainfall. Rainfall distribution varies regionally, depending upon the direction of the moisture-bearing winds and the location of the mountain ranges. Mean annual rainfall varies from 965 to 4,064 millimeters annually, with the eastern parts of the country receiving the greatest amount of rainfall and the southernmost part of Mindanao receiving the least. Mean annual temperature is  $26^{\circ}C$ . January is the coolest month, with a mean temperature of  $25^{\circ}C$ , while May is the warmest with a mean of  $28^{\circ}C$ .

Tropical cyclones have a great influence on the climate and weather conditions of the Philippines, affecting rainfall, humidity, and cloudiness. They generally originate in the region of the Marianas and Caroline Islands in the Pacific Ocean. Their movements follow a northwesterly direction, sparing Mindanao from being directly hit by a majority of the typhoons that cross the country. This makes the southern Philippines very desirable for agriculture and industrial development.

Although generally blessed with abundant rainfall all year round, some areas in the country encounter water supply difficulties while other areas face serious water problems most of the time due to the uneven distribution of rainfall with respect to time and space. This is further exacerbated by the occurrence of extreme climate events such as floods and droughts associated with the El Niño/La Niña phenomena. Based on rainfall distribution, the country has four climate types (Figure 2):

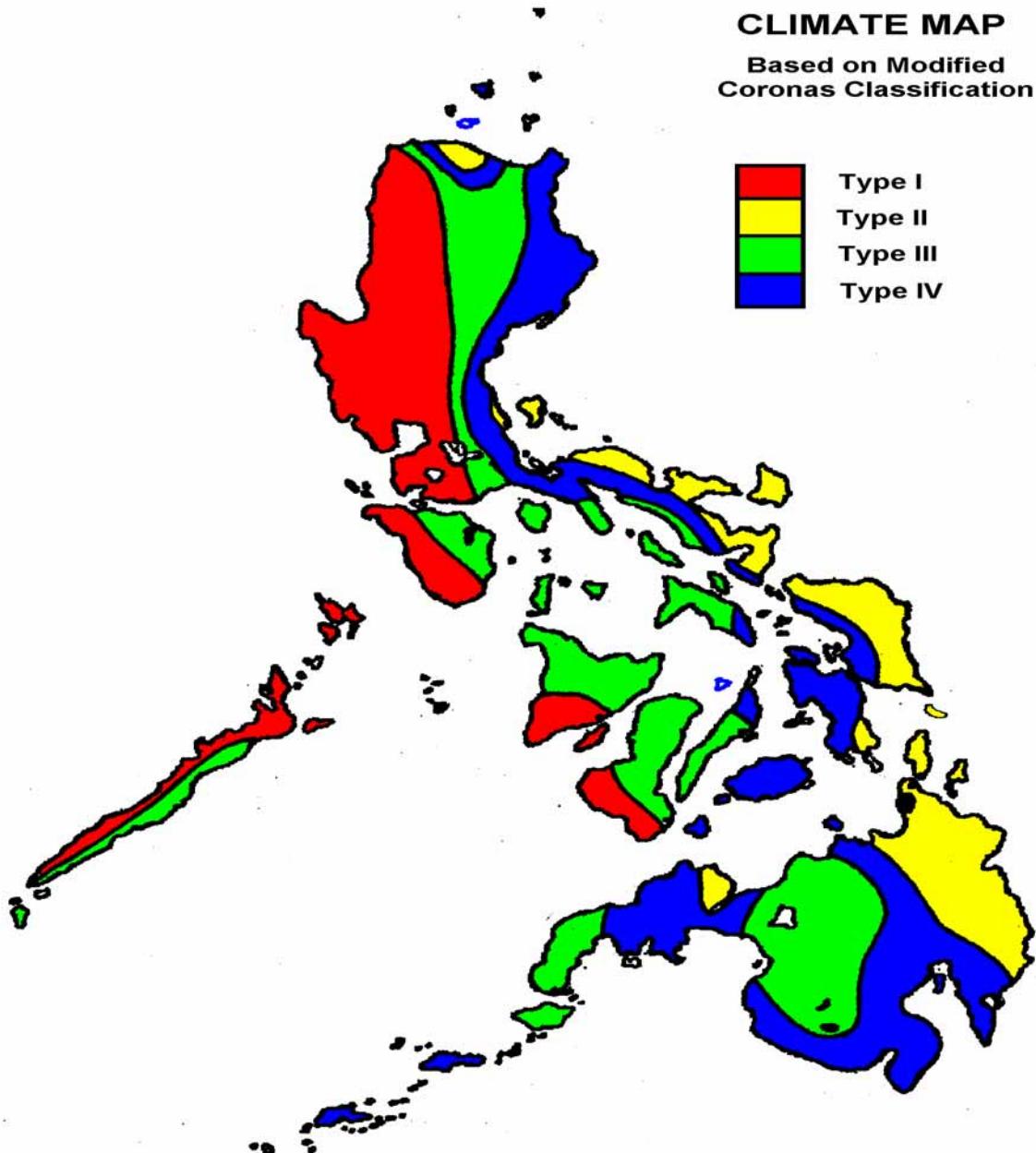


Figure 2. Climate map of the Philippines based on modified Coronas classification.

Type 1 -- two pronounced wet and dry seasons, wet during the months of June to November and dry from December to May. The controlling factor is topography. Areas under this type are shielded from the northeast monsoon and, even in good part, from the trade winds by high mountain ranges, but are open only to the southwest monsoon and cyclonic storms.

Type 2 -- no dry season, with a very pronounced maximum rain period in December, January, and February. Regions belonging to this type are not sheltered from the northeast monsoon and trade winds or from the cyclonic storms.

Type 3 -- an intermediate type with no pronounced maximum rain period and short dry season, lasting from 1 to 3 months only. Areas under this type are only partly sheltered from the northeast monsoon and trade winds and are open to the southwest monsoon or at least to frequent cyclonic storms.

Type 4 -- uniformly distributed rainfall. The regions affected by this type receive the moderate effects of the northeast monsoon and trade winds as well as the southwest monsoon and cyclonic storms.

## **Overview of the Agriculture Sector**

The Philippines is an agricultural country with a land area of 30 million hectares (ha), 47 percent of which is agricultural land. In the Philippines, prime agricultural lands are located around the main urban and high-population density areas. Land resources in the country are generally classified into forest lands and alienable and disposable lands. A total of 15.8 million ha are classified into forest lands, and 14.2 million ha are alienable and disposable lands. Out of the 14.2 million ha alienable and disposable lands, 13 million ha are classified as agricultural lands.

The total area devoted to agricultural crops is 13 million ha distributed among food grains, food crops and non-food crops. Food grains occupied 31 percent (4.01 million ha), food crops utilized 52 percent (8.33 million ha), while 17 percent (2.2 million ha) were used for non-food crops. For food grains, the average area utilized by corn was 3.34 million while rice occupied 3.31 million ha. Of the total area under food crops, coconut accounted for the biggest average harvest area of 4.25 million ha. Sugarcane with 673 thousand ha; industrial crops with 591 thousand ha; 148 thousand ha for fruits; 270 thousand ha for vegetables and root crops; 404 thousand ha for pasture, and 133 ha for cut-flowers. According to land capability, 78.31 percent of the alienable and disposable land is prime agricultural area, and 6.1 million ha are highly suitable for cultivation.

## **Farm Systems and Structure**

A mixture of small, medium, and large farms characterizes Philippine agriculture. A majority of the farms in the country are small, averaging about 2 ha, and owned and managed by single families. In 1988, two-thirds of all farms were no larger than 3 ha. Eighty-five percent of all farms were no more than 5 ha. A typical farming system consists of a major crop, with rice, corn, and coconut as common base crops, and a few heads of livestock and poultry.

## **Agriculture in the Economy**

Playing a vital role in the economy, the government wants to transform the country's agriculture into a modern, dynamic, and competitive sector. A sustained expansion of the national economy requires sustained growth in the agricultural sector.

Agriculture, including forestry and fishery, plays a dominant role in the Philippine economy. The country's population is predominantly rural (70 percent of the total) and two-thirds of this population depends on farming for their livelihood. In terms of employment, about one-half of the labor force is engaged in agricultural activities.

The agricultural sector's contribution to the economy was a substantial 23 percent of gross domestic product since 1995 when it registered a growth rate of 3.2 percent. The growth was mainly due to the expansion of the poultry, livestock, and palay sub sectors. Primarily, Philippine agriculture consisted of rice, corn, coconut, sugar, banana, livestock, poultry, other crops, and fishery production activities.

## **Agrometeorological Service in the Philippines**

Philippine agriculture is dependent on climate and weather, and as such, the PAGASA is mandated to continuously render/contribute meteorological services supportive of the program thrusts of the Philippine government towards self-sufficiency in food and the attainment of a progressive and sustained economic growth without jeopardizing environmental safety.

Agrometeorological services in the country are delivered not only at the farm operation level but also at the strategic level where planning of agricultural operations, both short- and long-term, are included.

## **PAGASA Network of Observing Stations**

The PAGASA operates a network of weather stations all over the country. Synoptic, agrometeorological, rainfall, climatological, upper-air, and radar stations, located all over the country, make up the entire network of observing stations. To cater to the needs of the agriculture sector, there are around twenty agrometeorological stations that the PAGASA operates in collaboration with state colleges and universities, government research institutions, and private entities. These operational stations provide the necessary meteorological and agrometeorological data required in the formulation of advisories, bulletins, warnings, and other weather and climate-related information. Observed data are transmitted to the central office and other users through single side-band radio circuits and telephone/fax lines.

List of synoptic stations in the Philippines:

Alabat	Daet	NAIA
Ambulong	Dagupan	Pagasa Island
Aparri	Davao	Port Area
Baguio	Dipolog	Puerto Princesa
Baler	Dumaguete	Romblon
Basco	Gen. Santos	Roxas
Borongan	Guiuan	San Francisco
Butuan	Hinatuan	San Jose
Cabanatuan	Iba	Sangley
Cagayan de Oro	Iloilo	Science Garden
Calapan	Infanta	Tacloban
Calayan	Itbayat	Tagbilaran
Casiguran	Laoag	Tanay
Catarman	Legaspi	Tayabas
Catbalogan	Lumbia	Tuguegarao
Clark	Maasin	Vigan
Coron	Mactan	Virac
Cotabato	Malaybalay	Zamboanga
Cubi Point	Masbate	Zurriago
Cuyo	Munoz	

List of the PAGASA network of agrometeorological stations:

Albay	Isabela	N. Samar
Batanes	Laguna	N. Vizcaya
Camarines Sur	Lanao del Sur	Palawan
Capiz	Leyte	Quezon City
Davao	N. Ecija	Tagaytay
Ilocos Norte	N. Occidental	Tarlac

## **Agrometeorological Products**

Good management and timing of agricultural activities could mean the difference between success and failure in agricultural production. Based on this premise, the PAGASA provides a wide range of agrometeorological products that would serve as primary tools in the formulation of plans and implementation of activities particularly at the farm level. Some of the products include:

- Farm Weather Forecast and Advisory
- Tropical Cyclone Warning for Agriculture
- Ten-day Regional Agri-weather and Advisories
- Philippine Agroclimatic Review and Outlook
- Crop Weather Calendar
- Agroclimatic Impact Assessment

Farm Weather Forecast and Advisory -- This is a daily farmcasting prepared and issued by the Climatology and Agrometeorology Branch (CAB) of PAGASA. Timely farm weather forecasts and advisories are made available to the farmers through an area-wide

agrometeorological network of stations. Information includes the weather forecast for agricultural areas, soil conditions, range of temperature, relative humidity, and agri-weather tips and advisories.

Tropical Cyclone Warning for Agriculture -- This is issued during the occurrence of tropical cyclones within or expected to enter the Philippine Area of Responsibility (PAR).

Ten-day Regional Agri-weather and Advisory -- The idea of a regional agri-weather forecast is to go along the regional administrative setup of our main client, which is the Department of Agriculture. It is also meant to make a “progressive improvement” over the broad generalities of a nationwide forecast, albeit in a tabulated form.

Crop Weather Calendars -- Planting calendars wherein the weather factors of rainfall, potential evapotranspiration, temperature, winds speeds, radiation, and others of significance to the plant’s growth and development are incorporated to guide farmers on agricultural operations/decisions. This is the result of a matching process wherein a cropping season for a particular crop is recommended. This recommended growing season tries to approximate the optimum time wherein most of the crop requirements are met. Crop weather calendars are available for all the regions of the country and for various crops such as rice, corn, vegetables, and other crops.

Agroclimatic Impact Assessment -- The development of two agroclimatic indices, i.e., yield moisture index and generalized monsoon index, has led to the realization of this agrometeorological product that provides a wider perspective of the impacts of past seasonal climate (2 to 6 months), specifically rainfall, on standing crops in identified regions of the country. Issued at the end of the month, it serves as an additional tool for planners and decision makers in the formulation of mitigating strategies particularly for rice and corn crops.

### **Present and Future Thrusts and Initiatives**

The present thrusts of the agrometeorological service are geared towards the government’s economic development programs. With around 20 tropical cyclones that visit the country annually, typhoons cause loss of lives and damages property. Nevertheless, these disturbances also bring in the much-needed rains for irrigation and domestic supply. To address the problem on the recurrence of typhoons and floods, one major activity is focused on the enhancement of weather and flood forecasting capabilities. Upgrading of radar, synoptic, and agrometeorological stations to track incoming tropical cyclones and monitor extreme weather/climate events is one of the ongoing priority projects. The use of satellite information for real-time weather analysis, monitoring, and forecasting has been strengthened through the upgrading of existing satellite receiving facilities. GIS-based techniques have been formulated and developed to provide rapid assessment and evaluation of crop damages in typhoon prone areas. Strengthening the dissemination system and the efficient application of an effective damage mitigation method are also being put in place.

# **Monitoring and Early Warning Systems for Potentially Dangerous Vegetation Fires in Cuba**

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## **Abstract**

The early warnings alert is a result of the agrometeorological monitoring system that includes information on the content of soil moisture, living vegetation, and dead biomass. Starting from this, the danger potential conditions can be inferred to originate and to spread vegetation fires. The alert system was designed to operate at different temporal scales at the national level (early warnings alert) and provincial level (advanced and immediate warnings alert). The resulting information flow of the danger-potential alert conditions of vegetation fires surveillance is explained. Some results of the practical application of this potential danger index in long-term early warnings alerts are reported. The index was evaluated with forest fire reports during 2001 and 2002, for the early warnings alert of the occurrence of danger conditions of vegetation fires. This system has allowed the Cuban Body Keepers to strengthen preventive activity and to achieve operative efficiency during the high-danger occurrence period of forest fires in Cuba.

## **Introduction**

During the last decades, the world has observed a remarkable tendency toward an increase in forest fires and the area affected by them. The Cuban forests have not been an exception in this tendency.

According to the investigative results of the Meteorological Institute Climate Center, in the last three decades, the average air temperature has increased by 0.6 °C, the presence of severe storms has increased (accompanied by strong winds and electric discharges), and the frequency and intensity of south winds and droughts has risen (Centella, et al., 1997). All of these events contribute to a greater occurrence of vegetation fires. The general increase in temperatures has been accompanied by a reduction of annual total rainfall from 10 to 20 percent and an increase in the interannual variability from 5 to 10 percent. Another feature noted is diminishing rainfall in the rainy period (May - October) and increased rainfall in the drier period of the year (Lapinel, et al., 1993).

According to Gutiérrez, et al., (1999), the expected combination between the generalized decrease of biomass potential density and the forest net primary productivity caused by the effect of the climatic change during the current century, specifically in the eastern region of the country, bring as a consequence a progressive reduction of forest sustainability and an evolution to more dry forests, very dry forests, or savannas. These drier ecosystems, in presence of higher temperatures and higher air saturation deficit, will see considerably more exposure to forest fire danger than the current ones (Ávila, et al., 1985).

The general objective of this work was to use the more novel agrometeorological knowledge in the international literature, adapt them to the Cuban conditions, and to formulate a theoretical framework. The necessary algorithms were used to simulate the effect that the

climatic conditions produce on the vegetation and other aspects related with the environment where they grow. Finally, advanced techniques of data prosecution and geographical information systems (GIS) were used to apply this knowledge to evaluate the danger potential conditions of vegetation fires.

The specific objectives were: 1) to obtain an evaluation method that describes, using objective methods, the danger potential conditions of vegetation fires in an appropriate scale for an exploratory purpose; and 2) to apply the results obtained in the operational agrometeorological services and in the future generation of a database that allows developing new agrometeorological investigations and risk studies for vegetation fires.

## **Materials and Methods**

The alert system based on the integration of different indexes containing elements that initiate the beginning and the propagation of the forest fires (Solano, 2001). Contributing in its elaboration, the different meteorological components according to the temporary scale warning are as follows.

<i>Index</i>	<i>Danger condition</i>	<i>Condition to evaluate</i>
0	None	Presence of humid conditions during the last three 10-day periods.
1	Little	Humid conditions don't exist during the last three 10-day periods or dry periods.
2	Moderate	Agricultural drought process in evolution but with some humid or lightly dry decades during the last three 10-day periods.
3	Much	Agricultural drought process in evolution. The modified humidification index during the three or last four 10-day periods has been very dry or severely dry.
4	Extreme	Established agricultural drought process. The modified humidification index during the last five 10-day periods has been very dry or severely dry.

Table 1. Weather and climate characteristics used to evaluate the danger conditions expressed in the agrometeorological danger potential vegetation fires index.

The meteorological and agrometeorological information used in the danger potential conditions of vegetation fire surveillance comes from the meteorological networks of the Institute of Meteorology (ground, radar, aerological, and satellite stations) and the rain gauge networks belonging to the Institute of Meteorology and the National Institute of Hydraulic Resources.

To evaluate the long-term danger potential conditions of vegetation fires, an index determined by Solano (2001) was used, modified to a five-values scale and described in Table 1.

The index was evaluated with the forest fires information that occurred in the whole country during “January, first 10-day period 2001 to July, third 10-day period 2002,” and also the agrometeorological information corresponding to the previous 10-day period was used “December, third 10-day period 2000 to July, second 10-day period 2002” (Solano, et al., 2003). For this particular purpose, a Cuba Body Keepers fire database was prepared, with extracted information: occurrence day, municipality name, the degree of catastrophe, and the

affected area. This information was organized by 10-day periods (decades) for each one of the municipalities studied. Required ground station climatic data for reference evapotranspiration by Penman-Monteith method according to Menéndez, et al., (1999), and their analysis and spatial distribution in the country according to Solano, et al., (1999), were organized. The soil-water balance was made according to Solano, et al., (1999); the calculation of the modified humidification index and their spatial distribution was made according to Solano, et al., (2000) and Solano and Vázquez (1998); and the evaluation of the agricultural drought was made according to Solano, et al., (2000). With this information, the vegetation fires danger index according to Solano (2001) was evaluated for each one of the municipalities and decades used.

To issue the early warnings alert on vegetation fires potential, the traditional agrometeorological prediction method was used. It was based on the vegetation, formed by inertia of agrometeorological conditions at the end of a 10-day period, and the dependence of the current inertia in the vegetation with regard to the present and past meteorological conditions. Also used was the potential danger of vegetation fires index determined by Solano (2001) calculated at the end of a particular decade, to calculate the explosiveness of potential danger conditions of vegetation fires in the next 10-day period.

## Results

An alert system was designed that included the issuance of warnings for three different temporal scales and the analysis of different agrometeorological indices and meteorological elements, which are described below:

- *Alert early warnings* are elaborated using information of the climatic risk and the surveillance of the following weather parameters: precipitation; meteorological elements that intervene in the calculation of the evaporative power of the atmosphere, (such as temperature and humidity air), the speed of the wind and the solar radiation, observation of agrometeorological index obtained of the soil water balance (such as the reserve of soil productive humidity), conditions of vegetation, agricultural drought potential, and conditions of potentially dangerous vegetation fires. These warnings are designed to cover a temporal scale of 10 days or more.
- *Alert advanced warnings* are made including the previous information and the existence of weather systems. Short-term and medium-term forecasts are provided for: rainfall, air temperature and air humidity, direction and speed of wind, and behavior of the weather for the following 5 days. These warnings cover a temporal scale from 1 to 10 days.
- *Alert immediate warnings* are elaborated from the previous information and rainfall information, dry-bulb and wet-bulb air temperatures at 13:00 hours of the 75° W meridian, the speed and direction of wind, the Nesterov danger integral index, information provided by meteorological radar on cloud cover, rain and movement of weather systems, and sounding information of atmospheric stability. These warnings cover a temporal scale up to 6 hours.

The alert early warnings are produced by the Agricultural Meteorology Department of the Institute of Meteorology and the alert advanced and immediate warnings are made by the Provincial Meteorological Centers.

Alert early warnings, supported by a system of specialized observations, guarantee an effective supply of accurate and authorized information for decision makers at the national, provincial, regional, or local levels.

The alert system has allowed Cuba National Body Keepers to keep its specialists informed about the danger conditions caused by weather and climate extremes; strengthen preventive activity and improve operational efficiency in fire monitoring surveillance; and more effectively combat forest fires.

Risk Category <b>1/</b>	Fires of potentially dangerous conditions in vegetation in the 10 days before the fires happened									
	<b>4</b>		<b>3</b>		<b>2</b>		<b>1</b>		<b>0</b>	
	Decadal Alerts	Days with reported fires 2/	Decadal Alerts	Days with reported fires 2/	Decadal Alerts	Days with reported fires 2/	Decadal Alerts	Days with reported fires 2/	Decadal Alerts	Days with reported fires 2/
Jan-Dec. 2001	652	126	468	43	1 601	84	1 880	27	979	5
Jan.-Jul. 2002	830	160	465	53	769	60	880	13	311	16
Jan 2001-Jul 2002	1 482	286	933	96	2 370	144	2 760	40	1 290	21

Table 2. Number of advanced alert warnings by risk level and number of fires occurring in the decadal period following the alert, for all Cuban municipalities, 2001 and 2002.

1/ = no danger, etc.

2/ = fires occurring in decade following alert decade.

**0** = No danger

**1** = Little danger

**2** = Moderate danger

**3** = Much danger

**4** = Extreme danger

Note: Taking into account the dimensions of the Havana City Province, which has been considered as a municipality.

Table 2 shows, for categories of potential vegetation fire danger (for the year 2001 and for the period January to July 2002), the total fires that occurred in Cuban municipalities and the number of times the danger category was issued in the previous decade to the occurrence of the fire. There was a tendency for the number of forest fires to increase as the index increased. It is necessary to point out that fires can happen even when present conditions for fire risks are low or absent. This explains the differences between the number of evaluated decades and the days with fires reported in those decades.

Evaluating the distribution of the fires and the categories of potential danger from January to July 2002 (Table 3), out of 1,290 cases 21 cases were reported with zero fire potential in the next decade, with an error rate of 1.6 percent. Nevertheless, 86 percent of the fires were in Pinar del Río Province, where the frequency of fires originated by electric discharge is highest. The average affected area of the fires rose in this category (two ha) shown in the Table 3, suggesting that the same ones did not have very favorable conditions for their propagation. The 21 fires occurred in the following municipalities: Guane (6), Mantua (8), Minas de Matahambre (2), Viñales (1), La Palma (1), Martí (1), Moa (1), and Buey Arriba (1).

Of a total of 587 forest fires reported in January 2001 through July 2002, 566 (96 percent) happened in decades following alerts in categories of danger 1 to 4 (Table 3).

Danger level	FIRES		Average fire area (hectares).
	Number	Percent of total	
0 None	21	3.6	2.0
1 Little	40	6.8	14.1
2 Moderate	144	24.5	19.2
3 Much	96	16.4	65.5
4 Extreme	286	48.7	67.8
Total	587	100.0	

Table 3. Distribution of fires and average fire area by alert risk level in Cuba, January 2001-July 2002.

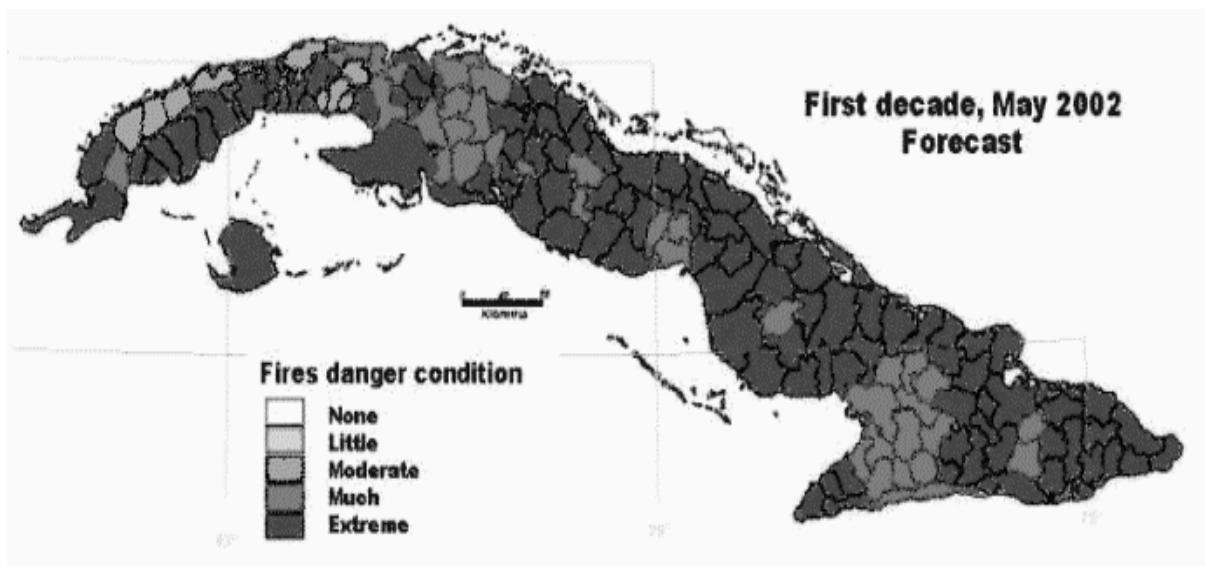


Figure 1. Prediction of potential danger conditions for the occurrence of forest fires predicted for first 10 days of May 2002.

Figure 1 shows the early-warning alerts of potential danger for the occurrence of forest fires that were forecast for the first decade of May 2002. Figure 2 shows the actual danger conditions for the same decade. Comparing the forecast and actual potential danger conditions for each municipality in the second 10 days of May 2002, 95 percent of these forecasts were accurate for the remaining 3 percent (5 municipalities). Real danger conditions were a little more severe than the foreseen ones, raising the risk to a superior category beyond what had been predicted.

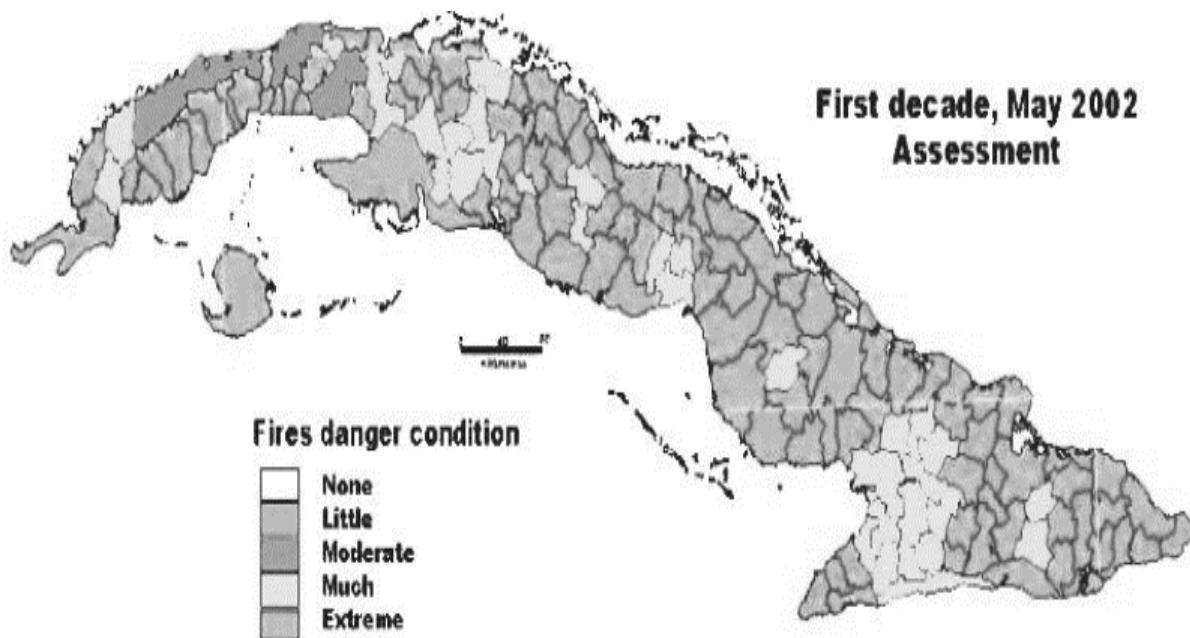


Figure 2. Assessment of potential danger conditions for the occurrence of forest fires during the first 10 days of May 2002.

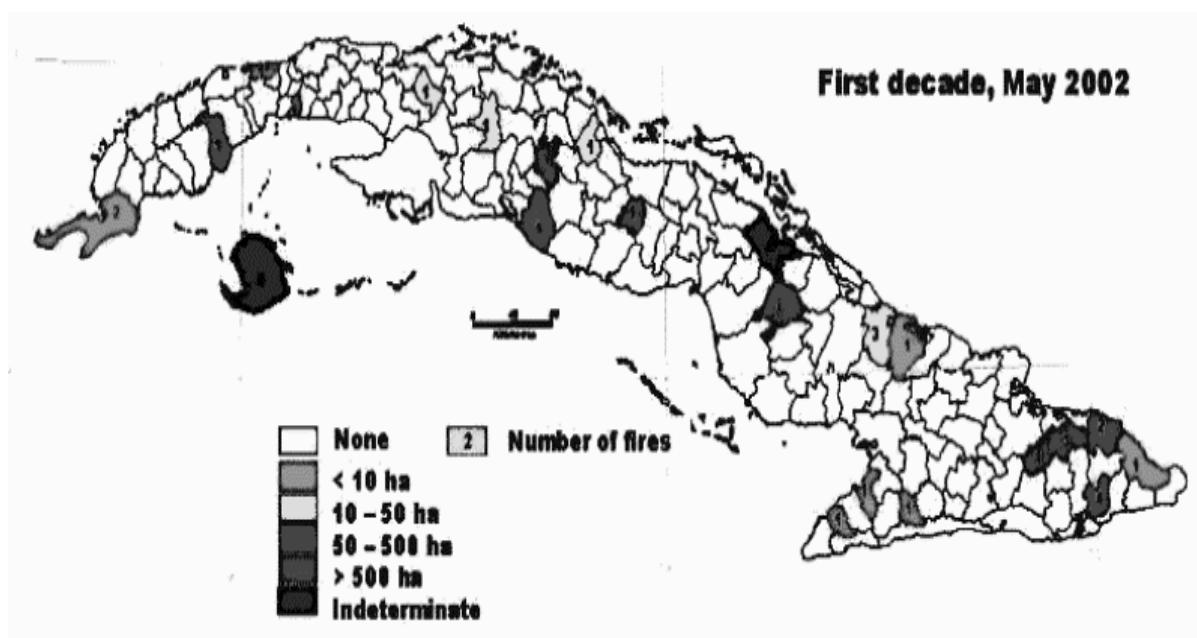


Figure 3. Fires during the first 10 days of May 2002.

Figure 3 shows the municipalities in which forest fires were reported during the first decade of May 2002. A total of 41 fires occurred in that period in 23 municipalities of the country. The number that appears inside the municipality indicates the number of fires and the background shade indicates extent of area damaged, in ha. Of the 41 fires, there was one in the category of moderate danger covering less than 10 ha, and four in the category of the severe danger (two covering less than 10 ha, one between 10 and 50 ha, and one covering more than 500 ha). The remaining 36 forest fires happened in the extreme hazard category. Five fires were smaller than 10 ha, three were between 10 and 50 ha, five were between 50 and 500 ha, three were more than 500 ha, and for two the covered area was not determined.

The results obtained from agrometeorological observation of potential danger conditions of fires in vegetation have been very encouraging. Nevertheless, better results in the system of alert early warnings of potential fire danger conditions could be obtained. For the spatial distribution of this index in municipalities, provinces, and country, the danger index could be improved by modifying the mean value of the danger index for municipalities used at the present time. The results obtained to date in predicting potential fire danger conditions, using the method of the inertia of the agrometeorological conditions formed in it, suggest that acceptable predictions could be achieved for periods between 10 and 20 days or more.

Another possible improvement would be to combine the forecast based on the inertia of the conditions formed in the vegetation with other models that include the rain prediction for larger temporal period. Lastly, combining the indexes obtained from information observed in terrestrial stations with those of high spatial resolution (remotely sensed data), would improve the information on agrometeorological conditions; especially in those areas where the surface meteorological information is insufficient.

The forest fires danger conditions observation system has been used by the Cuban National Body Keepers forces to strengthen prevention. For example, forest fire occurrences declined by 6 percent (52 fires) compared with the same period 3 years earlier. The early warning alerts make it possible to concentrate forces and resources on the more fire-prone danger areas; optimize the use of aviation resources used in observation, optimize specialized forces to combat these catastrophes; and inform the population about the potential hazard.

The results shown in this work have great importance for the planning activities in preventing fires in both cattle and agriculture sectors under sustainable conditions and non-irrigated land.

## **Conclusions**

A system for assessing the danger of vegetation fires has proven effective in all the Cuban regions. This system makes it possible to monitor conditions and issue alert warnings for three different temporal scales, helping the Body Keepers to strengthen preventive activity and aid operational efficiency during the period of high fire danger in Cuba.

Early warning alerts with a 10-day forecast period explained 96 percent of the fires during the decade under consideration. This indicates the efficiency of this system for making early warnings of fire danger, and it provides valuable index to determine danger conditions for vegetation fires under tropical conditions in Cuba.

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# *Operational Agrometeorological Services: Regional Perspectives*

## **Perspectives from Regional Association I (Africa)**

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### **Abstract**

Operational agrometeorological services in Africa were described based on the responses to a questionnaire designed by the World Meteorological Organization (WMO) Secretariat. The questionnaire was sent by fax and e-mailed to 51 countries and centers in Africa. The countries that responded included: Cape Verde, Mali, Eritrea, Mauritius, Ethiopia, Republic of Central Africa, Gabon, Guinea, Kenya, Malawi, Sudan, Tanzania, Togo, Tunisia, and Zimbabwe.

The distribution of these countries is fairly representative for the different geographical regions of Africa. It should, however, be noted that it is rather risky to draw meaningful results from such limited responses. Considering the short period devoted to consultation, it is desirable to try to highlight the present state of the agrometeorological services in Africa and to draw useful guidelines for activities and future prospects.

### **Introduction**

#### **Summary of Responses to Questionnaire:**

#### **Agrometeorological Units**

Most of the meteorological services in Africa have independent agrometeorological units and a few of these are based in the agricultural services (usually ministry of agriculture). The major role of these units is to provide data on a real-time or historical basis and to make simple data analyses in addition to a routinely published bulletin. The units provide services for the agriculture, water and the environment sectors, and other related concerns. However, there is a high staff turnover due to poor working conditions which results in well-experienced agrometeorological staff and well-trained scientists and technicians leaving the meteorological services to join other institutions.

#### **Major Customers**

Major customers include government institutions such as ministries of agriculture, livestock, fisheries, water and forest services, rural development, etc. In Malawi, Zimbabwe, and other countries, the major customers include:

- Government departments
- Donor community
- Private sector
- Banking community

- Non-government organizations
- Schools and colleges
- Agricultural extension department
- Food security department
- Disaster management department
- Early warning unit
- The media
- Research institute
- Farming community

Many countries provide services for international organizations such as the Food and Agricultural Organization (FAO), the World Food Programme, and the World Health Organization. In countries like Ethiopia, about 70 Non-governmental Organizations (NGOs) are users of agrometeorological information.

### **Operational Aspects**

A large majority of the countries issue regular agrometeorological bulletins and offer advisory services. Nearly half of the respondents mentioned that they issue early warning information valuable for strategic planning and efficient monitoring. More than 70 percent of the respondents indicated that they have an efficient role in assessing the impact of extreme events. Ethiopia also provides information on frost.

### **Major Types of Agrometeorological Services**

Most of the countries undertake studies to help reduce the impact of natural disasters, including pests and diseases. Only Kenya indicated that they do not provide short- and medium-range weather forecasting for agricultural purposes. Malawi indicated that it issues the forecasts, but not specifically for agricultural purposes.

WMO's Climate Information and Prediction Services (CLIPS) organize training courses for the different countries of the region in centers designated for capacity building for the different regions. The purpose is to acquire skills and use tools to predict the rainy season. The project is successful with new strategies to enhance food production and supply in the relevant countries. The model is still experimental although the results continue to be good in many countries. The model showed negative response in Ethiopia, however, efforts are continuing to improve model performance at the national level.

Only Mali and Tunisia acknowledged provision of services to help reduce the contributions of agricultural production to global warming. It appears that studies targeted towards such services need some attention.

Zimbabwe is currently generating production estimates for the rain-fed agricultural sector, using the FAO model based on crop-water requirement satisfaction index (WRSI). Efforts to improve the understanding of this model are underway.

### **Work limitations**

Data for agrometeorological purposes are usually inadequate in many countries. The density of observational network is low and network communication is not satisfactory. The

distribution of the existing observational network is uneven. Countries like Mali have demanded CLImate COMputing (CLICOM) and INSTAT software. Provision of analytical tools such as GIS is, however, challenging. Tools to allow precise analysis and better presentation are needed.

Training the staff is another problem in addition to educating farmers. Closer contact with farmers is vital; it is very beneficial to train them at least to make field observations and collect and transmit data. The help and direction given to farmers by extension workers could be useful but there is always a lack of a direct link between extension workers and agrometeorological staff.

Operational services are not adequate due to limited financial resources, at times, in many countries. The priority given to the agrometeorological services is not yet well identified. Station inspection is crucial, but it is unlikely to be achieved in most cases due to budgetary problems.

### **Limits of Collaboration**

In some countries ties with agricultural research units are relatively good but agrometeorological units interact with extension services only in a few countries. Data flow could be made easy for some users, but in some countries data have commercial value and access is restricted. Collaboration hardly exists between agrometeorological units and research units and extension services. Countries like Ethiopia and Kenya investigate problems related to agriculture without sharing information with agricultural research units. This might be because the infrastructure of the agrometeorological units in these countries is so strong as to achieve independence.

Extension services are available in a few countries. In Mali, there is a multidisciplinary body forming a working group for monitoring the growing season. The list of participants includes the agrometeorological unit and the extension services.

Most countries adopt decadal (10-day) analysis in addition to the monthly and annual analysis, especially at district level. Only a few countries adopted the system of weekly analysis instead of the decadal analysis. Daily observational data, which are requested at times by the agricultural research units, are provided in a format easily transformable into weekly or decadal values. Interaction with these users is either slow or irregular.

### **Global Connection**

Many countries are aware of the requirements of the International Conventions and agreements related to the United Nations Framework Convention on Climate Change (UNFCCC), UNCCD, and the Convention on Biological Diversity. More than 30 percent of the countries have no clear understanding on the World Food Summit Plan of Action. More than 25 percent of the countries have no clear access to plans of action of these international conventions and agreements.

## **Improved Operational Services**

Respondents expressed a variety of ideas on methods and tools of analysis to improve operational agrometeorological services at the national level. A summary of these ideas, based on the respondents, indicates the following order of priority:

- 1) Improve and rehabilitate agrometeorological stations and introduce automatic stations;
- 2) Improve communication links and consider new facilities;
- 3) Provide training (short and long-term) and analytical tools (introduce and improve methodologies);
- 4) Update and strengthen information system and technology (computers, software, GIS technology, etc.);
- 5) Develop user-tailored products;
- 6) Enable monitoring and inspection;
- 7) Initiate roving seminars; and,
- 8) Improve bulletins and introduce automation of data collection, processing, and information transfer.

## **Strategy to Build National Capacity**

The questionnaire raised several key points. Accordingly, national capacity building can be achieved through:

- A capacity-building project and training of personnel;
- A project for acquisition of automatic stations;
- Making agrometeorological services semi-autonomous to enable resource mobilization from private sectors and to deliver quality products; and,
- Training and acquisition of tools (equipment and software).

Several other points were drawn, but they are rather low in priority.

## **Future Prospects**

Africa is rich in natural resources and the agricultural potential is high. Genuine efforts are needed to utilize the resources for the benefit of mankind.

Operational tools for agrometeorological activities have been greatly developed, taking advantage of the rapidly developing technology. Training, among other things, is vital to bridge the existing gap between scientists and farmers. Contacts, sharing knowledge, improving techniques, and exchanging ideas remain important tools for improving agrometeorological services.

## **Automation**

Conventional instruments and equipment used for measurement in the agrometeorological stations are simple and easy to handle and maintain. It is now becoming difficult to maintain the stations because some conventional instruments are not manufactured anymore. A striking example is Robitch (a mechanical instrument for measuring global and diffused radiation) that is no longer available in the market. Old equipment cannot be replaced to

keep continuous data records. The alternative is a high-precision electrical instrument, but electrical power is often either irregular or not available. Other examples also exist.

Conventional instruments for agrometeorological measurements are on their way to be replaced by automatic weather stations. Most of the sensitive elements are measured by sensors and recorded automatically without much interference from the staff. This will enable rehabilitation of the network and reduce the number of the staff required, provided that technicians are well trained to run and maintain the automatic stations.

### **Agricultural Production**

Many countries in Africa complain of a frequent shortage in grain crops. This is mainly attributed to climate variability. Drought is frequent in Northern Africa and floods are frequent in Southern Africa. A combination of the two is likely at any location. Estimates of crop yield and production become vital in planning rescue operations at the national level.

FAO has already proposed the Crop Water Stress Index (CWSI) as a qualifying model for drought impacts. However, little work has been done to enable routine use of the model at the national level.

Agriculturists have their own traditional way (for instance the crop-cutting method) for estimates of national grain production. Such estimates usually become available 2-3 months after complete crop maturity. Use of the FAO model, which provides earlier indications of crop performance, can bridge the time gap. Other similar models can also be used. The agrometeorologists will take the lead when they are able to provide such earlier information on crop yield and production nationwide. Efforts are needed to organize application missions.

### **Remote Sensing**

Remote sensing is widely used in developed countries for provision of accurate information that may help in improving agrometeorological services for agriculture and other related disciplines. The technique is not easily available for developing countries due to technical restrictions, high costs, and lack of resources.

Information on rainfall estimates and Normalized Difference Vegetation Index (NDVI) is vital for all agrometeorologists to improve services and gain confidence. The Inter-Governmental Authority on Development (IGAD) countries took the lead to consider providing remote sensing technology for all member countries for provision of information on rainfall estimates using the Primary Data User System (PDUS) and monitoring the progress of the cropping season (NDVI). Other downloading facilities for some other elements are also considered. The project, which is just starting, shall strengthen national capacity and provide links with different users in the region and in each country. Similar examples are encouraged.

### **Conclusions**

Although many African countries can provide improved agrometeorological services for the different users, they are still lagging behind. The flow of information is limited and methodologies have to be improved; technology is in high demand.

The density of the observational network is low in many countries. Some countries have only one or two agrometeorological stations, limiting agrometeorological activities. Agrometeorological units are hampered by lack of trained personnel and limited budgets. Efforts are needed to assist these countries.

The flow of data to users continues to be a high requirement. Users, especially the farming community, usually request information on the onset of effective rains (to know when to plant), the length of the cropping season (to decide what to plant), the behavior of the dry and wet spells within the cropping season, and how likely an extreme event is likely to occur. The provision of this information is currently very limited.

Governments and farmers are greatly interested in knowing how much grain yields and crop production are expected by the end of the rain/crop season. This knowledge helps strategic planning.

Genuine efforts are, therefore, needed to improve agrometeorological services and make their products accessible to users.

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## **Perspectives from Regional Association II (Asia)**

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### **Abstract**

Agricultural meteorology is one of the most important fields of applied meteorology. Every year, widespread damages are caused to the agricultural sector mainly by weather-related impacts. In recent years, large parts of Asia have suffered from drought spells, frequent floods, heat extremes, and many other severe phenomena. In order to assess agrometeorological activities and strengthen operational agrometeorological services in Regional Association (RA-II) countries, a questionnaire was sent to all member countries of the region via e-mail. Most of the countries provided information indicating that they did have agrometeorological services that produce agrometeorological information and these products were disseminated to the end users. In Qatar and Bahrain, agrometeorological activities are conducted within the Ministry of Agriculture. However, in other countries like Japan and Vietnam, such operations are managed jointly by the Ministry of Agriculture and a meteorological organization. In Iran, the agrometeorological department is in the Iranian National Meteorological Service.

The survey revealed that a few countries including Russia, Japan, Mongolia, and China operate agrometeorological activities in both the private and governmental sectors. Details of the agrometeorological stations, nature of data collected, crops observed, and the various services provided in different countries in RA-II have been given with suitable examples. Progress is being made in the region in using new technologies in agrometeorology for the purpose of providing better services for users. The means of transferring agrometeorological data and statistics and operational agrometeorological services to users vary and these are described with suitable examples. Several recommendations for Operational Agrometeorological Services in World Meteorological Organization (WMO) Regions have been made. Activities of the Agricultural Meteorology Department in the Islamic Republic (I.R.) of Iran are described as an example of operational services provided at the national level.

## Introduction

Regional Association II (Asia) is the biggest of the six WMO regions (Figure 1).

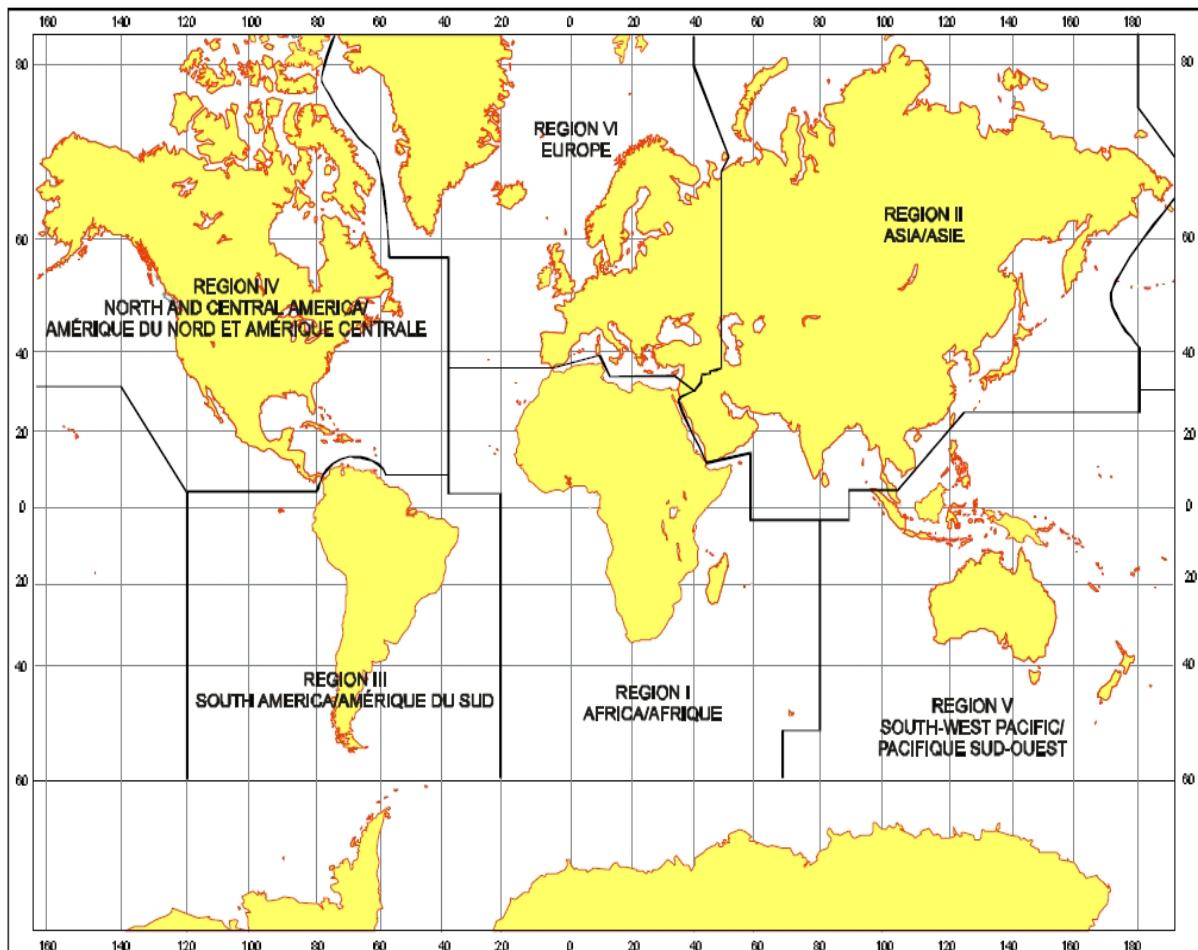


Figure 1: The six WMO meteorological regions.

The countries in RA-II are: Afghanistan, Islamic State of Mongolia, Bahrain, Myanmar, Bangladesh, Nepal, Cambodia, Oman, China, Pakistan, Democratic Peoples Republic of Korea, Qatar, Hong Kong, Republic of Korea, India, Republic of Yemen, Islamic Republic of Iran, Russian Federation, Iraq, Saudi Arabia, Japan, Sri Lanka, Kazakhstan, Tajikistan, Kuwait, Turkmenistan, Peoples Democratic Republic of Lao, United Arab Emirates, Macao, Uzbekistan, Maldives, Socialist Republic of Vietnam.

Regional Association II covers a vast expanse of the Indian Ocean and part of the Pacific Ocean and contains a large and diverse range of ecosystems, including desert, forests, rivers, lakes, and seas. The desert extends from east to west encompassing central and western Asia. Each country has a different climate regime.

Compared to other WMO regions, the Asian region includes the highest mountains, the rainiest areas, and the driest deserts, with their associated variation in culture and biodiversity. Over the long period of human occupation in the region, exploitation of natural resources, urbanization, industrialization, and economic development have led to land degradation and environmental pollution. Climate change and climate variations also represent future stress.

## **Current Status of Agricultural Meteorology Activities in Regional Association II**

In order to assess agrometeorological activities and strengthen operational agrometeorological services in RA-II countries, a questionnaire was sent to all member countries of the region via e-mail. Because of the shortness of the time for preparing this paper, we have received only a few replies. The replies have been reviewed and prepared for consideration in this workshop. Also, we used some information from this questionnaire and other questionnaires that we had before.

The first question pertains to the availability of agrometeorological services, date of establishment, and service provider. Most of the countries provided information indicating that they did have agrometeorological services that produce agrometeorological information and these products were disseminated to the end users.

The first country in RA-II that initiated agrometeorological operations was the Republic of Kazakhstan, which started its activities in 1922. Later, India in 1945, China in 1953, Vietnam in 1960, and Iran in 1978 joined this activity. The last country to begin a service was Bangladesh, which started its operations in 1986.

Affiliation of agrometeorological departments in RA-II is very different. For instance, in Qatar and Bahrain, agrometeorological activities are conducted within the Ministry of Agriculture. However, in other countries like Japan and Vietnam, such operations are managed jointly by the Ministry of Agriculture and a meteorological organization. In Iran, the agrometeorological department is in the Iranian National Meteorological Service.

The survey revealed that a few countries including Russia, Japan, Mongolia, and China operate agrometeorological activities in both the private and governmental sectors. In other countries, such as Iran, the government is solely responsible for agrometeorology.

Results obtained from the replies indicate that horticulture, fisheries, animal husbandry, forestry, and crop production activities are the primary sectors receiving information from the agrometeorological services of member countries. Some countries such as Bangladesh focus only in the farming sector exclusively; while Japan, Nepal, Vietnam, and Thailand have a wider scope, serving all the above-mentioned sectors.

The survey revealed that in Bangladesh, Nepal, Kazakhstan, and Laos there are no agrometeorological stations. They only record data at agricultural centers and provide it to users. Agrometeorological observation in these countries depends on specific case requirements.

The number of agrometeorological stations in each country varies widely, as shown in Figure 2. In Vietnam, about 15 agrometeorological stations are classified as essential and the remaining are subsidiary stations. In Uzbekistan, two stations out of five are considered specialized agrometeorological stations and three other stations are called operational subdivision.

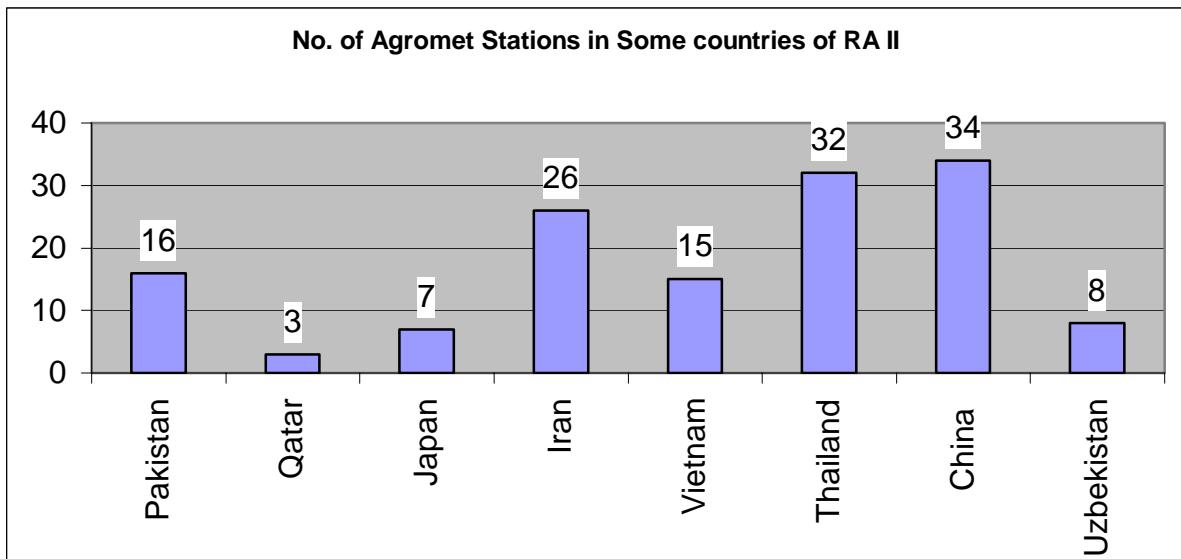


Figure 2: Number of agrometeorological stations in RA-II countries.

The Republic of South Korea owns one main and nine supplementary agrometeorological stations. In Japan, there are seven stations in total for this purpose. In India, there are some agrometeorological stations that conduct study and research activities in four different regions, namely Pune, Rahur, Anand, and Bangalore.

There are two agrometeorological stations in Mongolia, which observe parameters on wheat and potatoes and six other stations perform activities related to cattle, sheep, and goat.

There are 50 stations in China that study meteorological parameters for field crops, gardening, forestry, and pasture.

Regarding the kind of observation, most of the countries make biometrical measurements and soil and phenological observations in addition to climatological observations. However, only a few members, like Korea, do one or at most two kinds of observations mentioned in the questionnaire.

Regarding agrometeorological bulletins, most countries, including China, Korea, Mongolia, Bahrain, and Pakistan, produce agrometeorological data and information such as 10-day or monthly and growth-season bulletins. Moreover, other countries produce various bulletins in different periods. For example, in the I.R. of Iran, all the climatic, phenological, biometrical, and soil data are produced in weekly, 10-day, monthly, and seasonal bulletins, and also specific reports are issued regularly.

Agrometeorological weather forecasts are one of the most important items focused in these bulletins. In this context, short- and long-term forecasts bear particular importance in bulletins, which are widely applied by users.

Short-term predictions are used in cultivating operations such as the suitable date for applying pesticides, irrigation, and date of planting in different short-term periods.

Long-term predictions, provided based on statistical methods, are also issued by Bangladesh, Nepal, and Laos. These kinds of predictions lack agrometeorological forecasts and they

suffice only for weather predictions with a lead-time of 48 hours. In addition to weather predictions, some countries have agrometeorological forecasts that may include some piece of advice for operational agrometeorological services. It should be noted that sectorial requirements of some users upon request might be met through preparation of special bulletins giving the probability index in the forecast. Such special cases are among additional obligations of these services. The agrometeorological forecasts depend on the variety of vegetation and climate of each country.

Considering the climatic variations in different countries in Asia, most of the existing cultivated crops in the world are grown in this region. Regarding the fact that each cultivated crop has a prominent role in the country, the agricultural meteorology related to that specific crop is studied and included in the bulletin provided for the crop.

Wheat is the main agricultural crop studied and observed in Bangladesh, Iran, India, and China. Parameters related to rice are observed in South Korea, Uzbekistan, Iran, Thailand, India, China, and Laos.

The survey indicates that fruit trees are the other orchard plants being observed and studied from an agrometeorological point of view. Vegetables such as tomatoes, cucumbers, flowers, potatoes, grapes, barley, maize, oily plants, and other cultivated orchard plants are among other cases that are considered for study and research in this field. Some advice on individual crops is provided in this regard for users.

Farmers are the primary users of agrometeorological information. In some countries, such as Mongolia, China, and Russia, cattle breeders and the private sector also use agrometeorological data.

All the countries in the region have agricultural meteorological data banks, including phenological observations for different cultivated plants and data for soils and climate. These data are classified to be processed by users.

In some countries, the applied analyzed data are available. Data quality controls based on standards are regularly accomplished.

The period of climatological data is from 4 to 25 years in different countries. In some countries, climatic information covers a period longer than 70 years, but data on soil and plants usually cover short statistical periods. Information in databases is recorded on paper. However, data files are usually offered on electronic copies for the users.

Agricultural meteorological statistics and data including general information and bulletins for agricultural meteorology are offered free of charge in all countries. In India and Iran, agricultural meteorological data and statistics are free of charge only for the researchers and scholars. Other users are expected to pay related charges based on approved tariffs.

In Kazakhstan, some costs for giving agricultural meteorological data and statistics and bulletins for operational agrometeorological services are also received from private sector applicants. Governmental sectors receive agricultural meteorological data and statistics free of charge.

In most of the countries in the region, users of agricultural meteorological data, statistics, and their products such as bulletins are connected to governmental sectors. Farmers do not receive the information directly through the yearbooks, but receive it through the Ministries of Agriculture and Natural Resources, Forests, and Pastures and Animal Husbandry.

In South Korea, Uzbekistan, and Mongolia the meteorological services, in addition to providing data for agricultural ministries, offer the information directly to the farmers.

In Kazakhstan, Iran, Thailand, and India, in addition to related agricultural ministries and organizations in the government, these data are transmitted to the large industrial and cultivation companies. Sometimes specific bulletins for operational agrometeorology are provided to these users. In all of the countries, researchers, TV broadcasters, and print media organizations are considered as the important and essential users.

The means of transferring agricultural meteorological data and statistics and operational agrometeorological services to users vary. In some countries, such data are disseminated online and via establishing direct communication links; while in others, data are provided in print and mailed to the users.

In Bangladesh, Nepal, and Laos, data are printed and sent to the users; while in Qatar, Japan, Vietnam, Uzbekistan, Kazakhstan, Iran, Thailand, China, and Mongolia, the agrometeorological data and bulletins are provided in the form of hard copy and electronic data files. In most countries of the region, time-critical news and information are broadcast publicly, particularly to farmers through mass media.

Mongolia, China, India, Thailand, Iran, and Uzbekistan have a mass media system to disseminate necessary data during the growth period. One of the most important duties of National Meteorological Services (NMSs) is early warning to mitigate the impacts of natural disasters. In agrometeorological operations, these types of warnings can play a crucial role in improving the farm operations and lead to a better financial situation for farmers.

All of the countries are trying to do more operational services for agriculture. Services such as early warning of weather disasters, untimely extremes, and plant pest and disease forecasting are the most frequent services reported.

Early warnings, the most important operational service, are prepared in the form of notifications and announcements by NMSs in all the countries. These are given to the authorities in the agrometeorological division to adopt measures for mitigation of natural disaster impacts.

In some countries, these warnings, in addition to NMSs, are made by other organizations. For instance, in Qatar, early warnings are announced by the Agricultural and Water Resources Division. In Vietnam, the Ministry of Agriculture is responsible for early warnings. In South Korea, a joint committee comprising of South Korean NMHS and the National Institute of Agriculture, Science, and Technology makes them. In Laos, a joint committee makes the early warnings for users, relevant organizations from the weather prediction division, and flood prediction and warnings sector. In some of the above-mentioned countries, there are defined systems to consider these early warning issues to apply methods to mitigate the natural disaster consequences.

The survey shows progress in using new technologies in agrometeorology for the purpose of providing better services for users. Vietnam uses GIS and modeling methods. While Bangladesh, Nepal, South Korea, and Laos do not yet use them. Japan uses GIS and modeling in its prediction and crop-growth measurements function. Uzbekistan uses satellite data in agrometeorology to monitor area under cultivation. Kazakhstan uses GIS and modeling for grains prediction in agrometeorology. Mongolia, India, and Thailand use various software facilities to make agrometeorological data operational.

Evaluation of the effectiveness of agrometeorological information and bulletins on agriculture indicates that the products serve gardening and field crops most effectively.

Analyzing feedback of services from the countries by categories shows a high effectiveness rate as follows:

A) Gardening and field crops:

- 60 percent in Qatar and Vietnam;
- 90 percent in South Korea;
- 75 percent in Kazakhstan;
- 50 percent in Iran; and,
- 80 percent in India and China.

B) Horticulture:

- 25 percent in Qatar;
- 10 percent in Vietnam, Kazakhstan, and South Korea; and,
- 20 percent in Iran and India.

C) Forestry:

- 10 percent in Vietnam, Iran, and India.

D) Animal husbandry:

- 5 percent in Qatar;
- 10 percent in Vietnam and China;
- 15 percent in Kazakhstan; and,
- 30 percent in Mongolia.

E) Fisheries:

- 10 percent in Vietnam.

Analysis of the results indicate that most activities in the regional countries happen in farming and other activities like horticulture, fishery, and animal husbandry and they vary depending on different countries. In addition, there might be other activities of little importance as well.

The major problem of most countries is the long distance between the place of producing data and the place of application. This distance mostly causes delay in receiving and decreasing efficiency of the data.

## **Recommendations for Operational Agrometeorological Services in WMO Regions**

Basically, in developing countries, most of the agrometeorological activities are concentrated on producing data. Application of the data in agricultural practices is less important. For instance, data of phenological phases and biometrical measurements of crops are collected in agrometeorological stations; however, they are rarely used in decision making and executive actions. What are the main reasons?

The following are some major reasons:

1. Experts of many disciplines in the agricultural ministry are not familiar with applications of agrometeorological data in agricultural practices like planting, protecting, and harvesting steps of the gardening and field crops. Disciplines like animal husbandry, fishery, and plant protection use agrometeorological data and information inadequately. In this regard, FAO can play an effective role in countries which NMHSs and Agricultural Ministries are distinct sections, because agricultural experts have little information about the application of agrometeorological data. Perhaps, regional, joint training courses and workshops with the cooperation of WMO would be useful in promoting application of agrometeorological data.
2. There is not a pronounced plan for agrometeorological activities. For making agrometeorological data applicable and advancing agrometeorological stations in most of developing countries, requests of end users were not taken into consideration. This is more obvious in countries where NMHSs and agricultural departments are distinct. In some countries where agricultural and meteorological activities are located in one ministry, problems of coordination are less. However, it seems this is a major problem in most of the countries. One solution is the establishment of joint committees between NMHSs and agricultural department staff.
3. There is no defined feedback for assessment of the applicability of operational agrometeorological data in various disciplines of agriculture. Feedback can promote required reforms of operational services of agrometeorology.
4. There are shortages in experimental instruments for agrometeorological activities like soil moisture tools in most of the transition countries. There is no specific program for processing an application; data are only being archived.
5. Little attention is given to agrometeorological research and studies like estimating yield, chilling, relationship between meteorological parameters and growth and geographic distribution of field crops, and long-term predictions in various strategic and tactical parts of agriculture.
6. We do not have distinct studies about the effects and roles of agrometeorology in increasing agricultural production and food security of nations. Does agrometeorology basically play any role in increasing agricultural production? What will happen to yield prospect if agrometeorological services are removed? Replies to these questions can justify the importance and the value and funding of countries in these fields.
7. The role of extension should be highlighted in making agrometeorological activities operational and agrometeorological knowledge more important. In most countries, agrometeorological data are not sent on time to the end user. In most of the countries, agrometeorological information is published in newspapers and broadcast via TV and radio and there is less direct dissemination to farmers through bulletins and warnings.
8. Most farmers are not familiar with agrometeorology and its products and services.
9. Many agrometeorological products/services are not understandable to farmers because of their complexity.

10. Some agrometeorologists do not have a good understanding of the actual meteorological information/services needed by farmers.
11. Farmers getting to know meteorology do not believe in the usefulness of agrometeorological information for increasing and protecting yields.
12. Because of lack of suitable, fast, and extensive transmission methods, the potential users receive useful information with too much delay; even the most accurate data, when expired, are not useful to anyone.

### **Agricultural Meteorology Department in I.R. of Iran**

Agricultural meteorology is one of the sub-administrations of the general Department of Meteorology. The network of stations provides meteorological data for agricultural and/or biological purposes and makes other meteorological observations under the programs of agrometeorological research centers and other relevant organizations. There are 26 agricultural meteorological stations at the present.

Each agricultural meteorological station is located at experimental stations or research institutes for agriculture or horticulture.

At each agricultural meteorological station, the observing program includes the standard climatological observations, observations of physical environment, and observations of the biological environment.

Agricultural meteorological departments have a specialized staff of two Master of Science experts. This department also has suitable scientific relations with educational and research organizations, especially the Ministry of Agriculture and the Karaj Agricultural College of Science & Meteorology higher-training institute as well.

### **Main Activities of the Agrometeorology Department of Islamic Republic of Iran Meteorological Organization (IRIMO)**

#### *1) Monthly Agrometeorological Bulletins*

The results of biometric measurements and phenologic observations for different crops of the agricultural meteorology research stations are provided in the form of monthly bulletins and sent to the agricultural meteorology department. This information is kept in the information center for users. In addition to sending the information in electronic form, a hard copy of the bulletins is sent to the agricultural meteorology department as well.

In addition to this information, there are meteorological parameter observations and temperatures at different depths of soil.

Each year, every station dispatches 12 monthly bulletins for any crop, and a growth-season bulletin at the end of the season.

#### *2) Weekly Agrometeorological Bulletins*

This information includes crop phenologic data, climatic information, weekly growing-degree days, and growing-degree days from sowing time to date, which are sent to the agricultural meteorology department.

Every year, agricultural meteorological research stations send 52 pages of weekly agricultural meteorology information to be inserted in the weekly meteorological organization bulletins.

### *3) Ten-Day Agrometeorological Bulletins*

Ten-day Agrometeorological Bulletins are sent at the end of each decade of months via the Switching System. During the year, every station sends 36 sheets of 10-day information for certain crops, which is then kept in the information center of the meteorological organization.

## **Future Plans of IRIMO for Strengthening Operational Agrometeorological Services**

There is a need to:

- Increase the number of agrometeorological stations in the major agricultural regions;
- Improve the number of crops and fruit trees under examination in agrometeorological stations all over Iran;
- Provide a concise agrometeorological database, including phonological and climatologically data;
- Establish stronger scientific relations between the agrometeorological department and international organizations; and,
- Enhance the extension in agrometeorology through the right type of intermediaries.

## **Plans for Enhancement of Operational Services of Agrometeorology**

- All the countries have a strategic plan for more applied agrometeorological services.

## **Recommendations of Regional Association II NMSs for Strengthening Operational Agrometeorological Services**

The following recommendations are made to strengthen operational agrometeorological services in Regional Association II:

- Developing agrometeorological forecasting centers;
- Developing forest meteorology, predicting yield/biomass before planting;
- Studying sand movement or desertification elements;
- Using AMS for measuring climatic elements and soil moisture;
- Measuring evapotranspiration;
- Establishing the domestic infrastructure of a flux measurement network;
- Developing agrometeorological models for crop growth and development and evaluate agromet environment using agromet advice model "AMBER";
- Integrating agrometeorological information services;
- Collaborating with the World Agrometeorological Information System (WAMIS);
- Cooperating with the International Society of Agricultural Meteorology (INSAM);
- Strengthening agrometeorology networks including station density, fine equipment, and capacity building;
- Providing more detailed agrometeorology information; and,
- Developing the infrastructure of the information network to transfer agrometeorological information to farmers more easily and faster.

# **Agrometeorological Services Required Under Emergency Situations: An Example from Afghanistan**

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## **Abstract**

In this paper, the requirements under emergency situations for a fully operational Agrometeorological Services in Afghanistan are presented. The requirements include: installation of meteorological stations, data transmission, data archiving, data control, data processing, analysis, results, and products issued. Important consideration has been given to the development of agrometeorological database, information systems, and statistical analyses. The paper also describes the process of capacity-building through intensive on-the-job training courses in Kabul and the use of advanced agrometeorological tools. All of these tools are necessary to respond to any question emanating from the Ministry of Agriculture and Animal Husbandry (MAAHH), as well as from the decision-makers in the country such as: the Food and Agriculture Organization (FAO), the Famine Early Warning System Information Network (FEWS-NET), the Ministry of Rural Rehabilitation & Development (MRRD), the World Food Program (WFP), the Ministry of Irrigation, Water Resources and Environment (MIWRE), and food security audience, in general. All these tools, equipment, and means are presently being used in Afghanistan.

## **Introduction**

An FAO project supporting the Food, Agriculture and Animal Husbandry Information Management and Policy (FAAHM) Unit gathers all available information regarding:

- Agro-economic and statistical data/information for food crops;
- Historical meteorological data (time-series) from the Afghan Meteorological Authority (AMA); and,
- Historical crop yields/production (time-series emanate from the Central Statistics Office [CSO]).

The project supports the establishment of an agrometeorological unit located under the FAAHM Unit within MAAHH. A fully operational agrometeorological service in Afghanistan will still require the remainder of 2004 for a full-time team of well-trained agrometeorologists (International Expert + five local specialists + logistics support) to implement the program. To build such a system, the agrometeorological project of the Food Security and Early Warning System of the FAO Emergency Programme, includes the following steps:

- Establishing a wide-rainfall stations network, (at least 205 reliable stations for this preliminary period), combined with a crop-monitoring network (80 reporting fortnightly stations: crop stages/pasture and condition;
- Installing 26 complete agrometeorological stations (including 6 automatic complete stations with solar panel) over all the country;

- Designating focal persons at the regional agrometeorological office levels (Hirat, Mazar-I-Sharif, Kunduz, Kandahar, Fayzabad, Jalalabad, and Ghazni);
- Defining efficient scheme of circulation of the meteorological and agrometeorological information (modern transmission tools);
- Installing appropriate computer programs for data entry, management, and analysis of agrometeorological data;
- Preparing required meteorological reporting forms such as Microsoft (MS) Excel worksheets, mailing list for users of agrometeorological bulletins, and checklist for an agrometeorological spreadsheet bulletin, etc.;
- Defining the layout and contents of the decadal, monthly, and yearly agrometeorological bulletins;
- Setting up an agrometeorological data management system, including Crop Water Requirement Satisfaction Index and utilization of remote sensing products (for staple and pasture);
- Setting up an integrated database for data collection, analysis, and reporting on early warning and food security;
- Setting up an operational methodology (crop-yield forecasting model) for the conduct of crop assessment and food production;
- Setting up an operational methodology for the conduct of pasture assessment (Livestock Early Warning System [LEWS]); not yet established;
- Improving and standardizing permanent agrometeorological early warning information system methodologies, tools, and techniques;
- Organizing workshops and on-the-job training at different levels and matters regarding agrometeorological techniques, methodologies, and computer science to raise the level for the local staff; and,
- Setting up an operational website and information system.

## **Inputs**

This part of the paper explains the meteorological situations in Afghanistan. Afghanistan is an arid to semi-arid country whose agricultural production depends on the availability of water, either as direct rainfall or in the form of irrigation. In Afghanistan, rainfall data is difficult to access due to the fact that most of the old time-series was stopped in 1977 or, in some cases, in 1992. Meteorological stations have been damaged and no rainfall data are being collected (except from four agrometeorological stations: Kabul, Jalalabad, Mazar-I-Sharif, and Herat installed in 1999 under the FAO project). The Meteorological Department and the Institute of Meteorology are not functioning regarding field observation.

Due to this particular situation, agrometeorological observations have become a very important task for the country. Due to the area of the country (646,000 km<sup>2</sup>) and the very erratic spatial distribution of rainfall for mountainous regions, data from a large network of rain gauges are required. In addition to rainfall, other parameters are highly important and needed in Afghanistan. They are: snowfall and snow cover, upon which most of the country's irrigated sector depends; and frost and low temperature. Accurate and timely information on agrometeorological observations, including all weather parameters, actual planting time, areas planted, harvested crop, and crop conditions and pasture are highly needed for each agro-ecological zone and each district in Afghanistan. In other words, the agrometeorological approach to helping agriculture can only be effective if reliable, real-time, and timely data are available.

The timely collection and the proper utilization of agrometeorological information help promote increased farm profits under favorable weather conditions or decreased farm losses under unfavorable conditions. In this sense, a fortnightly form of crop and pasture monitoring is used for 80 sites that cover the most important agricultural areas in Afghanistan. The field observations come through pre-printed forms from: agriculture services, some non-government organizations (NGOs), and meteorological department staff.

To be accurate and reliable, the forms are filled out with care regarding the quality of the data recorded, the representation of each site of observation, and the timetables of summaries of all observations according to the international norms in force emanated by the WMO.

### **Crop and Pasture Monitoring Forms**

Rules were followed regarding:

- Levels of measures (heights of sensors): same for all selected stations;
- Time and numbers of daily observation, to be standardized for the whole country;
- Use of standard and same type of instruments compliant with the official network that we installed with the agrometeorological FAO project; and,
- Respect of standard for representation of the sites of measures (security problems and some fund limitations have hampered the best choices concerning the site's representation).
- Regular reporting procedures regarding: Timely data transmission; Data collection and archiving using software such as FAO-AgroMetShell, MS-Excel, and MS-Access; Data calculation and analyses of weather impact on crop production (several agrometeorological tools are used presently in the FAO project).

The need for observation requirements for Afghanistan regards essentially the biological information with fortnightly frequency for all administrative areas for wheat, maize, rice, and barley. The observations are carried out on crops and rangeland conditions in the neighborhood of each installed rain gauge station or complete meteorological station (in general, less than 5 km radius from the meteorological station). The goal and objectives of biological observation is to assess crop status, pests, and diseases incidence; pasture availability, plus livestock movement route and transhumance. These observations concern, at a glance: crop stages, crop growth and condition, adverse effects, forecasted crop harvest for the current year in comparison to previous year's harvest.

Field crops and pasture reporting actually practiced in Afghanistan are:

- Phenological: main stages (easy to observe) for three staple crops;
- Crop condition;
- Pasture condition: agrometeorological support services for livestock (relation between water, grazing, and livestock condition) in conjunction with the LEWS. However, this work is not implemented yet. The cattle breeding nomads are the Kuchi in Afghanistan. The Kuchi comprise an estimated 7 percent to 10 percent of the Afghan population. They also form the Peulh (Foula) in all of West Africa.
- Phytosanitary conditions: the status of phytosanitary conditions concerns insect infestations. For instance, Moroccan locust attacks in areas infested and treated (as well as other insects) depend on the agroecological zone areas and incidence of plant diseases.

All of their apparitions are strongly linked to: a) essentially the climatic conditions that are harmful, especially for the critical phenological period; b) plant species/varieties; and c) farming practices in the production area. Observations, in cooperation with the Plant Protection Department, concern frequency, incidence, and recognition of the danger in the fields. The information collected is very useful for Plant Protection Services.

- Phyto-sanitary treatments: eradication of weeds and frequency and use of any chemical products;
- Planting and replanting times (including delays) and average length of season by agricultural area;
- Input used: fertilizer [Urea, Diammonium Phosphate (DAP)], manure, phytosanitary products, or shortage of inputs.

## **Meteorological Information**

This section provides details of the information that is collected and summarized into the decadal agrometeorological bulletin, along with the type and frequency of observations at each agrometeorological station. In this matter, each parameter is recorded daily along with the values accumulated and/or calculated for each current decade, which are sent using a timely transmission tool to the respective FAO sub-offices in Afghanistan.

The goal of physical observations is to know more about the biotope surrounding the field of cultivation. In other words, to know more about the weather conditions that regularizes the life of the plants. For our purpose, meteorological data are recorded at various types of stations (traditional rainfall and automatic agrometeorological stations). All the agrometeorological stations are situated in agricultural areas where instruments are exposed to atmospheric conditions similar to those of the surrounding crops. At these complete stations, air temperature, humidity, wind speed, and sunshine duration are typically measured at 2 meters (m) above ground level. Climatic data for selected stations are regularly collected in addition to the respective coordinates (latitude, longitude) and elevation. To maintain the accuracy and representation, the instruments are installed inside radiation shelters having natural ventilation except for rain/snow gauges.

The weather variables collected in Afghanistan are:

- Total daily rainfall in millimeters (mm);
- Intensity/frequency/duration of the rain (rain recorder);
- Snowfall: snow depth and water equivalent in mm;
- Decadal rainy days;
- Air temperatures (mean, maximum, minimum);
- Daily temperature feature (thermograph);
- Relative humidity in percent (hygrograph);
- Wind speed at 2 m level;
- Sunshine duration in hours;
- Evaporation (pan A evaporometer) in mm and wind speed at 0.5m, plus water temperature; and,
- Dew point temperature.

On the other hand, information about rivers' flow discharge and hydrometeorology information in general can be added, in relation with the importance of winter snow (in collaboration with Afghan Water Resources and Irrigation Departments).

## Determination of Some Derived Parameters

The list of the derived outputs follows:

- Decadal Potential Evapotranspiration (PET): calculated according to Penman–Monteith method, (decadal step);
- Or, estimated by Pan Evaporation class A or, estimated by satellite Aqua/MODIS method (daily step);
- Decadal Water Requirements Satisfaction Index (WRSI): Crop Water Balance Model (decadal step) using FAO AgroMetShell program;
- Soil water stored at each end of the decadal;
- Water deficits and/or surplus; and, actual evapotranspiration (the use of such a water balance model to analyze the impact of agrometeorological conditions, essentially water, extends the scope and abilities of agrometeorological methodology).
- Historical WRSI for wheat, rice, and maize to determine minimum, maximum, and standard deviation WRSI values for the available time-series (1942 to 1977) in Afghanistan (useful as a predictor for the future crop-yield forecasting model);
- Mean water requirements (in mm) for different planting dates (wheat, barley, rice) and different crop coefficients by decade and each selected site (we change the planting date to see the variation of water requirement);
- Simulation and determination of the best planting dates;
- Accumulated degree days for different thresholds ( $0^{\circ}$  and  $10^{\circ}$  C);
- Global radiation estimated from sunshine duration in mm water equivalent (not yet implemented);
- Soil moisture (for Agricultural Research Station only) in percent of the soil volume;
- Satellite files and pictures (remotely sensed data: Normalized Difference Vegetation Index (NDVI), snow cover and depth, estimated rain (RFE) and actual daily evapotranspiration);
- Snow-cover surveillance, ground observation, and expected potential water availability (water supply) during the summer for irrigation.

## Livestock Transhumance and Pasture Availability

This section refers to the LEWS. In the future it will be included in the workplan of the FAO Agrometeorological Project due to the importance of livestock in Afghanistan. The assessment will be done by using the following:

- Biomass estimated by NDVI, and water balance model used for grazing and forage (rangeland index: 100 days cycle length and  $K_c=1$ );
- Transhumance and livestock movement routes and date's observations;
- Hydrological information (in collaboration with irrigation world bank project);
- Level of water table in the wells;
- Rivers stage and discharges, spring stream, and river flows and,
- Satellite imagery (to be received through Rome FAO Headquarters and United States Geological Survey (USGS), Afghanistan, MS Windows product).

The NDVI assesses covert vegetation according to the total biomass (reflecting biomass levels) and freshness (water stress in crop or grass result in lower NDVI values). The trend in NDVI from decade to decade for specific areas is a good indicator for onset of rain, dry spells, and the quality of the season. Comparisons with previous decade and previous years or average values provide useful information.

Decadal files of NDVI are received at decadal steps via e-mail through the Artemis system at FAO headquarters in Rome, Italy, and from which numeric values are extracted and analyzed, summarized, and can be used as a predictor in the future into the Crop Yield Forecasting Model. The staff of the agrometeorological project are summarizing and analyzing the overall NDVI time-series (several years, since 1998) for Afghanistan.

### **Aqua/MODIS Estimated Evapotranspiration PET**

#### **National Aeronautics and Space Administration (NASAs) Earth Observing System (EOS)**

The evapotranspiration will be retrieved at 500 m spatial resolution and composite on an 8-day basis using the Aqua/MODIS satellite instruments. Evapotranspiration is described as a fractional value called “Evaporation Fraction (EF),” which is a fraction of latent heat energy to available energy. This value represents not only the “dryness” of the land surface, but also the characteristics of the land surface in terms of energy partitioning, which have a large influence on the local and regional climate and environment.

Professional staff have been trained to analyze these images and in the use of the appropriate hardware and software equipment. Satellite images are widely used in semi-arid areas. Decadal digital files are obtained through the sensors installed onboard National Oceanic & Atmospheric Administration (NOAA) and other satellites. A full-system process for entering and processing the data and summarizing results in MS-Excel files have been put into operation in Afghanistan this year.

### **Processing and Analysis**

Calculation requirements refer to the statistical analysis of weather data sets and data acquisition and processing. Technical outputs for each agroecological zone or agricultural area are produced but preliminary control must be performed. The procedure for the statistical correction and completion of partial or missing weather data are:

- Data quality checking (data error);
- Approximate (estimating), formatting, and replacement of missing data;
- Completing data sheet by data interpolation;
- Analysis of the statistical homogeneity of data series;
- Determination of statistical laws that govern decadal, monthly, and yearly rain distribution for the Afghanistan weather conditions;
- Data entry (worksheets and databases);
- Second data checking on the entered data.

## Preliminary Processing and Analyzing of Meteorological Data

This section discusses the preparation of agroclimatic studies. Many methods and tools are used regarding several climatic parameters. As preliminaries studies, an agroclimatology analysis includes:

- Calculation of decadal rain from monthly values of rain;
- Calculation of derived parameters such as solar radiation (sunshine duration), daylight duration, potential evaporation (PET), etc.;
- Calculation and maps for the mean meteorological conditions and for the actual observed values in addition to the departures from the agroclimatic normal conditions (rainfall, temperatures, frost, snow days, rainy days, starting of the rainfall season, etc.);
- Production of output maps for the mean planting dates, both as actual values and as departures from the medium conditions (at the beginning of each agricultural season);
- Production of output maps of the mean cycle length for the main crops (technical inquiries);
- Production of output maps of the mean Water Requirements Satisfaction Index for three planting dates, water storage capacity of the soils and for the main crops (three for Afghanistan);
- Production of output maps of the mean yield for wheat, maize, barley and rice crops, plus tables;
- Calculation of decadal rainfall probabilities (Pearson III Law);
- Calculation of decadal PET probabilities for the mean stations (Gauss Law);
- Determination of favorable crop planting dates using water balance and rainfall probabilities. Notion of agrometeorological risk;
- Production of output maps of the average NDVI for Afghanistan (1998-present);
- Determination of “average” dry and wet period in days (Using Markov’s Chains);
- Determination of “median” starting and ending of rainfall season. Daily records not yet obtained;
- Determination, for irrigation purposes, of the relationship between Pan A Evaporation and actual ET;
- Determination of agro-ecological zones (on climatic basis: rain and temperatures) for Afghanistan. Using Principal Component Analysis (PCA) method;
- Relationship altitude vs. length of growing season (using/drawn by Hopkins phenological approach);
- Determination of relationship between elevation and PET, to correct PET values against elevation (draw isolines on mountainous areas);
- Table of exact location of selected stations using Differential Global Positioning System (DGPS) instrument;
- Map of location of selected stations;
- Mapping of agro-ecological zones: New map obtained through climatic approach;
- Map of hydrologic basins of Afghanistan;
- Map of capacity soil storage (water-retaining) and useful deep soil; and,
- Tables for probabilities calculated by incomplete Gamma law (decadal rainfall) and Gauss law (PET), for the stations where the data series are available and sufficient.

## **Analyses Related to the Agroclimatic Risk Atlas for Afghanistan**

This document is in preparation and will be edited as a technical document serving as reference for major climatic elements influencing agriculture. The *Agroclimatic Risk Atlas in Afghanistan* should include the analysis of the variables: rainfall, temperature, radiation, potential evapotranspiration, water balance, and wind.

### **Data Transmission**

In the FAAHM Unit, 33 Codan radios to transmit the data from stations to the Kabul office have been purchased and will be installed soon. The existing radios and e-mail connections available at the FAO sub-offices level within the country can be used for transmitting agrometeorological information. For some areas, the recorded data are physically carried during the organized field trips or by the stations' staff.

### **Outputs and Products**

Tasks of the future agrometeorological service, after its complete establishment, should be to:

- Provide all agro-climatic information on the Natural Ecological Regions (agro-ecological zones) for Afghanistan; especially regarding rainfall, temperatures (air and soil), wind, radiation, air and soil humidity, snow, and frost;
- Help with the planning and improving of agricultural projects and institutions according to the renewable and natural resources available by providing information, which will be precise and applicable;
- Establish a basis of knowledge permitting changes in time concerning the climate or natural elements related to weather reporting, and the impacts on overgrazing, deforestation, desertification, drought, and variation of biological diversity;
- Define the microclimatic (water and energy balances) zones, with specific characteristics, which are worthy of special attention from the programmers and decision makers of agricultural projects when determining these enhancements.

The results and products of agrometeorological projects will also contribute to the development, planning, and design of agricultural projects in Afghanistan. Consequently, these efforts will take into account the following objectives:

- Providing useful information for soil and water conservation;
- Reducing the risk from unusual or extreme meteorological events;
- Improving availability and management of irrigation water;
- Assuring adequate aeration through adequate drainage;
- Assuring adequate water availability for economical crop production;
- Selecting more suitable crops for the climate;
- Optimizing climate fertility interactions on yields;
- Forecasting wheat yield and phenological phases;
- Preparing adequate agrometeorological bulletins and climatic advice (that farmers can use for improving dry land and irrigation agriculture production).

At this stage, the agrometeorological project can provide for agricultural research, agricultural production, meteorological departments, FAO projects, various technical

documentation products, and guidelines for expanding over-all activities related to agrometeorology.

### **Yield Forecasting Model for Wheat in Afghanistan**

The practical applications of agrometeorological forecasting resulted in the development of scientific hypotheses to define the process description to which agrometeorological conditions affect crop production. These relationships will be defined with the help of statistical processing of agrometeorological observations data. They are described by prediction equations that enable the calculation of the expected yields 1 or 2 months in advance using a crop simulation model. There are a variety of generic forecasting methods that can be applied to crop forecasting. The WRSI in percentage of “area averaged” is used as a predictor to build the Afghan model at the level of agroecological zones. Phenological forecasts of crop and natural fodder development are not finished yet. The degree-days method with different thresholds that cover the staple plants in Afghanistan is also used.

These forecasts should be distinguished as very important, as compared to many other types of agrometeorological forecasts. Phenological forecasts include: 1) dates when field operations are initiated in winter and in spring; and, 2) the beginning of the growing cycle (dates) for main plant development stages (critical phenological phases for crops and pasture plants regarding water, frost, etc.) and for harvest time. The majority of phenological forecasts are characterized by an adequate validity.

As said above, to determine the dates of main crop development stages and duration of the inter-stage periods, we use the method of cumulative active temperatures (interrelationship between the plant growth and development factors).

### **Decadal Agrometeorological Outlook Using Rainfall Probabilities**

For each station the following parameters are calculated: tables of rainfall probabilities, and decadal PET probabilities. It is useful to know in advance the probable water availability for crops during the next period for each agricultural area. This helps us analyze the agrometeorological risk in advance and inform the farmers through Extension Services so they can make better decisions.

### **Agrometeorological 10-Day/Food Security Monthly Bulletin and End-of-Season Rainfall Analysis**

Advice to farmers has not yet begun. This list shows the kind of advice that can be given regularly to the farmers through research institutions in Afghanistan:

- Choice of the new species/varieties to be introduced in Afghanistan (FAO emergency-improved seed production in Afghanistan);
- Sowing and re-sowing dates according to the prevailing weather conditions;
- Sowing density and number of plants per hole according to the character of the started rainfall season;
- Dates for application of fertilizers (weather forecasts at short-time step);
- Period of treatment against pests and diseases (weather forecast at short-time step);
- Date of the winding (weather forecasts at short-time step);
- Dates of harvesting;

- Dose/quantity of water supply for irrigation according to prevailing weather conditions for the sites;
- Particular advice in early summer, when good or bad snowfalls occur during the winter and expected water availability for irrigation purposes (importance of the area that can be grown): What the farmers have to do in concordance with the snow that falls during the current rainfall season (or not);
- Kinds of horticultural greenhouses, orientation, type of films, film thickness, heat needs in calories, water supply under greenhouse conditions, heat supply during the winter, how many months we have to warm the greenhouses, more accurate kind of heater that has to be selected for each particular agroclimatic region, etc.;
- Windbreaks and spacing between the trees, the types of trees (porosity), and space protected behind the trees. Determining which kind of trees are the most efficient; and,
- Irrigation design and scheduling taking into consideration agroclimatic (max-water requirements) conditions for the respective regions.

Common agrometeorological studies with agricultural/irrigation projects, universities, etc. This affects the way that we can use weather as a production factor for agriculture.

Different technical notes were prepared on how we can use the products that are issued by Operational Agrometeorological Service (agroclimatic information). Agrometeorological projects are organized through field inspectors with frequent field trips consisting of three teams with different itineraries countrywide. The aim is for crop monitoring of conditions and phenological stages; verification between model results and field reality; and especially to collect timely recorded data.

### **Training and Workshops in Agrometeorology**

The project organized several 1- to 2-week workshops (seven sessions) for more than 40 participants at each session. More than 200 participants were trained. The sessions have been organized by international experts with the help of national counterparts, other consultants, and specialists from the AMA, the Irrigation Ministry, and the Agriculture Ministry.

The training involved staff of various levels including training of the trainers (higher technician and engineers) as well as field observers (crop and pasture condition, pest and diseases, crop phenology) and the training of agrometeorologists (university degree) in charge of the management of an operational agrometeorological service or complete agrometeorological station.

The training sessions have been organized at the AMA's training room (Kabul/Airport), followed by general practical sessions on the field. The trainees work in agrometeorological stations/services after their training, including some students from other ministries and NGOs.

The agrometeorological training course for field staff and observers for rainfall and snowfall stations focused on the following aspects:

- Role of agrometeorological stations/network for food security MAAH/FAAHM and early warning system.
- Presentation of selected sites for Afghanistan;

- Presentation of ordinary rain gauges;
- Rain gauge installation;
- Rain measurements;
- Snow measurements: depth and water equivalent;
- Preliminary quality control data;
- Data archiving; and,
- Data transmission: radio and e-mails.

The agrometeorological training course for observers (field staff for complete agrometeorological stations) focused on the following aspects:

- Meteorology and agrometeorology (notions).
- Instrumentation (practice of observation and working instruments: rain gauge; snow gauge; rain recorder and graph examination; temperatures records (mean, mini, and maxi thermometers); soil thermometers and soil temperature; grass temperature; humidity recorder and graph examination; psychrometer - welt point and relative humidity in % using of the tables; Class A Evaporation pan with anemometer and temperature; anemometer/weathercock (wind vane); heliograph Campbell-Stokes (sunshine recorder); establishment and maintenance of agrometeorological stations (Instruments: installation and reliability). 1<sup>st</sup> degree; proper use of instruments and observation practices and how to maintain the installed equipment; quality of recording and reporting/archiving; and, data transmission (radio or e-mail)).

## **Required Software**

To achieve all the planned tasks, various software products have been used; most are listed below:

- Word-processing, spreadsheet, databases (Microsoft Office Professional);
- Statistical and processing (StatGraphics Plus);
- Drawing geographical maps and graphics (Windsurfer);
- E-mail/Internet management;
- Geographical Information System (ArcView, ArcGIS); and,
- Agrometeorological software: (AgroMetShell).

## **Conclusions**

The requirements for a fully operational Agrometeorological Services in Afghanistan have been presented. Two issues are of fundamental importance: (1) the rehabilitation of pre-war existing meteorological stations and the installation of new stations; (2) the capacity-building at local level through intensive on-the-job training courses and the use of advanced agrometeorological tools. In this way, it is possible to provide technical advice to the MAAHH, as well as to other decision makers related to food security issues.

## **Perspectives from Regional Association III (South America)**

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### **Abstract**

It is known that agricultural production still depends on daily atmospheric conditions and the climate resource, among other factors, despite the fact that rapid technological progress had been made in the last years.

An adequate and appropriate awareness of the environment feature and the forecast of weather conditions allow guidelines to be established for decision making concerning planning and carrying out routine operational activities in agriculture. The National Meteorological Services, through their agrometeorological departments, are in charge of analyzing and interpreting the behavior of the various atmospheric variables and their impact on agricultural production and orienting the outputs of this process to the farmers in order to contribute to operational decision making and planning.

A summary of how the different agrometeorological services in the Regional Association III (RA-III) work and how they provide their operational services to the different users in each country is presented here.

### **Introduction**

Agrometeorology relates the meteorological parameters with the life of animals and plants, and if used correctly, it can contribute to increased production and/or reduced damages caused by adverse meteorological phenomena to the agricultural activity. In recent years, at a global level, this branch of meteorology has been developed in an impressive way, due to such factors as the world food crisis, which has induced people to seek new techniques to increase agriculture and fishery production, enabling them to allocate greater financial resources to activities related to agriculture. In South America, where agriculture, fishing, and forestry represent 12 percent of the gross domestic product (GDP), adverse climate conditions are frequent. The need of users to know about these conditions has increased the demand for agrometeorological services and has led national meteorological services to incorporate operational areas dedicated to meet this need. Thus, nowadays, some services have gradually incorporated in their operational activities the preparation of short-, medium-, and long-term agricultural forecasts; early warning notice; and agrometeorological bulletins and advisories; and have developed agrometeorological studies with the purpose of contributing, through the use of appropriate tools and methodologies, to agricultural planning.

In order to know the evolution of weather and climate of a given place in a timely and reliable way (using a representative spatial range), it is necessary to have qualified staff and the necessary infrastructure to be able to obtain, compile, validate, analyze and store the data, in a way that it could meet the established expectations, especially if it will be used for the generation of services (WMO 2001).

The present work presents in a global way an outlook of the agrometeorological services established in the member countries of RA-III. It is based on a questionnaire suggested by the Agriculture Meteorology Division of WMO, slightly modified to obtain more information. Nevertheless, some brief responses didn't permit more detailed analysis.

The questionnaire was distributed by e-mail. Eight countries, from a total of 12 countries answered: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, and Venezuela. They provided enough elements to identify the strong and weak points of the operational agrometeorological services in each country. In the case of Paraguay and Uruguay, responses obtained in a 2002 questionnaire were used.

### **Visualization of the Present Agrometeorological Services in South America**

The Regional Association III (South America) consists of 13 countries: Argentina, Bolivia, Brazil, Colombia, Chile, Ecuador, Guyana, French Guyana, Paraguay, Peru, Surinam, Uruguay, and Venezuela (Figure 1). Twelve out of the 13 countries have meteorological services, except French Guyana.



Figure 1: Member countries of Regional Association III.

A high percentage of agrometeorological services in South America are part of the national meteorological services and depend, to a great extent, on the financial resources provided by the government; however, there are also some countries like Paraguay and Venezuela with agrometeorological units in institutions that are independent from the national meteorological

service. In the case of Paraguay; the Agriculture Research Directorate and Agrometeorological Program of the Ministry of Agriculture and Livestock is the institution that assumes the role of agrometeorological services. In the case of Venezuela, this role is assumed by the Agriculture Research Institute (INIA) and the Ministry of Environment (MARN).

Seventy percent of the national meteorological services, according to the survey (Table 1), have independent agrometeorological units concerning the operational aspects, and 100 percent of those consulted, financially depend on the governments funds, which makes them highly vulnerable to the budgetary allocation when the national economy is in crisis or when the governmental priorities change (WMO 2003).

National Meteorological Services with independent agrometeorological units									
Argentina	Bolivia	Brazil	Colombia	Chile	Ecuador	Paraguay	Perú	Uruguay	Venezuela
Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No

Table 1: National meteorological services with independent agrometeorological units.

The main users of the agrometeorological services generated in each country are, without a doubt, the individual farmers who benefit from these services in making decisions regarding daily agricultural matters, and/or planning at a medium term. In addition to farmers, current agrometeorological information is distributed through official institutions that use this information in their own management (ministries of agriculture, media, regional governments, forest corporations, agricultural and livestock services, students and researchers, and others).

### Agrometeorological Products

It is important to note that some institutions, such as the National Meteorological Services of Argentina and Peru, publish all of their products through a web site in which is possible to get information of decadal water balance, decadal agroclimatic bulletin, evolution of main crops, status of the soil moisture, daily forecasts for agriculture, and processed satellite images.

The operational agrometeorological products provided by the National Meteorological and Hydrological Services in South America are mainly disseminated through regularly issued bulletins and agrometeorological announcements, such as daily forecasts and information on special events and warnings that in the specific case of Chile, refer to frost, forest fire, and vegetable diseases and pests. The last one mentioned was suspended after a decade of issuing warnings, due to the lack of information related to the insects caught in the farms where this activity occurred.

Generally speaking, national agrometeorological services, of the member countries that were consulted, incorporate within their functions the elaboration of studies and research to support the agricultural sector. For example, the National Meteorological Service of Brazil disseminates information in support of the agricultural reform and subsistence agriculture. Chile elaborates on agricultural zoning of some regions, and provides these to the INIA, and Regional Secretariats of the Agriculture Ministry. Peru elaborates agroclimatic studies for different regions that are useful to farmers and decision makers and persons involved in planning. Bolivia carries out these activities cooperating with research institutions, etc.

In general, all the Agrometeorological Services consulted in South America provide severe weather events forecasts, but only 30 percent of the Services elaborate the assessment of the impacts caused by these events (Table 2).

	<b>Argentina</b>	<b>Bolivia</b>	<b>Brazil</b>	<b>Colombia</b>	<b>Chile</b>	<b>Ecuador</b>	<b>Paraguay</b>	<b>Perú</b>	<b>Uruguay</b>	<b>Venezuela</b>
Issuing regular agrometeorological bulletins and advisories	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Issuing early warnings/alerts as appropriate	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Helping with strategic studies, (agroecological zoning)	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
Assessment of the impact of extreme events, e.g., floods, cyclones etc.,	Yes	Yes	No	No	No	Yes	No	No	No	No

Table 2: Operational agromet services provided by meteorological & hydrological services in South America.

The evaluations are carried out in general by other organizations or are private or governmental like the Ministries of Agriculture or the Interior; with the exception of the Agrometeorological Service of Argentina, Ecuador, and Bolivia, which carry out these evaluations.

Sixty percent of the countries consulted (Argentina, Brazil, Ecuador, Paraguay, Peru, Uruguay) generate services that contribute to natural disaster reduction. Thus, for example, concerning early warnings, the totality of the Services provides some form of aid to the agriculturist by means of warnings related to precipitation events (excessive rain, hail, and drought), conditions of wind outside the normal ranks, eruption of warm or cold air masses abnormally (frost, heat waves), etc.

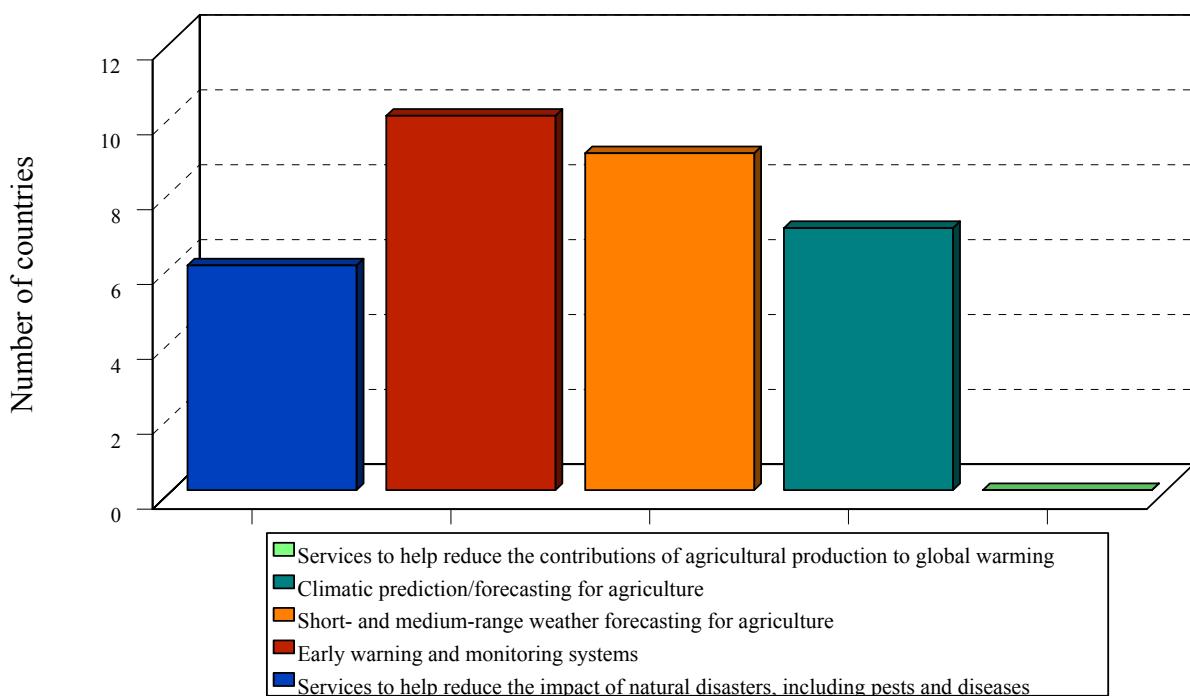


Figure 2. Important agrometeorological services provided by Meteorological Services.

As the forecasts time period extends, it is less likely that the services can incorporate them into their routine activities; this is why 90 percent of the services responding to the survey provide medium-term forecasts and 70 percent generate long-term outlooks.

	Venezuela	Uruguay	Perú	Paraguay	Ecuador	Chile	Colombia	Brazil	Bolivia	Argentina
Services to help reduce the impact of natural disasters, including pests and diseases	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No
Early warning and monitoring systems	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Short- and medium-range weather forecasting for agriculture	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Climate prediction/forecasting for agriculture	Yes	Yes	Yes	Yes	Yes	Yes	Not	Yes	No	No
Services to help reduce the contributions of agricultural production to global warming	No	No	No	No	No	No	No	No	No	No

Table 3. Important agrometeorological services provided by the National Meteorological Services.

As you can see in Table 3, from the environmental point of view, it is important to highlight that the Meteorological Services consider they are not providing specific products to help diminish global warming; which is related to the agricultural activities.

### **Availability of Data, Analytical Tools, and Methods**

Seventy percent of the countries that were consulted (Table 4) consider the availability of data to be inadequate, even though they have an easy access to computer databases and there is still quite a discontinuity of information. In the case of Chile, they hope to incorporate the information generated in the agrometeorological network during 2005 into the climate data base of the National Meteorological Service. In Peru, despite the fact that we have an agrometeorological network consisting of 47 automatic stations, their range is still limited. For this reason, the availability of data is considered inadequate. Most of the meteorological services have analytical tools, but they are not sufficient or limited in their use. Computational development has allowed 30 percent of the countries (Chile, Peru, and Venezuela) to use analytical tools, especially statistical, which have been applied in studies and research to support the productive agricultural sector.

The capacity to use these analytical tools (software) should be associated with the capacity of the professionals to understand and apply them as well; but, in practice, this doesn't apply in most parts of the region, because they learn to use this software in an autodidactic way. Eighty percent of the national meteorological services have established methodologies in forecasts as well as in other aspects related to the dissemination of meteorological services applied to agriculture.

	Venezuela	Uruguay	Perú	Paraguay	Ecuador	Chile	Colombia	Brazil	Bolivia	Argentina
Current availability of data	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Analytical tools	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No
Methods of provision of operational agrometeorological services	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

Table 4. Deficiencies and limitations in developing agrometeorological work.

Concerning research and agricultural extension, all national meteorological services carry out investigations and agricultural extension on a daily, weekly, monthly, annual, and irregular basis.

	Venezuela	Uruguay	Perú	Paraguay	Ecuador	Chile	Colombia	Brazil	Bolivia	Argentina
Daily	X									
Weekly		X								
Monthly		X	X	X						X
Yearly		X								X
Irregular	X				X		X	X	X	X

Table 5. Frequency of research services and agricultural extension.

### Support for International Agreements

It was not possible to obtain information from Paraguay and Uruguay. From the 8 responding countries, 63 percent of the services are more aware of the agreements related to climate change (United Nations Framework Convention on Climate Change) and desertification (United Nations Convention to Combat Desertification). In view of the primary activities in meteorology and the need to respond to the most frequent requirements of the community, the aspects related to Biological Diversity and World Food Supply have received a minor attention (50 and 25 percent respectively) (Table 6).

	Venezuela	Uruguay	Perú	Paraguay	Ecuador	Chile	Colombia	Brazil	Bolivia	Argentina
United Nations Framework Convention on Climate Change (UNFCCC)	No	Yes	Yes	Yes	Yes	No	--	Yes	--	No
United Nations Convention to Combat Desertification (UNCCD)	No	Yes	Yes	Yes	Yes	No	--	Yes	--	No
Convention on Biological Diversity	No	Yes	No	Yes	Yes	No	--	Yes	--	No
World Food Summit Plan of Action	No	Yes	No	No	Yes	No	--	No	--	No

Table 6. Knowledge of international conventions and agreements.

The agrometeorological services, at the same time, consider that their activity should be improved as time passes, by training their agrometeorologists and agronomists in all the aspects related to forecasts and local agriculture and in a way that allows them to provide accurate, agrometeorological outlooks. This training could be done through WMO experts' consultancy, universities, agricultural research institutes, etc., attending specific short-term courses, hands-on training, exchange of knowledge and information between the agrometeorological services in the region, etc.

### **Sustainability of the Services**

A meteorological service is considered to be working efficiently if it assures the continuous provision of basic data, which means that it will have to use resources to regularly maintain the present network, with the purpose to obtain continuous quality data. The networks should become automatic and extend their range to agricultural areas lacking information.

The services should favor the best way to attain sustainability and to maintain a progressive development in time; incidentally, the operators of the agrometeorological services consider that one of the most important aspects is to make the authorities and users, in general, aware of the important role that the agrometeorological information has for the operational part of agriculture and its planning.

In the last 5 years, some agrometeorological services have faced a reduction in their budgets, which is very dangerous to sustainability and development. To solve this increasing problem, the services considered it necessary to generate a strategy to convince relevant authorities to provide funds to maintain networks, replace instruments, foster the dissemination and application of agrometeorological information generated in each country, train the technical and professional staff of the services, and implement agrometeorological models, among other things.

The information obtained from the members of the Commission for Agricultural Meteorology in RA III who gave their answers to the questionnaire used in the present work suggests the following conclusions and recommendations:

### **Conclusions**

- A high percentage (70 percent) of the 10 meteorological services that were surveyed, have independent agrometeorological service units, which makes it easy to generate agrometeorological products.
- National meteorological services could be affected in the development of their various application areas because they depend financially on the government and also on the competition of private institutions with more financial resources, who recently entered the agrometeorological community.
- Farmers are main users of agrometeorological services and the ones who constitute the most progressive sector in this activity.
- In most of the national meteorological services, the agrometeorological activity is at a disadvantage with respect to other areas of national meteorology. These disadvantages are directly related to the budget, training, and prioritization in the development of their corresponding services. This contributes to delays in the agrometeorological progress that everyone hopes to attain.

- Most of the services issue bulletins, agrometeorological warnings, and agrometeorological and weather forecasts; carry out agrometeorological studies and research, and some of them assess the impacts caused by extreme weather events.
- The services agreed that their activities do not provide support to reduce the emissions of greenhouse gases from agricultural activities.
- A high percentage of the services (70 percent) considered that the range of the information and the extension of the data series are not sufficient. The same percentage considers that they have limitations and deficiencies in obtaining analytical tools.
- Eighty percent of the services estimate that they have deficiencies and limitations in the way they deliver agrometeorological services.
- One hundred percent of the services have incorporated into their activities interactions with research services and agricultural extension. However, these exchanges are irregular and only a limited number of services do this on a daily basis.
- The meteorological guidelines that national meteorological services have, and community pressure, causes them to become more interested in aspects related to United Nations Conventions on Climate Change and Desertification than on the Convention on Biological Diversity and the World Food Summit Plan of Action.

### **Recommendations**

- Improve spatial resolution and adapt global models as tools for prognosis.
- Invest in the dissemination of meteorological tools applied to agriculture, oriented to the small and medium farmers.
- Implement the services modern tools that combine the different levels of information, besides the agrometeorological one, obtaining a global view that could be of help to the farmers and different levels of decision making in a country. (For example, the implementation of a geographical information system.)
- Implementation of radar use and satellite information.
- Carry out strategic associations with institutions that may need the agrometeorological products to be able to increase the agrometeorological stations network, maintain the existing ones, and develop competitive agrometeorological products.
- Implement a regional training program to include aspects related to climate modeling, interpretation of satellite imagery oriented to agriculture, geographical information systems, and handling of agrometeorological databases and analytical tools.
- Standardization of products, services, methods, and regional climatic and agroclimatic procedures.
- Carry out a program of regional exchange that will consider the transfer of methodologies and knowledge of the professionals of the different services, by means of seminars, workshops, or hands-on training.
- Carry out studies on climate variability and climate change and its impact on agriculture at a regional level.

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## **Perspectives from Regional Association IV (North and Central America)**

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### **Abstract**

A questionnaire containing nine questions was circulated in Regional Association IV (RA-IV) of the World Meteorological Organization (WMO), as well as in the other regions. The original questionnaire suggested by the WMO Division for Agricultural Meteorology was sent to members of RA-IV Agricultural Meteorology Working Group. The region has 26 members and the RA-IV Agricultural Meteorology Working Group has 19 members. We received 14 answers from 13 countries, representing 74 percent of their active members. The evaluation of the answers was not easy because, from many countries, two to three answers were given instead of one short answer. The members were asked not only to answer the specific questionnaire but also submit examples. The total amount of the submitted materials, the answers, and the examples averaged more than 60 pages. The paper evaluates the information about the state-of-the-art of operational agrometeorological services at the national level in RA-IV, but it applies to only those parts of the region that provided survey answers.

### **Introduction**

Agriculture can be considered a big factory in the open air in which all the tasks depend on weather and climate. Agriculture is the world's single largest employer. Agriculture is one of the main sources of export earnings in North and Central America and the Caribbean countries. The importance of the agricultural sector is significant not only from the foreign exchange point of view but also for employment-generation capacity. From the World Meteorological Organization (2004) point of view, variations in weather and climate as well as their interaction with agricultural operations from sowing to harvesting have a significant impact on yield variations. Despite the advances made in our understanding of the influence of climate on agricultural production, climate variability has been, and continues to be, the principal source of fluctuations in global food production. Farmers, herders, foresters, and fishermen have to adapt to the range and frequency of shocks that climate variability brings, and they continue to try to use the available knowledge and information to develop coping strategies.

The countries of North America, Central America, and the Caribbean in RA-IV of the World Meteorological Organization include mountains, rainy areas, deserts, and tropical islands. With their associated variations in culture and biodiversity and the long period of human occupation, exploitation of natural resources, urbanization, industrialization, and economic development have led to land degradation and environmental pollution. Climate change and climate variations also represent future stress.

The major challenges to the development of the region include natural and environmental disasters, climate change, climate variability, water management, over-fishing of coastal and sea resources, freshwater resources management and development, land use and land degradation, energy availability, tourism management, poverty alleviation, and conservation

of biodiversity (Kamali and Lee 2002). Weather and climate observation and analysis are required to address these issues which are of relevance to the present social and economic conditions as well as for future generations.

A direct interdependence exists between the forest, crops, weather, and soil. Although the influence of the weather on agricultural production is well understood, it is evident that seasonal and inter-annual climate variability has been, is, and will continue to be the principal source of fluctuation in global food production (WMO, 2001). Global food production is essential to enhance economic development and alleviate the scourge of poverty. The provision of timely, accurate, and cost-effective agrometeorological forecasts and information has proven to be a useful resource base or tool which, when implemented, can help farmers make management decisions and guide policy makers in adopting strategies that will promote food security (Solano and Frutos 2002).

## **Background**

The North America, Central America, and Caribbean Regional Association (RA-IV) comprises 26 countries: Antigua & Barbuda, Bahamas, Barbados, Belize, Canada, Costa Rica, Cuba, Dominican Republic, El Salvador, French Antilles, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Netherlands Antilles & Aruba, Nicaragua, Panama, Saint Kitts-Nevis, Saint Lucia, Trinidad & Tobago, the United States, Colombia, Venezuela, and Guyana.

The RA-IV Working Group on Agricultural Meteorology of WMO has 19 members from 13 countries.

## **Methods and Materials**

A survey was carried out by sending a questionnaire via e-mail to all active members of the RA-IV Working Group on Agricultural Meteorology. Some problems were encountered in contacting Guatemala, Haiti, Jamaica, Barbados, Netherlands, Antilles, and Aruba, and hence, no answers were received.

As a consequence, not all the countries in RA-IV have been analyzed, and survey responses reflect the current condition of thirteen nations of Central America and the Caribbean (Antigua & Barbuda, Bahamas, Belize, Colombia, Costa Rica, Cuba, El Salvador, Guyana, Honduras, Nicaragua, Dominican Republic, Trinidad, Tobago, and Venezuela).

## **Operational Agrometeorological Services at the National Level**

As seen in Table 1, four of the countries have an independent Agrometeorological Service Unit.

Country	Answer	
	Yes	No
Antigua & Barbuda		X
Bahamas		X
Belize		X
Colombia		X
Costa Rica		X
Cuba	X	
Dominican Republic	X	
El Salvador		X
Guyana	X	
Honduras	X	
Nicaragua		X
Trinidad & Tobago		X
Venezuela	X	
TOTAL	5 (38%)	8 (62%)

Table 1. Existence of an independent Agrometeorological Service Unit in RA-IV countries.

Nevertheless, in the Bahamas, Belize, Colombia, El Salvador, and Nicaragua meteorological applications develop agrometeorological functions. The major customers for agrometeorological services in RA-IV are:

<b><u>Customers</u></b>	<b><u>Percent of countries total</u></b>
Ministry of Farmers	85
Farmers	46
Agricultural enterprises, cooperatives, and association of producers	38
Researchers	31
Advisors	23

### **Type of Operational Agrometeorological Services Provided by the National Meteorological and Hydrological Services**

With regard to type of services provided, 77 percent of the National Meteorological and Hydrological Services (NMHSs) issue regular agrometeorological bulletins and advisories (Table 2); 77 percent issue early warnings or alerts as appropriate (Table 3); 54 percent provide help with strategic studies (Table 4); and 77 percent evaluate the impact of extreme events.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belice	X	
Colombia	X	
Costa Rica		X
Cuba	X	
Dominican Republic	X	
El Salvador	X	
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela	X	
TOTAL	10 (77%)	3 (23%)

Table 2. Issuing regular agrometeorological bulletins and advisories.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belice	X	
Colombia	X	
Costa Rica	X	
Cuba	X	
Dominican Republic		X
El Salvador	X	
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela	X	
TOTAL	10 (77%)	3 (23%)

Table 3. Issuing early warning or alerts as appropriate.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belice	X	
Colombia	X	
Costa Rica		X
Cuba	X	
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras		X
Nicaragua	X	
Trinidad & Tobago		X
Venezuela	X	
TOTAL	7 (54%)	6 (46%)

Table 4. Helping with strategic studies.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belice	X	
Colombia		X
Costa Rica	X	
Cuba	X	
Dominican Republic	X	
El Salvador	X	
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela	X	
TOTAL	10 (77%)	3 (23%)

Table 5. Assessment of the extreme events impact.

Moreover, Belize, Costa Rica, Cuba, and Venezuela conduct agrometeorological studies on crops, early warning systems for forest fires and floods to farmers, assessment and meteorological tendency, climatological reports, and climatic risk.

### Operational Services Provided

As can be seen from Table 6, services to help reduce the impact of natural disasters, including pests and diseases, are provided by 46 percent of national meteorological and hydrological services; 69 percent have early warning and monitoring systems; seven countries provide short- and medium-range weather forecasting for agriculture; and all but three provide climate prediction and forecasting for agriculture. Only four provide services to help reduce the contribution of agricultural production to global warming.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belice	X	
Colombia		X
Costa Rica		X
Cuba	X	
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela		X
TOTAL	6 (46%)	7 (54%)

Table 6. Services to help reduce the impact of natural disasters, including pests and diseases.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belice	X	
Colombia	X	
Costa Rica		X
Cuba	X	
Dominican Republic		X
El Salvador	X	
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela	X	
TOTAL	9 (69%)	4 (31%)

Table 7. Early warning and monitoring systems.

Country	Answer	
	Yes	No
Antigua & Barbuda		X
Bahamas		X
Belize	X	
Colombia	X	
Costa Rica	X	
Cuba	X	
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela		X
TOTAL	7 (54%)	6 (46%)

Table 8. Countries that provided short- and medium-range weather forecasting for agriculture.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belize	X	
Colombia	X	
Costa Rica	X	
Cuba	X	
Dominican Republic		X
El Salvador	X	
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela	X	
TOTAL	10 (77%)	3 (23%)

Table 9. Climate prediction / forecasting for agriculture.

Country	Answer	
	Yes	No
Antigua & Barbuda		X
Bahamas		X
Belize	X	
Colombia		X
Costa Rica		X
Cuba		X
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela		X
TOTAL	4 (31%)	9 (69%)

Table 10. Services to help reduce the contributions of agricultural production to global warming.

#### **Shortcomings and Limitations in Regional Association IV:**

Current availability data:

- Insufficient spatial cover;
- Quality of the information;
- Difficult access to daily data; and,
- Small amount of information in electronic format.

Analytical tools:

- Few developments of forecast models to local scale;
- Low utilization of crops forecast models, etc;
- Insufficient number of personal computers; and,
- Low utilization of geographical information systems.

Methods of providing operational agrometeorological services:

- New techniques and methodologies in the analysis of agrometeorological data, and their presentation are not well known to many specialists engaged in the preparation of bulletins for the NMHSs.
- There is poor access to methodologies for analysis of soil water balance, monitoring of vegetation conditions, monitoring of drought, and potential danger conditions for forest fires.

It is necessary, therefore, to seek international and inter-institutional experts who can provide technical assistance and training to agrometeorologists. They could then observe the experiences of other countries strong in this field and add greater value to their operational agrometeorological services and become more user-friendly to farmers.

## Cooperation between Operational Agrometeorological Services and Agricultural Research and Extension Services

All but three countries reported that their operational agrometeorological services work with agricultural research and extension services (Table 11). However, only three countries reported interacting with research and extension services on a daily basis (Table 12).

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas	X	
Belice	X	
Colombia	X	
Costa Rica		X
Cuba	X	
Dominican Republic	X	
El Salvador	X	
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela		X
TOTAL	10 (77%)	3 (23%)

Table 11. Countries where agrometeorological services and agricultural research and extension services in Regional Association IV cooperate.

Country	Answer	
	Yes	No
Antigua & Barbuda		X
Bahamas		X
Belice	X	
Colombia	X	
Costa Rica		X
Cuba	X	
Dominican Republic		X
El Salvador		X
Guyana		X
Honduras		X
Nicaragua		X
Trinidad & Tobago		X
Venezuela		X
TOTAL	3 (23%)	10 (77%)

Table 12. Countries with daily interactions with agricultural research extension services.

As can be seen from Table 13, no countries reported weekly frequency of interactions with agricultural research and extension services. Some countries, like Cuba, provide agrometeorological information twice per week to term 5 days (the Monday, of the Monday to Friday; the Friday, of the Friday to Tuesday).

Country	Answer	
	Yes	No
Antigua & Barbuda		X
Bahamas		X
Belize		X
Colombia		X
Costa Rica		X
Cuba		X
Dominican Republic		X
El Salvador		X
Guyana		X
Honduras		X
Nicaragua		X
Trinidad & Tobago		X
Venezuela		X
TOTAL	- (0%)	13 (100%)

Table 13. Countries with weekly interactions with agricultural research extension services.

Five countries reported monthly interactions with agricultural research and extension services (Table 14). They are Cuba, Dominican Republic, El Salvador, Guyana, and Nicaragua. Three countries reported yearly interactions with agricultural research and extension services.

Country	Answer	
	Yes	No
Antigua & Barbuda		X
Bahamas		X
Belize		X
Colombia		X
Costa Rica		X
Cuba	X	
Dominican Republic	X	
El Salvador	X	
Guyana	X	
Honduras		X
Nicaragua	X	
Trinidad & Tobago		X
Venezuela		X
TOTAL	5 (38%)	8 (62%)

Table 14. Countries with monthly interactions with agricultural research extension services.

Country	Answer	
	Yes	No
Antigua & Barbuda		X
Bahamas		X
Belize		X
Colombia		X
Costa Rica		X
Cuba	X	
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras		X
Nicaragua	X	
Trinidad & Tobago		X
Venezuela		X
TOTAL	3 (23%)	10 (77%)

Table 15. Countries with yearly interactions with agricultural research extension services.

As seen in Table 16, eight countries provided agrometeorological information with irregular frequency.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas	X	
Belize	X	
Colombia	X	
Costa Rica		X
Cuba	X	
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras	X	
Nicaragua	X	
Trinidad & Tobago		X
Venezuela		X
TOTAL	8 (62%)	5 (38%)

Table 16. Countries with irregular interactions with agricultural research extension services.

Regional Association IV operational agrometeorological services aware of the new requirements from the following international conventions and agreements:

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas	X	
Belize	X	
Colombia	X	
Costa Rica	X	
Cuba	X	
Dominican Republic	X	
El Salvador	X	
Guyana	X	
Honduras		X
Nicaragua	X	
Trinidad & Tobago	X	
Venezuela	X	
TOTAL	12 (92 %)	1 (8 %)

Table 17. United Nations Framework Convention on Climate Change.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas	X	
Belize	X	
Colombia	X	
Costa Rica	X	
Cuba	X	
Dominican Republic	X	
El Salvador	X	
Guyana	X	
Honduras		X
Nicaragua	X	
Trinidad & Tobago	X	
Venezuela	X	
TOTAL	12 (92 %)	1 (8 %)

Table 18. United Nations Convention to Combat Desertification.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas	X	
Belize	X	
Colombia		X
Costa Rica		X
Cuba	X	
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras		X
Nicaragua	X	
Trinidad & Tobago	X	
Venezuela	X	
TOTAL	8 (62%)	5 (38%)

Table 19. Convention on Biological Diversity.

Finally, only 38 percent of the countries reported they didn't know the new requirements from World Food Summit Plan of Action.

Country	Answer	
	Yes	No
Antigua & Barbuda	X	
Bahamas		X
Belize	X	
Colombia		X
Costa Rica		X
Cuba		X
Dominican Republic		X
El Salvador		X
Guyana	X	
Honduras		X
Nicaragua		X
Trinidad & Tobago	X	
Venezuela	X	
TOTAL	5 (38%)	8 (62%)

Table 20. Awareness of World Food Summit Plan of Action.

## **Methods and Tools to Improve Agrometeorological Services**

The survey asked for recommendations on how to improve operational agrometeorological services. The following methods and tools were suggested:

- Introducing or improving agrometeorological monitoring services and early warnings and alerts to help reduce the agricultural impact of extreme events (Bahamas, Cuba, Dominican Republic, El Salvador, Nicaragua, Guyana, Honduras, Trinidad & Tobago, and Venezuela);
- Improving observation networks and agrometeorological databases (Bahamas, Belize, Cuba, Dominican Republic, El Salvador, Guyana, Honduras, Nicaragua, and Venezuela);
- Training national meteorological and hydrological services technical staff and the extension-related agricultural sector (Bahamas, Belize, Cuba, Dominican Republic, Guyana, Honduras, Trinidad & Tobago, and Venezuela);
- Improving computer tools used to analyze agrometeorological data, for example, reference evapotranspiration estimation, soil water balance at the depth root, vegetation conditions; meteorological, hydrological, and agricultural drought; and potential forest fire danger (Bahamas, Colombia, Cuba, Dominican Republic, El Salvador, Nicaragua and Trinidad & Tobago);
- Using agrometeorological models to evaluate existing and expected conditions on different agricultural sectors--crops, livestock, forest, pests, and diseases (Belize, Cuba, Dominican Republic, El Salvador, Guyana, and Nicaragua);
- Creating capacity and apply operational GIS technology (Belize, Cuba, Honduras, Nicaragua, and Venezuela); and,
- Using high-resolution satellite images (vegetal cover, Normalized Difference Vegetation Index [NDVI], soil humidity, etc.) in the operational agrometeorological services (Colombia, Cuba, and El Salvador).

## **Strategies to Strengthen Operational Agrometeorological Services**

Respondents suggested the following capacity building strategies:

- Create capacity in the agricultural meteorology specialty, either NMHSs or agrometeorological information users (Bahamas, Belize, Cuba, Dominican Republic, Guyana, Nicaragua, and Venezuela);
- Identify funding sources and promote financial support to national agrometeorological services with users who guarantee to keep the agrometeorological services (Costa Rica, Cuba, Dominican Republic, El Salvador, Guyana, and Trinidad & Tobago); and,
- Create a National Technical Committee that promotes agrometeorological applications that meet the needs of the agricultural sector and coordinates this work among institutions and disciplines (Belize, Colombia, Costa Rica, Cuba, and Venezuela).

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## **Perspectives from Regional Association V (South-West Pacific)**

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### **Abstract**

A questionnaire containing nine questions was circulated in the Regional Association V (RA-V). Responses were received from four countries: Fiji, Indonesia, Malaysia, and Philippines. Based on the responses, it was revealed that Fiji has no independent agrometeorological services unit, while in Indonesia such a unit was developed in 2003. The main customers of the National Meteorological and Hydrological Services (NMHSs) in the four countries are government agencies, in particular the Ministry of Agriculture. In Fiji and the Philippines, the industrial companies are also the customers. The services which are provided in the form of bulletins, assist in conducting strategic studies, provide early warnings, and help with impact assessments.

The main constraints for strengthening the operational agrometeorological services in the four countries are lack of human resources, analytical tools such as simulation modeling, and data. Therefore, recommendations given by the countries for strengthening the operational agrometeorological services include training activities on the use of remote sensing technology and simulation modeling for yield monitoring, forecasting, improvement of climate observation networks, and dissemination systems.

### **Introduction**

There is currently an indication that the impacts of extreme climate events (ECE) on many sectors, particularly in agriculture, are increasing from year to year. For example, in Indonesia before 1994, the loss of national rice production due to ECE was about 0.2 million tons per event and after 1994 it increased to at least 1.0 million tons per event (range between 1.1 and 1.7 million tons per event; Boer and Las, 2002). This condition occurs as a result of increasing population in areas where subsistence agriculture is practiced, and increasing pressure on land and water resources (Jones, 2003). Thus, a small deviation in normal climate could cause a major food shortage and permanent damage to society. In addition, farmers who make routine decisions about production in existing farming systems use very little climate (forecast) information in making their decisions or setting up planting strategies.

The role of NMHSs is to increase the use of climate (forecast) information in many sectors of agriculture. Jones (2003) stated that the effective application of climate forecasts depends on 1) the availability of regional forecasts of adequate lead time and accuracy, 2) the vulnerability of agriculture to weather variability; 3) the existence and awareness of options for using knowledge of future weather to improve agricultural practices, and, 4) the ability and willingness of decision makers to modify their decisions based on climate forecast information. To create conditions that allow for the effective application of climate forecast, the NMHS faces many constraints and limitations.

This paper briefly describes the results of a survey on operational agrometeorological services, and a literature review of operational agrometeorological services in RA-V.

## **Survey on Operational Agrometeorological Services in RA-V**

This section briefly describes the results of a survey conducted in the World Meteorological Organization RA-V (Appendix 1). It might not well represent the condition of the region, since only four countries responded to the questionnaire (Appendix 2), i.e., Fiji, Indonesia, Malaysia, and the Philippines (Appendix 3). The Philippines proposed another set of questions for the survey (Appendix 4).

### *Agrometeorological Service Unit*

In the four countries, only Fiji has no independent agrometeorological service unit. Indonesia just recently established the unit, which also covers air pollution.

### *Agrometeorological Services*

In the four countries, the major customers for the agrometeorological services are the Ministries of Agriculture, research institutes, agricultural industries, and national task forces dealing with climate. The services, which are mostly in the form of issuing regular bulletins or advisories, provide early warnings as appropriate and strategic studies. In the four countries, only the Philippines provide services to help reduce the contributions of agricultural production to global warming. In Indonesia, this type of service is provided by agricultural research agencies.

### *Constraints and Limitations*

Common reasons given by the countries to explain the limited capacity of the NMHS in providing the agrometeorological services are inadequate human resources (low skill), technology, computing facilities, and limited coverage of a national climatological stations' network (in particular for rainfall), and data discontinuity. Indonesia recognizes that lack of skill in forecasting and translating global climate forecasts on a local (downscaling) scale as well as its dissemination to users (farmers in particular) are crucial in strengthening operational agrometeorological services. At present, the NMHSs in the four countries have no regular program to work with agriculture extension. These aspects should get more attention in the future.

## **Strategy to Strengthen Operational Agrometeorological Services**

Most countries feel that the use of agricultural simulation modeling, GIS/remote sensing technologies, and downscaling techniques to localize the regional climate forecasts should be encouraged in order to strengthen operational agrometeorological services. Key factors for the success of operational agrometeorological services are improvement of climate station networks (particularly rainfall networks), timely transfer of local data to an analysis center, forecast delivery from data analysis center to users, ability to localize climate forecast information and assess the impact, and availability of an effective dissemination system. Therefore, a strategy to strengthen the operational agrometeorological services should cover these aspects.

## **Review of Operational Agrometeorological Services in RA-V**

Based on the responses to the questionnaires, the countries felt that skill in using simulation-modeling techniques in strengthening operational agrometeorological services might be important. Development of skills for downscaling global climate forecast to local climate forecast, conducting impact analysis, and designing adaptation strategies to variable climate, such as tailoring crop management to climate forecast, are necessary. Collaboration between NMHSs with other agencies in the country that may have such capacities should be enhanced. International research agencies should also open up free access to global climatic data such as Categorical Climate Forecasts (GCM) outputs and software.

The use of simulation modeling tools in agrometeorological services has been well adopted in Australia (e.g., Rosenthal and Hammer, 1978; Strong, 1981; Woodruff and Tonks, 1983; Hammer and Nicholls, 1996; Hammer, et al., 1999; Meinke & Hochman, 2000; Meinke and Stone, 2003). The simulation modeling tools are used to quantify the risks associated with various decision options by integrating knowledge from simulation and other studies using the long-term climate record. The tools are also used to assess the likely distribution of yield or gross margin for a given climate forecast.

Simple models to forecast regional rainfall from global climate-forcing factors have been developed by Australia, such as RAINMAN or Rainfall Information for Better Management (Clewett, et al., 2002). In the RAINMAN, the monthly Southern Oscillation Index (SOI), key indicator of El Niño/Southern Oscillation (ENSO) (Coughlan, 1988) was used to assess the changes in distribution of seasonal rainfall under a given SOI class or phase. The SOI was partitioned into three classes with average  $\text{SOI} > 5$ , average  $\text{SOI} < -5$ , and average SOI between -5 and 5 (Clewett, et al., 1991) or into five distinct phases, the change in the SOI from month to month, i.e., rapidly raising, rapidly falling, consistent positive, consistent negative and near zero (Stone and Auliciems, 1992, Stone, et al., 1996). It was found that there were consistent differences in probability distributions of rainfall associated with seasons following the SOI classes or phases types. Further effort to include other global climate forcing factors such as IOD (Indian Ocean Dipole) and decadal climate variability indicators such as Interdecadal Pacific Oscillations (IPO) into existing seasonal climate schemes has also been underway (e.g., IOD see Saji, et al., 1999, Yamagata, et al., 2001; IPO see Meinke, et al., 2001).

As global climate-forcing factors to some extent affect the rainfall variability in certain regions, the use of these factors to evaluate the likely yield distributions in the following season under given crop-management strategies has also been adopted in many countries. In this approach, a number of yield data series were generated by running the crop-simulation models using a number of given crop management strategies and long-term daily climatic data. Yield distributions under given global climate-forcing factors were developed. Changes in the distribution will indicate the strength of relationship between yield variability and the factors. For example, a study case at Pusaka Negara, Indonesia, indicated that planting soybeans after April is still possible if the value of SOI phase in April was not 1 or 3 (Figure 1). Chances of getting soybean yield of more than 750 kg/ha for May planting would be more than 50 percent if the April SOI were 2, 4, or 5.

In Fiji, the Philippines, and Indonesia the use of simulation modeling tools in agrometeorological services, to some extent, is still in research stage. The tools are used for setting up crop-management strategies, determining alternative decisions for second planting, and designing optimal land allocation under a given climate forecast (e.g., Indonesia, see

Boer, et al., 2003 and 2004; Philippines, see Messina, et al., 1999; Fiji, see Fiji Meteorological Service, 2003). However, there is a need to make use of such knowledge for influencing policy makers into making decisions and farmers into deciding crop-management strategies. The challenge remaining is to find effective ways to communicate such knowledge and information to policy makers and farmers and to inform local staff about the use of such knowledge.

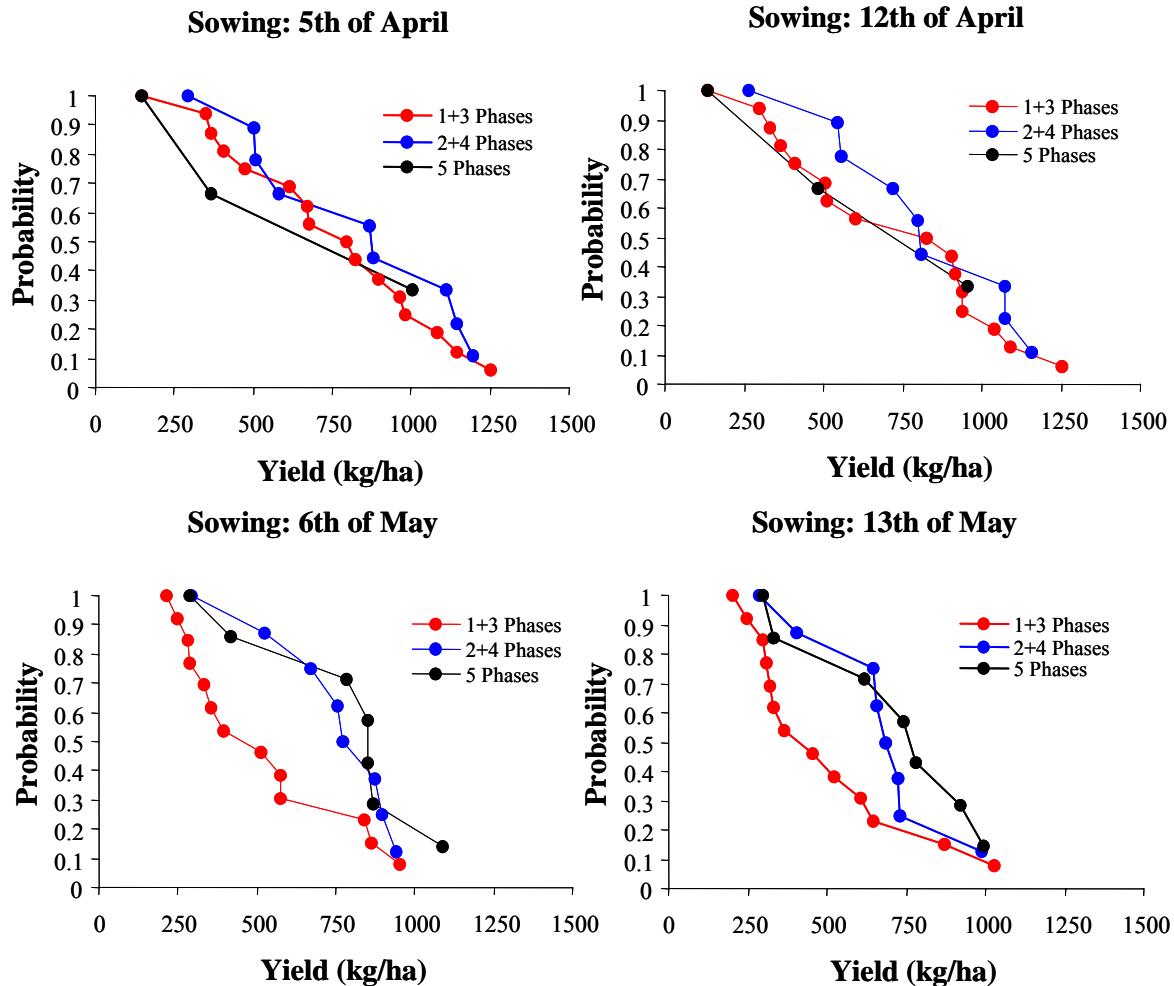


Figure 1. Yield probability at Pusaka Negara using previous month SOI phase (Boer, et al., 2003).

Another technical problem that still remains for using such an approach in developing countries is the availability of long-term records of daily climatic data. In many cases, the long-term data records are available on a monthly basis. Therefore, one possible solution to cope with this problem is to use climatic data generator models that are capable of generating daily, long-term climatic data from the long-term monthly data record. A number of climatic date-generator models with that capacity are available (e.g., Epstein, 1991; Boer, et al., 1999; Boer, et al., 2004).

## **Conclusions**

The main limitations and constraints for strengthening the operational agrometeorological services in Fiji, Philippines, Malaysia, and Indonesia are a lack of human resources and analytical tools such as simulation modeling and data. Training activities on the use of remote sensing technology and simulation modeling for yield monitoring and forecasting and improvement of the climate observation network and dissemination systems are the priorities for improving agrometeorological services in the four countries.

Agricultural simulation modeling is already being used for operational agrometeorological services in developed countries such as Australia. In developing countries, such an approach is still in the research stage. There is a need to influence policy makers into making decisions and farmers into deciding crop-management strategies. The challenge is finding effective ways to communicate such knowledge and information to policy makers and farmers and to help local staff in the use of such an approach.

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**APPENDIX 1. List of Members of the  
RA-V Working Group on Agricultural Meteorology  
(XIII-RA V)**

Country	Address	Contact
Australia	Bureau of Meteorology 83 Carnarvon Road STRATHMORE, VIC 3041 Australia	Mr. Russell Stringer Tel.: (+ 61-3) 9379 4641 (H)/9669 4225 (W) E-mail: <a href="mailto:r.stringer@bom.gov.au">r.stringer@bom.gov.au</a>
Fiji	Fiji Meteorological Service Private Mail Bag, NAP 0351 NADI AIRPORT, Fiji	Mr. Simon McGree Tel.: (+ 67-9) 6736038 Fax: (+ 67-9) 6736047 E-mail: <a href="mailto:Simon.McGree@met.gov.fj">Simon.McGree@met.gov.fj</a>
Indonesia	Dept of Geophysics and Meteorology FMIPA – Bogor Agricultural University Jalan Raya Pajajaran BOGOR 16144, Indonesia	Mr. Rizaldi Boer Tel.: (+ 62-251) 376817 Fax: (+ 62-251) 313384/376817 E-mail: <a href="mailto:rboer@fmipa.ipb.ac.id">rboer@fmipa.ipb.ac.id</a> or <a href="mailto:rizaldiboer@yahoo.com">rizaldiboer@yahoo.com</a>
Malaysia	Malaysian Meteorological Service Jalan Sultan 46667 PETALING JAYA, SELANGOR Malaysia	Mr TAN Lee Seng Tel.: (+ 60-3) 7967 8221 Fax: (+ 60-3) 7955 0946 E-mail: <a href="mailto:tls@kjc.gov.my">tls@kjc.gov.my</a>
New Zealand	National Institute of Water and Atmospheric Research (NIWA) P.O. Box 109-695 Newarket, AUCKLAND New Zealand	Dr M.J. Salinger Tel.: (+ 64-9) 375 2053 Fax: (+ 64-9) 375 2051 E-mail: <a href="mailto:j.salinger@niwa.com">j.salinger@niwa.com</a> or <a href="mailto:j.salinger@niwa.co.nz">j.salinger@niwa.co.nz</a>
Papua New Guinea	PNG National Weather Service P.O. Box 1240 BOROKO, NCD 111 Papua New Guinea	Mr Kasis Inape Tel.: (+ 67-5) 325 2788 Fax: (+ 67-5) 325 5201/325 2740 E-mail: <a href="mailto:kinape@pngmet.gov.pg">kinape@pngmet.gov.pg</a> or <a href="mailto:kinape70@yahoo.com">kinape70@yahoo.com</a>
Philippines	Weather and Flood Forecast Centre Philippine Atmospheric, Geophysical and Astronomical Services Administration Agham Road, Dilima Quezon City, 1101, Philippines	Mr. Bonifacio G. Pajuelas Tel.: (+ 63-2) 929 4865 Fax: (+ 63-2) 929 4865 or 926 3151 E-mail: <a href="mailto:odstaff@pacific.net.ph">odstaff@pacific.net.ph</a> or <a href="mailto:bipajuelas@pagasa.dost.gov.ph">bipajuelas@pagasa.dost.gov.ph</a>
Philippines	Philippine Atmospheric, Geophysical and Astronomical Services Administration 3 <sup>rd</sup> Flr. Asia Trust Bank Bldg. 1424 Quezon Avenue QUEZON CITY, Metro Manila Philippines	Mrs. Flaviana D. Hilario Tel.: (+ 63-2) 373 3427 Fax: (+ 63-2) 373 3433 E-mail: <a href="mailto:fhilarioph@yahoo.com">fhilarioph@yahoo.com</a> or <a href="mailto:fhilarioph@yahoo.com">fhilarioph@yahoo.com</a>
Vanuatu	Vanuatu Meteorological Service PMB 9054 PORT VILA Vanuatu	Mr Kaniaha Salesa Nihmei Tel.: (+67-8) 23866 or 24686 Fax: (+67-8) 22310 or 22745, 27414 E-mail: <a href="mailto:kaniaha@yahoo.com.au">kaniaha@yahoo.com.au</a> or <a href="mailto:skaniaha@meteo.vu">skaniaha@meteo.vu</a>

## **APPENDIX 2. Questionnaire sent to WMO Members of RA-V**

1	Does the Meteorological Service of your country have an independent Agrometeorological Service Unit?
2	Who are the major customers for Agrometeorological services in your country?
3	What kind of operational Agrometeorological services are provided by the NMHS (National Meteorology and Hydrology Service) in your country?
4	What are the operational services provided by the Meteorological Service in your country?
5	What are the shortcomings and limitations of your work?
6	Do you work with agricultural research and extension services in your country?
7	Are you aware of the new requirements from the following International Conventions and Agreements (UNFCCC, UNCCD, CBD, World Food Summit Plan of Action)?
8	What additional activities, methods, and tools could help you improve the operational Agrometeorological services in your country?
9	What strategy should be employed to build the capacity of your service to strengthen operational agrometeorological services in your country?

## **APPENDIX 3. Questionnaire Responses from RA-V**

<b>No</b>	<b>FIJI</b>	<b>INDONESIA</b>
1	No	Yes, just established in 2003 under Agroclimatology and Air Pollution Division at the BMG. Department of Agriculture also has Research Agency on Hydrology and Agroclimate
2	The Fiji Sugar Corporation, Ministry of Agriculture-government and individual farmers	Agriculture offices (local government), Department of Agriculture, Ministry of Forestry, Ministry of Environment, and National Task Forces
3	Issuing regular Bulletin on Seasonal Climate Prediction  Issuing early warnings/alerts as appropriate  Helping with strategic studies such as agroecological zoning  Assessing impact of extreme events such as floods, cyclones, etc.	Issuing regular Bulletin on Seasonal Climate Prediction  Issuing early warnings/alerts as appropriate such as flood, forest fire, and drought  Helping with strategic studies such as agroecological zoning in collaboration with other agencies
4	Services to help reduce the impact of natural disasters, including pests and diseases  Early warning and monitoring systems  Short- and medium-range weather forecasting for agriculture  Climate prediction/forecasting for agriculture	Early warning and monitoring systems  Short- and medium-range weather forecasting for agriculture (weather Modification);  Climate prediction/forecasting for agriculture (for vulnerable districts)
5	Meteorological and sugar data is good however there is little yield and production data for other crops  Do not have climatological staff trained in statistical analysis  Have problems getting correct and useful information to the farmers	Many rainfall stations are not in operation. Only 35 percent of the total is in operation and data transferring system from local to headquarters is not timely. Many stations have discontinued data records.  Do not have dynamic-based climate forecast models, numerical models  Skill for downscaling global climate forecast into local forecast is still low  Local authorities/farmers are not able to use climate (forecast) information issued by the BMG  Lack of staff with strong statistical and agrometeorological background

### APPENDIX 3. Questionnaire Responses from RA-V (Cont.)

<b>No</b>	<b>FIJI</b>	<b>INDONESIA</b>
6	Yes, but irregular	Yes, but irregular. It is expected that the local authorities and agriculture extension has capacity to translate the climate forecast information for end users (in particular farmers). Climate Field School is being developed in collaboration with Bogor Agricultural University, local agriculture office, and Directorate of Plant Protection. It is intended to help farmers use climate (forecast) information for crop-management strategies
7	No	Yes
8	<p>Provide adequate training opportunities for meteorological staff in agrometeorology and statistics</p> <p>Provide funding for training and research</p>	<ul style="list-style-type: none"> <li>--Have access to satellite data, General Circulation Models (GCMs) outputs, downscaling models, and other simulation models (crop simulation models)</li> <li>--More training opportunities for meteorological staff in agrometeorology and statistics</li> <li>--Have more staff at the Baden Meteorologi dan Geofisika (BMG) with strong background in agrometeorology, statistics, and simulation modeling</li> </ul>
9	No answer	<ul style="list-style-type: none"> <li>--Improve computing facilities (super computer)</li> <li>--Increase number of climate/weather observation networks (particularly rainfall)</li> <li>--Improve skill of climate forecast through the use of dynamic and statistical models</li> <li>--Provide training for Meteorological staff in simulation modeling and statistics</li> <li>--Develop maps of vulnerable areas to extreme climate events</li> <li>--Develop better (drought, flood, forest fire) monitoring system, such as using satellite</li> <li>--Strengthen collaboration with local authorities (Agriculture Office) to capacitate extension workers to translate climate information for farmer use</li> <li>--Develop new bulletins/newsletters on agrometeorology tailored to specific user needs and further development of web-site for agrometeorology services</li> </ul> <p>Improve climate data transfer systems from local to headquarters office and develop better skills for climate forecast</p>

### APPENDIX 3. Questionnaire Responses from RA-V (Cont.)

<b>No</b>	<b>MALAYSIA</b>	<b>PHILIPPINES</b>
1	Yes	Yes
2	The Agriculture Department, Agriculture Research Institute, The Rice Institute, Rubber Research Institute, Forest Research Institute, Palm Oil Research Institute and the Agriculture Research Institute, and the farmers	Department of Agriculture, fertilizer company, farmers
3	Issuing regular bulletin on seasonal climate prediction  Issuing early warnings/alerts as appropriate  Helping with strategic studies such as agroecological zoning  Assessing impact of extreme events such as floods, cyclones, etc.	Issuing regular bulletin on seasonal climate prediction  Issuing early warnings/alerts as appropriate  Helping with strategic studies such as agroecological zoning  Assessing impact of extreme events such as floods, cyclones, etc.
4	Early warning and monitoring systems  Short- and medium-range weather forecasting for agriculture  Climate prediction/forecasting for agriculture (for vulnerable districts)	Early warning and monitoring systems  Short- and medium-range weather forecasting for agriculture  Climate prediction/forecasting for agriculture  Services to help reduce the contributions of agricultural production to global warming
5	Current availability of data adequate but needs better coverage  Analytical tools lacking  Methods of provision of operational agrometeorological services needs to improve	Some important agrometeorological data are not being observed/measured (soil moisture, evapotranspiration, etc.).  There is weak communication link with farmers. Radio programs could facilitate the timely broadcast of the agrometeorological forecast.
6	Yes, but irregular	Yes, but irregular
7	Yes	No (Partly)
8	NDVI Remote sensing tools and methodologies GIS Other Agrometeorological methodologies	The utilization of remotely sensed data in operational agrometeorological services.  Development of yield forecast model
9	Training and to acquire technical skills	Improvement of data collection Capacity building on yield forecast modeling

#### **APPENDIX 4. Proposed List of Questions from Philippines**

**Country Name:** \_\_\_\_\_

**List the name/s of existing model/s describing the relationship between weather and agriculture (such as pests/diseases). Indicate whether this is operational or not.**

**Operational?**

- |          |                              |                             |
|----------|------------------------------|-----------------------------|
| 1. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 2. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 3. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 4. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 5. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 6. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 7. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| 8. _____ | <input type="checkbox"/> Yes | <input type="checkbox"/> No |

**Indicate the title of paper(s)/publication(s) describing the model including the source. (Please indicate the internet address where these papers can be viewed.)**

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**When did these models become operational?**

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**What are the skills of these models?**

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**Please list the name of contact person including e-mail address/phone number.**

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## Perspectives from Regional Association VI (Europe)

Zoltan Dunkel and Adriana Marica

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### Abstract

This report summarizes the results found in the questionnaire (Table 1). The questionnaire was circulated among the Commission for Agricultural Meteorology (CAgM) members of Regional Association VI (RA-VI) of Europe and volunteers in agrometeorology. It is concluded that the application of agrometeorological information, advice, and support issued by the meteorological community for the agricultural, horticultural, forestry, and including the fishery users, depends on the tradition and economical environment. Improvement of operational agrometeorological services needs better technology and better business policy. The Internet seems to be a developing tool for information dissemination. The decision makers are interested in monitoring the agricultural campaign to help the farmers in difficult years or with agroclimatological information for agriculture planning. The decision makers concerns are extreme events causing damages to agricultural systems or to the environment; such as hurricanes, extreme droughts, floods, frost, strong winds, and intense rainfall. For delivery to farmers, the information should be punctual, succinct, and coherent given the possible choices they have, and written in comprehensible agricultural technical language.

1. Does the Meteorological Service of your country have an independent Agrometeorological Service Unit?	
2. Who are the major customers for agrometeorological services in your country?	
3. What kind of operational agrometeorological services are provided by the NMHS in your country?	
a) Issuing regular agrometeorological bulletins and advisories	Yes/No
b) Issuing early warnings/alerts as appropriate	Yes/No
c) Helping with strategic studies e.g., agroecological zoning	Yes/No
d) Assessment of the impact of extreme events e.g., floods, cyclones etc.,	Yes/No
e) Others - please specify	
4. Five major types of agrometeorological services were identified at the International Workshop on Agrometeorology for the 21 <sup>st</sup> Century held in Accra, Ghana in 1999. Please identify which of the operational services below are provided by the Meteorological Service in your country?	
a) Services to help reduce the impact of natural disasters, including pests and diseases	Yes/No
b) Early warning and monitoring systems	Yes/No
c) Short- and medium-range weather forecasting for agriculture	Yes/No
d) Climate prediction/forecasting for agriculture	Yes/No
e) Services to help reduce the contributions of agricultural production to global warming/cooling(?)	Yes/No
5. Identify the shortcomings and limitations in the following aspects of your work:	
a) current availability of data,	
b) analytical tools;	
c) methods of provision of operational agrometeorological services?	
6. Do you work with agricultural research and extension services in your country?	Yes/No
If yes, please indicate the frequency of your interactions with agricultural research and extension services	Daily/Weekly/Monthly/Yearly/Irregular
7. Are you aware of the new requirements from the following International Conventions and Agreements?	
a) United Nations Framework Convention on Climate Change (UNFCCC);	
b) The United Nations Convention to Combat Desertification (UNCCD);	
c) Convention on Biological Diversity; d) World Food Summit Plan of Action	
8. In your view, what additional methods and tools could help improve the operational agrometeorological services in your country? Please list in order of priority (most important as (a) and least important as (e)!	
9. What strategy should be employed to build the capacity of your service to strengthen operational agrometeorological services in your country?	
10. Please give the contact name(s), address, and e-mail address concerning the 'agrometeorological activity' in your country!	

Table 1. The circulated questionnaire.

## Introduction

The Regional Association VI consists of 49 countries. Every European country is a member of the Association and a few countries from the Near East also belong to the RA-VI. Only parts of two countries (Russian Federation and Kazakhstan) belong to the RA-VI. These two countries are members of RA-VI and RA-II, simultaneously. The position of the World Meteorological Organization (WMO) Regional Associations is shown in Figure 1. The basic goal of the current survey was to collect as much information as possible from not only the members of the national meteorological services but also specialists involved in agrometeorology. WMO is the global organization of the National Meteorological and Hydrological Services (NMHSs) that is responsible for meteorology. We wanted to find a connection within the framework of NMHSs as well as anywhere else we could find agrometeorological activity. Unfortunately, not every member nation has nominated a representative for the CAgM. Thus, we have no starting contact point in these few countries.

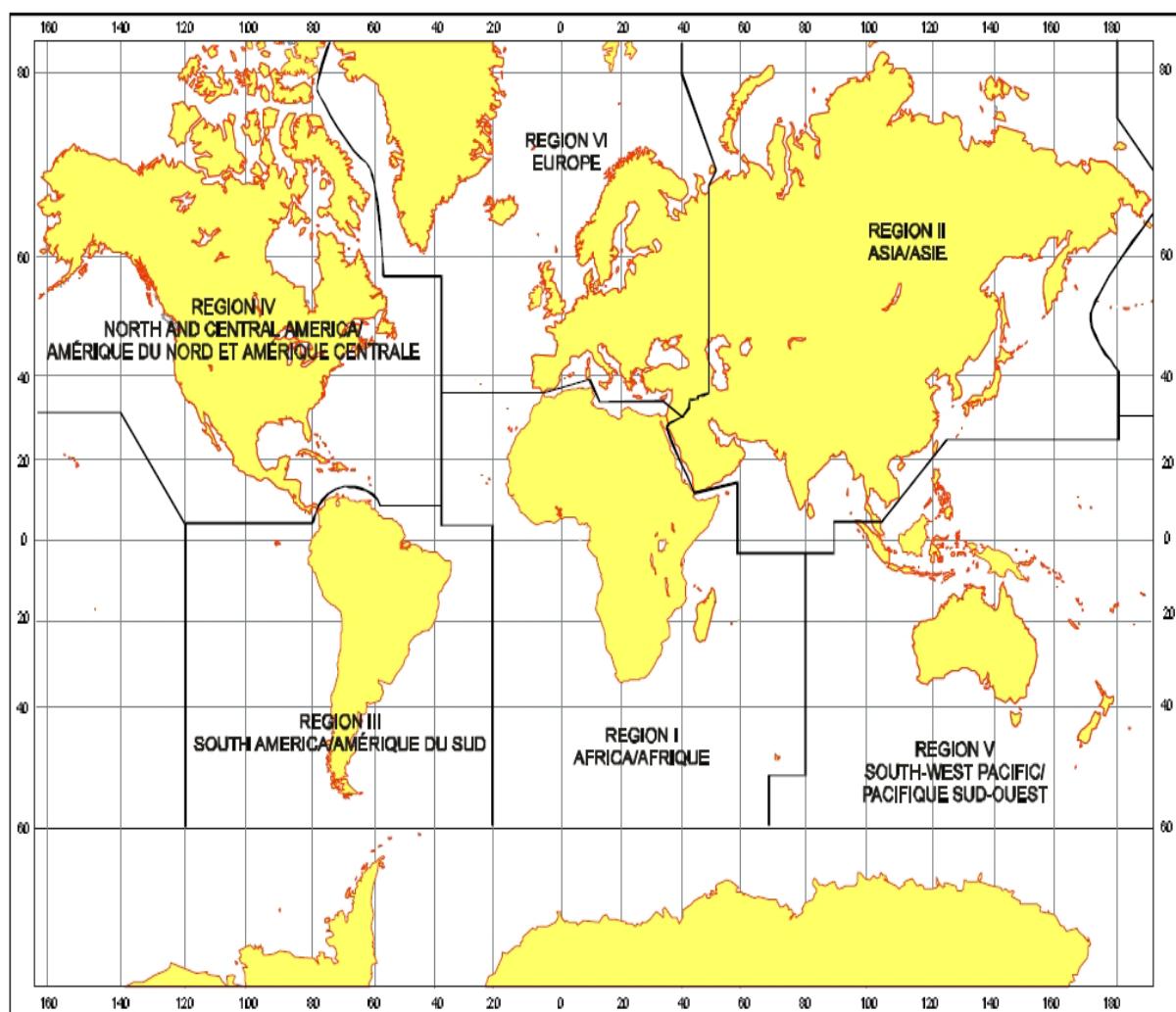


Figure 1. The Regional Association of the World Meteorological Organization.

Table 2 shows the members of RA-VI. Table 3 shows the countries that have no nominations for CAgM. In some cases, a country may not have a nomination for CAgM, but we are well informed about its agrometeorological activity because we have a good relationship with agrometeorological experts in other agencies, i.e., in Cooperation in the Field of Scientific and Technical Research COST Action 718, a European framework for the coordination of

nationally funded research. . There were two portions to the present survey. The first one was an earlier circulated questionnaire used for the Barbados workshop (Dunkel 2002). Three years ago, useful information was submitted, but we were not able to process the material in every detail because they were so voluminous. We have also used data from that questionnaire in this analysis.

Albania	Georgia	Netherlands, The
Armenia	Germany	Norway
Austria	Greece	Poland
Azerbaijan	Hungary	Portugal
Belarus	Iceland	Romania
Belgium	Ireland	Russian Federation
Bosnia and Herzegovina	Israel	Serbia and Montenegro
Bulgaria	Italy	Slovakia
Croatia	Jordan	Slovenia
Cyprus	Kazakhstan	Spain
Czech Republic	Latvia	Sweden
Denmark	Lebanon	Switzerland
Estonia	Lithuania	Syrian Arab Republic
Finland	Luxembourg	Turkey
France	Malta	Ukraine
Former Yugoslav	Moldova, Republic of	United Kingdom
Rep of Macedonia	Monaco	

Table 2. The Members of Regional Association VI.

Azerbaijan	FYROM	Moldova
Belgium	Iceland	Monaco
Bosnia and Herzegovina	Lebanon	
Estonia	Luxembourg	

Table 3. The countries of Regional Association VI, no nomination for CAgM.

The Barbados questionnaire had 13 questions circulated in the RA-VI region as well as in the other regions. The original questionnaire suggested by the WMO Division for Agricultural Meteorology was a little modified. The targeted audience was representatives of the experts in agrometeorology. As is the case of any questionnaire, it is always difficult to find the appropriate channel to get useful information. To collect as much information the National Representatives in the Region, the members of RA-VI Working Group on Agricultural Meteorology, and the members of the COST Action 718 were asked questions formally and informally as well. We received 31 answers from 30 countries and a response from the editor of the Monitoring of Agriculture with Remote Sensing (MARS) Bulletin.

The Region has 49 members. Thus, we received answers from more than 60 percent of the survey recipients. The evaluation of the answers was not an easy task because of the diverse type of responses. The people were asked to submit a few examples as well. The total amount of the submitted materials totaled more than 500 pages. This paper would like to evaluate the state-of-the-art agrometeorological bulletins for the entire RA-VI. However, we can cover the part of the Region that provided detailed information from the questionnaire.

The second portion of the survey was another questionnaire that was circulated among the same organizations and specialists. We were able to collect information from 33 countries, 85 percent of the represented countries in CAgM, and 67 percent of the whole RA-VI. Figure 2 shows the territorial distribution of the non-answering countries, and it shows that, from the point of view of territorial representation, we reported much better coverage of the Region. No information was available before the meeting from Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Estonia, the former Yugoslav Republic of Macedonia (FYROM), Georgia, Iceland, Jordan, Latvia, Lebanon, Lithuania, Luxembourg, Republic of Moldavia, Monaco, and Syrian Arab Republic.



Figure 2. The non-responding countries are marked with dark color.

Table 3 lists the questions of the circulated questionnaire. As is usually the case in every questionnaire, it is not easy to formulate the questions to ensure adequate response by everyone. Taking into consideration the problems of the questions, we can conclude a few common features of the agrometeorological activity in RA-VI.

### Preliminary Conclusions

Before trying to summarize the answers, we would like to set forth a philosophical question. Why do we need an applied science? Why do we need agrometeorology? If we would like to answer the question, it could promote the evaluation of the collected information. What is agrometeorology? Is it a supplementary service? Has it social or economical necessity or anything else? In very general or very simplifying terms, the answer we can give is that the basic goal of agrometeorology is to increase the quantity of yield, improve the quality, and reduce the environmental damage.

In most of the RA-VI, i.e., the European Union (EU), the basic problem is not increasing the quantity of the yield, but overproduction. The EU which consists of 15 members, increased to 25 members after May 1, 2004 (Figure 3). The EU dealt with the biggest enlargement in its history.



Figure 3. Members of the European Union after May 1, 2004.

When we try to evaluate the state-of-the-art of agrometeorology in RA-VI, we have to take into consideration, the present and near future political situation in the Region. The history of the EU (Common Market) started in 1958 with six members. The first enlargement was in 1973 when three new members were added to the organization. This was followed by one new member in 1981 and two new members in 1986. After 1995, the number of members reached 15 with three new countries. The Union harmonizes the countries activities. In case of the agricultural policy and activity, every country should follow the common agricultural policy (CAP). From the point of view of agricultural meteorology, if we would like to have an impression about the agrometeorological activity of the Union, we have to follow the work of Ispra Institute of Joint Research Centre. The details are shown in a separate paper of the present volume. We will only summarize the reports of national meteorological/hydrometeorological institutes.

Because there is no lack of food and overproduction exists, the national communities are generally not interested in a system that can promote the quantity of the food production. On the other hand, there is a very strict and difficult subsidization system (CAP) in the European Union that should be followed by farmers, and there is strict environmental protection which would minimize the environmental damage. Agricultural meteorology could be helpful in the optimization of the use of chemicals, herbicides, and irrigation water. From the point of view of the national and traditional organizations, agricultural meteorology is not in a favorable

position because many activities of insurance and pesticide companies exist which have got their own agrometeorological services.

Many companies sell the chemicals together with automatic weather stations and computer programs to help the farmers. We have no information either on quality or quantity of these services or systems. The other permanent problem of the meteorological data user community is the commercialization of meteorological data (as outlined in WMO Resolution 40 of Cg-XII).

## **Results of the Questionnaire**

The answer for the first question, independent agrometeorological unit, was a little surprising. We received 33 answers. Twenty countries reported having operated an independent agrometeorological unit, and only 13 countries responded having no independent unit. In a few cases, it was reported that few people deal with the agrometeorological service in the frame of other organizational units, mainly as a part of the commercial, forecast, or climate units.

The answers for the “major customers” question were not surprising. Every response put the farmers and the extension services in the first place. Almost everybody mentioned the research institution as users. In many countries the biggest users cited were the public administration and the government. In a few countries, the last two listed were the major customers of the national agrometeorological service.

Concerning the third question on agrometeorological services almost everybody answered that agrometeorological bulletins exist. It is a traditional tool of information dissemination. Taking into consideration the relatively low cost involved in its preparation, only a few services think that it would be better to stop its publication. A very detailed evaluation of the state-of-the-art agrometeorological bulletins was carried out during the Barbados Workshop (Sivakumar, 2001). A few examples of the types of bulletins are also presented here. For the real user, a direct immediate service would be the most useful. Many services have got direct information transmission, which is the Internet. Every national meteorological service has its own homepage. The complete list of the NMHSs can be found in the WMO’s homepage with a direct link to every website. Nearly all users have access to web sites with direct access to at least the basic meteorological information, and to the basic weather forecast.

Of course many of the meteorological websites are not directly organized for agrometeorological purposes, but we can assume that every meteorological website can be used for agrometeorological goals. For example, if someone searches for a weather forecast to organize an agricultural activity, we can consider it as agrometeorological use. We show here only three types (or possible categories) of websites. The first one is the simple national meteorological service’s homepage. The Bulgarian website is also shown. The second category (but maybe it is unique in Europe) is the direct agrometeorological homepage from Germany, and the third one is a plant protection institution’s homepage showing agrometeorological information (as the Norwegian institute does):

<http://www.meteo.bg>  
<http://www.agrarmet.de>  
<http://www.vips.planterorsk.no>

In the third case, the homepage includes a public portion and a subscriber portion.

The answers in the three first questions of the “five major types” block were homogeneous. Practically everyone answered that they would like to use the agrometeorological information to reduce the impact of natural disasters. It plays a role in the early warning and, of course, its main tool is the main-, short-, and medium-range forecast. The majority uses some climate prediction, but many countries reported that there are no case studies for climate prediction. The situation is opposite in the case of the reduction of the contributions to global warming. The majority saw that their activity has no connection with the global warming problems.

Most respondents mentioned that the main shortcomings and limitations of the agrometeorological services are the availability of data, unsuitable methods, and lack of well-developed analytical tools. As it was mentioned earlier, there exists a contradiction between national meteorological services and the users concerning data availability. In many countries, the state government does not totally support the work of the national meteorological service and the meteorological service should follow some commercial activity. One branch of the commercial activity is the selling of meteorological data. The national meteorological services, in general, do not want to open the data archives for the agrometeorologist or agricultural users as they would like as much income as possible or would like to pay for the service/information/data.

During the agrometeorological bulletin survey, it was realized that the cooperation with agricultural research and extension services highly depends on the organization and the basic task of the national meteorological services. The majority reported that they have connections and interaction with agricultural institutions; only a few respondents stated that there is practically no connection.

The responses were weak regarding connections with the great international organizations. The answers were strongly affirmative in the case of United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Convention to Combat Desertification (UNCCD) (desertification). A majority submitted “yes” in the case of Convention on Biological Diversity (CBD), but many reported “no.” A minority reported “yes” for the World Food Summit Plan of Action. The reason may be very simple. These global problems are not relevant for most of the European agrometeorological services.

It is always difficult to discover any relevant suggestions on how to improve the service. It was a common opinion of the reporters that it is important to modernize the monitoring system, use GIS, build into the system as many tools of the remote sensing techniques as possible, and to upgrade the computer-based management. All respondents mentioned the application of agrometeorological models, the new dissemination system, the use of SMS, and the Internet as useful for disseminating information.

We think the main purpose of any similar survey is to find a good suggestion for the common problem, i.e., in our case to find a strategy to strengthen operational services. For the question on “strategy” there was no answer. Only a tactical approach was given. The general opinion was that the agrometeorological information could be useful only in combination with other services. Agrometeorology could be useful as an auxiliary system, but it can not work alone.

If we would like to outline the type of the agrometeorological service summarizing the given answers, we can conclude that two different types of structures exist in Europe. The first category is where the national meteorological service has no agrometeorological activity, but in the country, other service systems exist. A good example is Italy where the national meteorological service has no connection with agrometeorological activity, but on a regional level (not a WMO Region), we find very strong services. Every region has its own service and issue agrometeorological bulletins. An ideal situation is found in Germany, where the national service has its own research and operational network within the federation system.

## National Examples

The position and organization of agrometeorological information systems changes from country to country. It would be very difficult to outline any common European feature of the agrometeorological system. Instead of searching for common lessons, we show a few examples extracting the most interesting part of submitted reports. The authors apologize if not every responding country is presented here.

As mentioned, we can identify some basic examples of the organization of the agrometeorological information system. The first is the countrywide national service belonging to the national meteorological service. The second example could be the more or less independent structure, not organized on the base of the organizational structure of the national institute.

Before the information era, the central element of the agrometeorological information distribution was the bulletin. We concluded that the agrometeorological bulletin can not compete with the more efficient distribution media; materials are the same notwithstanding the media. Many national meteorological services in many countries issue local or regional bulletins.

### *France*

In France, the delivery of a bulletin depends on its frequency of use. If the bulletin includes climate data (temperature, rainfall) or agroclimatological data (potential evapotranspiration, degree days, etc.), the purpose of this bulletin is to assess the impact of the meteorological parameters of previous months on one or many crops, and the dissemination is on a monthly basis. If the bulletin includes meteorological forecast, the purpose for the end-user (generally farmers) is to manage their work in the coming hours or days. The bulletins are updated about five times daily.

For departmental weather forecasting, France is divided into 95 administrative departments. These forecasts are accessible on answering machines and provide specialized information in agrometeorology adapted to the cultures of the department, including information over the previous days along with agronomical advice (pest and disease, irrigation, etc.). They are generally set up thanks to the collaboration of the Departmental Center of METEO-France and the Departmental Chambers of Agriculture and/or Services of the Protection of the Plants.

The METEO-France (videotext) provides weather forecasts on each department, for the 7 coming days. These forecasts are updated four times a day. From the METEO-France, the user can obtain the departmental forecast by fax. This means that access to information used

now by the farmers will be doubtless gradually abandoned for the benefit of the Internet in the next few years. To refine the meteorological forecasts at the local level, France has been divided into 700 homogeneous zones from the forecasting point of view. There are about 5 to 10 zones per department. The farmers can reach these very accurate, local forecasts elaborated by the Departmental Centre of METEO-France, by step 3 hours. They are valid up to 36 hours, and updated at least six times per day (ATMOGRAMME). This service represents a true tactical decision-making tool for the farmers, since it helps realize savings on chemical amounts and irrigation. ATMOFAX is a service of METEO-France, making it possible for the farmers to obtain by telefax the ATMOGRAMME of their zone of interest as soon as possible upon request. This service can be accessible through an organization of farmers such as the cooperatives and the Chambers of Agriculture. Upon request, each group member obtains an access code that allows connection to the fax server of METEO-France. In the same phone call, the farmer can obtain its ATMOGRAMME as well as the number of ATMOGRAMME consumed since the beginning of their subscription.

This service can be supplemented by the access to the weather reports (up to 7 days) worked out by the Departmental Centre of METEO-France. This bulletin is provided by fax to each farmer by the headquarters of the farmers group.

Another example is the Ministry of Agriculture bulletin about the state of crops at the national level elaborated with maps of rainfall, outputs of a water balance model, and output of Incident Support & Operational Planning (ISOP). This information is posted on the Internet by METEO-France on a monthly basis. Since 1997, an integrated system called ISOP has been developed between three French participants: the Ministry of Agriculture (through its Department of Statistics, SCEES), the Institute for Agronomical Research (INRA), and the national meteorological service. The purpose is to produce reliable estimations of the forage production, in order to give objective information to the Ministry of Agriculture to estimate real production losses in the case of local or global drought. Estimated from a national survey, input data are various and multiple, including spatialized daily meteorological parameters, percentages of soil types, nitrogen status, and amounts and frequency of mowing or grazing. The STICS crop model is applied to three kinds of grassland: permanent, temporary, and pure legumes. The results are available for 200 regions of forage production (RFP) and synthesized in alert maps and temporal graphs for selected drought-stricken areas.

The model is part of the multi-crop simulator STICS and simulates the evolution of grass above ground dry matter and water and nitrogen balances. The STICS crop model needs daily meteorological parameters (temperatures, rain, global radiation, and PET). These data should be available for the reference period (1982 to 1996) and also for the current year to provide real-time outputs with a short delay. The management practices for mowing frequency and nitrogen supply are estimated from a national survey (8800 fields surveyed in autumn 1998) for the 182 (out of 200) RFPs with representative grassland surface (more than 7000 hectares). The results were translated into direct inputs for the STICS crop model: values of thermal time between mowing, number of mowings, amounts of nitrogen supply during winter and spring, and initial nitrogen indices. To take into account the different soil types on which the grasslands are to be found, the EU (1/1.000.000) soil map is used to provide soil map units where only predominant soils are listed. These soils are then characterized by their water capacity and nitrogen mineralization properties per layer and introduced in the system.

Concerning the climate information, METEO-France has developed a service allowing a simple access to the climate data of the stations managed by the service. This service called COLCHIQUE is intended for the professional users needing climate data occasionally or on a regular basis. The technical institutes, the plant health and agricultural-alimentary companies, and research centers, frequently need climate data to refine their studies, compute crop models or pest and disease models, or estimate crop productions. COLCHIQUE allows the acquisition of a meteorological data-set less than 2 days after measurement, from about 150 synoptic stations of METEO-France and approximately 1,000 automatic stations. Observations of temperature, wind, pressure, and moisture are accessible on a daily, 10-day, or monthly basis and also elaborated products like deviation or ratio-to-normal water-content assessment.

For example, the agricultural institute involved in the sugarbeet study collects the meteorological and agrometeorological data of the METEO-France database using COLCHIQUE. It presents a specific bulletin each month taking into account the agroclimatic conditions. Agricultural technicians of the Chambers of Agriculture or cooperatives in the north of France, in cooperation with the technical institute involved in the sugarbeet study, provide detailed information for the bulletin. All agrometeorological services provided by METEO-France are also available on the Internet.

The bulletins disseminated by answering machines, Minitel, fax, and Internet can be evaluated based on the number of end-users and requests. At the departmental level, there are a lot of meetings between the end-users and the delegate of METEO-France to define the needs and evaluate the feedback of new services. Sometimes, the Commercial Services of METEO-France conduct national surveys to assess the impact of services. It is possible to evaluate if a farmer has realized savings on the chemical or irrigation amounts when he or she has taken into account meteorological information. But, it is difficult to estimate the economic value and also the real environmental benefit at a national level. For that, the Ministry of Agriculture would have to do a survey in partnership with the Ministry of Environment and METEO-France.

To estimate and monitor the risk of severe drought and determine the most affected areas, maps on agrometeorological parameters such as potential water balance or state of available water, are produced on a regular basis or upon request. This information is completed with other data like the levels of the water tables and compared with the statistical values. For more than 20 years in the southeast of France, studies and experiments have been performed to monitor and prevent forest fires. This activity is a core mission. The drought indices calculated by METEO-France are communicated to the Civil Protection Agency from June to September. The indices are calculated with meteorological data of ground network with meteorological forecasts. This information is spatially improved using remote sensing (surface temperature and vegetation index from NOAA-Advanced Very High Resolution Radiometer [AVHRR]). The Météoflash message informs the farmer by telefax of the arrival on its zone of a weather phenomenon which can affect the cultures, the cattle, the materials, and the program of work. The warning message concerns the phenomena such as storm, strong rain, frost, very strong frost, strong heat, etc. This service is available by subscription through the departmental centre of METEO-France.

Modern techniques such as remote sensing data (surface temperature and NDVI from NOAA-AVHRR) are used by METEO-France to improve forest fires bulletins. Simulation models are used by agricultural institutes (Chambers of Agriculture, technical institutes,

cooperatives, etc.). Interactions between Soil, Biosphere, and Atmosphere (ISBA) is a soil-vegetation-atmosphere transfer (SVAT) scheme developed at the National Centre for Meteorological Research (CNRM) at METEO-France which is used to model the exchange of heat, mass, and momentum between the land or water surface and the overlying atmosphere. The model is used in so-called stand-alone mode for development, and in coupled-mode in which the model supplies the lower boundary conditions to atmospheric numerical weather prediction models or the upper boundary conditions for distributed hydrological models. ISBA is currently coupled to the METEO-France operational numerical weather prediction model (ARPEGE), the METEO-France climate model or GCM (ARPEGE-climate), the non-hydrostatic meso-scale atmospheric model Meso-NH, and the distributed macro-scale hydrological model MODCOU. The purpose is to do an operational service in hydrology and agrometeorology using ISBA linked to MODCOU with interpolated meteorological data in input. The use of GIS is increasing in France. A lot of organizations involved in agriculture and in agrometeorology use GIS to define agricultural potentialities to define polluted areas.

AgriQuest (<http://www.agri-quest.com>) is an Internet agricultural monitoring service developed by a private agency that provides real-time nationwide mapping and monitoring of vegetation conditions calculated with NOAA-AVHRR data. More than any other economic sector, the food and agriculture industries are affected by climatic risks. Among the various methods available for anticipating variations in productivity, remote sensing offers a wide range of simple techniques tested and proven over the past twenty years by numerous national and international organizations. For agricultural monitoring, AgriQuest provides weekly maps and charts that help end-users make objective, real-time analyses of crop potential from sowing time to harvest.

### ***Germany***

The German Meteorological Service (Deutsche Wetterdienst or DWD) has its own agrometeorological unit. It consists of seven regional branches (Figure 4). The agrometeorological service does research in the interrelations between weather and agriculture and presents the findings to the farmer by the agrometeorological advisory service. In Offenbach, where the centre of DWD is located, is the central business unit. Braunschweig has the agrometeorological research. Schleswig (Schleswig-Holstein, Mecklenburg-Vorpommern, Niedersachsen, Bremen, and Hamburg), Halle (Thüringen, Sachsen-Anhalt, Sachsen, Brandenburg, and Berlin), Geisenheim (Hessen, Rheinland-Pfalz, Saarland, and Nordrhein-Westfalen), and Weihenstephan (Bayern, Baden-Württemberg) supply the information (federal states of Germany in parenthesis).

Every agrometeorological regional unit supplies agrometeorological information and advice to a few federal states of Germany. Meaning, not every federal state has its own agrometeorological institute. Deutscher Wetterdienst (DWD) has a business unit called Landwirtschaft, meaning it deals with agrometeorology. The agrometeorological service does not work alone; in some cases, regional agricultural chambers (or research) give contributions to the more biological parts of text (in advisories). Bulletins cover the previous weekly and monthly period as well as daily forecasts and advisories. The main users of the information are farmers, vegetable growers, horticulturalists, vine growers, extension service, and agricultural chambers. They are reached by telephone, answering machine, and fax. There is a service of DWD for forestry: [http://www.dwd.de/services/gflw/lw\\_home.html](http://www.dwd.de/services/gflw/lw_home.html).



Figure 4. The agrometeorological units of DWD (Germany), and the regions belonging to the centers.

The remote sensing or GIS is not directly used for agrometeorological information service at DWD. Simulation models are used for agrometeorological topics (crop and soil conditions, harvest conditions and quality, pests and diseases, etc.). Telephone service (renewed daily) is limited by time (2- to 3-minute advisories). The daily, regional weatherfax consists of one page with results of the most interesting topics for the season. Second-order important information is not given to the farmer. Limitations include the personnel available to produce the regional texts and fax sheets, although the models run automatically that create the morning tables.

### *Italy*

There are various types of agrometeorological information distributors in Italy. The results of the survey indicate that the role of the national meteorological service could be negligible in supplying agrometeorological information. The standard meteorological forecast is in the hands of the national services. In the case of EU, the basis of every standard weather prediction is the various types of forecasts issued by the European Centre for Weather Forecasts (ECMF), which is mainly the organization of the national meteorological services of the EU and a few other countries (Switzerland, Turkey, and Norway). The list gives the

main servers supplying the users with agrometeorological information in the Italian regions. As we can see in the list, there are various types of website supporters. The agrometeorological centers are shown in Figure 5.

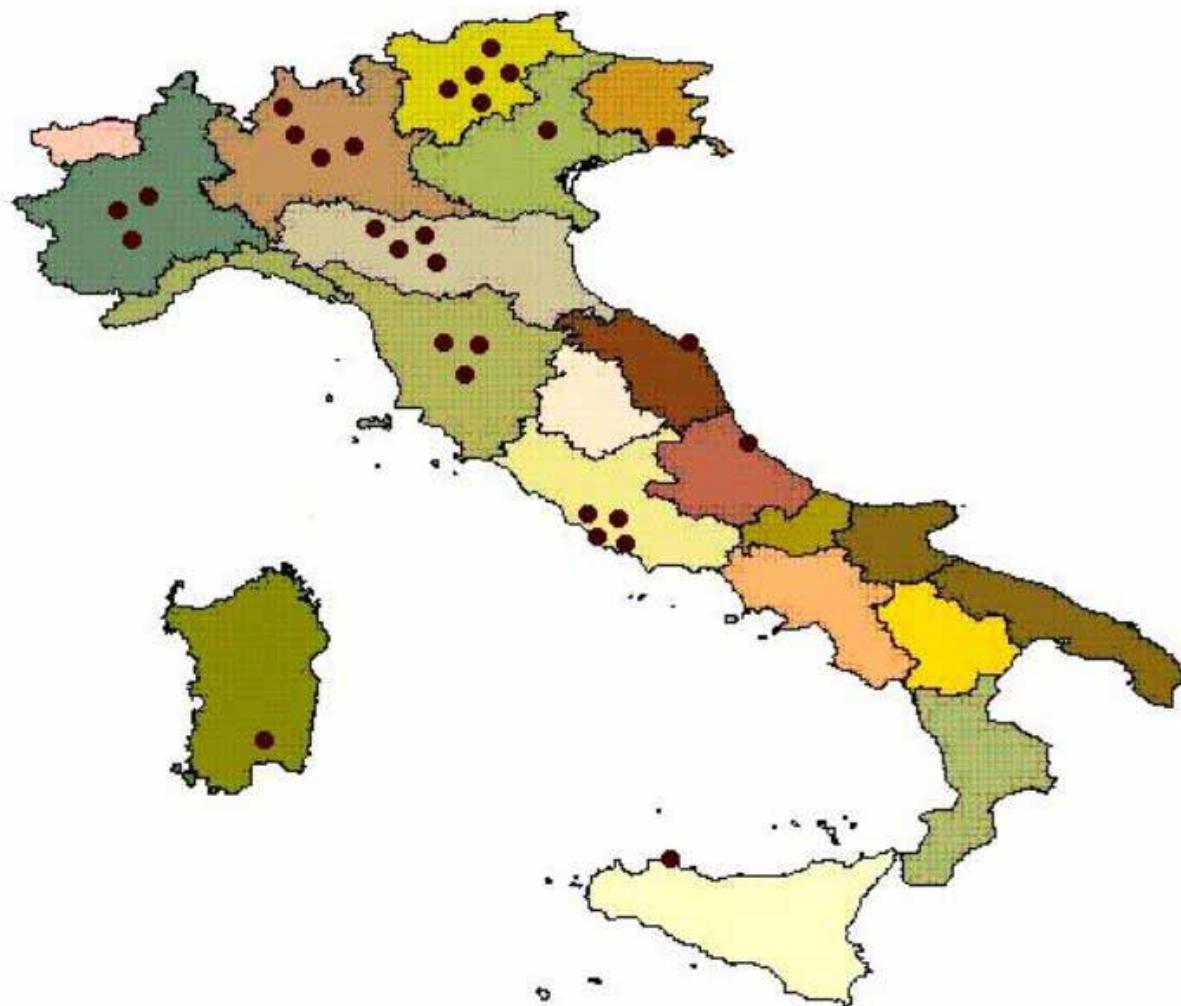


Figure 5. The regional centers in Italy where agrometeorological information is used.

The Italian regions and the agrometeorological information distributors are:

#### LIGURIA

Centro Meteo Idrologico della Regione Liguria, (<http://www.cmirl.ge.infn.it/index.html>),  
Assonautica (Ass.Nazi. per la Nautica da Dporto Sezione Provinciale di Savona):  
(<http://www.infocomm.it/AptPalme/Puntometeo.htm>)  
Tele Liguria Sud, (<http://www.itsyn.it/meteo/prev.htm>)

#### PIEMONTE

Società Meteorologica Subalpina, (<http://www.comune.torino.it/meteo/>)  
Regione Piemonte – Dir. Reg. servizi tecnici di prevenzione, (<http://www.regione.piemonte.it/meteo/boll.shtml>)  
LRC Cuneo (<http://www.lrcser.it/retecivica/meteo/>)

#### LOMBARDIA

Centro Geofisico Prealpino (<http://www.astrogeo.va.it/prevmete.htm>)  
Centro Nivometeorologico della Regione Lombardia di Bormio (<http://www.novanet.it/vvol/meteo/>)  
Brescia on Line (<http://bresciamagazine.numerica.it/meteo/>)  
Centro Rilevamento Ambientale (CRA) Comune di Sirmione (<http://gardanet.it/turismo/sirmione/meteo/>)

#### TRENTINO ALTO ADIGE

Centro Sperimentale Valanghe e Difesa Idrogeologica di Arabba ([http://www.sunrise.it/csvdi/csvdi\\_it.html](http://www.sunrise.it/csvdi/csvdi_it.html))  
Servizio Prevenzione Calamità Pubbliche Provincia Autonoma di Trento (<http://www.provincia.tn.it/meteo/>)

Centro Agrometeorologico Provinciale (S.Michele all'Adige) (<http://www.ismaa.it/html/ita/meteo.html>)

Provincia Autonoma di Bolzano-Ufficio idrografico, ([http://www.provincia.bz.it/hydro/index\\_i.htm](http://www.provincia.bz.it/hydro/index_i.htm))

DolomitiSuperski (<http://www.DolomitiSuperski.com/page04it.html>)

#### FRIULI VENEZIA GIULIA

Centro Meteorologico Regionale (<http://193.207.118.99/ita.htm>)

#### VENETO

Regione del Veneto -CSIM Centro Sperimentale Idrologia e Meteorologia Regione

([http://www.campiello.it/csim\\_teolo/csim.html](http://www.campiello.it/csim_teolo/csim.html))

#### EMILIA ROMAGNA

Servizio Meteorologico Regionale-CINECA (<http://www.cineca.it/meteo/>)

ARPA - Servizio Meteorologico dell'Emilia Romagna, (<http://www.arpamet.regione.emilia-romagna.it/default.htm>)

Regione Emilia Romagna (<http://www.regione.emilia-romagna.it/meteo/>)

Università di Modena-Osservatorio Geofisico (<http://rainbow.unimo.it/it/boll/>)

#### TOSCANA

La.M.M.A. Laboratorio per la Meteorologia e la Modellistica Ambientale-Regione Toscana

(<http://www.lamma.rete.toscana.it/>)

ARSIA-Servizio Agrometeorologico della Regione Toscana (<http://www.arsia.toscana.it/meteo/hpmeteo1.htm>)

IGT-Istituto Geofisico Toscano-Il Meteo (<http://www.igt.it/meteo/>)

#### MARCHE

Meteo Marche a cura dell'A.S.S.A.M (<http://www.agricoop.it/meteom.htm>)

#### ABRUZZO

Internet: Previsioni meteo Abruzzo (<http://www.ternet.it/meteo/pma.html>)

#### SARDEGNA

SAR-Servizio Agrometeorologico Regionale per la Sardegna (<http://www.sar.sardegna.it/>)

#### SICILIA

Telecolor (<http://www.telecolor.it/tempo.htm>)

#### ALTRI-ENEL Ricerca

CRAM (<http://elisa.cram.enel.it/index.html>)

Meteo.it (<http://www.meteo.it>)

Meteomont - Comando Truppe Alpine, (<http://www.sail.it/meteomont/>)

Epson Meteo (<http://www.rcs.it/quotidiani/meteo/prevision.spm>)

Dipartimento di Fisica e Sezione INFN di Bari ([http://sunba2.ba.infn.it/text/meteo\\_mrf.html](http://sunba2.ba.infn.it/text/meteo_mrf.html))

Testata Giornalistica Regionale TGR RAI (<http://www.tin.it/tgr/meteo/meteoit.htm>)

Meteo Italia: previsioni e consulenze meteorologiche professionali (<http://hosting.iol.it/meteo.italia/>)

Televideo RAI (<http://www2.telematica.it/televideo/index.html>)

Bollettino Agrometeorologico Nazionale UCEA (<http://www.inea.it/ucca/bollettino/>)

## Russia

In the Russian Federation, many regions (Oblast) issue their own agrometeorological bulletins. The structure follows the format of the traditional meteorological/agrometeorological bulletins. New technique plant-growth models and GIS are used, but the commercial services provide mainly special meteorological information to farmers and organizations. At the university, they work on models for crop growth and forecasts for pests and diseases. The phenological observation is an important part of the activity but because of its relatively difficult needs, very few services maintain phenological networks and observations.

Due to the significant number of survey responses, it was impossible to review the system submitted for every country in the present survey. We wanted to give an outline of how the agrometeorological works in RA-VI, mainly in Europe. We acknowledge all contributions, especially the services and bulletins mentioned in each national summary. For more details regarding specific countries, the readers are referred to the names and e-mail addresses of the contributors.

## Summary

In evaluating the submitted responses, it was very difficult to find any common lesson. We can conclude that the application of agrometeorological information, advice, and support issued by the meteorological community for the agricultural, horticultural, forestry, and fishery users depend on the traditions and economical environment. The biggest problem for the agrometeorological community is that there is no feedback from the real users, and there is an information gap between the producers and users. The lesson of our survey is that much information is out of the scope of the national services. General opinion was that the improvement of operational agrometeorological services needs both better technology and business policy.

In order to organize/reorganize or simply improve the agrometeorological service, we have to follow at least two basic positions. In the first position, we can speak about passive information transmission because we have no influence on the user. In the second position, we could be active in transferring the information to the user's contact point, and then the user can select what information is useful for their daily working practice. First, the users of a service could be various groups with different needs in information, so there should be the opportunity to prepare various kinds of services. In this case, it is more appropriate to talk about agrometeorological information systems. Secondly, the service evokes the idea of a printed document in a traditional approach, but to reach the targeted group, in many cases, it is necessary to use other means such as radio broadcasting or television. The best solution seems to be the internet or direct information transmission such as fax or sms.

Because the Internet is a developing tool of information dissemination, a general summary is shown in Figure 6, following Maracchi (2002). The first step is to define the targeted group to be reached. The main groups we can identify are: 1) the decision makers and the extension services for agriculture and the environment, 2) the farmers, and 3) the businessmen.

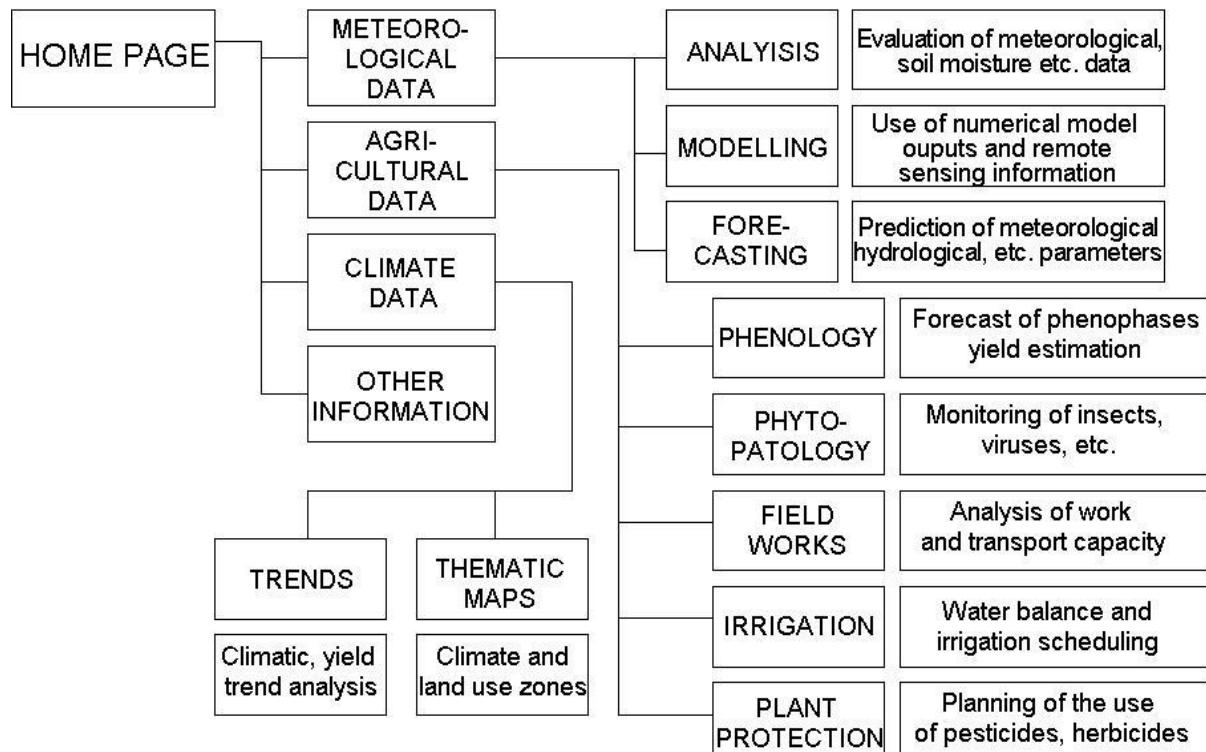


Figure 6. The structure of the agrometeorological homepage or information system.

The decision makers are interested in monitoring the agricultural campaign to help the farmers in difficult years or in the agroclimatological information for agriculture planning (Maracchi 2002, Thysen and Hocevar, 2004). They would know in advance the production estimates of the main crops, generally at a level of aggregation corresponding to the administrative subdivision of the country. The preparation of this type of information needs the conversion of meteorological data into crop yields in a format that could be compared with past statistical data. To compute the production, we can state how far we are from the average yields of each area as well as the evaluation of the acreage of the crop.

The decision makers concerns focus on extreme events causing damages to agricultural systems or to the environment; such as hurricanes, extreme droughts, floods, frost, strong winds, and intense rainfall. In these cases, the decision makers would need to know the area affected and the intensity of the phenomena.

The farmers' interests include knowing first, the characteristics of the season ahead of time in order to plan where to plant the crops. (At one time, this was not part of the forecast, but now the progress in knowledge of the seasonal climate together with the earth observation of sea surface temperature from space, makes it possible). And, secondly, during the season, using the information to make a decision in terms of crop management, planting, or not planting, spraying or not spraying, irrigate or not irrigating, and determining how much water is needed.

The farmers should receive the information punctually, and it should succinctly and coherently explain (in technical terms) the options they have. For example, it is not important to state the temperature or rainfall amount, but it is essential to communicate whether the farmers should plant or not.

In preparing advice, agrometeorologists should keep in mind the following issues: 1) what options the farmers have in relation to the information delivered; 2) the accuracy in terms of time and space of the information; 3) how to translate the meteorological or climate information into crop-management information; and 4) how to estimate the value of the advice.

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# *Operational Agrometeorological Services: International Perspectives*

## **Requirements for Agrometeorological Services**

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### **Abstract**

The current status of agricultural production and increasing concerns with related environmental issues calls for improved agrometeorological services for enhancing and sustaining agricultural productivity around the world. The requirements for agrometeorological services were described in the light of emerging issues related to environment, climate change, biodiversity, drought and desertification, food security, and sustainable development. Agenda 21, International Conventions including the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the United Nations Convention to Combat Desertification (UNCCD), the World Food Summit Plan of Action and the World Summit on Sustainable Development include elements that have implications for strengthening operational agrometeorological services which have been highlighted in this paper. Hydrometeorological disasters around the world have been increasing in the recent past and operational agrometeorological services could help the farming community with better preparedness and mitigation strategies. Perspectives from remote sensing and geographic information systems (GIS) for improved agrometeorological services were described. The World Agrometeorological Information Service (WAMIS) initiated by World Meteorological Organization (WMO) could help strengthen operational agrometeorological services around the world.

### **Introduction**

Agricultural production is a biological process which depends on the natural resource base, especially soil and water, and on favorable climatic conditions. Weather and climate have an important bearing on agricultural productivity in different agroecological regions around the world, especially in the arid and semi-arid tropical regions. While climate variability impacted agricultural productivity through the ages, in the past two decades climate change had emerged as a very important concern in sustainable agriculture.

The annual increase in world food production from 1960 to 1984 was 30 million metric tons and between 1984 and 1992, it dropped to 12 million metric tons (Jain, 1996). Recent data from the Food and Agriculture Organization (FAO) showed that the rate of growth of global crop and livestock has slowed down in each of the 3 years between 2000 and 2002. The slow rate of growth in 2002 of less than 1 percent at the global level implies a reduction in output in per capita terms. With population continuing to grow by nearly 90 million per year, the amount of grain produced per person is decreasing. Grain harvest per person showed a continuous decline from 1984 onwards. FAO's latest forecasts for global cereal production in 2003 and the first forecast for utilization in 2003/2004 indicate that output will remain below the expected level of utilization.

Developing countries are projected to increase their cereal demand by about 80 percent between 1990 and 2020 while the world as a whole will increase its cereal demand by about 55 percent (Pinstrup-Anderson, 1996). The projected demand for cereals, meat, and roots and tubers varies significantly among the developing-country regions. Sub-Saharan Africa is projected to increase its demand for these three commodity groups by at least 150 percent. Net cereal imports of the developing countries are expected to increase from 90 million tons in 1990 to 190 million tons by 2020 (Pinstrup-Anderson, 1996). The demand for meat will increase by 58 percent to reach 313 million tons.

The global agricultural scenario described above places a great deal of premium on our ability to continue to enhance productivity on a per hectare basis since the scope of extending cultivation to new areas is quite limited in scope. Given that rainfed agriculture continues to be the main mode of agricultural production, especially in the developing world, productivity enhancements per unit area in the rainfed ecosystems are a must. There is a need for a greater understanding of the effects of weather and climate variability on the rate of development, growth and yields of rainfed crops, and for improved methods of managing weather and climate risks in the rainfed ecosystems. Applications of agricultural meteorology are crucial in both these endeavours.

### **Growing Need for Agrometeorological Services**

In much of the tropics, especially in the semi-arid tropics, farming systems are mainly rainfed and are affected by inter-annual as well as intra-seasonal climate variability. Farmers had to adapt to the range and frequency of shocks that climate variability brings and they have tried to use the available knowledge and information to develop their coping strategies. But the adoption of improved technologies is too slow, especially in Africa, to counteract the adverse effects of varying environmental conditions, and climate fluctuations continue to be the main factors that prevent a regular supply and availability of food, the key to food security.

There are increasing demands for timely and effective agrometeorological information for on-farm applications by farmers. Farmers need information on expected rainfall for planting and harvesting activities. Rainfall forecasts are also crucial for farmers to determine when and how to apply fertilizers. Agrometeorological information to assist in irrigation planning is very important to both the farming community as well as managers of water resources. The importance of the type of weather information needed for a decision-making process depends upon the nature of the decision itself. For example, present weather and short-term forecasts are used in making daily operational decisions, while the analyses of past climate data are especially useful for planning decisions. Predictions of the potential for the incidence of diseases and pests are usually based on current and past weather conditions in a specific agricultural area and crop type.

Agricultural weather and climate data systems are necessary to expedite generation of products, analyses, and forecasts that affect agricultural cropping and management decisions, irrigation scheduling, commodity trading and markets, fire-weather management, and other preparedness for calamities, and ecosystem conservation and management. There is convincing evidence available from different parts of the world that judicious application of meteorological, climatological, and hydrological knowledge and information, including long-range forecasts, greatly assists the agricultural community to develop and operate sustainable agricultural systems and increase production in an environmentally sustainable manner. Medium and long-range forecasts, coupled with past climatological data, are valuable for

long-term planning decisions related to farm management. The need for reorienting and recasting meteorological information, fine tuning of climatic analysis and presentation in forms suitable for agricultural decision making and insulation of marginal farmers with small holdings from the adverse impacts of weather vagaries has become more pressing. Also, the growing concerns with the need for achieving greater efficiency in the natural resource use while conserving the environment is placing a much greater emphasis on understanding and exploiting the climatic resources for the benefit of agriculture and forestry.

Concurrent to the growing need for agrometeorological information, the developments in communications and electronic media, in particular the ever-expanding cyberspace linkages through the web, are placing greater demand on operational agrometeorological services. Information is needed and is being sought through the rapid search engines. Private initiatives to meet the increasing demands for information are growing and are giving scope to criticisms against publicly funded organizations for their inability to provide information in a manner similar to those of the private initiatives.

The challenge in front of the agrometeorologists around the world is that more than ever before, there is a great need to more effectively integrate and deploy the skills we have developed in operational, experimental, and theoretical aspects of agricultural meteorology to make agricultural production systems more reliable, more efficient, and above all, more equitable in the world at large.

## **Requirements for Agrometeorological Services**

### *Perspectives from Environment, Climate Change, Biodiversity, Drought and Desertification, Food Security, and Sustainable Development*

The need for improved agrometeorological services purely from a food production perspective was described earlier. Over the past three decades, there is a greater awareness of the importance of protecting the environment, adapting to climate change, arresting loss of biodiversity, coping with the impacts of drought and desertification, ensuring food security, and promoting sustainable development.

Over the past 12 years in particular, the world has seen a surging interest in environmental matters affecting mankind and its future. The organization of the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, in June 1992, led to the production of Agenda 21. Two major international conventions were negotiated separately from, but in parallel with, preparations for UNCED and were signed by most governments at Rio de Janeiro. These included the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). Subsequently, the United Nations Convention to Combat Desertification (UNCCD) was negotiated and entered into force on December 26, 1996.

In addition to the above, the World Food Summit Plan of Action (WFSPA), which was developed in 1996, and the commitments outlined in the WFSPA were also accepted by the international community. In August-September 2002, the World Summit on Sustainable Development (WSSD) was held in Johannesburg, South Africa, to take stock of the achievements, challenges, and new issues arising since 1992 when UNCED was held.

In the following sections, a short description is presented on the perspectives on agrometeorological services emerging from Agenda 21, the international conventions, and the WFSWA.

## **Environment**

UNCED was an unprecedented event because significant topics of vital importance to the peoples of the world, particularly in relation to sustainable development, were addressed at the highest level. The conference made it clear that we can no longer think of environment and economic and social development as isolated fields. The centrepiece of UNCED is the Agenda 21 (Centre for Our Common Future, 1993), a global plan of action, which resulted from the consensus among all the countries. Agenda 21 aims at reconciling the twin requirements of a high-quality environment and a healthy economy for all peoples of the world.

From the point of view of operational agrometeorological services, the following elements in Agenda 21 are of interest:

- a) Strengthening the knowledge base and developing information and monitoring systems for regions prone to desertification and drought, including the economic and social aspects of these ecosystems. Improvement and strengthening of meteorological and hydrological networks and monitoring systems to support data collection for research into the interactions between climate, drought and desertification, and for assessment of their socio-economic impacts.
- b) Developing comprehensive drought preparedness and drought-relief schemes, including self-help arrangements, for drought-prone areas. Research into seasonal forecasting and the strengthening of drought early warning systems and integrated packages at the farm and watershed level such as alternative cropping strategies, soil and water conservation, and promotion of water harvesting techniques.
- c) Identification of hazard-prone areas which are most vulnerable to erosion, floods, landslides, earthquakes, snow avalanches, and other natural hazards, and development of early-warning systems and disaster-response teams.
- d) Protecting forests from fires, pests, poaching, mining, and reducing pollutants that affect forests, including air pollution that flows across borders.

Chapter 32 of Agenda 21 calls for a more active role for farmers in influencing decisions. Operational agrometeorological services should include steps to promote more direct participation of farmers in agrometeorological field studies and in designing appropriate strategies for the provision of agrometeorological information to the users.

## **Climate Change**

There is evidence that global warming over the last millennium had already resulted in increased global average annual temperature and changes in rainfall, with the 1990s being the warmest decade in the Northern Hemisphere. During the past century, changes in temperature patterns have had a direct impact on the number of frost days and the length of growing seasons with significant implications for agriculture and forestry. Land-cover changes, changes in global ocean circulation and sea surface temperature patterns, and changes in the composition of the global atmosphere are leading to changes in rainfall. These changes may be more pronounced in the Tropics. For example, crop varieties grown in the

Sahel may not be able to withstand the projected warming trends and will certainly be at risk due to projected lower amounts of rainfall as well.

The UNFCCC came into force on 21 March 1994 and the Principles of UNFCCC (Article 3) highlight the need for countries to take precautionary measures to anticipate, prevent, or minimize the causes of climate change and mitigate its adverse effects. Article 3.4 underscores that policies to protect the climate system should be integrated with national development programs, which necessarily include agriculture. Similarly, Article 3.3, still without mentioning agriculture, underlines that all sources and sinks have to be taken into consideration.

The Commitments of UNFCCC (Article 4) call for cooperation in preparing for adaptation to the impacts of climate change and for the development and elaboration of appropriate and integrated plans for water resources and agriculture. Agriculture has the potential to adapt much faster in all those sectors where the management component plays a major part, i.e., essentially for field crops, livestock rearing, inland fisheries, and some forms of marine plant and animal production.

The 3rd Conference of the Parties of the UNFCCC, held in Kyoto during late 1997, led to the Kyoto Protocol. Compared with the UNFCCC, the Kyoto Protocol focuses much more explicitly on agriculture and forestry, in particular on sustainable forest management practices and on the promotion of sustainable forms of agriculture in the light of climate change considerations. It is interesting to note the wording “in the light of climate change considerations,” which stresses also climate extremes and variability, and, not just the sources of unsustainable agricultural practices.

Adaptation to the adverse effects of climate variability and climate change is of high priority for nearly all countries, but developing countries are particularly vulnerable. Effective measures to cope with vulnerability and adaptation need to be developed at all levels. Operational agrometeorological services should recognize the necessity for integrating agrometeorological adaptation strategies to climate change in the development of best agricultural practices. In developing adaptation strategies to cope with risk management at the farm level, it is essential to learn from the actual difficulties faced by farmers.

Agrometeorologists must play an important role in assisting farmers with the development of feasible strategies to adapt to climate variability and climate change. Some farming systems with an inherent resilience may adapt more readily to climate pressures, making long-term adjustments to varying and changing conditions. Other systems will need interventions for adaptation that should be more strongly supported by agrometeorological services for agricultural producers. This applies, among others, to systems where pests and diseases play an important role.

Seasonal to inter-annual climate forecasts will definitely improve in the future with a better understanding of the dynamic relationships between atmosphere, land, and oceans. However, the main issue at present is how to make better use of the existing information and dispersion of knowledge to the farm level. Direct participation by the farming communities in the pilot projects on the dissemination and use of climate forecasts will be essential to determine the actual value of forecasts and to identify the specific user needs. Old (radio) and new (Internet) communication techniques, when adapted to local applications, may assist in the dissemination of useful information to the farmers and decision makers.

## **Biodiversity**

Every cubic centimeter of the biosphere has been altered by human-induced changes in the climate and the chemical composition of the atmosphere, and this carries major implications for biological diversity. On the other hand, plants, animals, and microbes absorb and break down pollutants; help maintain a benign mix of gases in the atmosphere; regulate the solar energy the earth absorbs; moderate regional weather and rainfall; modulate the water cycle, minimizing floods and drought and purifying waters. Hence, it is clear that there are major interactions between climate and biological diversity. In the light of the growing concerns with the protection of biodiversity, the global community ratified the Convention on Biological Diversity (CBD), which entered into force on December 29, 1993. The Convention, which is based on a broad ecosystem approach, contains three national-level obligations: to conserve and sustainably use biological diversity and to share its benefits.

From the point of view of operational agrometeorological services, the following elements in CBD are of interest:

- a) Promoting environmentally sound and sustainable development in areas adjacent to protected areas where special measures need to be taken to conserve biological diversity; and,
- b) Rehabilitating and restoring degraded ecosystems.

Generally speaking, any natural resource conservation measures to maintain land productivity through sustainable agricultural practices could effectively contribute to the maintenance of biological diversity.

## **Drought and Desertification**

Drought is the consequence of a natural reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors (such as high temperatures, high winds, and low relative humidity) that can aggravate the severity of the event. Drought occurrences are common in virtually all climatic regimes. Of the many climatic events that influence the earth's environmental fabric, drought is perhaps the one that is most recognized by farmers around the world, especially in the arid and semi-arid tropics, as the most important extreme meteorological event that affects their crops and livestock and causes severe economic losses.

In view of the widespread impacts of droughts on agriculture, there is considerable interest in developing strategies for coping with droughts. An important component of such strategies is prediction and early warning with good lead time, about impending droughts, which provides the best solution for the minimization of the loss of life and property damages. Prediction and early warning information and products are vital in enhancing food and agricultural production as well as in the utilization and management of fresh water, energy, and other natural resources that are sensitive to extreme weather and climate events.

The United Nations Convention to Combat Desertification (UNCCD), which entered into force on 26 December 1996, gave a great deal of importance to early warning systems including use of seasonal climate forecasts. The following areas identified in the Convention could be of specific interest for operational agrometeorological services:

- a) Establishment and/or strengthening, as appropriate, of early warning systems, including local and national facilities and joint systems at the sub regional and regional levels;
- b) Strengthening drought preparedness and management strategies, including drought contingency plans at the local, national, sub regional and regional levels, which take into consideration seasonal to interannual climate predictions;
- c) Early warning and advance planning for periods of adverse climatic variation in a form suited for practical application by users at all levels, including especially local populations; and,
- d) Development of sustainable irrigation programs for both crops and livestock husbandry.

## **Food Security**

Food security is a major problem in most countries with low per capita food production and a high dependence on agriculture. Recent food security problems have originated mostly from weather-related hazards and extreme events such as droughts, floods, and cyclones.

The World Food Summit (WFS), which was hosted by FAO in Rome in November 1996, prepared the WFS Plan of Action with the main objective to improve food security at all levels, and to significantly reduce the number of undernourished people.

Poverty is seen as one of the main factors behind food insecurity, but the WFS document stresses the links between poverty and such factors as natural disasters and climate-related ecological changes. Climate fluctuations are indeed the main factors that prevent a regular supply and availability of food, which is the key to food security.

The WFS elaborated seven Commitments, of which Commitment 3 (sustainable policies and practices essential to adequate and reliable food supplies and to combat pests and drought and desertification) and, to a lesser extent, Commitment 5 (prevent and prepare for natural disasters and man-made emergencies and to meet transitory and emergency food requirements) are very relevant for the climate community in a sustainable development perspective.

Commitment 3 makes repeated reference to climate and climate change (including the UNFCCC) and the related problems of desertification, the loss of biodiversity, and the depletion of the ozone layer, which are all related, at least indirectly, to the unsustainable use of climate resources. This Commitment stresses the need for disseminating and applying climate forecast information that will increase sustainable agricultural, fisheries, and forestry productivity, and be of particular benefit to developing countries.

Commitment 5 emphasizes the need to maintain, promote, and establish the preparedness strategies and mechanisms, including development and application of climate forecast information for surveillance and early warning, drought, flood, other natural disasters, and pest and disease alertness. It also underlines the need to support international efforts to develop and apply climate-forecast information to improve the effectiveness and efficiency of emergency preparedness and response activities, with special efforts to create synergy and avoid duplication.

## **Sustainable Development**

The World Summit on Sustainable Development (WSSD) was held in Johannesburg, South Africa, in August-September 2002 to take stock of the achievements, challenges, and new issues arising since UNCED held in 1992. But more than that, it was an “implementation” Summit, designed to turn the lofty goals, promises, and commitments of Agenda 21 into concrete, tangible actions (United Nations, 2003). The Plan of Implementation adopted at WSSD carries certain elements of direct interest to operational agrometeorological services. These include:

- a) Improving the efficient use of water resources in agriculture;
- b) Developing programs for mitigating the effects of extreme water-related events;
- c) Reducing the risk of flooding and drought in vulnerable countries;
- d) Developing and strengthening early warning systems and information networks in disaster management;
- e) Improving early warning systems for predicting extreme weather events, especially El Niño/La Niña;
- f) Providing affordable local access to information to improve monitoring and early warning related to desertification and drought; and,
- g) Supporting efforts to prevent and mitigate the impacts of natural disasters by translating available data, particularly from global meteorological observation systems, into timely and useful products.

## **Requirements for Agrometeorological Services**

### *Perspectives from Natural Disaster Prevention and Mitigation*

During the past four decades, natural hazards such as droughts, floods, storms, tropical cyclones, and wildland fires have caused major loss of human lives and livelihoods, the destruction of economic and social infrastructure, as well as environmental damages. There is evidence available from different parts of the world that there was a rising trend of natural disasters from 1993 to 2002 (Figure 1a). Of a grand total of 2,654 disasters during this period, floods and windstorms account for about 70 percent of the disasters, while the remaining 30 percent of the disasters are accounted for by droughts, landslides, forest fires, heat waves, and others (Figure 1b). The economic cost associated with all natural disasters has increased 14 fold since the 1950s (World Disasters Report, 2001). World wide, annual economic costs related to natural disasters have been estimated at about \$50 to \$100 billion.

Communities that are most exposed to risk from climate extremes and natural disasters and are potentially at risk from climate change, are those with limited access to technological resources and with limited development of infrastructure. Small farmers with limited means in most of the developing countries are at risk. The losses they suffer from the impact of natural disasters cannot be entirely eliminated, but timely and appropriate mitigation measures can certainly reduce the impacts. Planning, early warning, and well-prepared response strategies are the major tools for mitigating the losses. The longer in advance a warning can be given about potentially damaging conditions, the easier it will be to mitigate and reduce its impact. Operational agrometeorological services must recognize the need for such advance warnings to help the farming community and integrate them in the advisories that are issued.

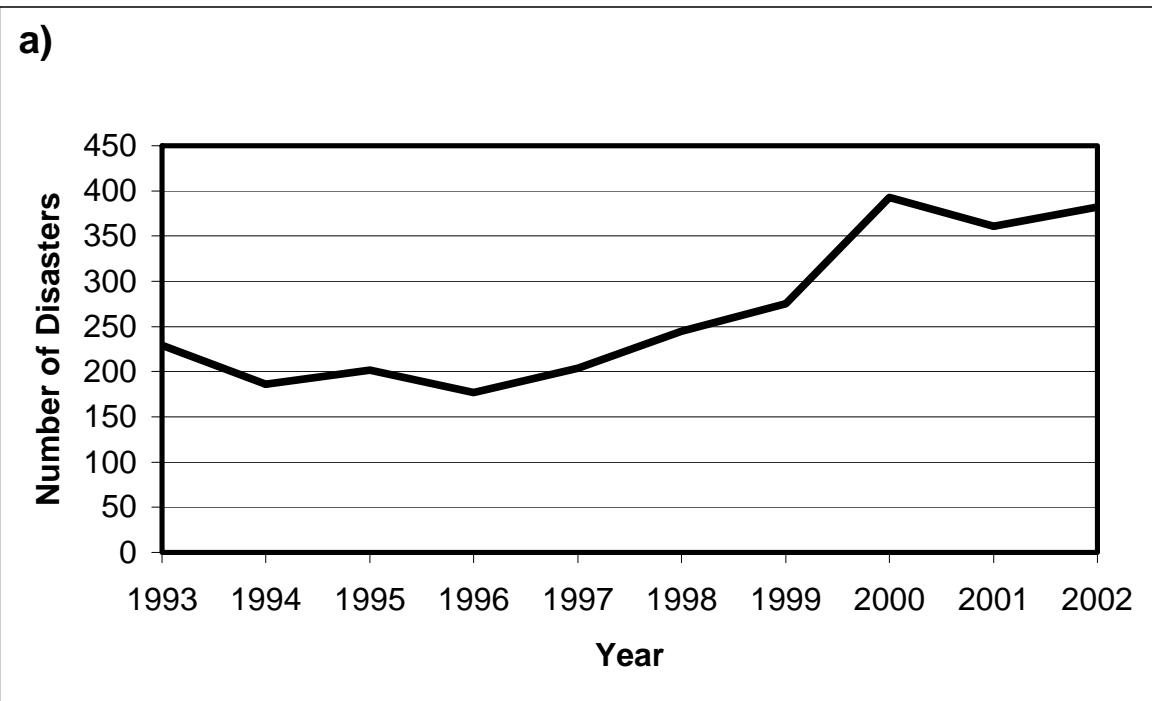


Figure 1a. Annual variations in the occurrence of hydrometeorological disasters during 1993-2002.

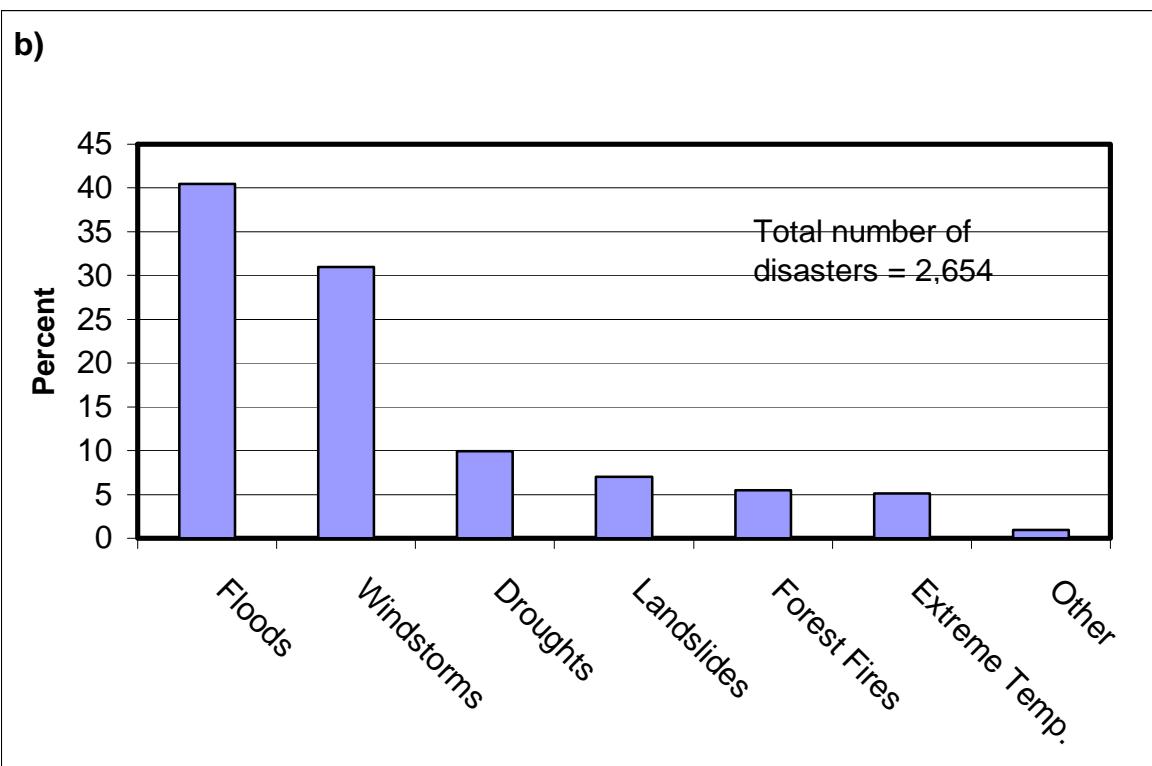


Figure 1b. The percentage of different hydrometeorological disasters as a percent of total number of disasters during 1993-2002.

Major advances in technology, notable progress in scientific understanding, and the accuracy and timeliness of weather and flood warnings have significantly improved over the last few decades. Today the accuracy of forecasts of large-scale weather patterns for 7 days in advance is the same as those for 2 days in advance only 25 years ago (Obasi, 1998). Now forecasts for up to 10 days are showing remarkable accuracy, and there is now capability to provide some skillful information on expected weather patterns several seasons in advance.

For example, early information on El Niño episodes is now allowing advanced national planning, with considerable advantage in many sectors of the economy, such as in water resources management, tourism, and fisheries and agricultural production (Obasi, 1996). In the case of the 1997-98 El Niño event, advances in El Niño-related science and in monitoring the sea-surface temperatures in the Pacific Ocean, enabled scientists in the National Meteorological and Hydrological Services (NMHSs) to predict its formation longer in advance than all the previous events. With recent developments in communication technology, including the use of Internet, information on the El Niño was disseminated in a rapid and timely manner throughout the world. These enabled many governments to take appropriate measures, and stimulated international cooperation and integrated efforts to address the associated impacts. Similarly, the accuracy of tropical cyclone track forecasts and the timeliness of warnings have been steadily improving in the past few years.

Operational agrometeorological services should recognize the potential of working closely with the departments and agencies involved in natural disaster preparedness and mitigation to provide quick and efficient help to the farming community.

## **Requirements for Agrometeorological Services**

### *Perspectives from Satellite Remote Sensing and GIS Applications*

Remote sensing provides spatial coverage by measurement of reflected and emitted electromagnetic radiation, across a wide range of wavebands, from the earth's surface and surrounding atmosphere. The improvement in technical tools of meteorological observation, during the last 20 years, has created a favourable substratum for research and monitoring in many applications of sciences of great economic relevance, such as agriculture and forestry. Each waveband provides different information about the atmosphere and land surface: surface temperature, clouds, solar radiation, processes of photosynthesis and evaporation, which can affect the reflected and emitted radiation detected by satellites. The challenge, therefore, is to develop new systems extracting this information from remotely sensed data, giving to the final users, near-real-time information.

Over the last two decades, the development of space technology has led to a substantial increase in satellite earth observation systems. Simultaneously, the Information and Communication Technology (ICT) revolution has rendered increasingly effective the processing of data for specific uses and their instantaneous distribution on the web.

The meteorological community and associated environmental disciplines, such as climatology including global change, hydrology, and oceanography, all over the world are now able to take advantage of a wealth of observational data, products, and services flowing from specially equipped and highly sophisticated environmental observation satellites.

Due to the availability of new tools, such as GIS, management of an incredible quantity of data such as traditional digital maps, database, models, etc., is now possible. The advantages

are manifold and highly important, especially for the fast cross-sector interactions and the production of synthetic and lucid information for decision makers. At the national and local level, possible GIS applications are endless. For example, agricultural planners might use geographical data to decide on the best zones for a cash crop, combining data on soils, topography, and rainfall to determine the size and location of biologically suitable areas. The final output could include overlays with land ownership, transport, infrastructure, labor availability, and distance to market centers.

The developments in remote sensing and GIS hold much promise to enhance integrated management of all available information and the extraction of desired information to promote sustainable agriculture and development. Active promotion of the use of remote sensing and GIS in the NMHSs could enhance improved agrometeorological applications. To this end, it is important to reinforce training in these new fields. The promotion of new specialized software should make the applications of the various devices easier, bearing in mind the possible combination of several types of inputs such as data coming from standard networks, radar and satellites, meteorological and climatological models, digital cartography, and crop models based on the scientific acquisition of the last 20 years.

### **World Agrometeorological Information Service to Strengthen Operational Agrometeorological Services**

Disseminating agrometeorological information is part of a process that begins with scientific knowledge and understanding and ends with the evaluation of the information. The Internet is one of the new and cost-effective technologies that can provide this information in an accurate and timely manner. Additionally, the Internet can also be effectively used to offer training modules to agrometeorologists to help them improve the quality of the agrometeorological products, which they produce.

During an Inter-Regional Workshop on Improving Agrometeorological Bulletins organized by WMO in Bridgetown, Barbados, in October 2001, participants recommended the development of a dedicated web server for dissemination of agrometeorological products (Sivakumar, 2002). As a follow-up to this recommendation, the Commission for Agricultural Meteorology (CAgM) of WMO organized an Expert Group Meeting on Internet Applications for Agrometeorological Products in Washington, D.C., during May 2002. The meeting recommended the establishment of the World AgroMeteorological Information Service (WAMIS).

The goal of WAMIS is to make agrometeorological products issued by WMO members available to the global agricultural community on a near real-time basis. These products are produced on either a weekly, monthly, or yearly time frame and the format of the products will range from text and MS Word files to PDFs. Provision of a central location for agrometeorological information also enables members to quickly and easily evaluate the various bulletins and gain insight into improving their own bulletins. To further help members improve the quality and presentation of their agrometeorological bulletins, WAMIS will also host training modules.

In December 2003, the Secretary-General of WMO sent a letter to all PRs requesting members to nominate a WAMIS focal point. As of the end of February 2004, responses were received from 90 countries.

Currently, the WAMIS web site is operational and can be accessed at [www.wamis.org](http://www.wamis.org). WAMIS aims at strengthening operational agrometeorological services to the agricultural community worldwide through effective dissemination of agrometeorological products. The training modules hosted on WAMIS should help the agrometeorologists, especially in the developing countries, in the preparation and dissemination of improved agrometeorological products, thereby strengthening their ability to provide better services.

## Conclusions

One common theme that emerges clearly from the discussion on the requirements for agrometeorological services from an international perspective is the need for the provision of improved agrometeorological services, not just for enhancing agricultural productivity, but also for protecting the environment and biodiversity, coping with climate change, and drought and desertification for ensuring sustainable development. Agenda 21 as well as the different International Conventions emphasize the need for better early warning systems of hydro-meteorological disasters that impact agriculture, especially droughts, floods, and cyclones. Preparedness strategies to cope with the impact of the meteorological extreme events require better information and monitoring systems and effective early warning systems. There is also much emphasis on better dissemination and application of climate forecasts, in particular the El Niño/La Niña events, for increasing and sustaining agricultural productivity. Operational agrometeorological services should recognize the potential of working closely with departments and agencies involved in natural disaster preparedness and mitigation to provide quick and efficient help to the farming community. Remote sensing and GIS applications hold a lot of promise for improving operational agrometeorological services and more attention needs to be paid to enhancing such applications. New initiatives such as the World Agrometeorological Information Service (WAMIS) could help strengthen operational agrometeorological services through the provision of agrometeorological products on a near-real time basis on the Internet and through training modules to enhance the quality of agrometeorological products.

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# **Coordinating Role of the Food and Agriculture Organization in Developing Tools and Methods to Support Food-Security Activities in National Agrometeorological Services**

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## **Abstract**

The first part of the paper presents a short description on the activities of the Food and Agriculture Organization (FAO) in the field of food security information and early warning systems (FSIEWS) with particular reference to their agrometeorological component. Starting in 1978, FAO has provided technical assistance with multilateral and bilateral financing to more than 50 projects for the establishment of regional and national FSIEWS around the world, to monitor all aspects of food availability, stability of supply, accessibility, and biological utilization. Focusing on the present and future availability of food, the agrometeorological component looks mainly at crop monitoring and yield forecasting, embracing an activity usually carried out by Agricultural Extension Services and National Agrometeorological Services. The second part of the paper concentrates on FAO's approach in the development of methods and tools (e.g., software, databases, training, publications, and advisory services to farmers) for the agrometeorological user community of FSIEWS.

## **Introduction**

The FAO of the United Nations was founded in 1945 with a mandate to raise levels of nutrition and standards of living, to improve agricultural productivity, and to better the condition of rural populations in the world. At present, FAO is one of the largest specialized agencies in the United Nations system and the lead agency for crop and livestock agriculture, forestry, fisheries, and rural development. Since its foundation, FAO has operated to alleviate poverty and hunger by promoting agricultural development and improved nutrition. While food production has increased at an unprecedented rate since FAO was founded in 1945, the world's population grew almost three times over the same period. A specific priority of the organization is encouraging sustainable agriculture and rural development, a long-term strategy for increasing food production and food security while conserving and managing natural resources.

As pointed out earlier, FAO's activities aim to reduce food insecurity in the world, especially in developing countries. This commitment was further reiterated at the World Food Summit (FAO, 1996) where a Plan of Action was adopted aiming at reducing the number of the world's hungry people in half by 2015. The commitment was renewed at the World Food Summit: Five Years Later (Rome, 2002b). This approach targets the increase of food production and improved access to food, but there is also a need to monitor the current food supply and demand situation, so that timely interventions can be planned whenever the possibility of famine, starvation, and malnutrition exists. With an imminent food crisis, actions need to be taken as early as possible to mobilize resources and because logistic operations are often hampered by adverse natural or manmade conditions, including war and civil strife. The availability of objective and timely information is, therefore, crucial and can be achieved by setting up an operational FSIEWS.

This paper stresses the importance of timely and reliable agrometeorological information and describes how FAO has, in the last 20 years, supported the enhancement of its quality and quantity. This was done through the development of appropriate tools and methods in line with the technological progress of software, hardware, and communication facilities but also by the availability of a large choice of geo-referenced data. The development of tools and methods always proceeded in a total and continuous synergy with field projects, where FAO's main investment is represented by capacity building.

## **Definition of Food Security**

At the World Food Summit (Rome, 1996), food security was defined as the situation “[...] when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life.” This definition links the four aspects of food security: availability of staple foods, stability of supplies, access for all to these supplies, and the biological utilization of food (FAO, 2001b). Since the 1970s, FAO has been active in supporting the establishment, improvement, and reinforcement of national food information systems, which are the main structure of food security monitoring.

## **Needs for Timely and Reliable Food Security Information**

Forecasting is the basic element of all warning systems, and it must be applied to the four aspects of food security (availability, stability, access, and biological utilization), giving decision makers enough time to react to the warning, with as high-as-possible a degree of reliability (the more long-term the forecasts, the less reliable they are). Very often, the most urgent needs for food information in a country relate to, first, the early identification of food crises among specific vulnerable population groups and their needs for relief assistance, and, second, domestic food production and the annual quantification of national cereal import requirements. The lack of systematic information is a serious constraint to effective planning of commercial and non-commercial food imports, and monitoring relief operations, including targeting of beneficiaries and matching types, quantities, timing, and duration of relief to actual requirements. For this purpose, there is a need for timely crop forecasts, plus information on cross-border or internal flows of people and food; livestock, grazing conditions, and herd sizes; market prices of agricultural inputs, basic foods, and livestock; and other major determinants and indicators of the food security status and risks of acutely and chronically vulnerable groups. Behavioral responses of population groups subjected to acute food shocks caused by armed conflict or drought must be continually monitored to provide indications of the depth of local food crises. The identification of vulnerable groups and using rapid and qualitative methods to complement available data are also needed to plan a timely and appropriate response.

## **Structure of a Food Security Information and Early Warning System**

Most of the existing food-security monitoring systems are organized around the following four main pillars:

- Agricultural production monitoring (APM), normally combined with monitoring products of livestock farming;
- Market information system (MIS) that usually monitors domestic trade and sometimes international trade (import/export);

- Social monitoring of the most vulnerable populations or monitoring of groups at risk (MGR) that focus on monitoring poverty; and,
- Food and nutritional surveillance system (also called food and nutrition monitoring) (FNSS), which generally, depending on the situation, monitors the health and nutritional status of populations.

These four pillars are generally countrywide and linked to the technical services of each of the ministries concerned. They have specific aims and set up their own means and organization, but it is fundamental that all of them set up an integrated system. Thus, the monitoring of food availability (production + imports - exports - losses) should be supported by monitoring information on both production and foreign trade supplied by the Market Information System; the monitoring of the stability of supplies, which uses data from the Market Information System as well as data on the status of infrastructure and stocks; the monitoring of access to these supplies, which should take into account mainly social indicators (poverty, unemployment, migrations, etc.); and the monitoring of biological utilization, which should use data acquired from health and nutritional monitoring. Figure 1 shows the conceptual framework of the FSIEWS (FAO, 2001b).

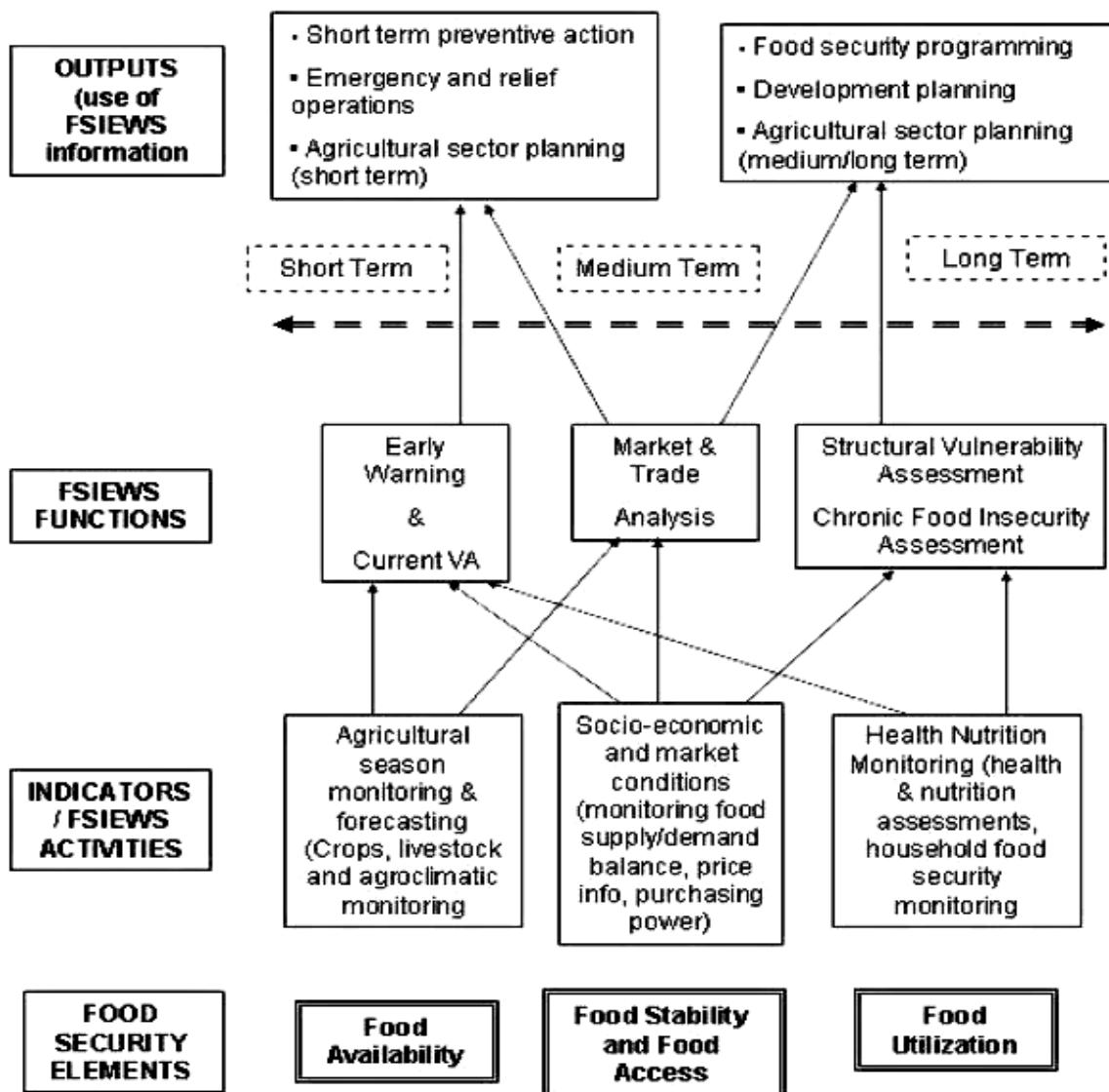


Figure 1. Conceptual framework of the FSIEWS.

## The Agrometeorological Component of FSIEWS

The agrometeorological component of the FSIEWS is integrated into the agricultural production monitoring, particularly, concerning cereal crops and pasture. Most of the crop monitoring and forecasting methods are developed around the water balance calculated during the growing season and take into account the phenological development of the plant. The agrometeorological approach produces better results in semi-arid areas where the water deficit is the main factor limiting crop productivity. This approach gives less satisfying results in regions (even semi-arid ones) where: 1) farming does not follow a homogeneous pattern, 2) area is not well represented by the neighbor weather stations; and, 3) excess of water, sunshine amounts, incidence of pests, and diseases tend to be the main limiting factor(s). Simple statistical (trend) models perform very poorly in semi-arid countries, where the inter-annual variability of yields reaches very high values.

*The monitoring of rainfed crops is based on the following principal tools:*

- Use of real-time meteorological data;
- Use of crop-specific water balance models;
- Processing of real-time satellite images (mainly by NOAA, SPOT – Vegetation and Meteosat satellites);
- Use of spatial interpolation tools;
- Use of gridded surfaces of crop-related parameters derived, or not, from satellite images (e.g., soil water holding capacity, soil type, land cover, land use, crop area sample, etc.);
- Use of seasonal forecasts;
- Field sample surveys, mainly for harvest estimates.

These tools can be used for rapid qualitative evaluations of crop status (development, stage in the cycle, condition, etc.), which can become quantitative depending on the availability of additional information (agronomic data, statistics on yields, long-term time series, etc.) and providing the information is validated.

The National Oceanic & Atmospheric Administration (NOAA) satellite produces digital images from which a Normalized Difference Vegetation Index (NDVI) is obtained. NDVI provides a measure of the amount and vigor of vegetation at the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigor and amounts of vegetation. NDVI is derived from data collected by National Oceanic and Atmospheric Administration (NOAA) satellites, and processed by the Global Inventory Monitoring and Modeling Studies (GIMMS) at the National Aeronautics and Space Administration (NASA). NDVI is a nonlinear function that varies between -1 and +1. Values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation. This satellite index is largely correlated with the volume of living vegetation. In arid and semi-arid conditions, the state of crops and the surrounding vegetation are closely linked.

The SPOT-Vegetation satellite produces digital images from which an NDVI is also obtained. The geostationary Meteosat satellite produces infrared temperature images every half-hour. In tropical regions, it can be assumed that areas with temperatures lower than about  $-40^{\circ}\text{C}$  are covered with rain clouds. The cumulated number of hours in a given period (i.e., 10-day) with this low temperature is defined as Cold Cloud Duration (CCD) and it can be represented as a digital image. The relationship between rainfall and CCD is positive, in

other words, high rainfall values generally coincide with high CCD values. As a result, a geo-referenced image is produced to provide decadal amount of rainfall over Africa, namely Rain Fall Estimate (RFE).

## The Agrometeorology Unit of FAO

The Agrometeorology Unit is part of the Environment and Natural Resources Service (SDRN) in the Department for Sustainable Development. SDRN is the FAO focal point for environmental data. The Agrometeorology Unit collects near real-time meteorological data (mainly precipitation) from various sources for several hundred stations around the world to be used for the agrometeorological crop monitoring and yield forecasting. Reference data, covering almost 30,000 weather stations worldwide, including normals (30-year averages) as well as time series, come from various published and unpublished sources, mainly National Meteorological Services and international research centres.

Since 1978, FSIEWS have been established in almost 50 countries and the agrometeorological component is an integral part of the structure of the FSIEWS. In conceiving and implementing field projects aiming at the creation of the FSIEWS, great attention (also in terms of budget) has always been devoted to capacity building. To achieve this goal, three axes are followed: 1) Direct and permanent link with national agrometeorological services and regional institutions to avoid building a new structure but rather to strengthen the existing one with particular attention to internal and external staff training; 2) Technical partnership with international organizations; and, 3) Continuous development of agrometeorological software for crop monitoring and yield forecasting, mainly database management and applications.

Starting in 1974, the Agrometeorology Unit has developed and continuously improved a crop-forecasting methodology with the aim of supplying updated information on crop conditions in sub-Saharan countries to FAO's Global Information and Early Warning System (GIEWS), and also to provide tools to the agrometeorological component of the various national Food Security Information and Early Warning Systems. In the early days, a qualitative (manual) methodology was elaborated, based on the relationship between the Water Requirements Satisfaction Index (WRSI), as produced by a crop-specific water balance, and the crop condition (Frère and Popov, 1986). Today, the methodology aims to predict crop yields (tons/hectare) and production before the harvest actually takes place, typically a couple of months in advance (May or June for the Northern Hemisphere).

This approach is characterized by the integration of the various tools as described in section 5 and the data-flow shown in Figure 2. The left-hand side of the figure (elliptic boxes) lists the sources of the data: the meteorological network, satellites, field observers (mostly agricultural extension staff), and national services dealing with soils (e.g., soil survey), crops (services of the ministry of agriculture), and national agricultural statistics. The number of partners and the diversity of data types create some difficulty, as well as interesting problems, which were described elsewhere (Gommes et al., 1996). Each of the sources may contribute one or more types of data (second column, rectangles). For instance, meteorological data can be provided, in addition to the ad hoc national network, by remotely sensed sources. Several methods are now available that are used to derive or interpolate rainfall or sunshine data from satellite information. The same applies to some crop data such as planting dates, which may be derived from NDVI time series. Based on the meteorological and agronomic data, several indices are derived which are deemed to be relevant variables in determining crop yield, for

instance crop-water satisfaction, surplus and excess moisture, average soil moisture, etc. The indices (variables) then enter an equation (the yield function) to estimate station yield. At this stage, the data are still station-based since most input is by station. Station yields are then area-averaged using, for instance, NDVI as a background variable, possibly adjusted with other yield estimated provided by national statistical services, multiplied by planted area to obtain a district production estimate.

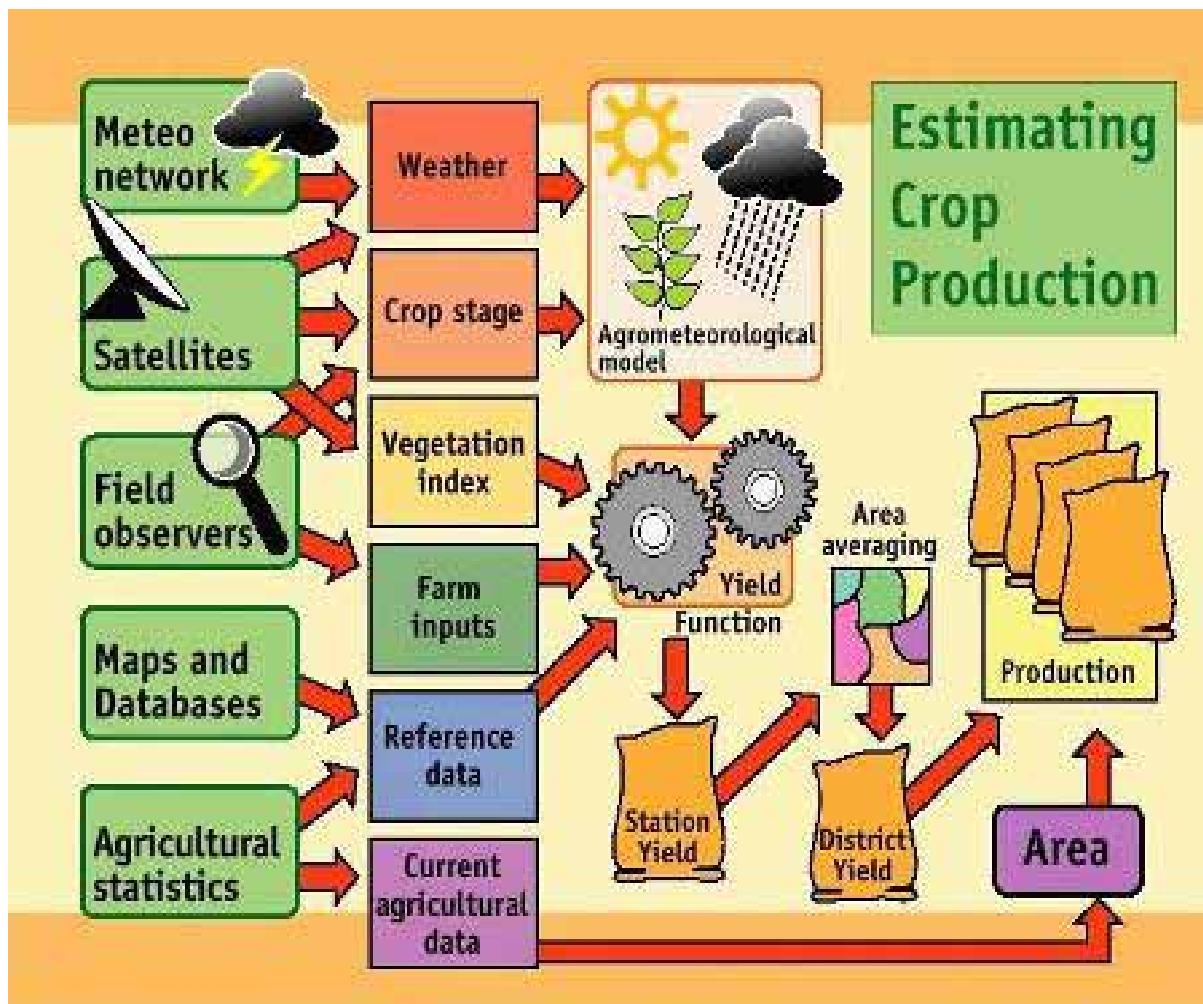


Figure 2. Estimating crop production.

### Institutional Situation of the Agrometeorological Component of FSIEWS

From an institutional point of view, the agricultural production and harvest forecast monitoring systems are usually established in two stages: establishment of an operational monitoring structure, and gradual fine-tuning of the system as it becomes a forecasting system, upon inclusion of further inputs such as information on nutrition and markets. The systems can be situated within two different institutions: a technical directorate under the ministry of agriculture, and the national meteorological services. The latter can be placed under the ministry of agriculture or, very often, under the ministry of transport. In principle, all the FSIEWS's institutions provide information in their particular areas but, often, their data management and their analyses capacities are main weaknesses. Furthermore, data and information exchange among various FSIEWS's institutions and external partners must often be authorized by specific agreements or by governmental decrees, creating large delays in implementing it.

During recent years, FSIEWS' concept has evolved in line with many governments' decentralization policy, at the district level there is a need to synthesize and analyze data and information to monitor emergency conditions and vulnerable groups and plan timely relief responses. However, the needed capacities at the district level are weak and human resources need to be adequately trained to assume these responsibilities.

### **Technical Situation of the Agrometeorological Component of FSIEWS**

Two of the reasons for the weak or non-existent data flow into FSIEWS from partner institutions are the weak institutional support structures and the lack of effective networking. A very important structure for an efficient data flow is represented by the agrometeorological networks, from the simple rainfall station to data transmission, collection, archiving, and analysis. Furthermore, the links between FSIEWS and its partners and among FSIEWS's institutions are crucial. At the same time, vertical institutional links between national and sub-national levels, as well as clearly identified and strong structures that support FSIEWS activities at sub-national levels, will require institutional capacity building through training and institutional organization of existing structures. This is reflected in a joint training effort between FAO and the national institutions. It can be estimated that about half of the FSIEWS in Africa have reached the situation where they are able to issue quantitative forecasts, while the other half are still in a situation of a simple crop monitoring. It is usually not the poor quality of data that prevents countries from going from qualitative to quantitative. The limiting factor tends to be the lack of properly trained agrometeorologists. Training and reduced staff turnover are two of the solutions to this situation. It is essential that users receive only products that are stable in time and space and are (tools and data) low-cost/free-ware. This is not only because financial resources of many national services are limited, but also because of the bureaucratic difficulties for the national services to spend money abroad. One of the ways to solve this problem is to have the tools developed and made available by FAO or other non-profit organizations.

At the end of the data processing, information is generated and must be disseminated, but the main limitation to the dissemination of information is the interaction between agrometeorologists and the extension workers, from basic understanding to practical applications. This is the reason why information and communication technologies must be a component of the training of agrometeorologists in order to provide the best possible advice to the decision makers and the farming community (Weiss et al., 2000).

### **FSIEWS and Agrometeorological Component Users' Needs**

The potential users of the FSIEWS and their needs could fill several pages. Referring to the agrometeorological component, it is relevant to quote the aims of agrometeorology by Austin Bourke (1968) and cited by Monteith (2000): "The task of the agrometeorologist is to apply every relevant meteorological skill to help the farmer make the most efficient use of his physical environment, with the prime aim of improving agricultural production; both in quantity and quality. The agricultural meteorologist can be helpful only in so far as inspiring the farmer to organize and activate their own resources in order to benefit from technical advice."

In order to play an efficient role for the improvement of the agricultural production, the agrometeorological service should implement the recommendations as clearly stated by Stigter, et al., (2000) at the International Workshop on Agricultural Meteorology in the 21st

Century held in Accra, Ghana. As far as the FSIEWS users' needs are concerned, the agrometeorological component has a major responsibility before and during the cropping season because the major factor affecting yields and production in developing countries is the inter-seasonal weather variation. It becomes more and more important to supply seasonal climate forecasts, in particular, before the start of the cropping season in order to adapt the agricultural system to increased weather variability (Archer, et al., 2003). Lessons learned from local initiatives show main constraints and corrective measures to improve communication between agrometeorologists and farming communities about seasonal climate forecasts (Patta and Gwatab, 2002). It must be stressed that agricultural production and food security in developing countries can be improved by more efficient agrometeorological advisory services to farmers, in order to stabilize their yields through management of agroclimatic resources as well as other inputs such as fertilizer and pesticides (Gommes, 1997).

## Databases and Applications Software Development Support

Most of the existing FAO agrometeorological tools were and are developed in pursuing the three axes listed in section 5 and in direct response to local requirements of the FSIEWS, but also taking into account the technological progress, particularly software and hardware. Concerning data, such as background information on field inputs and satellite indices, FAO has often been a precursor by testing the potential of new data types, in particular, remotely sensed data. The result is a near-optimal integration of meteorological, remotely sensed, and other geo-referenced data for the application of various agrometeorological tools in combination with GIS's routines.

The Y2K represents an important milestone for the FAO Agrometeorology Unit as, since then, most of the application's programs have evolved for a better response to users' needs (FSIEWS in particular), performance, and integration. The evolution looks at four objectives along the same viewpoint (from station value to gridded data): 1) Better meteorological data quality and accessibility to a larger audience; 2) integrated agrometeorological tools, mainly for crop monitoring and yield forecasting; 3) spatial interpolation tools, to create climate "surfaces" and to estimate local climate; and 4) GIS tools for agrometeorology, mainly for analysis of remotely sensed data.

Concerning the first objective, the Agrometeorology Unit has taken some initiatives to overcome the impasse caused by the end of support of the existing software operating under the DOS environment and to migrate the global climatic database into the FAO Oracle Data Warehouse. Climatic and real-time meteorological data from different sources are collected under various forms and, depending on the various input formats, data are either manually entered and stored digitally or processed by the Data Management Module of CLICOM (Climate Computing) software developed by the World Meteorological Organization (WMO, 2001), or by the Automated Climate Data Management (ACDAM) software developed by FAO (Verelst, 2000). The new system will allow you to incorporate data into a modular database running under a Relational Data Base Management System and link to an interface under MS-Access.

Another important objective is the development of AgroMetShell (AMS) which is an integrated toolbox used to assess the impact of weather conditions on crops, using statistical and crop-modeling approaches. It is a collection of tools for the integrated analysis of ground data and low-resolution satellite information, which have been brought together under a

common interface. AMS is built around a database of crop, weather, and climate data that are used to compute a crop-specific soil water balance and to derive some agronomic/agrometeorological value-added variables (indicators) used to assess crop conditions (FAO, 2004). The software integrates data analysis and Image Data Analysis (IDA) functions. The main functions of AMS include the following:

- Database functions (configure, input, output, and manage data);
- Daily of 10 total crop-specific soil-water balance measurements to monitor crops and carry-out risk analyses;
- Several methods of spatial interpolation of agroclimatic variables and other indicators and their output in gridded format; and,
- A number of calculations commonly carried-out by the operational agrometeorologist of the FSIEWS, such as calculation of crop-water consumption (potential evapotranspiration), rainfall probabilities, growing season characteristics, statistical analyses, etc.

The third objective is represented by LOCCLIM 1.0 (Local Climate Estimator), which is a computer program that estimates the climate for any location on Earth. It is based on the worldwide climatic database FAOCLIM2 (FAO, 2001a) developed and programmed by Dr. Jürgen Grieser of the German Meteorological Service (FAO, 2002a). Using the Inverse Distance Weighted Average (IDWA) approach, LOCCLIM 1.0 offers:

- Estimate of the climate (expectation values of eight variables) at any location specified either by coordinates or by a mouse click on a map;
- Estimate of the uncertainty of the given results with respect to regional variability;
- Estimate of the altitude dependency of the variables and of the horizontal gradient of the variables;
- Estimates of monthly as well as decadal and daily expectation values;
- Calendar day on which the variables have their maximum and minimum;
- Number of days with expectation values above a threshold;
- Calculation of the length of the "growing period" or "growing season" which is the period (in days) during a year when precipitation exceeds half the potential evapotranspiration.

The “NEW\_LOCCLIM” will be issued shortly. Next to other improvements, it will include eight different interpolation techniques next to IDWA and the possibility to operate on user-provided data.

WINDISP is multi-donor software developed for the display and analysis of satellite derived images of low-resolution, high-frequency satellite imagery available in near real-time through FAO-ARTEMIS (Advanced Real Time Environmental Monitoring Information System) such as from NOAA, Meteosat, and SPOT-Vegetation. The current version (WinDisp version 5.1, FAO, 1998) allows the user to:

- Display and analyze satellite images;
- Compare two images and analyze trends in a time-series of images;
- Extract and graph trends from a number of satellite images such as during the growing season for comparison with other years;
- Compute new images from a series of images, and extract statistics from a series of images;

- Display tabular data in map format;
- Build custom products combining images, maps and specialized legends;
- Write and execute batch files to automate routine and tedious tasks; and,
- Build a customized project interface for providing users with detailed menus of available data for a country or a specific area.

## **Conclusions**

Agrometeorology is an important component of the “food security information and early warning systems” that monitor the availability of food by evaluating the impact of weather and climate on crop development. A sizeable part of the staff and financial resources of the FAO Agrometeorology Unit is devoted to the technical support of FSIEWS around the world. The main activities of the Unit include the development of tools and methods for crop monitoring and yield forecasting, starting with the re-habilitation and/or strengthening of the agrometeorological networks, and all aspects linked to the data transmission, collection, archiving, analysis, and dissemination. The basic philosophy is a total synergy with national and regional institutions and the development of integrated toolboxes, such as AgroMetShell, involving agrometeorology, remote sensing, and GIS tools for data collection, spatialization, and analysis.

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# **EU/JRC Agrometeorological Monitoring Approach and National Services: Opportunities and Challenges**

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## **Abstract**

The Monitoring Agriculture with Remote Sensing (MARS) project started in the Joint Research Centre more than 12 years ago with the main objective to provide to the European Commission decision makers, mainly in the Agriculture Directorate-General (DG) and Eurostat, early, independent, and objective estimates about the production of the main crops in Europe (MARS-STAT). In the successive years, the activities got diversified into a technical support to the Common Agricultural Policy in several fields including the control of EU subsidies by remote sensing and the establishment of national land parcel identification systems (LPIS). This part of the activities is called MARS-PAC. More recently in 2001, a new activity of support to the European policy for Food Security and Food Aid was initiated (MARS-FOOD). Finally, in 2004, the spectrum of the activities was enlarged to the European fisheries policy and the unit name changed from MARS to AGRIFISH.

This article will concentrate on MARS-STAT and MARS-FOOD activities which both use agrometeorological models quite intensively, show how the current activities are linked with national services, and present related opportunities and challenges.

## **Introduction**

### **MARS Agrometeorological Activities in Europe (MARS-STAT)**

MARS-STAT is active both in crop-yield forecasting and crop-acreage estimation. The crop-yield forecasting activity is fully operational, with quantitative forecasts made for the European main field crops as early as April of each year, well in advance compared with the estimates given by the national statistical services, and regularly updated afterwards. Figures for the main crops have an accuracy of 2 to 5 percent and are used by European Commission (EC) decision makers in charge of the Common Agricultural Policy to anticipate important decisions. The MARS-STAT Crop-Yield Forecasting System is organised around an agrometeorological system called Crop Growth Monitoring System (CGMS), fed by about 1,450 ground weather stations. Satellite data from National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) and Spot-VEGETATION are used to complement the purely agrometeorological system. As for the crop-acreage estimation, research is still the main component, in order to achieve methods that fully meet DG agriculture needs, in particular as far as the accuracy and cost factors are concerned. Medium resolution satellite information, such as Medium Resolution Imaging Spectrometer (MERIS) and Moderate Resolution Image Spectroradiometer (MODIS), are currently being tested for this purpose.

Links with national services are very strong. National services are intended here in the sense of national government services but also national private companies, research institutes, universities, etc. Since the beginning of the MARS-STAT life, about 30 to 40 national services from the EU have been directly involved in the development of the activities and this process continues today. In addition, national services are very keen users of the information produced under the form of agrometeorological bulletins (access at <http://agrifish.jrc.it/marsstat/Bulletins/>). Concerning opportunities and challenges, national services from EU and outside can request access to the MARS-OP site (at <http://www.marsop.info>) to visualize real-time maps and graphs about the agrometeorological situation. In addition, for services interested, access to interpolated meteorological data or CGMS can be granted under certain conditions. Concerning exchange of information on phenology, MARS-STAT has recently started a phenological network for Europe, which already 10 countries have joined.

### **MARS Agrometeorological Activities Outside Europe (MARS-FOOD)**

MARS-FOOD main focus is to develop and operate improved methods for crop forecasting in regions outside of Europe, in particular in regions stricken by recurring food shortages. Global data are received daily and 10-day. Global meteorological and agrometeorological data are derived from the ECMWF (European Centre for Medium-Range Weather Forecast) global model, at a 1-degree spatial resolution. Global 10-day Normalized Difference Vegetation Index (NDVI) satellite syntheses from the Spot-VEGETATION instrument are also used. Different agrometeorological models are used according to the geographical area. A modified Crop Growth Monitoring System (CGMS) model is used for Russia, Central Asia, and the Mediterranean Basin. For the rest of the world, a more simple approach based on the FAO Crop Specific Water Balance is being put into place. Dry matter productivity is also calculated on a 10-day basis using a Monteith model approach with radiation derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) and interception efficiency from the Spot-VEGETATION data. Based on these methods, analysis is done on a regular basis and in real-time at the regional level on Russia and Central Asia, the Mediterranean Basin, the Horn of Africa, and at national level for Somalia. It's too soon to extend the bulletin production to South America and Sudan. Close collaboration exists with FAO, both on scientific and organizational matters.

As for MARS-STAT, links with the national services are strong. A particular effort has been made, jointly with FAO, to develop regional (sub-continental) thematic networks on crop monitoring for food security. Two networks were initiated for South America (November 2002) and Eastern Africa (January 2003), with the organization of two dedicated workshops in Cordoba (Argentina) and Nairobi (Kenya).

In 2004, a similar workshop was organized for the Russian and Central Asia area, in Ispra, in late September. Access to information is available to interested national services, either for bulletins (at <http://agrifish.jrc.it/marsfood/Bulletins/>) or for real-time maps (at <http://www.marsop.info>).

A special collaboration has been established with the Somalia Food Security Assessment Unit to initiate a crop-monitoring and forecasting system tailored to local needs. A similar path is intended to be followed in the near future for a number of countries (or regional institutions), such as Sudan or Afghanistan.

Finally, MARS-FOOD is providing scientific and technical support for the preparation of the Africa Monitoring of Environment for Sustainable Development (AMESD) project. AMESD is the follow-up of the EU-funded Preparation for the Use of MSG1\* in Africa (PUMA) project that 54 countries in Africa will have available by the end of 2004. A EUMETCAST receiving station installed (including Meteosat Second Generation and Spot-VEGETATION). MARS-FOOD will contribute through AMESD to the continuation of the capacity-building process with tools and systems for environmental (including agrometeorological) monitoring, which will be put into place.

\* Meteostat Second Generation (MSG).

# ***Strengthening Operational Agrometeorological Services: A Critical Review***

## **Shortcomings and Limitations in the Availability and Application of Agrometeorological Data**

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### **Abstract**

Operational agricultural meteorology services use a large range of physical and biological data. Agrometeorological data can be categorized as atmospheric and soil-parameter data, crop-stage data, and data on agricultural practices and production associated with field crops, fisheries, forestry, pastures, and rangelands. There are many shortcomings and limitations in the availability and application of these data that can hinder the accuracy and utility of products disseminated to agricultural decision makers. This paper surveys some methods, guidelines, and recommendations that agrometeorologists can use to overcome data shortcomings and limitations.

### **Introduction**

The foundation of any scientific analysis is accurate and timely data. This is especially true in the field of agricultural meteorology where data are needed from a large range of physical and biological elements such as meteorological, climatological, remotely sensed, soil, and agronomic data. These data are used in agricultural applications as varied as dryland and irrigated crops, fisheries, livestock, forest, pastures, and rangelands. They are used by agrometeorological services for input into routine temperature and precipitation charts and graphs and into sophisticated crop models to aid agricultural decision makers. In addition, radar-based and remotely sensed data are becoming more widely used. However, there are many shortcomings and limitations with the availability and application of these data to be overcome. This paper will address these shortcomings and limitations and offer recommendations and guidelines to help agrometeorologists improve and strengthen their services and products.

### **Scope of Agrometeorological Data**

A large scope of observed data can be used in operational agrometeorology. Of course, data needs are dependent on the application. The most basic agrometeorological applications are time series and spatial analyses of weather and phenological data. More advanced applications are crop yield, irrigation, and animal production models requiring an added layer of complexity to the standard weather data.

Agrometeorological data fall into roughly the following categories (WMO, 1981):

- Data relating to the state of the atmospheric environment;
- Data relating to the state of the soil environment;
- Biological (phenological) data relating to organism response (crops, livestock, fisheries, and pathogenic elements affecting them);

- Information concerning the agricultural practices used (management systems, chemical applications); and,
- Data on agricultural area, yield, and production (crops, animals, and forestry) used for model validation and econometric modeling.

The following list of elements and parameters is not exhaustive but it is provided to detail the large scope of data that agrometeorologists use (Hayhoe, 2000; WMO, 1993). Atmospheric data includes measurements on temperature, humidity (dewpoint), precipitation (including snowdepth), wind, sunshine and radiation, evaporation, soil moisture, and temperature. When dealing with transport of animal and plant diseases and insects, boundary layer data such as the surface, 850 millibars (mb) and 700 mb of wind speed, direction, temperature, and dewpoint are needed. Agrometeorologists also need climatological data for the various atmospheric data. Climatological data are averaged from monthly atmospheric data across a standard 30-year period. With the advent of weather generators to generate daily temperature, precipitation, radiation, relative humidity, and wind data for crop models, the amount of input parameters based on climate data can be overwhelming. The following is a partial list of input parameters for the WGEN weather generator used in the EPIC model (Richardson, 1984): 10-year frequency of 0.5 and 6-hour rainfall; number of years of 0.5-hour rainfall, monthly averages and standard deviations of maximum and minimum air temperatures and precipitation; monthly probabilities of a wet day after wet day, wet day after dry day, average number of days of rain per month, monthly average daily solar radiation, relative humidity, and wind velocity. Remotely sensed data includes radar rainfall estimates and satellites measurements of NDVI, temperature, and crop greenness. These remotely sensed data are temporally and spatially varied.

Soils data can include water-holding capacities (wilting point, field capacity), soil texture, nutrient contents, soil ph, organic carbon, and soil layer depth. For most operational agrometeorological applications, these soil data elements will not vary temporally. However, if erosion is being studied, historical erosion data will be used in the validation of the erosion model.

Agronomic data includes crop-management information such as planting dates; plant spacing and depth; phenological observations (various crop stages); irrigation management; cultivar selections; historical yield series; and disease, pests, and weed information. These data can be acquired through expert opinion, literature values, and agricultural statistics (Hayhoe, 2000). Information is also needed on the timing, amount, method, and type of chemical applications.

Livestock and fishery applications will include data on the animals and their diseases. Kapetsky (2000) lists water temperature, water availability, and effects of inclement weather as the obvious connections between meteorological data on inland fishing and aquaculture activities. Forest fire and forest management models will need data on the various characteristics of undergrowth and forest species.

## **Discussion of Shortcomings and Limitations**

One of the most significant shortcomings is the quality of all these various types of agrometeorological data. With the meteorological and climatological data, the quality of the data can be affected by station placement, changes in station site, instrument error, and processing errors. The Guide to Agricultural Meteorological Practices (WMO, 1981) can

give guidelines to some of these issues. A significant amount of work has been done on the quality of the atmospheric data. However, there is much work to be done on understanding the quality problems with collecting data on soils and phenological observations. One suggestion is for national agrometeorological services to work closely with national agricultural services to standardized phenological observations. Existing agricultural extension services should be a starting point for data standardization.

Vigorous quality control procedures will flag suspect data and disregard the suspect data (Arndt, et al, 1998). When adequate quality control procedures on atmospheric data have been implemented, this inevitably creates gaps in the temporal resolution of the dataset. Quality control improves data quality but it does not solve problems with the temporal resolution of the dataset. Whether the data is of bad quality or is missing altogether, the same problem exists: there is no data value for that particular time period (hourly, daily, weekly, decadal, monthly, etc). Therefore, data gaps appear in the dataset and need to be filled by some estimation method in order for a continuous dataset to be created.

Another problem is limited spatial resolution of the data. The spatial density of weather stations is sometimes not dense enough to adequately represent the area of concern. The nearest weather station may be 50 to 100 kilometers from an agricultural field. Also, topography needs to be taken into account when agricultural fields are in hilly or mountainous areas.

Hayhoe (2000) reviewed the data requirements, acquisition, and application of two widely used modeling systems: The Decision Support System for Agrotechnology Transfer (DSSAT) and the Erosion Productivity Impact Calculator (EPIC). One of the biggest problems stated in using these process models is assembling the required data.

The following is a summary from that paper on the shortcomings and limitations of applying agrometeorological data to multi-process crop models:

- Different models have different input formats;
- Scale of application ranges from precision farming to national or continental study;
- Inadequate solar radiation, wind, and relative humidity data;
- Lack of uniformity in collection methods and standards;
- Data were not collected to provide the detailed information to run the model at specific locations;
- Low temporal and spatial resolution;
- Soil and weather data are not spatially compatible (soil data recorded on areal basis and weather recorded at station locations);
- Large set of input data and multiple disciplines are needed to test comprehensive multi-process models;
- For site-specific applications, lack of weather data which accurately represented the field, especially for precipitation;
- Using the Theissen polygon method to calculate areal averages may not be optimum, co-kriging may be more appropriate;
- EPIC and similar models should be primarily used to provide relative comparisons instead of absolute numbers; and,
- Model errors were probably also caused by unreliable yield data, estimated soil parameters (hydraulic properties, slope, and slope length).

The paper concludes that these multi-process models have been used in a number of successful applications, and they have occasionally failed to explain the year-to-year variations. The clear reason for this was the limitations in the quality and quantity of input data. One study that uses EPIC to understand soil management in the Canadian Prairies suggests that the results should be presented as degradation classes rather than numerical values. One recommendation is that members of interdisciplinary modeling groups should present training sessions for scientists in developing countries.

From an Expert Group Workshop on Software for Agroclimatic Data Management, participants listed shortcomings and limitations to data management (Motha, 2000). While some of these were specific to software packages, they are also applicable to data availability and management techniques.

#### *Shortcomings for Climatic Data Management*

- Inadequate data exchange standards;
- Diverse and incomplete quality control standards;
- Lack of data continuity over long time periods;
- Inaccessible or difficult-to-access data sets;
- Cost of systems and data;
- Insufficient or absent metadata;
- Sparse station coverage in agricultural areas;
- Lack of long-term commitments to sustaining station networks;
- Widely diverse levels of expertise; and,
- A lack of full commitment to exchange necessary data sets at regional, national, and international levels.

#### *Shortcomings for Crop and Soils Data Management*

- Soils data sets lack a shared structure or standardization;
- Databases tend to offer more information about chemical (fertility) properties than soil physical properties;
- While pH data are available, there is a need for better pedon transfer functions;
- High resolution (field-scale) digital soils data are often not available;
- Soil observations (pedon descriptions) are not utilized to estimate soil biota; and,
- Many soil attributes and properties are under-utilized by crop growth models.

#### *Shortcomings and Limitations in the Use of Current Software for Remote Sensing and Integrated Modeling Packages:*

- Majority of the crop models are data intensive and the needed climate/crop/soil data are often not readily available, especially in the developing countries;
- While the modelers' data needs are often quite rigid and they expect the data to come from a single source, in reality data sources and formats are quite variable across countries;
- The problem is further complicated by the fact that climate, soil, and crop data are not often collected or available from the same location;

- A good majority of the current software packages that facilitate spatial analysis are not equipped to perform adequate temporal analysis; and
- In developing countries there is a growing "digital divide" between senior managers and their younger work force.

## **Overcoming Data Shortcomings and Limitations**

There are several methods for overcoming data gaps in the temporal record. Jeffery, et al., (2000) discuss patched data sets that are continuous temporal weather data used for crop modeling. A patched data set is comprised of observed data, spatially interpolated data, and long-term means. For missing data or bad quality data, values are interpolated and in absence of observational data, mean daily values were supplied. Each data value is assigned a data flag denoting the source of the data.

Another method is to average climatically similar weather data into larger units. In the United States, the National Climatic Data Center devised 344 climate divisions across the country (Karl et al, 1986). Temperature and precipitation data in each climate division are averaged together into a single unit. This data is then used to compute various climate and agrometeorological indices such as Standardized Precipitation Index (SPI) and the Palmer Drought Index. The Joint Agricultural Weather Facility (JAWF) of the Department of Agriculture developed 350 sub-regions for the world based on similar climatic, geographic, and agricultural attributes (Puterbaugh, 2000). These regional files encompass all major agricultural areas, representing a wide variety of crops and climates. Stations are assigned into sub-regions based on station density, elevation, reliable reporting, availability of normals, and crop-area considerations. Weather data in each region is averaged together and various analyses of temperature, rainfall, potential evaporation, and estimated soil moisture can be made. These agriculture-based sub-regions help JAWF to effectively organize and analyze data from over 8,000 WMO weather stations and help eliminate missing data values.

GIS software and other means of interpolating weather data can be used to overcome this problem (Jefferies, 2000; Shannon and Motha, 2002). However, a more detailed overview of this using these tools will be discussed in the companion paper on analytical tools (Andresen, 2004).

With recent advances in computer technology, there are many database tools available that can help agrometeorologists maintain their many databases and provide the necessary links. These software packages include MS Excel, MYSQL, MS Access, and Oracle. There are many different examples of operational databases for dealing with weather, climate, soils, remotely sensed, and spatial data (Motha and Sivakumar, 2001; and Doraiswamy, et al., 2000).

## **Recommendations**

There are several general and specific recommendations that can help agrometeorologists overcome the above shortcomings and limitations. Motha (2002) provided an excellent overview of some general recommendations on improving agrometeorological bulletins that can also be used for overcoming shortcomings on the application of agrometeorological data. Motha began by asking pertinent questions such as: What information does the user need? When does the user need this information? In order to answer these questions, there must be an established mechanism between the users of the information (farmers and decision

makers) and the producers of the information (agrometeorologists and extension personnel). He also listed some of the following recommendations:

- Don't promise too much too quickly.
- Relate the weather data to meaningful agricultural information.
- Don't oversell the information.
- Establish credibility slowly but surely.
- Implement new products with proper introduction.
- Be proactive in demonstrating the usefulness of your products.
- Don't hesitate to pool resources.
- Training and education are essential components.

The following is a list of specific recommendations and potential guidelines from the Expert Group Meeting on Software for Agroclimatic Data Management, October 16-20, 2000, held in Washington, D.C., USA (Motha, 2000). These recommendations were edited to list those items only pertaining to data limitations.

- More Automatic Weather Stations (AWS) are needed in order to provide coverage and support for risk management, crop assessment, crop productivity, fire and rangeland management, and natural resource conservation;
- There is a need for long-term support and commitment (funding, capacity) to sustain reliable station networks;
- Systems should be developed to facilitate data sharing/exchange;
- Continuous data records must be established using standardized methodologies (such as the Patched Point Dataset in Australia);
- Information delivery systems should be Internet-based (Internet data distribution);
- Systems should be able to link with other data providers to ensure that the appropriate information is accessible in a timely and usable format;
- Metadata information needs to be developed and should conform to International Organization for Standardization (ISO) standards;
- All data should be georeferenced and time-stamped for effective integration into GIS software systems;
- Member nations should make basic geopolitical data sets available on the Internet. WMO should maintain a web-site with links to these data sets;
- A website should be developed with pointers to relevant decision-support software, data, and development tools with the capacity for online demonstration of its ability;
- Soil data management systems should be harmonized and integrated, similar to Soils and Terrain Digital Database (SOTER);
- National systems need to be identified as sources of information;
- Since some models and databases are scale independent, an understanding of "data loss" from one scale to another must be acknowledged explicitly;
- Time trend analyses are needed for land use databases;
- National meteorological and hydrological services should be urged to share their knowledge and tools in spatial interpolation with database managers and application developers; and
- Special efforts must be made to develop and disseminate uniform formats and data sheets for recording crop and soils information in a format that is compatible for use with crop models and remote sensing applications.

*Potential Guidelines for Improved Management of Databases in Support of Agroclimatic Applications to Assist Training and Capacity Building*

- Data sets must have a minimum metadata base, standard format, standard quality control procedures, and adequate continuity of records;
- Personnel must be trained to recognize inconsistencies of data and establish appropriate patch-point methods to maintain continuity;
- Software must be compatible with both temporal and spatial data sets to allow for the integration of point source data with georeferenced digital data sets, modeling technology, and remotely sensed data;
- New technology in telecommunications should be used to bridge the gap between automated data collection systems and web-based information systems;
- GIS metadata are required for appropriate coordinate systems, projections etc.;
- A listserve or other virtual community should be established; International Soil Reference and Information Centre (ISRIC), Netherlands, will develop a website to serve as a portal for soil information, including metadata information on existing soil databases worldwide;
- Improved data exchange will be fostered by the continued development of geographic frameworks and adoption of standards;
- Guidelines need to include new measures and better assessment of soil data reliability given that more robust estimates are obviously linked to data quality and resolution (data resolution is a continuing need previously identified);
- Recommend determining indices of data reliability (quality) vs. error percentages and sources of the data (ISO metadata standards). Examples of error tracking and reporting from the agroclimatic community include the IQ index from France and the quality indices from South Africa;
- Guidelines need to emphasize explicit accounting for variability in the soils arena. The USDA Soil Survey uses a diversity index to characterize and report soil variability. Similar variability measures are the key and they should be associated with input to soil and crop models. Similarly, plant variability (e.g., emergence and growth) needs to be represented, especially if this variability is a key to management under a given production scenario;
- Guidelines are needed to report national crop yields including sub-national trends and geo-spatial time trends;
- An industry, international standard for agroclimatic data, particularly crop data, should be developed. Minimum metadata, database formats, and database content should be resolved, accepted by industry, international centers and academia, and published basic agroclimatic applications;
- More telecommunication research that develops new applications using web-based technologies and automated observations should be supported. These developments will help reach more users and encourage standardization;
- Current measures of standardization are considered mature for meteorological data, but poor for crop data and emerging for soils data. Hence, uniform measures of standardization for agroclimatic purposes must be established; and,
- Spatial interpolation methods for specific applications should be recommended.

## Conclusions

This paper presents the interdisciplinary scope of agrometeorological data and discusses several of the shortcomings and limitations in their availability and application. Accurate and timely data are needed in operational agrometeorological services to generate reliable products for agricultural decision makers. One of the biggest limitations is the quality and quantity of input data for applications and models.

Even when appropriate quality control procedures are used and bad data are flagged, data gaps are created in the dataset. These data gaps still need to be filled by some estimation routine in order for a continuous dataset to be created for the various applications. Other limitations include the lack of detailed data for input into crop models and non-standard input formats and sources.

It is important for agrometeorologists to realize that there are many resources (papers, reports, and proceedings) that have been developed over the years by agrometeorologists across the world providing examples of their data problems and the solutions that they have developed. This paper highlights some of these procedures to overcome of these shortcomings and limitations and summarize general and specific guidelines and recommendations.

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# **Shortcomings and Limitations in Analytical Tools and Methods of Provision of Operational Agrometeorological Services**

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## **Abstract**

Improvements in communication technology and in the understanding of the physical components of the plant/earth/atmosphere interface have combined to increase the quality, sophistication, and potential utility of agrometeorological services offered to or provided to the agricultural industry. Regardless, many problems and shortcomings in analytical techniques and in the way in which the products are provided remain. These include long-term issues such as the spatial analysis of agrometeorological variables as well as new concerns such as the economic challenges facing many elements of the agricultural industry worldwide. Recent advances in the development of spatial analytical techniques such as Geographic Information Systems (GIS) offer some solutions to these difficulties. To become more effective, agrometeorologists need to demonstrate the utility of their products, including potential economic benefits. Finally, in order to provide the best quality agrometeorological information in the future, greater collaboration is needed among the major participants in the information provision system: farmers, agricultural meteorologists, and agricultural extension services.

## **Introduction**

Demand for meteorological and climatological information in support of worldwide agricultural operations has increased dramatically in recent years, the result of increasing economic and environmental pressures as well as recognition of the importance of such information in operational decision making (Motha, 2001). Users of the information include individual growers, commercial agribusinesses, and local or national government agencies. The information itself is typically utilized in a variety of activities, ranging from tactical issues such as monitoring plant disease risk to strategic problems like the selection of climatologically suitable crop varieties for a given location. Overall, agrometeorological information products should be designed and developed with several important requirements in mind:

- *Accuracy.* The information should address or pertain to a solvable issue or problem based on sound science.
- *Robustness.* The method or product should be versatile to effectively operate under a variety of conditions.
- *Meaning.* The information should be helpful and easily understandable by the user.
- *Timeliness.* The information can be created and provided in a reasonable time frame.
- *Environmentally sound.* The information supports or encourages environmentally friendly procedures and techniques.
- *Economics.* The information can be economically justified by the user.

Of these requirements, accuracy might be considered the highest priority, although meaning and timeliness have also been identified by individual growers as critical (Carlson, 1989).

Once target problems, issues, and possible solutions have been identified, meteorological services must also consider possible approaches to the development of agrometeorological products. An excellent scheme suggested by Maracchi, et al., (2002), includes: assessment of spatial scales involved and feasibility of possible methodologies, identification of possible models and model data requirements, integration of ground-based and remotely sensed data, and estimation of the cost-effectiveness of the methodology.

### **Limitations of Analytical Tools: Some Examples**

While progress has been made in the number of types, capabilities, and overall usefulness of agrometeorological information, shortcomings and limitations remain. A list of some major limitations includes:

- Data scarcity/paucity in meteorological, climatological, agronomic, soil and other similar data bases needed for agrometeorological assessment (e.g., see Stefanski 2004 paper in this volume);
- Difficulty in application of the tool or method;
- Accuracy of the methodology (e.g., integrated pest management (IPM) methods, long-lead weather forecasts);
- Complete automation of the method or tool in question, desirable for many operational applications, may not be possible (e.g., field scouting and biofixes are still necessary in many IPM techniques);
- Use of “Black Box” approaches may result in unintentional errors;
- A trade off in accuracy and complexity between empirical and deterministic approaches remains (e.g., crop models);
- No simple method exists for spatio-temporal analyses; and,
- There is no internationally agreed-upon measurement standard for leaf wetness, a key variable for the determination of plant foliar disease risk.

While far from being an exhaustive list, these issues provide examples of current difficulties and limitations facing providers of meteorological services. Some illustrative application examples follow.

Among the most troublesome of these analytical difficulties is the scarcity and/or poor quality of input data, for which there are limited solutions. Complicating matters further, users of agrometeorological information frequently need to provide the information in a two-dimensional spatial format across the area(s) of interest, which typically requires spatial interpolation or some type of objective analysis performed on the original data, usually taken from individual locations. Typical procedures used for interpolation include kriging, co-kriging, and the inverse weighted-distance method, or other schemes. However, while these schemes are used almost universally in data analysis, there are potential pitfalls. For example, failure to consider topographical features in an area of interest may result in a highly erroneous averaged surface far different from the observed surface. This problem was well illustrated by Daly, et al., (1994), who developed the Parameter-elevation Regressions on Independent Slopes Model (PRISM) technique that accounts for the physical impact of topography on spatially averaged climatological variables in the western United States. Another potential problem is the application of the analytical technique in an area of uneven spatial density or coverage, a condition present in many operational networks around the world. The solution by interpolation is estimated with a cubic spline technique. In the original, unedited version of this product, the presence of physical boundaries such as lakes

and local station microclimates result in artificial gradients and erroneous estimated values. Such errors can only be prevented by careful, informed human analysis of the output (very difficult to do in an automated fashion), or by the incorporation of additional data into the original analysis.

One must also consider that, even under the best circumstances, error and uncertainty can be introduced during each stage of analysis. This error, whether the result of inadequate input data or the analytical method itself, may be passed cumulatively on to each successive analytical stage in a “cascade of uncertainty,” resulting in relatively (and sometimes unexpectedly) high errors in the final output product. This type of problem is illustrated in the results of a recent experiment in the United States to determine small scale, localized spatial variability of leaf wetness duration and its impact on associated foliar plant disease risk associated with apple scab (*Venturia inaequalis*).

In this experiment, leaf wetness was monitored at eight different sensors placed at different locations in the same field in an identical fashion (all within 100 meters distance of each other). A 9<sup>th</sup> sensor was placed outside the orchard/plant canopy in the same fashion for reference. The method of Jones, et al., (1980) was used to determine the risk of foliar infection based on the length of leaf wetness duration and average air temperature during the wetting event. There are three resulting levels of infection: light, moderate, and heavy. There was a large variability of the degree of infection among the different sensors for some events (e.g., the event on calendar day 170), even though the sensors were located in the same field. Given a spatially interpolated surface of wetness duration derived from individual data of much less station density (and typical of most operational agrometeorological networks), it is logical to assume that the variability of the dependent disease infection level variable would be at least equal if not greater in magnitude. In essence, the local level variability described here can be interpreted as unavoidable “white noise” or random error associated with the data, which may be carried on through additional analytical stages and serve as an upper limitation of the accuracy of the information product.

# Apple Scab Infection Frequency

## SWMREC, 2000 Growing Season

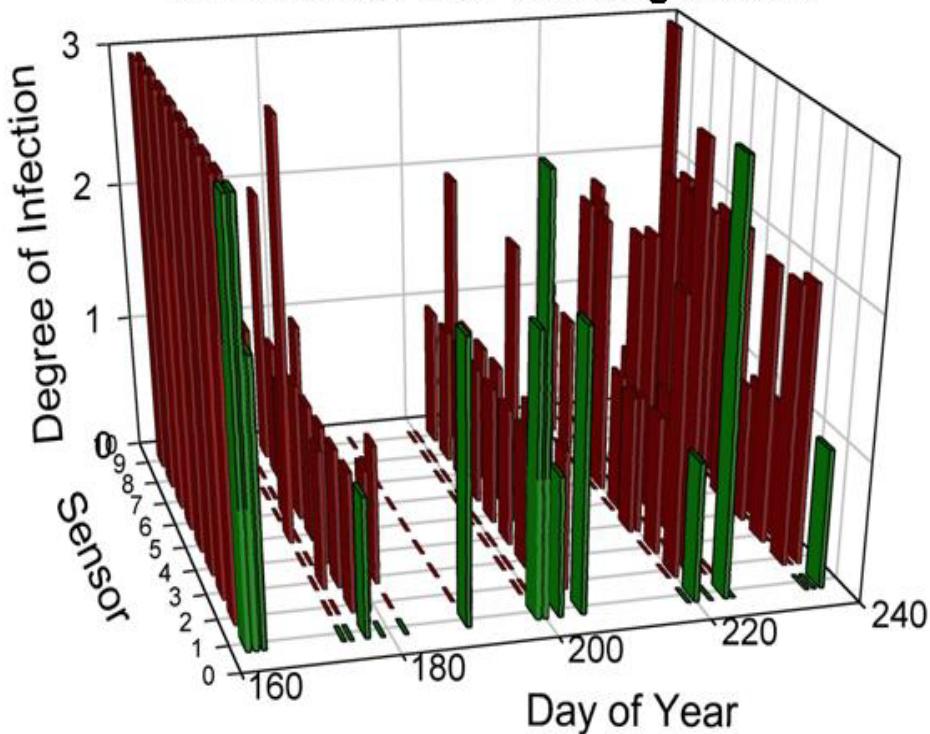


Figure 1. Model estimated apple scab disease infection frequency and severity vs. calendar day, 2000 growing season, Benton Harbor, Michigan, USA. The severity or degree of infection is given numerically from 0-3, with “0” indicating no infection and “3” indicating a heavy infection.

The degree of spatial continuity of meteorological and climatological variables (a factor that must be considered in analytical processing or in the creation of derived products) is strongly dependent on the variable type. A landmark study by Gandin (1970) analyzed the spatial variability of several different meteorological variables over extended periods of time in the former USSR and concluded that three different levels of station density are needed for representative operational networks: a relatively sparse network on the order of 150-200 kilometers (km) between stations for air pressure, soil temperature at depth, and solar radiation; a second intermediate group of medium density of 50-60 km for air temperature and humidity, wind speed, and cloud cover; and a third group of relatively high station density at 30 km for the most discontinuous variables including precipitation, snow cover, and other localized meteorological phenomena. Similar results were obtained in a subsequent study by Hubbard (1994) in the Great Plains region of the United States.

Unfortunately, for those who utilize such data operationally, there are other complicating factors to consider. Besides the differences between variable types, there may also be differences in spatial variability between climate types for the same climate variable (Camargo and Hubbard, 1999). Lastly, developers of agrometeorological products frequently are faced with decisions regarding the order of spatial averaging between the input variables

and the output variables (i.e., should spatial averaging take place before or after individual analytical processing steps?). In a study of meteorological variables used to estimate potential evapotranspiration (PET) in the United States, Ashraf, et al., (1997) concluded that the order of averaging was of relatively little importance in comparison to the method of spatial interpolation (best results in the study were obtained with kriging and co-kriging procedures).

### **Some Limitations of Provision**

Besides shortcomings in the analytical methods used to prepare and develop agrometeorological information, there are also concerns with its provision. Some major issues include:

- Lack of a standardized communication technology format. Advances in communication technology have occurred rapidly in the past few decades, leaving some segments of the agricultural industry around the world without access to timely and useful information disseminated over relatively new media like the worldwide web;
- Shrinking resources for agricultural extension services. Agricultural extension services have been integrally involved in the two-way interaction between the providers and users of agrometeorological information and have traditionally been supported financially by local, state, or federal government services. Due to decreasing fiscal resources in many areas of the world, some of these services have been replaced by private, commercial services, or are no longer available; and,
- Lack of communication between providers of service and the users. Consider the simple hypothetical example of operational agrometeorological information provided to the industry but not fully utilized because the user either does not consider it accurate or useful, or does not understand how to properly use it.

One final special limitation worth mentioning is the issue of globalization of agriculture, in which technological advances have led to more efficient production, increasing numbers of global markets for commodities, and a transport system that enables distribution of those commodities worldwide. In combination, globalization has raised the level of competition between food producers, benefiting producers with relatively low costs and penalizing those with high costs (Blank, 2002). It is essential for providers of agrometeorological information to understand the economic impacts of globalization and resulting changes in the operations of their respective agricultural industries.

### **Some Possible Solutions and Directions**

New techniques and technologies have made it possible to address some of the concerns raised above. These include:

- Use of remotely sensed data or regional climate model output to supplement existing data networks;
- More effective analysis of existing data with GIS;
- Incorporation of automated weather stations. Typically, the output from such stations is more comprehensive. They may also provide data in more convenient formats (e.g., digital, real-time). However, it is critical to remember network quality and standardization issues;

- Greater collaboration between providers and users of agrometeorological information, including training and education. This is especially true given expectations of further technological improvements and government fiscal shortfalls in the future (National Research Council, 2003). Remember that communication with clientele is a “two-way street,” and requires actively engaging clients for feedback and ideas for product improvements and new research directions. Also, given the financial challenges facing agriculture around the world, try to first determine and then demonstrate the utility of the information provided, including economics if possible;
- Provide further technical training for service providers or require minimum background when hiring, especially when they lack background or experience in agricultural science. It is important for service providers to learn and know the problems and issues of agriculture from the perspective of the grower or industry; and,
- Charge some type of fee for service. Many governmental agrometeorological service providers around the world have instituted fees for certain types of services in recent years. While some information users may refuse or be unable to pay for services, fees may help supplement operational expenses.

Of the listed issues, the first three are of special interest to all providers of agrometeorological information, as they may supplement or improve the quality of the input data used to create information products, directly impacting the quality of the output. GIS software and techniques are now used routinely for processing and analyzing all types of input data and information (e.g., Shannon and Motha, 2002; Bernardi, 2002; Hayhoe, 2001).

Finally, when supplemental remotely sensed or station data are not available for analysis, there may be one further option. Improvements in the complexity, accuracy, and timeliness of regional scale climate simulations (RCMs) have resulted in a relatively new source of potential input information. These simulations process massive amounts of input data over a given region and provide an even larger range of gridded output including variables not routinely measured such as net radiation, latent heat flux, and boundary layer height. Spatial and temporal resolution may be much finer than in operational weather forecast or climate model simulations, typically on the order of 10 km on an hourly basis. While not real data, the output from such systems may provide usable estimates for a whole range of potential analytical applications, such as forest fire potential, mesoscale weather forecasts, and hydrological forecasting (Mass, 2003).

## **Conclusions**

While scientific and technological advances have resulted in higher quality information and increased capabilities in providing agrometeorological information, major difficulties remain. Remotely sensed data technologies and GIS analytical techniques should help reduce some of these problems in the future. In an era of decreasing fiscal resources and globalization of agriculture, greater collaboration is needed between major participants in the system: i.e., growers, agricultural meteorologists, and agricultural extension services. Agricultural meteorologists need to demonstrate and publicize the utility and effectiveness of their products, including economics.

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## **Dissemination of Agrometeorological Information**

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### **Abstract**

Much climate data are available that can only be utilized if there is a flow of information to agri-business and farmers. As dissemination is the distribution of information, two-way communication channels are a necessity. The content of the message must be relevant to the decisions of the client. The process should involve the identification of climate sensitive decisions and interactions between the climatologists and the role players to develop technological products that should be evaluated prior to introduction at an operational level. Various modes of delivery can be used including mass and electronic media, as well as group and individual relationships. Dissemination of agrometeorological information is illustrated with examples from the Florida Consortium, FARMSCAPES in Australia, seasonal forecasts in Burkina Faso, and irrigation scheduling in Mexico. Critical factors for successful dissemination include good communication channels, preferably based on a relationship between the agrometeorologists and the role-players in the agricultural industry; and the collaborative development of products that can bridge the gaps and be relevant to climate-sensitive decision making in agriculture.

### **Introduction**

The National Meteorological Services (NMSs) around the world are collecting daily weather data that are archived into state-of-the-art electronic databases (e.g., World Weather Watch, 2004) or at least as written copies. However, for these data to become useful to the many users, they must be processed or transformed into relevant information and also be communicated to specific users or the general public. This paper will address some aspects of the process involved in the flow of information from the NMSs to the users and give some examples of successful utilization of available climate data by the agricultural sector.

Linkages and information flow between the users and the NMSs are vital for the successful application of all types of weather and climate information. These linkages should provide opportunity for the flow of information in two directions, from the NMS to the client as well as from the user to the NMS. When the users are in the agricultural sector, these tasks can largely be fulfilled by the agrometeorologists who have training and expertise in both meteorology and in agricultural production. This enables them to understand and communicate with the NMS climatologists and forecasters as well as with the extension personnel and the farmers themselves.

The needs of farmers and agri-business should be identified. Often the farmers are acutely aware of the effects of the weather and climate on both the day-to-day and planning activities in crop and livestock production. However, many times these relationships are not clearly defined or described in a scientific fashion, or able to be applied to the specific farming system or transferred from one system to another due to lack of environment characterization (White, et al., 2002). Therefore, a detailed analysis of the influence of weather parameters on production must form part of the needs assessment.

From the meteorological services point of view, these needs should be linked to the available climate data by using various types of analysis or application tools. Often a new approach may be needed to address the specific queries and requirements of the farmers in a particular region. This then becomes an ongoing challenge for the climatologists, meteorologists, and forecasters to work together with the agrometeorologists and extension personnel and clients to answer a particular need or requirement by developing a new application. In this way, the science will be advanced and become more and more applicable as well as user-friendly. This is also where the international connections, enabled by organizations such as the World Meteorological Organization (WMO) and particularly the Commission for Agricultural Meteorology (CAgM), can be most useful as they enable scientific exchange between regions and also exchange of applications and experiences between colleagues across the world.

To consider dissemination of agrometeorological information, first define what is meant by “dissemination” and “communication.” Then, a model can be constructed for this process to achieve successfully the dissemination of agrometeorological information.

### **What is Dissemination?**

Technology transfer can be defined as the transmission of goods, data and information, and knowledge, know-how, and skills (Day, et al., 1995). The extension task is to provide access to information and skills to help farmers make the best possible use of resources and services available to them (Mosher, 1978). However, the downfall here is that two assumptions are made: 1) that there is a lack of relevant knowledge and skills; and, 2) a one-way flow of communication (Day, et al., 1995). Many times, the lack of adoption or use of the products can be due to this one-way communication channel and little or insufficient time being spent listening to the farmers themselves. Dissemination can be defined as the scattering or spreading abroad or distribution or dispersion of certain information (Reader’s Digest, 1998). The diffusion of innovations is considered to be the process by which a new product is spread among users, in contrast with adoption which is when it is absorbed and utilized in the decision making process (Fisher, et al., 2000). However, if the agrometeorologists do not want their efforts to be wasted, it would be most advisable to have good communication and working relationships with the agricultural extension, cooperatives, and agricultural suppliers’ staff and to promote participatory methods for interactions with farmers (Martin & Sherington, 1997). In this way, it can become a focused effort and collaborative learning process that is more likely to achieve its aim.

### **Communication Model**

Communication is vital for the dissemination of information. Most definitions of communication include five fundamental factors: an initiator, a recipient, a mode or vehicle, a message, and an effect (Bembridge, 1991, Mukhala, 2000). So, the message is first conceived by the sender and then encoded into a format that can be sent by a specific medium. This must further then be decoded by the recipient before it can be acted upon and a return message is sent regarding the successful understanding or not of the message (Mukhala, 2000). So communication must include a sharing of meaning or understanding for it to be successful (Mukhala, 2000). It must also be a two-way process to be considered successful.

The dissemination of agrometeorological information illustrates the vital parts of communication. Communication begins with the farmer who formulates a request to the

NMS via the extension officer. For example, a useful forecast is needed for the onset and amount of rainfall for the upcoming growing season. In this case, the farmer, as sender, must formulate (or encode) the request in such a manner that it is specific with sufficient detail. The message or request is then sent to the NMS via some medium (e.g., postal service or telephone). When the NMS receives the request, they must be able to interpret (decode) it into a scientific formulation to perform the data analysis. For communication to be completed, the NMSs must reply to the farmer indicating that they received the request and have understood it. Again, the message must be encoded in a format and language that the farmer can understand. The agrometeorologists, acting as a part of the channel, must first interpret the statistics and the scientific analysis and translate it into layman's terms so that the farmers can understand it. Thus, the agrometeorologists play a vital role in the encoding and decoding of the messages from the climatologists to the agricultural sector. The institutional dissemination channels are a vital part of the chain including the farmer association, non-governmental organizations (NGOs), input suppliers, village leaders, and influential or lead farmers (Hansen, 2002).

The content of the message is also important to its value. It must be relevant to the decision making processes of the clients (Hansen, 2002) and must also alter actions in a way that improves outcomes (Mjelde, et al., 1997). The desired information can be obtained from users by exploratory surveys or participatory methods of personal interactions with users. The critical issues consistently highlighted from such studies have been categorized and summarized by Hansen (2002) as follows: a) site specificity – that farmers are aware of spatial variability and can recognize scale mismatches between the forecasts and their on-farm decisions; b) temporal specificity – including timing relative to decisions and impacts, highlighting factors such as onset of rainfall, dry spell distribution, and weather conditions during harvest; and, c) skill of the forecast – often in different terms from the forecasters but relative to the other risks within their farming operations.

In general, much of the dissemination of agrometeorological information may have to be considered unsuccessful as there is often a breakdown somewhere in the communication process. So, it is necessary to go to the various parts of the communication model and identify gaps in transferring or encoding the content of the message. Bridging these gaps is an ongoing challenge (Hansen, 2002) and additional action needs to be included into the process to avoid these points of breakdown in communication. A good model of the process that considers all the aspects pertinent to the flow and content should be used; thus, enabling a good strategy to be developed for dissemination of agrometeorological information (Hansen, 2002).

## **Process of Dissemination**

The influence of climate on agriculture is considered to be complicated, including uncertainty, and large temporal and spatial differences exist as well as irreversible consequences (Joyce, 2003). There may be several different approaches to the development of climatological technology that the agricultural sector can use and the means to communicate it to the relevant persons. The nature of meteorological information is that it is always changing and so repetitive actions of communication are usually necessary. Therefore, it is easy to adopt a reiterative process. This should include an awareness and description of real-life experiences, a systematic reflection on these, and diagnosis of gaps in the system (van Veldhuizen, et al., 1997). This can lead to a conceptualization and formulation of aspects that require further analysis and development and gathering of more

information (van Veldhuizen, et al., 1997). Following these analyses and experimentation (including field work, critical reviews, analysis of case studies, experiments, etc.) the main findings can be integrated and translated into the work activities (van Veldhuizen, et al., 1997). If both the meteorologists and the members of the agricultural sector (e.g., farmers, extension staff, and agricultural suppliers) are involved, then it is possible for this participatory technology development to be user-friendly, meet the needs of the user, and have stretched the limits of the climate-science expertise.

The process should include the following (adapted from van Veldhuizen, et al., 1997):

- a) Identification of the clients or target groups;
- b) Interaction between the service provider and clients to identify the climate-sensitive decisions that are made during the course of everyday business. This step enables a relationship (Relationships Foundation, 2004) to be built between the NMS, agrometeorologists, and specific clients so that they can identify or diagnose the gaps in weather information available from the NMS;
- c) Development of products or technology into useful packages or forecasts by further specific climate-data analysis, the use of modeling techniques to simulate the effect of weather variability on the agricultural production system, and risk and sensitivity analyses for various climate parameters;
- d) Further interaction with the clients to evaluate the results from the scientific analyses. This gives an opportunity for clients and climatologists to reflect on the needs expressed in (b) and the products developed in (c). It also provides an opportunity for the client to experiment with the products and to test and evaluate their usefulness and applicability. There needs to be a re-iteration process back to (c) and (d) before proceeding to (e); and,
- e) Introduction and integration into the routine operational forecasts and products of the NMS, when the product or technology or forecast is acceptable and usable for the clients. This will be an implementation phase in which it must be publicized and distributed to the clients on a wider scale, so that they can begin to utilize it in their day-to-day operational decisions.

As the interaction between the weather and the agricultural production is so complex (Hoogenboom, 2000), it is not just a case of applying a simple solution and expecting implementation by the farmers. As each year or season will bring a different set of circumstances, the actions required will also be different. That is why the participation approach involving the NMS and the agricultural community and farmer clients is necessary. So first, an awareness of the influence of the weather and climate parameters on sustainable agricultural production is needed (Sivakumar, et al., 2000). In many cases, this awareness is already acutely present and many farmers are looking for intelligent low-risk solutions. This should stimulate an interest among the farmers to be willing to evaluate the forecast products produced by the NMS. If the NMS or agrometeorologists are willing to work together with the farmers, then new technology will be developed during the experimental phase of a project (Bembridge, 1991; Mosher, 1979). Once this type of product has been developed with a small group of farmers, they can be made available to a wider audience to be tested and adapted before widespread adoption. This technology, innovation, or forecast product should have a firm scientific base and meet the requirements and specified needs of the users or clients. In this way, during the initial phases of the development of the technology or forecast product, it will already be tested and improved or adapted. These farmers can then also be used in a farmer-to-farmer technology transfer action to distribute it further afield.

## **Modes of Dissemination**

The practical methods or channels that can be used for the actual dissemination of agrometeorological information depend on the client to be reached and the sender as well as the format of the message or information (Bembridge, 1991). The communication channels can be broadly divided into three groups, namely mass and electronic media, group methods, and individual contacts. In general, the use of more than one channel gives a greater chance of reaching the client or user (Bembridge, 1991). The individual contacts can be time consuming but also build good rapport and help maintain credibility between the role-players. It is a vital part of the participatory technology development (van Veldhuizen, et al., 1997) and the training and visit method of extension (Benor & Baxter, 1984).

In identifying the clients, it is often useful to focus on a specific homogenous target group likely to have sufficiently similar needs and, therefore, can also benefit from similar information (Bembridge, 1991). This target group may not be existing groups, as such, but more a category of clients or farmers who would be able to identify similar weather dependent decisions. Therefore, the same sort of uniform recommendations, advisories, or information can be formulated to address these critical decisions and provide the desired weather information using the same format and language, etc.

The group methods include the use of already existing study groups or other interest groups such as sewing, church, or sports groups (FAO, 1999). This also provides face-to-face contact with people who are the clients and enables the agrometeorologists to obtain more general feedback from more users concerning the information provided. This is a way of making better use of scarce human resources, and groups can meet on a regular basis or be one of the meetings (Bembridge, 1991). Group meetings can be informal or formal, a discussion, or formal farmers' days of information meetings. There are advantages for both the farmers and for the extension staff. The groups allow farmers to be exposed to other farmers' successes as well as realize that they may encounter similar problems or obstacles. This encourages them to preserve and to consider alternatives that may have been used by others. It also helps to share experiences and opinions and identify gaps in the knowledge or information flow (Joyce, 2003). Groups can also commit together to take certain action and then support each other throughout the process (Bembridge, 1991). Groups generally should save the extension staff some time as the message is only explained once to the whole group. The groups can be used in follow-up to both mass media and previous individual contacts.

The use of mass media has the advantage of reaching many more people with each action. The format can be a written article on a specialized printed pamphlet, newspaper, magazine article, or e-mail or Internet posting. Alternatively, it can be distributed via the electronic media including radio, television, tape recording, e-mail, or Internet. The disadvantage of the audio and visual media is that the receiver only has to rely on their memory to recall the information at a latter stage. Therefore, it is often good to have a follow-up with printed matter and diagrams, especially if this can be in the local language. The use of electronic media such as e-mail file transfer protocol (FTP) or the Internet will depend on the availability and access of these methods to the users or clients who make up the target groups (WMO, 2000).

## Examples

One of the best ways to illustrate what has been explained is to look at some examples of the process that have resulted in successful dissemination and utilization of agrometeorological data. Examples that integrate the whole range of weather and climate data and information transfer to farmers include the following:

- From research to application by Florida Consortium (FC) (Jagtap, et al., 2002). As agriculture is one of the most important sectors of the economy and climate variability is a major source of risk in the southeast USA, the FC was formed to capitalize on the potential predictability of the climate. The FC aims to bridge the gaps by characterizing users' needs, then adapting research tools to support agricultural decision making. This process was also evaluated and mechanisms were developed to deliver useful climate forecast applications.

The framework that the FC developed had many activities that were integrated into a whole and yet ran parallel, including physical, biological, social, and economic aspects. Basically, the framework consisted of four integrated components of climate information, namely a) generation; b) communication; c) use, and d) implementation; and evaluation of a) to c).

The generation of climate information was mainly a diagnostic analysis of historical climate and agricultural data in which the influence of El Niño-Southern Oscillation (ENSO) on climate and thus agriculture was characterized using models. The second component of communication of climate information had already been identified as a challenge (Hammer, et al., 2001, Keating & McCown, 2001). This included distribution of information and the maintenance of communication channels by interaction with stakeholders. This enabled learning about the current decision making processes and what influences them, so that gaps could be identified for improvement. Some matters identified were referred back to the first component as areas that needed climatological research and analysis. The methods included the Florida automatic weather network, the Florida cooperative extension service, as well as the stakeholders. Rapid rural surveys were also conducted to gather information on climate-sensitive decisions that farmers and ranchers have to make. Training was conducted on how growers can incorporate weather data into management tools to assist with day-to-day management decisions. The third component was the use of the climate information. Benefits have long been identified in climate-sensitive sectors, but for success it must induce a change in the decision making process and actions of stakeholders (Sonka, et al., 1992). In this case, the use of climate information was applied to irrigation and planting dates of peanut production; winter tomato production using ENSO models to address labor constraints; cow-calf livestock operations with decisions such as when to plant hay, and seeding and fertilizer rates versus purchase of bulk-feed and nutritional supplements for the cattle. Models of these specific farming operations were then used together with the ENSO forecasts to develop advisories. The fourth component of implementation and evaluation actually ran parallel to the others. This part included an analysis of the effect of extension as a means of transferring and disseminating research results together with the infrastructure needed and the process of interactions as bridge builders between extension and stakeholders.

Some of the conclusions include the following:

- That farmers do require climate information;
- End-users trust information from a credible or trusted source;
- A wide range of opinions from no confidence to high level; and
- Active involvement of agencies with good, strong and established relationships was required to improve chances of delivering operational applications.

Therefore, while dissemination of climate-agricultural information is necessary, the agent delivering it needs to have a track record and be a trusted source. They also need active involvement of the agencies with a good relationship with the stakeholders to achieve a wide acceptance of the information.

- Farmers', Advisers', Researchers', Monitoring, Simulation, Communication and Performance Evaluation (FARMSCAPES) approach to decision support in northeastern Australia (Carberry, et al., 2002, McCown, 2002).

The FARMSCAPE approach to a decision-support system was developed as a program of participatory action research (Martin & Sherington, 1997) with the farming community in northeastern Australia. The initial question that was asked was "who are the clients?" This is to identify the group of society whose needs were to be addressed in the program. The approach taken throughout was that of participatory action research where a cycle is followed together with the selected role-players from planning to action to observations to reflection and then returning to planning again. The Agricultural Production Systems Research Unit (APSRU) was formed to conduct the on-farm research including collaborative experimentation and monitoring production variables and using simulation models to explore other issues and options. The FARMSCAPE project included the development of networks of individuals and groups of farmers and consultants, advisors, extension officers, etc., who were engaged in monitoring on-farm activities. It also included investigation of alternative ways that other farmers and advisors could be incorporated to derive some benefit resulting in training and communication activities. The communication activities included different media, e.g., video, newsletters, field days, printed articles, internet website, on-line sessions, etc. One of the approaches developed was the "WifAD" or "What if? Analysis and Discussion," which is an interactive discussion with collaborating farmers and advisers. This allowed scenarios (Urli & Nadeau, 2004) for alternative management options to be developed which were then run with a simulation model to evaluate strategies and develop tactical plans which used yield forecasting as an evaluation tool (Podesta, et al., 2002). The seasonal forecasts developed using Southern Oscillation Index (SOI) phases was one of the scenarios together with soil as a resource, soil monitoring, and industry acceptance of modeling. Changes in production expectations and consideration of innovative changes in farming decision making and practices were all evaluated.

A wide range of dissemination modes was used in this project. The innovative methods included direct links by individual relationships between researchers and advisors and farmers, and the use of models as a demonstration tool and also as a practical scenario-building tool to explore outcomes to "what if questions" on a specific farm. However, one mistake was a "failure to deliver" by researchers due to the time-consuming, stressful, confronting, demoralizing participatory mode of working. This can be a

learning curve, but one solution was to train accredited users who could take the process to a wider range of stakeholders.

- Use of seasonal precipitation forecasts in Burkina Faso, West Africa (Ingram, et al., 2002).

This project addressed several aspects of the seasonal rainfall forecasts and the path from producers (NMS or other sources) to the farmers. There was an overwhelming demand and request for the rainfall-forecast information as rain-fed farming is their main livelihood. The specific requests included the quantity, duration, and distribution in space and time at least 1-2 months prior to the onset of the rainy season, so the producers can use this information in the decision-making process to optimize labor, land allocation to various crops, seed choice, etc.

The consensus about dissemination of the message was that the local language radio would achieve the best widespread and timely distribution of the forecast, as most had access to battery operated radios. However, they requested a follow-up by the extension officers, possibly on market day or at the mosques as these were general meeting places. The most useful forecasts were also those that included information from both the NMS and the agricultural and development and resource management experts. In this way, the message could include some strategies to consider such as crop diversification, land allocation, and suggestions as to resource management.

- Transfer of irrigation scheduling technology in northern Mexico (Quiñones, et al., 1999).

This real-time irrigation forecasting system integrates crop, soil, weather, and water distribution networks to schedule irrigation water applications on a plot-by-plot basis with easy up-scaling to a district level. The system involves part of the national agrometeorological network of automatic weather stations connected, via radio-repeater stations, to a computer server from which users can download climate data via a direct telephone line. Reference evapotranspiration is calculated for the real-time irrigation forecasting system, available on a 24-hour basis due to 15-minute automatic downloading from the weather stations. The station data is also available in hypertext from the web page that is updated periodically. Maize and wheat field experiments were used to calibrate aspects such as rooting depth, allowable soil water deficit, and calculation of crop factors. During the evaluation part of the project, the users participating in the real-time irrigation forecasting system obtained 12 percent and 26 percent higher crop yields in maize and wheat, respectively. Under the real-time scheduling system, the water productivity of maize improved by 18 percent and wheat by 59 percent, relative to the traditional irrigation scheduling methods despite applying more water than the model predictions. Following the success in the prototype system in the Carrizo Valley, the system was transferred to the Del Fuerte Valley with adaptations including additional weather stations due to the variable microclimate and the use of growing degree days to adapt the length of the phenological phases of the crops. Further expansion of this program, by transferring the technology to other important irrigation districts in northern Mexico, is planned. The principle mode of information distribution in this irrigation scheduling system is the farmers' access to weather data and other water use information directly from the database via computer links, either on a dial-up system or via the web page. This information is available on a routine basis to the users, 24 hours per day.

## Conclusions

Dissemination is vital if agriculture is to benefit from the available agrometeorological data and products. It is necessary to have two-way communication between the climatologist or forecaster and the potential clients, whether farmer or agribusiness advisor or extension staff. This can be best achieved when there is a personal relationship between the parties with continuity being maintained by regular contact and interactions with open communication channels (Relationships Foundation, 2004). It is critical to identify the climate-sensitive decisions that are used in planning or on a daily operational basis and to identify gaps in information needed so that technology can be developed to bridge these gaps. The products must then be evaluated before being integrated into the operational forecasts for dissemination to a wide range of decision makers. Since the relationship between the NMSs and agricultural role players is so critical, it would be good to assess whether they have shared values and aims, have respect for each other, and are aware of each other's circumstances and roles (Relationships Foundation, 2004). The way forward is to form good relationships so that new agrometeorological applications can be developed as a cooperative and collaborative learning process to bridge the identified gaps in the knowledge chain, and thus, enable meteorological science to contribute to the economic benefit of the agricultural industry.

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## ***Strengthening Operational Agrometeorological Services: Needs from Agriculture Sector***

### **Current and Potential Functions of National Agrometeorological Services: The Agricultural Demand Side**

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#### **Abstract**

Agriculture, providing basic needs and services and one of the biggest employers, is one of the most weather-dependent industries. A crucial role of the National Meteorological Service (NMS) is timely provision of accurate information on agrometeorology. With few NMSs under the agriculture portfolio, priorities rarely focus on serving agriculture. Even those with observation networks do not always provide services, often due to the shortcoming in their analytical capability. Along with staff and budget constraints, the service suffers from a poor understanding of the diverse agricultural users and their requirements.

Information requirements vary with different farming practices, while research and education require more detailed information with different emphasis. Among the variables with strong effects on crop growth and farm management are daily temperature, precipitation, solar radiation, and wind speed. More general information is required in advance by agricultural policymakers, planners, and institutional support systems for better planning. With challenges in climate change, desertification, and biodiversity, many NMSs can play a crucial role in improving understanding and finding ways to mitigate and adapt. The NMS can take advantage of advances in computer and communication technology to improve analytical capability and service delivery.

With limited resources available, an effective way to benefit from the progress is through cooperation among countries within a region. By putting together the best resources and expertise, the limited resources can be more efficiently utilized. Presently, many climate institutions provide near real-time global observations of the ocean and atmosphere and periodically post the analytical results of their implications on regional climate. NMS can take advantage of the information by calibrating the results in the region for local use and by providing feed back for the improvement of the service.

#### **Introduction**

As the largest employer in the world, involving about 49 percent of the world's work force (60 percent in developing countries), a healthy agricultural sector is a prerequisite for sustained economic growth in most countries. Adequate supplies of affordable food are essential for poverty alleviation and economic development. As one of the most weather dependent of all human activities, variations in weather and climate, as well as their interaction with agricultural operations from planting to harvesting, determine appreciable parts of the yield variations. Despite the advances made in our understanding of the influence of climate on agricultural

production, climate variability will continue to be the principal source of fluctuations in global food production.

Advances in the transportation systems and refrigeration technologies have substantially reduced the cost of transporting goods and allows agricultural producers to reach further markets. Along with the growing regional cooperation, agricultural trade among countries has become more common. The ongoing change requires good agrometeorological information for the envisioned sustainable agriculture that not only requires sound technology, but must also be economically feasible and socially acceptable.

The growing interest on the potential impact of natural- and human-induced climate variability and long-term climate change on agriculture and forestry requires agrometeorological information and assessments. The growing demand for food and concern about the need to achieve greater efficiency in the use of natural resources while conserving the environment is placing a much greater emphasis on understanding climatic resources. The need for reorienting and recasting meteorological information, fine tuning of climatic analysis, presentation in forms suitable for agricultural decision making, and insulation of marginal farmers from the adverse impacts of weather vagaries has become more pressing.

Data are the fundamental basis for the provision operational agrometeorological services. However, it is the informational products that are the framework for any knowledge-based decision process. The ability to integrate the information from interdisciplinary sources utilizing new computer-based technologies and telecommunications creates a great opportunity to enhance the role of agrometeorologists in many decision-making processes. Information may be in the form of advisories regarding planting or spraying decisions to be used by extension services for the agricultural community. It may also be incorporated into early warning alerts related to food security or market implications. Early warning information allows improved long-term planning that will benefit agriculture.

Beyond daily and seasonal farm-management decisions, agrometeorological information can also play a valuable part in risk management. The information can be used with new technological tools and data base infrastructures to assess risk and to quantify probabilities associated with the variability. The implications are enormous not only for agricultural extension services but also for policy level decision makers who are responsible for food security and marketing decisions for agricultural products.

### **Current Functions of National Agrometeorological Service (NAS)**

According to a survey conducted by World Meteorological Organization (WMO) among its members in 2003, agriculture along with disaster management, were the second largest applications of meteorological services after aviation. Environmental protection and mass-media come third and fourth, respectively. Agriculture is perceived as the most important user equal with aviation in Asia and exceeding it in South America. In the least developed countries (LDC) and countries in transition (CIT), agriculture is equally as important as aviation. In the developing and developed countries, disaster management was ranked the second highest application. The importance assigned to aviation probably because most of the NMSs (52.9 percent) fall under the Ministries of Transportation and Communication. Only 9.1 percent of the services come under agriculture, mainly in Asia, America, and Europe. The other NMSs are under Environment, Science, Defense, and others; including Water and Natural Resources, Public Works, and Energy portfolios.

Overall national funding, modernization, capacity building, and the definition of the role of the services at the national level are listed as the most pressing issues facing NMSs. Of the 103 services that responded to the questionnaire on budget, it ranged from US\$7 million for LDC to US\$135.9 for developed countries. The average NMS annual budgets per capita are 0.27; 0.75; 1.59, and 3.48 US\$, for LDC, CIT, developing countries and developed countries, respectively. Region-wise, the highest is in North America with 3.12 US\$ per capita, followed by South West Pacific 2.44 US\$, Europe 1.95 US\$, Asia 0.95 US\$, Africa 0.71 US\$, and South America 0.32 US\$. These budgets are about as much or less than one-day cost of living for the poorest in each region. The low budget has caused the services to try and improve their income through cost recovery for specialized services. This is another reason why aviation is the main customer of many NMSs, as they pay for the services.

Of 181, 481 NMS total staff in 120 countries that responded to questionnaire on personnel, 44 percent were professional, 46 percent were technicians, and 10 percent were in administration. A closer look reveals that the share of professionals is far lower in the less developed countries whereas 16.3; 18.6; 23.9 percent, respectively for Africa, South America, and Southwest Pacific compared to 47.9; 59.1; 53.0 percent for Asia, America, and Europe. Based on the stage of development, the professionals are 25.6 percent in LDC, 38.7 percent in developing countries, 45.7 percent in CIT, and 53.5 percent in developed countries.

The relative importance of technicians indicates the opposite trend with the highest percentage of 60.2 percent occurs in LDC, followed by 50.8 percent in developing countries, 46.6 percent in CIT, and 38.6 percent in developed countries. This is reflected by the educational level of the NMS staff, where a high proportion of high school levels compare to those with bachelor or higher degrees in regions like Africa and Southwest Pacific or in less-developed and developing countries (Figure 1).

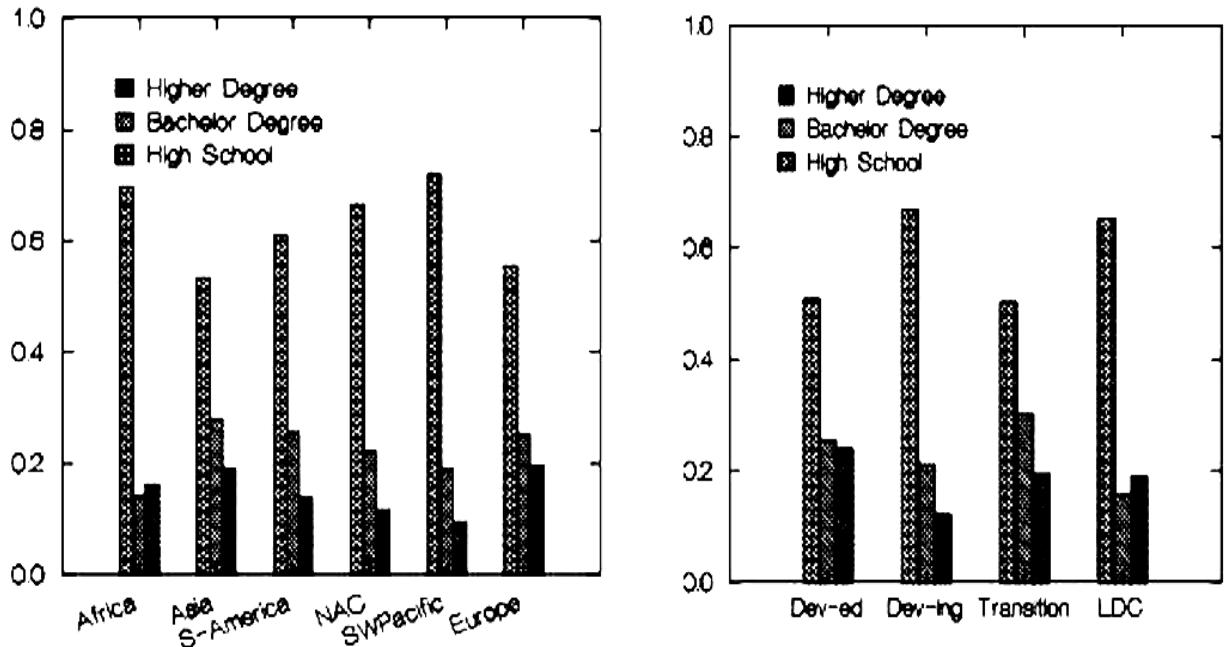


Figure 1. Proportion in the level of education of the personnel of the meteorological services by region and stage of development.

In most countries, the NMS is the leading or sole institution that manages the agrometeorological networks (from 51.3 percent in North America and the Caribbean to 96.2 percent in Africa). Only 39 NMSs stated that they play a minor role and 7 do not participate in observation and monitoring for agrometeorological purposes. In Africa, 11 services playing minor roles and 2 services are not involved in agrometeorology and in Europe 10 services play a minor role. Based on stage of development, 100 percent of observation and monitoring are carried out by the NMS in the LDC, 83.7 percent in CIT, 73.9 percent in developing countries, and only 50 percent in developed countries.

A high proportion of the NMS stated that they provide agrometeorological services. However, except in the CIT, not all those doing the observation and monitoring provide agrometeorological services. The agrometeorological services are provided by 83.3 percent of the NMSs in LDC, 87.7 percent in CIT, 69.6 percent in the developing countries, and 50.1 percent in developed countries. Almost half of those in developed and more than 30 percent in developing countries do not provide agrometeorological services probably indicating the diminishing share of agriculture to the economy. The other reason, both in the developing and developed countries, is that there are many other institutions both private and public that have the capacity and are providing the services.

The NMS running observational and monitoring networks have maintained valuable long historical records, either as hard copies or digital databases. But, valuable data are not always utilized for the benefit of the farmers. The problem seems to be very serious in the South West Pacific and Africa where only 62.5 percent and 68.0 percent of the services that stated they are the sole or leading institutions are doing agrometeorological observations and providing services. In Asia and Europe, the proportion of those doing observation and monitoring and also providing the service is higher, 92.3 percent and 81.5 percent, respectively. The fact that many countries do observations but do not provide services indicates the pressing need of capacity building, particularly in analytical methodologies. Raw data are of little value and hardly understood by farmers without being transformed into information by good analysis.

Besides participating in formulating national policies on natural disaster reduction, environmental protection, and sustainable development, the NMSs are also involved in international programs such as United Nations Framework Convention on Climate Change (UNFCCC), Vienna Convention on the Protection of the Ozone Layer, and the UN Convention on Combating Desertification (UNCCD). A high proportion of NMSs play a leading role, 81.5 percent in Africa, 70.8 percent in Asia, and 81 percent in South West Pacific, but only 44.4 percent, 60.0 percent, and 59.0 percent respectively, in South America, North America and the Caribbean, and Europe. Probably because the research infrastructure and institution are more developed in the industrial world, the role of meteorological services in UNFCCC is lower when the country is more developed. The role of the UNCCD was more significant in Asia and Africa with 54.5 percent and 40.7 percent, respectively, compared with only 16.6 percent in South America, 26.7 percent in North America and the Caribbean, 20.0 percent in Southwest Pacific, and 28.6 percent in Europe. The problem of desertification is less predominant in the last four regions.

A lower proportion of professional staff and a low operating budget, in the less developed countries where the clients are mostly marginal farmers with inadequate means to access the information, certainly affects the quality and delivery of the services. Unfortunately, the less developed countries do not have adequate resources to address this problem. Modernization

and capacity building are only possible when adequate budgets are available. Further, many developing countries give greater priority to the most visible and quick yielding programs. With few exceptions, it is hard to expect that NMS will focus on providing appropriate services to agriculture. Without assistance from more developed countries or related international institutions, the problem will take a longer time to be solved.

The NMSs also do not put significant efforts into providing information to serve human health and medical services, although most of the public health problems are related to climate. For example, dengue fever, caused by mosquitoes during monsoon, or respiratory diseases caused by hazes in prolonged droughts. Triggered by heavy rain during climate anomalies, epidemics of rift valley fever have decimated livestock and affected humans as well in East Africa. Pollen of particular plants is also known to spread over wide areas and affect human health.

In the survey of the economic sectors that were served by NMSs, health and medical services ranked 17th both by region and stage of development. It ranked 12th in Africa after tourism, 13th in Asia after construction, 18th in South America after sports, 16th in North America and the Caribbean after legal services, 20th in South West Pacific after leisure, and 23rd in Europe after urban planning. The more developed the country, the less significant the role of NMS in providing information on health-related matters. High investment in health services in the more developed world may have negatively affected the initiatives of the NMS to venture in this field.

### **Agricultural User Categories**

Agricultural users can be roughly divided into four broad categories: 1) farm operations and farm management; 2) agricultural institutional support systems; 3) agricultural policy and planning; and, 4) agricultural research and education. Each of the groups (and their sub-groups) requires specific agrometeorological information for the safety and sustainability of the business. For agricultural institutional support systems and agricultural policy and planning, a more general type of agrometeorological information such as monthly rainfall and temperature along with spatial and temporal climate variability are usually adequate. For farming operations and research and education, more detailed information is necessary. Farmers require detailed information when deciding on the appropriate time for land preparation, planting, spraying insects, or harvesting crops. Researchers, on the other hand, require detailed information to understand the intricate interactions between plant, soil, and climate.

The farming management practices specifically include annual and perennial crops, forestry, animal husbandry, inland, freshwater and brackish water fishery, and mixed or integrated agriculture where two or more of the ventures are actually practiced on one piece of land. When the farmer cultivates crops along with trees next to each other on his farm, the production system is referred to as agro-forestry. By arranging plants in a multiple storey way more solar radiation is absorbed by the vegetation from the same size of land. Trees are also planted as a fence or wind barrier to protect the crops from strong wind. Each of these practices requires very specific information for the selection of production systems to decide which is the most suitable for a particular piece of land with a unique combination of soil and climate.

Among the agricultural institutional support systems are: agricultural extension services, financial institutions like rural credit, insurance, seed growers, etc. The extension service needs adequate knowledge of the general climate of the area and how that affects the farming practices in the area. Rural credit, insurance, and seed growers require long-term climate forecasts to know what type of venture they are going to make in the coming season or year. Forecast information is needed in advance, so the timely release of forecasts is imperative for a more profitable business.

Agricultural policy makers and planners require comprehensive soil and climate information to plan new agricultural ventures. Facing the ongoing change, such as regional cooperation or competition from other producers, agriculture has to adjust. With proper planning, agriculture in developing countries can be a way to pursue political, economical, social, and environmental goals. For political goals, agriculture can be re-planned to strengthen national integration through promoting inter-regional trade within the country or region. Economic goals can only be achieved when the agriculture products can compete on broader markets. Social goals such as rural development and poverty alleviation are strongly associated with agriculture, because farmers are in rural areas and they are mostly poor. For this purpose, agrometeorological information is indispensable, since it is one of the factors that cannot be modified in selecting suitable crops for a particular area.

The agricultural research and education institutions usually do not have adequate observational and monitoring facilities for agrometeorology, in terms of time and space. Agrometeorological data required by research institutions are usually rather detailed and precise on a daily or hourly basis. The database collected by the meteorological service with wide coverage both in space and time will be very useful in understanding the dynamic nature of agrometeorology. Delineation of somewhat similar combinations of soil and climate in one region is commonly called the agroecological zone, where crop cultivation with all management aspects can be expected to perform similarly. This approach will help the agricultural research to easily find where to transfer the agricultural technology generated in the experimental stations.

Agrometeorological data can be further analyzed to determine how they affect crop performance to understand the intricate relationship between crops, soil, weather, and management. Simulation models constitute the ideal tool to carry out these analyses. Before they can be used, the models must be tested and validated in different places, which requires a good dataset of all variables involved. This includes not only agrometeorological data but also crops data such as phenology along with management that has been applied. From the experimental and research results, useful feedback can be expected on necessary data required that are presently not available to run the models for a wider application. Therefore, a continuous communication and consultation between NAS and research is imperative, to improve the services provided to farmers as well as the advancement of knowledge. With better understanding of the relationship between agrometeorology, crop, soil, and management, the NMSs can prepare better services to the users.

## **Crop Farming**

A great variety of farming systems exists in different parts of the world. Earlier, before trading existed, driven by the basic needs for subsistence, farmers usually cultivated staple foods. With the advancement of transportation and trade, farmers with sufficient land gradually moved from food security as their main objective to crops that provide the best

return. But, many small farmers in the developing countries, because of the limited land availability, tried to intensify the use of their small farm by cultivating various field crops at once in a system called multiple cropping. This is also part of the strategy of poor farmers for food security: in case one crop fails, the other provides a substitute.

Farmers take the harvested parts of the crops (flowers, fruits, grain, or tubers), but often leave the straw, stalks, or haulms in the fields as compost. To better utilize crop residues, farmers raise animals, poultry, and small or big ruminants depending on the quantity of the residues. Chickens and ducks are often raised to control insects and other predators. When adequate amounts of water are available (as indicated by a continuous surplus in the water balance), farmers can raise fish in ponds, where parts of the agricultural waste can also be recycled. All these agricultural activities require a better understanding of agrometeorology, for both the selection of an appropriate production system and for the day-to-day management of farms. Each crop requires specific agrometeorological information for better growth, and a combination of resources is certainly needed to balance the requirements for the best outputs. The list of crop-based farming systems for food, horticulture, and industrial crops are presented in Appendix 1.

## **Animal Husbandry**

Animals can be raised in open fields and left grazing or confined within their pens and be provided feed. The selection of the type of animal raised in a particular region requires very general agrometeorological information. For instance, water buffaloes need humid conditions, while dairy cattle require cooler temperatures compared to beef cattle. Goats can stand harsh climate such as dry and hot desert but those conditions are not suitable for sheep. Ducks require large amounts of water but chickens will be adversely affected by high humidity. When land is in short supply and transporting the products to the market becomes a constraint, animal husbandry is moving closer to the consumers in peri-urban areas. Large animals like beef cattle, such as 1-year old calves, are brought close to market and kept in pens for fattening before being slaughtered.

Because animals are kept on limited space, the climate can often be managed. Animal husbandry produces not only meat, but also honey, milk, eggs, fleece, and hides. Those outputs probably require specific agrometeorological conditions for optimum yields. For instance, honeybees require high solar radiation that induces plants to flower and favor the production of nectar.

## **Fisheries and Aquaculture**

As land grows scarce due to increasing population, fisheries are often seen as a valuable alternative source of protein. Unfortunately, fish catches in international waters already exceeded the sustainable limit, thereby jeopardizing their very existence. Aquaculture, i.e., fish farming both on land and in the sea close to the land, has become an attractive option for the future. Aquaculture includes fresh water fisheries where farmers raise carp, tilapia, catfish, snakehead, and others and brackish water fisheries where farmers raise shrimp or milk fish. Aquaculture requires water bodies where the fish are raised for a certain time period, if necessary in man-made ponds.

Along with soil information, agrometeorological information is needed to establish aquaculture schemes. Essential information is derived from the local water balance, where

surplus water is necessary during most of the year if rainfall constitutes the main source of water. Otherwise, to keep the fish ponds full of water, other water sources have to be found. For brackish water fisheries, a specific balance between fresh and saline water is required for both shrimp and milk fish, as rainfall is a source of fresh water that cannot be controlled. It is very important to know the right amount of fresh water supplement from other sources.

## **Forestry**

With the size of natural forests declining, particularly the tropical rain forest, efforts in re-forestation or replanting the degraded forest using fast growing trees presently has become a trend. It is still highly disputed whether this is the best approach, since by planting only a few species bio-diversity is lost, as well as the intricate interactions that prevail in natural ecosystems.

Leaving forests to naturally grow to near-initial conditions will take hundreds of years, a timeframe far exceeding the term of any administration. Therefore, for a quick result, many public lands of the former natural forests are leased to private companies for wood tree plantation. Fast growing soft wood trees are usually planted for pulp to produce papers or timber for packing or disposable wood products like toothpicks or chopsticks.

Other than finding which particular wood species are suitable, foresters are very concerned with forest fires in some parts of the world. Forecast of relevant elements such as temperature, humidity, and wind may be required during the dry season when fires commonly occur. The NMSs may also need to monitor the dryness of the forests to keep the public informed of the degree of danger of fires each day. When the danger is extreme, a warning will be required. Another requirement may be forecasts of calm conditions for aerial spraying of insect pests.

## **Agrometeorology Data Requirements**

### *Factors Reducing Yields*

For optimum growth, crops require heat and water as well as plant nutrients. Except for a few like mushrooms, plants need solar radiation for photosynthesis to produce the harvested parts. Crops will produce optimally when all the requirements of nutrients, water, heat, and solar radiation are satisfied in all stages of growth. Potential yield is determined by crop genotype and environmental conditions (including management) and can be reduced below the expected value because of limitations to the accumulation of dry matter during specific phases of growth. Attainable yield, determined as well by water availability and extreme meteorological conditions, can additionally be affected by restrictions on the initiation of harvested parts of the crops such as flowers, fruits, grain, or tubers. The ratio between actual and attainable yield can be further reduced below normal by prolonged delay in the essential farming operations that affect crop establishment. The yield is also affected by timeliness of fertilizer and biocide applications and by harvest effectiveness. Meteorological phenomena that are mostly responsible for the yield reduction are: low temperature or frost, high temperature, excessive rainfall, insufficient rainfall, excessive wind speed, and low solar radiation. The most common agrometeorological variables, and how they affect crops, are presented in Table 1.

<b>Variable</b>	<b>Effect</b>
Daily minimum temperature	frost damage; lower limit of temperature tolerance
Daily maximum temperature	heat stress
Daily mean temperature	rate of crop growth and production
Atmospheric humidity:	
Lower limit	desiccation
Upper limit	crop disease indicator
Wind speed	crop mechanical damage
Excessive rainfall	water logging, crop inundation, trafficability, disease
Solar radiation:	
Upper limit	rate of maturing
Lower limit	delayed grain filling, raised moisture content
Excessive evaporation	crop stress
Soil water shortage	drought
Soil water excess	water logging
Actual/potential evaporation	prolonged low ratio implies crop stress

Table 1. Agrometeorological variables and their effects on crops.

When the limiting factor for crop growth is water, farmers resort to irrigation and drainage. Certainly these can only be carried out when the water resources and the means to withdraw it are available. Farmers in developing countries have traditional ways to deal with water excess by preparing the fields using the ridge/furrow system, planting crops that cannot stand water logging (corn, legumes) on the ridge, and rice in the furrow. However, when the problem is heat, solar radiation, or strong wind it will be very difficult and expensive to rectify the weather conditions except for those crops planted in greenhouses.

Weather also will affect agricultural activities in the field from land preparation, sowing, fertilizer application, plant protection, harvest, and post harvest activity. Excess or shortage of water will make the tilling of heavy clay soils very difficult and expensive. As in many of the more developed countries, with less and less farm workers doing rice transplanting in Asia, a new technology of rice planting (direct seeding) is widely applied. The application of direct seeding requires precise information on rainfall because heavy rainfall will wash away the seeds that were broadcast in the fields. High rainfall also will hinder the broadcast fertilizer application and spraying of biocide for plant protection.

High rainfall and wind speed will adversely affect harvest and post harvest activities. Certainly the harvest can be delayed, but it will reduce the quality of the crop. Drying grain in periods of high rainfall will be difficult and expensive. In Cauca Valley of Colombia where sugarcane is a major commodity, for easy handling, the canes are usually burned before harvesting. The smoke from the fire will disturb the population in nearby settlements; therefore, wind direction is essential information required to schedule the burning of the canes in order to minimize the adverse effects.

### **Importance of Phenology**

Crops require specific agrometeorological conditions at different growth stages and different crops require different conditions. The growth stages are divided into initiation,

establishment, vegetative, reproductive, and ripening. Shortage or excess of water, heat, and solar radiation at particular stages of development will have adverse effects on the crops. Crops generally require high amounts of water during the vegetative phase but less water and high solar radiation during reproductive stages. Specific agrometeorological conditions also induce the flowering of some crops.

Weather during early growth is very crucial for further development of crops. Adverse weather conditions may delay crop growth or even kill the germinating seed, therefore requiring replanting. Temperature and water content of the soil will determine whether the seed broadcast in the field will germinate. Even the establishment of winter cereals such as wheat and barley is greatly harmed when the temperature falls below 3°C and shortage of water will cause uneven establishment in the field. Therefore, more precise information on agrometeorology is required in determining the right time to start sowing or planting.

<b>Crop/Growth Stage</b>	<b>Temperature</b>	<b>Rainfall/Moisture</b>	<b>Wind</b>
<b>Rice</b>			
Establishment	$\leq 10^{\circ}\text{C}$ , $\geq 35^{\circ}\text{C}$	$> 25 \text{ mm/d}$ after sowing	
Vegetative	$\leq 10^{\circ}\text{C}$ , $\geq 27$ night $\geq 32^{\circ}\text{C}$ day	AE/PE < 0.3 for $\geq 30 \text{ d}$	
Reproductive	$\leq 10^{\circ}\text{C}$ , $\geq 27$ night $\geq 32^{\circ}\text{C}$ day	continuous rain AE/PE < 0.3	$\geq 6.7 \text{ m/s}$
Ripening	$\leq 13^{\circ}\text{C}$ , $\geq 27$ night $\geq 32^{\circ}\text{C}$ day	continuous rain AE/PE < 0.3	$\geq 6.7 \text{ m/s}$
Harvest		continuous rain	
<b>Wheat/Barley</b>			
Establishment	$\leq 3^{\circ}\text{C}$ for $\geq 30\text{d}$ from sowing	$> 25 \text{ mm/d}$ after sowing	
Vegetative	$\geq -10^{\circ}\text{C}$ for $10 \text{ d}$	$\geq 100 \text{ d}$ flooding AE/PE < 0.3 for $\geq 30 \text{ d}$	
Flowering	$\geq 32^{\circ}\text{C}$ for $1 \text{ d}$ $1^{\circ}\text{C}$ for $\geq 2 \text{ d}$	3 mm/d continuous AE/PE < 0.3	$\geq 6.7 \text{ m/s}$ $+ 12 \text{ h rain}$

Table 2. Alarm criteria for selected crops during different stages of growth.

## Seasonal Forecasts

When reliable forecast of the coming seasonal weather is available in advance, risk analysis and assessment of different cropping and management options can be performed to select the best one. Farmers can benefit from various crop options with different weather requirements and expanding markets to make the best from expected seasonal weather. However, this requires good planning, particularly the availability of the necessary seed, etc.

Forecasts can provide useful guidance to agricultural communities by informing them of expected weather conditions in time to schedule farming operations such as plowing, planting, irrigating, spraying, and harvesting or to take action to reduce losses from drought, flood, or other severe weather phenomena. They can also assist in scheduling the transport to market of vulnerable produce, so that potentially damaging weather conditions like freezing

temperature that can damage potatoes and other vulnerable crops are avoided en route (WMO, 1999).

## **Warning Systems**

When adverse effects of weather on the already planted crops cannot be avoided, it is very important to assess the impacts not only on farmers but also for society and the country. There are three steps of precaution on the possible adverse effects of weather on crops; those are warning, alert, and alarm (Keane, et al., 1998). Warning is issued when the adverse effect is small and in a limited area, alert is issued when the effect is higher over a wider area. For a real-time coverage of wide areas, the use of external data such as radar and satellite imagery along with the data from observational networks is required for the assessment. Specific agrometeorological conditions are said to be alarming, used when the possible impact on crop yield reduction is exceeding 20 percent over an area of more than 10,000 km<sup>2</sup>, or yield reduction of more than 30 percent over 5,000 km<sup>2</sup>. Alarm criteria for selected crops at different stages of growth are presented in Table 2.

## **Strengthening the National Agrometeorological Service**

### *The Institutional Position of Agrometeorological Services*

As stated at the Commission for Agricultural Meteorology's 13<sup>th</sup> Session (CAgM-XIII), legal instruments and capacity building are relevant issues on the role and operation of the NMSs. The survey also indicates that almost a third of the NMSs operate based on ministerial or lower administrative levels when the rest are established on a higher legal basis, either on parliament acts or presidential decrees. This will put them in a less authoritative position in dealing with other sectors and also affects their budget allocations. The majority of the NMSs are under the Ministries.

Transportation and communication budgets are comparatively lower than other sectors, even within the same ministry, compared to other areas such as aviation, shipping, and land transport systems. Since national organization set-up is a matter of national policy, it is desirable that in countries where agriculture is still an important economic sector and an important employer, to put more emphasis on agrometeorology.

Agriculture is a dominant activity in many developing countries and in some developed ones as well, so that the provision of services to agriculture should receive very high priority. But the NMSs often face constraints, that either because they are not equipped to provide appropriate services or the institutional infrastructure does not permit them to reach the end users, or both. A better service to agriculture can only be implemented by strengthening the agrometeorology section where it already exists, and by developing one when necessary. Effective services can be attained by closer cooperation with the Department of Agriculture, particularly in interpreting the agrometeorological events and their relevance to farming practices as well as in delivering the information to the farmers.

Using the observational networks, long historical series of meteorological data have been collected, and in many cases, put into a computerized database. However, the data remain in the services and are not used optimally for the benefit of the farming community. The absence of agrometeorological services in many countries that have observational and monitoring networks is an indication of the shortcoming in the analytical capability of some

of the services. Valuable data that have been stored into databases are often understood by and accessible to very few people, mainly those who are involved in planning and collecting. In the agricultural sector, those data will be very useful if they are made available to the research and educational institutions in an attempt to further improve the understanding of climate and how it relates to crop growth and agricultural activities. In order to reach a wider community of users, analysis is needed to transform the data into information. Information, in turn, has to be regularly delivered to the public in the form of forecasts and, when it is of urgent nature, timely advisories or warnings given.

## New Methods and Tools

There has been enormous progress in the development of new methods, tools, and sources of data in the last decade. Many easy to use and free statistical packages tailored for climate data analysis are presently available. They can often be downloaded from the Internet. One example of a statistical package is Instat+ developed by the Statistical Service Centre, University of Reading. It has extensive climatic analysis tools and provides a specific "climatic guide." However, a more powerful analytical program is required for advanced analysis, particularly when intended to serve specific government in areas such as food security.

FAO has embarked on developing AgroMetShell (AMS), a combination of climatic database, analysis, and decision-support system (DSS). It includes crop water balance, crop satisfaction index, satellite data interpolation, as well as interpolation techniques to convert point data into maps. Certainly, the packages can only be of any use when trained personnel and equipment such as computers are available. Capacity building should be a priority for the NMSs to improve the technical skills of the staff in analytical methodologies and the use of computer tools.

Only after their analytical capacity has significantly improved can the NMSs embark on the development of a DSS for more specialized agrometeorological services. In a specialized service, cost recovery can usually be negotiated with the intended users such as commercial agricultural businesses. A DSS and the simulation of the implications of alternative actions to be taken to minimize the risks are desirable to provide better service to the users. The development of DSS requires the expertise and the close cooperation of many experts such as agrometeorologists, agronomists, soil scientists, as well as anthropologists and other social scientists. This will require a close collaboration also among different government departments outside the NMS.

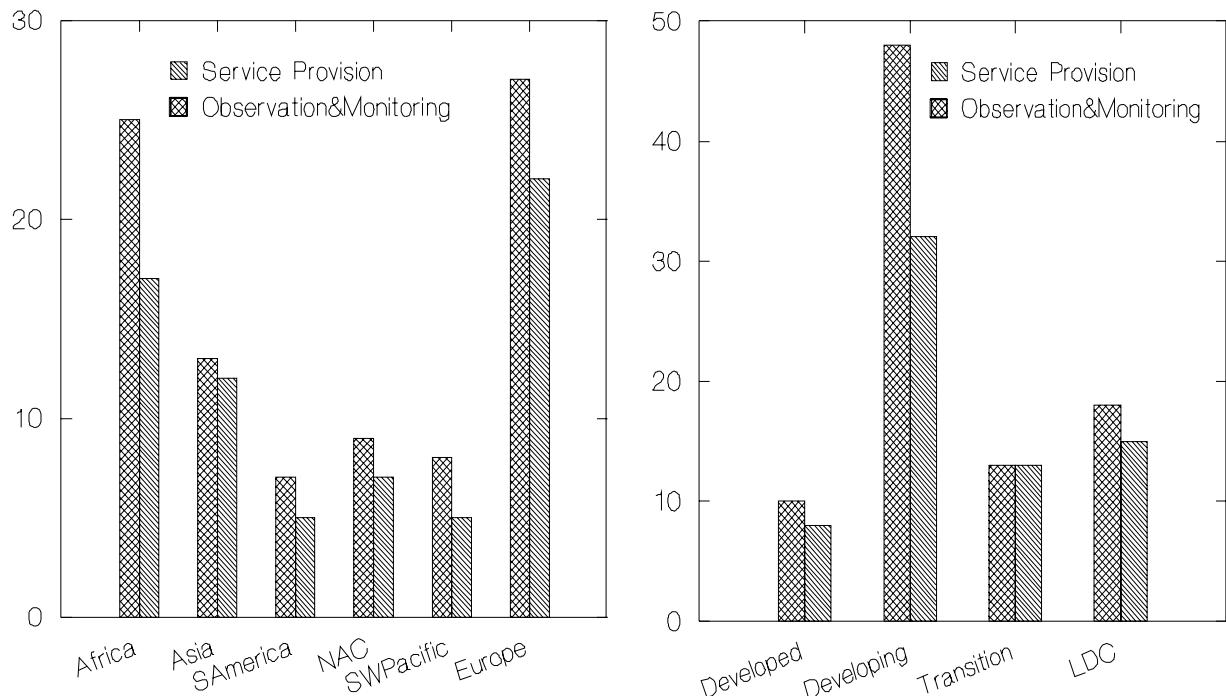


Figure 2. Number of national meteorological services with agrometeorological observational and monitoring networks and service provision.

### Capacity Building and Regional Collaboration

Certainly, capacity building, particularly human resource development is not a simple task for resource poor countries. Furthermore, the efforts will take a relatively long time to give clear and significant results that are often beyond the time frame of democratically elected governments.

Another more plausible approach in improving the capacity of the NMS is strengthening regional cooperation by developing regional centers like the European Centre for Medium Range Climate Forecasting. By putting together all the best resources such as expertise and equipment, the Centre can better serve not only Europe but the other parts of the world as well. The services of the Centre are very useful to the CIT in Central and Eastern Europe.

Driven by the catastrophic droughts of the 1970's and 1980's, regional collaborative work was strengthened in Africa such as Southern Africa Development Community (SADC), Inter-governmental Authority on Drought and Development (IGADD) in Eastern Africa and CILSS in the Sahelian region of Africa. CILSS established its Agrhyemet in 1974, a regional centre that specializes in providing services to member countries particularly to ensure food security.

Southeast Asian countries organized a workshop in 2001 to forge close cooperation on agrometeorology and have established working groups on meteorology and geophysics. The working groups among others, monitor forest fires and haze during prolonged drought, repeatedly causing economic losses in the regions.

## **Climate Change, Desertification, and Biodiversity**

Long historical data series collected by the NMS will be of great value in improving understanding of global concerns such as climate change and desertification. It is the time to start exploring the proper ways to mitigate climate change and desertification and to find proper adaptation strategies in facing what looked inevitable. Agriculture can reduce greenhouse gas emissions by adjusting the farming practices to achieve higher production while reducing unnecessary release of wastes from crops and animals. The trend and development of climate change and desertification either natural or human made also have implications on another global concern, biodiversity. The loss of biodiversity is further aggravated by population pressure in the less developed countries that exploit the natural habitats for their meager living.

A diverse range of organisms contributes to the resilience of agricultural and natural ecosystems, their capacity to recover from environmental stress, and their ability to evolve ([www.fao.org/biodiversity](http://www.fao.org/biodiversity), 2003). Further losses of biodiversity have to be prevented and the NMS can play an important role in this effort by providing necessary climatic information required for the conservation of the genetic resources.

## **Improved Weather Forecasts**

In the last decades, we have seen enormous increase in the accuracy and lead time of forecasts and warnings due to the introduction of computers and satellites. This trend can be expected to continue as more sophisticated numerical models of the atmosphere and oceans are developed. Improved analytical software run on smaller computers, provided they have a sufficiently dense network of observations as input, and will increase the accuracy and resolution of forecasts for limited areas of high economic value (WMO, 1999).

Using advanced software and inputs from extensive observation networks, some national and international institutions presently provide analytical results such as climate outlooks and forecasts with global coverage, which are posted periodically on their websites. Among others, the International Research Institute for Climate Prediction releases four trimester forecasts of temperature and precipitation every month. The National Weather Service of the National Oceanic and Atmospheric Administration of the United States provide a weekly update on the development of Pacific Ocean sea surface and subsurface temperature as an early indication of the development of an El Niño event. Greater understanding of El Niño and similar phenomena in other oceans, together with improved computer models, should also lead to more reliable seasonal forecasts and prediction of drought some months ahead ([www.cpc.ncep.noaa.gov/products](http://www.cpc.ncep.noaa.gov/products), 2004; [www.iri.columbia.edu/climate/cid](http://www.iri.columbia.edu/climate/cid), 2004). This valuable information can be accessed by Internet. It is well worth being calibrated with the data observed by the NMS and it will be very valuable when used for agriculture planning in the country.

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# **Establishing and Improving Linkages between National Weather Service and Agricultural Sector: A USDA Perspective**

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## **Abstract**

Agricultural production is highly dependent on weather, climate, and water availability. Weather variables such as precipitation, temperature, and radiation are crucial for plant growth and development. Some of the important extreme weather and climate events from an agriculture and livestock point of view are tropical storms (cyclones, hurricanes, typhoons, etc.), flooding, and storm surges; floods (other than those related to tropical storms), heavy rains during monsoon and water logging; severe thunderstorms, hailstorms, tornadoes, and squalls; drought and heat waves; cold spell, low temperature, frost, snow, and ice storms; dust storms and sand storms; weather conducive to fires (lightning); and weather encouraging pests and diseases of crops and livestock.

## **Introduction**

Air and soil temperatures are important factors for the development rate of plants. Each crop experiences an optimum temperature range for plant growth. Periods of extreme temperature values, which are well below the threshold value or well above the maximum value are hazardous to plant development and growth. Periods of extreme temperature conditions such as those experienced during extreme cold spells causing cold stress and frost, or high temperatures and heat waves leading to heat stress can affect agricultural production. Snow and ice storms in late spring or early autumn are very hazardous to many temperate crops, exposing them to layers of snow and ice and causing freezing of the crop.

Similarly, extreme moisture conditions, namely dry desiccating winds, drought episodes, and low moisture availability as well as heat spells, affect agriculture. High soil moisture in situations of water logging and flooding associated with heavy rainfall and tropical storms also adversely effects plant growth and development since it influences the rate of transpiration, leaf-area expansion and, ultimately, plant productivity. Drastic changes in rainfall distribution can have a very significant impact, particularly in climatically marginal zones such as arid, semi-arid, and sub-humid areas where the incidence of widespread drought is frequent.

There are, however, some advantages to dry spells or drought at certain stages of the development of crops such as sugar cane where a brief dry spell is essential during the pre-harvest stage. This helps to concentrate or increase the sucrose content of the cane. Additionally, there is often a lower incidence of pests and diseases in periods of drought. Grain crops need an optimal dry-down period prior to harvesting as well.

Since there is a direct relationship between weather and fire danger and weather and fire behavior, knowledge of past, present, and future weather is desirable. This should include temperature, relative humidity, wind, precipitation, and thunderstorm data. Information is also required on the state of forest litter and its ability to burn.

The ability of cattle in the open air to withstand low temperatures is fairly strong. However, it is the secondary effect of weather often accompanying a cold wave that causes widespread livestock losses. Snow covers forage and drinking water supplies freeze. As a result, cattle caught in a winter storm can starve rather than die directly from the cold temperatures. Livestock are adversely affected by high temperature together with high relative humidity. Meteorological data on these aspects are very useful in forecasting extreme episodes and minimizing losses.

All of these relationships illustrate the importance of weather and climate information for agriculture, forestry, and livestock. Accurate information on meteorological events is extremely important to farmers in maximizing their production, modifying the crop environment, protection from frost and strong winds, and also irrigation scheduling. The extension of cultivation into less suitable climates increases the potential risk of damage due to the increased likelihood of meteorological extremes. The successful development of a country's agricultural economy is, therefore, dependent on the use of climatic information. This dependence grows with both agricultural and technological expansion. Meteorological data are essential not only for operational applications to sustain agricultural development at the local level but also for research studies to foster new long-term agricultural strategies.

What is clearly demonstrated by the discussion is the strong influence of meteorological factors on every facet of agriculture. Farmers understand this importance; namely, the success or failure of their livelihood often depends on daily and growing-season weather events. Agricultural extension personnel are trained to assist farmers and agriculturalist with new innovative technologies to cope with nature's vagaries and to sustain agricultural development. Scientists and researchers are diligently gaining better insight and knowledge into the operational understanding and interrelationships needed to improve models and applications of science and technology. Decision makers at all levels, from local community officials to national government policy-makers, are utilizing information technology more efficiently to collaborate and develop local, regional, and national policy.

A major hurdle must be overcome for many of these interrelationships to be achieved. Agricultural meteorology bridges two disciplines of science; i.e., meteorology and agriculture. While meteorology is very important to agricultural applications, the field of atmospheric science is sufficiently broad to cover other important economic sectors such as the transportation industry and commerce. Very often, meteorological services are located in transportation or commerce agencies of the Federal Government. It becomes an essential task to establish a channel of communication agencies involved in national weather services and agencies involved with the agricultural sector of society to ensure that necessary data, information, technology, and policy flow to all appropriate users. The remainder of this paper reviews ways of establishing and improving linkages between national weather services and the agricultural sector.

### **Agricultural Weather and Climate Services - A USDA Perspective**

The climate and weather services requirements of individual United States Department of Agriculture (USDA) agencies reflect the varied and diverse missions and programs that currently exist throughout the Department. Internet access to both real-time and historical climate data, along with software tools to support critical economic and natural resource decisions have now become essential to the Department's mission. This paper, however,

provides a historical perspective of the role of climate in agriculture leading up to the present status. It outlines these critical mission areas and their dependence on climate information to support climate-based decisions dealing with production agriculture, water supply availability, drought assessment, and other natural resource conservation activities.

### **A Brief History of Climate and Agriculture: 1890 - 1940**

The National Weather Service was created as a branch of the Signal Service, later the Signal Corps of the Army, by a Joint Congressional Resolution approved February 9, 1870. It provided "for taking meteorological observations at the military stations in the interior of the continent and at other points in the States and Territories of the United States, and for giving notice on the northern lakes and at the seacoast, by magnetic telegraph and marine signals, of the approach and force of storms." (NOAA, 2003.)

"While the Weather Service was originally designed for the benefit of navigation on the seacoast and the Great Lakes, it was soon extended to include the interior districts and the great rivers of the central valley. The benefits of a National Weather Service were soon recognized and business industries, the general public, and farmers demanded special forecasts and warnings applicable to their needs. These demands soon became so voluminous that the urgent need of a new organization, devoid of militarism, and with a more scientific status, became apparent. Accordingly, when this need was brought to the attention of Congress, an Act, approved October 1, 1890, transferred the weather service of the Signal Corps to the Department of Agriculture effective July 1, 1891." (NOAA, 2003.)

The Act of October 1, 1890, charged the Chief of the newly created civilian agency with the following duties: The Chief of the Weather Bureau, under the direction of the Secretary of Agriculture (Commerce), shall have charge of the forecasting of weather, the issuing of storm warnings, the displaying of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers, the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation, the reporting of temperature and rainfall conditions for the cotton interests, the displaying of frost and cold-wave signals, the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties (15 U.S.C. 313).

The Weather Bureau was transferred from the Department of Agriculture, where it had been a constituent bureau since July 1, 1891, (Act of October 1, 1890, 26 Stat. 653) to the Department of Commerce (DOC) on June 30, 1940, under authority of Reorganization Plan No. IV of the President, which was submitted to the Congress on April 11, 1940. In his message submitting Reorganization Plan No. IV, with reference to the Weather Bureau, the President said: "The importance of the Weather Bureau's functions to the Nation's commerce has also led to the decision to transfer this Bureau to the Department of Commerce. The development of the aviation industry has imposed upon the Weather Bureau a major responsibility in the field of air transportation. The transfer to the Department of Commerce, as provided in this plan, will permit better coordination of Government activities relating to aviation and to commerce generally, without in any way lessening the Bureau's contribution to agriculture." (NOAA, 2003.)

## **USDA Weather and Climatic Research**

During USDA's 49-year stewardship of climate and weather services, a significant number of research activities were focused on the relationship between climate and agriculture with the establishment of the Climatic and Physiographic Division in 1935. Scientific research was aimed at discovering the interaction of climate and erosion, the stages of natural and culturally induced erosion, and the characteristics of erosional landforms. Climatic studies, employing existing Weather Bureau records as well as original field observations, were concerned with drought and wind erosion, the long-term aspects of rainfall, and the short-term problems of rainfall intensity and storm patterns (NARA, 2003).

The 1938 seminal publication by C.W. Thornthwaite, USDA Soil Conservation Service, summarized the role of climate factors in water and wind erosion, intensity and duration of rainfall for reservoir design, frequency of rainless periods for determining drought and consequent erosion hazard, rainstorm morphology, spacing of rain gauges, determination of the maximum storm, field moisture deficiency as a climate factor, and studies of evaporation (Thornthwaite, 1938).

This research culminated in the publication of the *Atlas of Climatic Types in the United States 1900-1939* (Thornthwaite, 1941). The atlas categorized climate by moisture regimes (i.e., super-humid, humid, sub-humid, semiarid, and arid), provided definitions of effective precipitation, the use of vegetation as a climatic indicator, and discussed climatic variation. The atlas also contained annual crop season climate type maps for the period 1900-1939. Normal crop season maps were also published. Climate mapping has seen a renaissance with USDA co-sponsored efforts performed in partnership with Oregon State University (Daly, 2002).

## **DOC and USDA Weather, Climate, and Agriculture Activities: 1941 - 1979**

With the outbreak of World War II, the Weather Bureau had very little statistical data describing foreign climates in a useable form at the outbreak of war. Significant efforts were placed in summarizing climate for armed forces aviation, gathering upper air information, standardizing climate summary punch card formats, determining degree-day climatologies, and the standardization of procedures to process and publish climate summaries.

As a result of security plans formulated previously by the Defense Meteorological Committee, the Weather Bureau, in December 1941, was enabled to continue forecast and warning service to the public and comply with security requirements. Most of the weather service provided to public individuals was in the form of operational advisories. For example, orchardists desiring to spray fruit trees were informed as follows: "Spraying conditions satisfactory next three days" (NOAA, 2003).

In 1971 the Department of Commerce published a "Federal Plan for a National Agricultural Weather Service" (NOAA, 1971). This plan summarized user requirements and potential service value, the National Oceanic & Atmospheric Administration (NOAA) Agricultural Weather Service Program, and NOAA's Plan for an Improved Agricultural Weather Program. Implementing an Agricultural Weather Service relied on cooperation between the National Weather Service, Environmental Data Service, State Universities, State Climatologists, and the Department of Agriculture. The plan was never implemented for a variety of reasons.

In August of 1979, the General Accounting Office published a report titled "Agricultural Weather Information is Not Effectively Communicated to Users" (GAO, 1979). The purpose of the report was to survey the agricultural community in order to clarify the Department of Commerce (DOC) and USDA respective roles, responsibilities, and goals, in order to establish an effectively coordinated Agricultural Weather Service Program. The GAO report stated that, "Congress has never specifically mandated the extent to which NWS should provide specialized weather services for users, such as agricultural weather information, and recommended that Congress clearly define NWS's role and responsibilities for providing such services." The report concluded, "Agricultural weather information is not being communicated to users and potential users. The need for certain improvements in the program has been noted by the Departments of Agriculture and Commerce. As a result, the Departments have reached some agreements to improve cooperation; however, much more remains to be done."

The 1979 report recommended that the "DOC, in cooperation with the Secretary of Agriculture, clarify and strengthen the roles of your Departments in the Agricultural Weather Service Program. This should include: 1) improving the methods for publicizing and communicating weather information to users and potential users, and 2) providing program coordination by updating the "Federal Plan for a National Agricultural Weather Service."

### **The Joint Agricultural Weather Facility**

In response to the GAO report, an Interagency Agreement between the DOC and USDA established the Joint Agricultural Weather Facility (JAWF), which has been in existence for 25 years. The JAWF was created as a world agricultural weather information center located in USDA and is jointly staffed and operated by DOC/NOAA/NWS/Climate Prediction Center (CPC) and USDA/OCE/World Agricultural Outlook Board (WAOB). The JAWF is located in Washington, D.C., and serves as USDA's overall focal point for weather/climate information and agricultural impact assessments.

JAWF consists of a team of NWS operational meteorologists and WAOB agricultural meteorologists that monitors global weather conditions and prepares real-time agricultural assessments (Puterbaugh, et al., 1997; Motha and Heddinghaus, 1986). These assessments keep USDA commodity analysts, the Chief Economist, and the Secretary of Agriculture and top staff well informed of worldwide weather-related developments and their effects on crops and livestock. When integrated with economic analyses and information, these routine and special crop-weather assessments provide critical information to decision makers formulating crop production forecasts and trade policy. JAWF's primary mission is to monitor global weather and determine the potential impacts on agriculture. JAWF meteorologists rely heavily on weather and climate data from over 15,000 stations from international and U.S. sources. Consequently, one of JAWF's most critical tasks is to process large volumes of data in an efficient and timely manner, and to generate products and agricultural assessments that are meaningful to the user community (JAWF, 1994).

For over two decades, JAWF has developed techniques for the acquisition, processing, and archival of these data, creating a blend of "existing" and "newly-developed" methods and products used in agrometeorological data management and analysis. A database management system (DBMS) effectively handles large volumes of available information and allows full integration of data into other Windows-based packages (Puterbaugh, et al., 1997). Products currently utilize Geographical Information System (GIS) techniques at JAWF, providing the

agricultural meteorologists with additional tools to produce crop-weather assessments and enhancing analytical techniques. JAWF's assessments are the final product of a series of steps that include: 1) meteorological data acquisition and management, 2) data processing, 3) data analysis, and 4) product and information dissemination.

### **DOC and USDA Agricultural Weather and Climate Activities in the 1990s**

Agricultural weather activities and user needs took on greater importance and urgency with the termination of the NWS Agricultural Weather Program on April 1, 1996. An NWS letter to Agricultural Weather Services Customers (NOAA, 1996) stated that, "the NWS will make every effort to maintain agricultural weather observation networks in the months ahead. The inventory of NWS weather observing equipment will be examined closely to determine what data sources will remain available for use by private meteorologists. The NWS will continue observations and records pertaining to recording and predicting the nation's climate and for other programs such as public forecasts and warnings. The basic data critical to making agricultural forecasts is still available to all users such as freeze and frost warnings."

A paper presented to the American Meteorological Society 10th Conference on Applied Climatology (Motha et al., 1997) provided a comprehensive definition of climate services for agriculture. Accurate and timely weather and climate information is needed for operations risk assessment and research. Examples include agricultural yield and productivity, natural resource conservation, forest fire potential, insurance and compliance programs, crop disaster assistance and emergency relief programs, integrated pest management, and crop yield modeling. The role of data collection and product generation in USDA for agricultural weather and climate monitoring and impacts assessment was addressed. The important roles of national, regional, and state climate offices in providing climate services were also highlighted. This is essential because not all data flow into the NWS offices but are available at local, state, or regional offices for unique or specific applications. The cooperative network, for example, represents the entire suite of local station networks operated by federal, regional, and state agencies. Moreover, access to the full suite of historical meteorological data for analog comparisons may also necessitate coordination with various agencies and data sources.

In 1998, the DOC requested the USDA to prepare a report of requirements for weather and climate data, services, and information. An interagency USDA committee produced a report titled "Operational Meteorological Data Requirements (USDA, 1999). Nine USDA agencies contributed to the report; the World Agricultural Outlook Board and Joint Agricultural Weather Facility, Farm and Foreign Agricultural Services, Farm Service Agency, Risk Management Agency, Forest Service, Natural Resources Conservation Service, Agricultural Research Service, Cooperative State Research, Education, and Extension Service, and National Agricultural Statistics Service.

While the requirements of USDA are numerous, they can be categorized into four basic areas that are covered by weather service operations as follows:

- *Current Measurement and Observational Data and Services* - These services consist of the operation of acquisition programs, observing systems, data collection and quality control, and networks to provide the data essential to defining the state of the atmosphere and its impacts on man and his activities. They are largely concerned with assembling

- weather observations into useable databases and providing them for use in analyses and applications;
- *Climate Services* - These services provide for the acquisition, storage, management, and summarization of historical weather data. They also include the analyses of climatological data to characterize climate conditions or regimes for different geographical areas or time periods. Climate services also include the development of normals, freeze probabilities, and drought indices;
- *Forecasting Services* - Prediction of future weather events or climatic conditions and their associated probabilities;
- *Other Services* - Consultation, analyses of particular weather events, interpretation of forecast materials, monitoring and summarizing recent weather events, weather briefings and summaries, special studies and analyses, and user education.

Converting voluminous weather data into crop-specific agronomic information that can be easily understood by its non-meteorological community is one of the largest challenges faced by USDA. The worldwide scope of production agriculture and exchange of agriculture products has driven the need for a wide variety of weather and climate data. Fifteen general data requirements are described in Table 1 that describes the type of data required, desired reporting frequency, and the significance to agriculture.

<b>National &amp; International Agricultural Production General Data Requirements</b>		
<u>Data Type</u>	<u>Time Period</u>	<u>Agricultural Significance</u>
National and International Surface Observations	Hourly and/ or 3-hourly	Required to monitor current conditions affecting agriculture and in planning agricultural activities
Local and Regional Automated Weather Data Networks	15-minute intervals, hourly	Required for accurate assessments of rainfall rates that affect erosion and runoff processes. Precision agriculture needs high resolution spatial and temporal data for irrigation, research and regulatory issues, livestock operations, and crop management
Cooperative Network Surface Observations (station level)	Daily	Required for daily monitoring of agrometeorological conditions that affect agricultural operations and production. Many of these sites are located in agriculturally important areas
Global Daily Summary Data (station level)	Daily	Required for daily monitoring of global weather conditions that affect agriculture
Global Weekly Summary Data	Weekly	Required for determining the cumulative effects of weather on agriculture during the growing season
Global Monthly Summary Data	Monthly	Required for determining the cumulative effects of weather on agriculture on a monthly scale
CLIMAT Data for the World	Monthly	Required for quality control of Global Monthly Summary Data
Global Normals	Daily, Weekly, Monthly	Required to determine anomalous weather conditions that may affect agriculture
Freeze Dates	Spring and Fall	Required for Weather Risk Assessment and Crop Vulnerability
Historical Data	Daily, Weekly, Monthly	Required for analog growing season comparisons
Global Satellite Data (cloud imagery)	Variable Hourly to Daily	Required to document significant weather features and likely coverage within a crop area and in quality control of surface data
Sea Surface Temperature Data	Weekly and Monthly	Required for monitoring El Niño-La Niña conditions
Radar Data	Variable	Required to augment precipitation data in areas of limited data coverage
Upper Air Data (all mandatory pressure levels)	Variable	Required to monitor weather patterns on a synoptic scale that are affecting agriculture
Forecasts and Outlooks (local, regional, national, and international)	Hourly, 1-3 days 3-5 days, 6-10 days, Monthly, Seasonal, El-Niño, La-Niña	Required for plant disease forecasting, agricultural research and extension service models, resource allocation, policy-level briefings and decision making, drought and flood monitoring, daily weather write-ups, and weekly briefings to the Secretary and top staff

Table 1. National and international agricultural production general data requirements.

Weather plays a vital role in all phases of agricultural production. In addition to general weather requirements for agricultural production, each type of agricultural activity has a unique set of weather variables that affect it. Twenty-two specific weather data elements are given in Table 2. Individual agricultural activities are described for each weather element.

<b>Specific Weather Data Requirements for Agricultural Activities</b>		
<u>Data Type</u>	<u>Time Period</u>	<u>Agricultural Activities</u>
Temperature (global)	Hourly and accumulated means and extremes	Planting, harvesting, crop-weather monitoring, freeze detection/protection, defoliation, crop modeling, disease risk, lambing and calving shelter, pest control, sheep shearing, PET computations, vapor pressure deficit computations, chill hours for stone fruit, growing degree day computations
Maximum Temperature (global)	Daily and Weekly Extremes	Required to determine optimum or unfavorable conditions for crops and livestock, crop modeling, extreme events monitoring, snow cover estimations, growing degree day computations
Minimum Temperature (global)	Daily and Weekly Extremes	Required to determine optimum or unfavorable conditions for crops or livestock, freeze detection, defoliation, crop modeling, overwintering conditions, and extreme events monitoring, snow cover estimations, growing degree day computations
Precipitation (global)	Daily	Planting, harvesting, fertilizer applications, cultivation, spraying, irrigation, crop-weather monitoring, crop modeling, disease risk, livestock and poultry protection and watering, extreme events (drought or flood) monitoring, snow cover estimations
Rainfall Intensity	15-minute, Hourly	Flood potential, erosion, runoff, water quality
Dew Point and Humidity (global)	Hourly	Harvesting, determine freeze potential, pollination, spraying, drying conditions, vapor pressure deficit computations, crop stress potential, PET computations
Hail	Hourly	Crop damage, risk assessment, productivity impact
Temperature Inversions	Hourly	Aerial spraying for agriculture, frost protection measures
Atmospheric Pressure (global)	Hourly	General crop-weather monitoring, type of freeze (radiation, advection etc.)
Sky Cover (global)	Hourly	Fertilizer application, spraying or dusting, PET computations
Cloud Height (global)	Hourly	Fertilizer application, spraying or dusting,
Present Weather (global)	Hourly	Snow Cover estimations, fieldwork, crop stress potential
Wind Speed (global)	Hourly	Planting, defoliation, harvesting, freeze potential/protection, lambing and calving shelter, pest control, pruning, PET computations, spraying or dusting, pollination, blizzard conditions
Wind Direction (global)	Hourly	Freeze potential/ protection, cold or warm air advection over crop areas
Vapor Pressure Deficit (global)	Hourly	Derived from temperature and dew point
Solar Radiation, Duration of Sunshine, or Amount of Cloud Cover (global)	Daily	PET computations, crop modeling, planting, harvesting
Snow Depth (global)	Daily	Monitor overwintering conditions for winter wheat, prepare water supply forecasts for water users in the western U.S., estimate soil moisture reserves for the next growing season
Soil Moisture (global)	Daily	Planting, harvesting, fertilizing, crop modeling, transplants, spraying, irrigation, monitoring of growing conditions, stress indices
Blizzards, Hurricanes, Tropical Storms	Daily	Crop monitoring, risk and productivity damage assessments, resource conservation
Storm Tracks/Storm Strengths	Daily	Agricultural impacts, risk management, flood potential, drought monitoring
Soil Temperature (global)	Daily	Planting, overwintering conditions, crop modeling, transplants, fertilizing
Pan Evaporation (global)	Daily	Irrigation scheduling, water budget computations, PET comparisons, crop-water usage

Table 2. Specific weather data requirements for agricultural activities.

For decision making, USDA needs current weather information for research and to assist growers with their management operations. This includes strategic decisions (what to plant), or tactical decisions (when to irrigate). As a result, USDA agencies that assist farmers in their decision-making require a more detailed set of weather requirements. The weather data requirements for 14 specific agricultural activities, ranging from soil preparation to freeze protection, are published in the USDA report. Near real-time access to these weather data through the Internet is highly desirable and preferred.

Historical and current weather data are also used by insurance services and compliance programs as an additional information resource in determining if losses are reasonable and if producers and reinsured companies are in compliance with the insurance contracts. USDA also had a leading role in the National Drought Policy Commission (NDPC) and is working on drought policy issues, which require monitoring of drought conditions and forecasting (NDPC, 2000).

## **Weekly Weather and Crop Bulletin**

The *Weekly Weather and Crop Bulletin* (WWCB) is deeply rooted in the past. The *WWCB* originated in 1872, two years after the U.S. Congress passed a resolution that was signed by President Ulysses S. Grant on February 9, 1870, to establish a new service in the War Department for taking meteorological observations. The Secretary of War promptly assigned the new service to the Chief Signal Officer of the Army, General Albert J. Meyer, who named it “the Division of Telegrams and Reports for the Benefit of Commerce.” In 1872, the Division began publishing the *Weekly Weather Chronicle* for the benefit of commerce and agriculture. This publication was the forerunner of today’s *WWCB* and contained a 2-page printed release that contained a general summary of weather for each week ending on Wednesday.

The publication has evolved over the past 129 years into one that provides an invaluable source of information pertinent to regional, national, and international agro-business. Since 1978, the *WWCB* has been produced by JAWF and jointly operated by the DOC’s CPC, USDA’s WAOB, and the National Agricultural Statistics Service (NASS). The publication is a shining example of how two major departments within the Federal Government can mutually cooperate, combining meteorology and agriculture to provide a service that benefits the economic well being of the Nation. Data and information contained within the *WWCB* are generated by the efforts of thousands of people, including about 3,000 county extension agents, NASS crop reporters, field office personnel, State Universities, National Weather Service Forecast Offices, and more than 5,000 weather observers, mostly volunteer, working with the NWS. The *WWCB* highlights weekly meteorological and agricultural developments on a national and international scale, providing written summaries of weather and climate conditions affecting agriculture, as well as detailed maps and tables of agrometeorological information appropriate for the season.

The national portion of the *WWCB* summarizes weather and crop information supplied by thousands of people throughout the Nation, including about 3,000 county agents of USDA’s Cooperative Extension Service; a core of NASS volunteer crop reporters, sending in information to the State Statisticians of NASS; NOAA meteorologists, and more than 5,000 weather observers, mostly volunteer, working with the NWS. NASS volunteer crop reporters are persons who voluntarily report information about their farms or localities for use in NASS forecasting and estimation programs.

NASS tracks crop progress based on data collected from county extension agents and volunteer crop reporters. Each Monday during the growing season, weekly crop reports are prepared based on information gathered from these co-operators. The NASS headquarters in Washington, D.C., manages a network of 44 field offices serving the 50 states, through cooperative agreements with State departments of agriculture or universities. At the same time, NOAA meteorologists in designated weather offices in each State (or State climatologists or personnel from land-grant universities in a few States) summarize weekly weather observations received from rural observers and urban weather stations. These detailed weather and crop summaries are released to the public each Monday afternoon and are transmitted to NASS in Washington for publication in the *WWCB*. These reports usually discuss crop weather conditions suitable for fieldwork and crop development, pest and disease outbreaks, soil moisture conditions, crop progress, and pasture and livestock conditions.

The *WWCB* emphasizes the cumulative influence of weather on crop growth and development. Weather conditions influence important farming operations such as planting and harvesting, and greatly influence yield at critical stages of crop development. The bulletin provides timely weather and crop information between regular monthly *Crop Production* and *World Agricultural Supply and Demand Estimates* reports.

The main users of the *WWCB* include crop and livestock producers, farm organizations, agribusinesses, State and national farm policy-makers, foreign buyers of agricultural products, and Government agencies. Agricultural statistics are used to plan and administer other related Federal and State programs in such areas as consumer protection, conservation, foreign trade, education, and recreation.

### **U.S. Drought Monitor**

The NDPC found that about 22 Federal programs have some responsibility for drought monitoring, prediction, and research. In relation to monitoring and prediction, these programs focus on weather patterns, climate, soil conditions, and streamflow measurements. Examples of three major networks are USDA's Soil Climate Analysis Network (SCAN)/Snow Telemetry Network (SNOWTEL), the NOAA/NWS's Cooperative Observer Network (COOP), and the U.S. Geological Survey's streamgaging and groundwater monitoring network. Federal programs often join with universities, private institutions, and other non-Federal entities to provide additional information. This is especially crucial for agriculture as data observation networks are often sparse in rural agricultural areas. It is well recognized that comprehensive weather, water, soil moisture, mountain snow amount, and climate observations are the foundation of the monitoring and assessment activity that alerts the nation to impending drought.

The vigorous debates and discussions during the NDPC meetings helped to formulate an important new operational drought product. This product was important to develop as it became the first prototype tool to integrate the basic data on current conditions and translate these data into meaningful information to the user community. The emergence of the U.S. Drought Monitor (Svoboda, et al., 2002), established in 1999, was a major advancement in drought monitoring products. The Drought Monitor classifies drought severity into five categories. The category thresholds are determined from a number of indicators, or tools, blended with subjective interpretation. The United States Drought Monitor was developed as

an operational tool for monitoring drought conditions, including aerial extent, severity, and type, around the country. The Drought Monitor has become a highly successful tool for assessing the development and duration of drought conditions. The USDA, DOC, and the National Drought Mitigation Center publish the drought map and text weekly and post them on the Internet (<http://drought.unl.edu/dm>). The product serves as an exemplary case of interagency cooperation. A major strength of the Drought Monitor is its inclusion of input from climate and water experts from around the country.

The Monitor requires a major collaborative effort to pull together the various sources of weather data and compile them in a single, comprehensive, operational, national report. The map not only delineates stages of drought but also specifies drought type when the impacts differ. For example, if severe drought affects wildfire danger and water supplies, but is not in a significant agriculture area, then the map would depict W (water) and F (wildfire danger) only. If drought affected a major crop area, that area would be denoted with "A" for agriculture. The map also reflects forecast trends. If the forecast of drought is expected to intensify, a "+" is depicted in affected area. Similarly, if the forecast calls for rain to diminish drought conditions, a "-" is depicted in the affected area. No change in the drought classification forecast is depicted by no sign. The text of the Monitor provides a detailed discussion of the map.

The Drought Monitor itself is not an index, nor is it based on a single index, but rather is a composite product developed from a rich information stream, including climate indices, numerical models, and the input of regional and local experts around the country. No single definition of drought works in all circumstances (Wilhite, 2000). Water planners and agricultural producers may rely on completely different sets of indicators. The Drought Monitor authors must rely on a number of key and ancillary indicators from different agencies. The map fuses these indicators, using human expertise from across the United States, into an easy-to-read image presenting a current status of drought conditions. The Drought Monitor process is an evolving one as new, or better, indicators and information sources become available.

Lead responsibility for preparing the Drought Monitor rotates among nine authors from four agencies who sequentially take 2 to 3 week shifts as the product's lead author. Nationwide experts respond to the lead author's first draft when it arrives by Internet and through an e-mail list-server every Monday. An interactive process continues until the final product, both the map and text, are released on Thursday morning.

Classification of drought magnitude in the Drought Monitor is based on farm levels using a percentile approach. The percentiles are standardized for the year rather than for all times of the year at once. They are not meant to imply an average areal extent value for the United States at any given time. The categories include: D0 (abnormally dry), 21 to 30 percent chance occurring in any given year at a given location; D1 (moderate drought), 11 to 20 percent chance; D2 (severe drought) 6 to 10 percent chance; D3 (extreme drought), 3 to 5 percent chance; and D4 (exceptional drought), 2 percent or less chance.

The Drought Monitor's severity categories are based on six key physical indicators and many supplementary indicators. The indicators are the Palmer Drought Severity Index (PDSI; Palmer 1965); CPC Soil Moisture Model Percentiles (CPC/SM); Huang, et al., 1996); U.S. Geological Survey (USGS) Daily Streamflow Percentiles (<http://water.usgs.gov/waterwatch/>); Percent of Normal Precipitation (Willeke, et al. 1994);

Standardized Precipitation Index (SPI; McKee, et al., 1993); and remotely sensed Satellite Vegetation Health Index (VT; Kogan, 1995).

Ancillary indicators include the Palmer Crop Moisture Index; the Keetch-Byram Drought Index (KBDI; Keetch and Byram, 1968); evaporation-related observations, reservoir and lake levels, and ground water levels; USDA field observations of surface soil moisture; and USDA snow pack and snow water equivalent measurements.

Classification of drought impact types is also included in the Drought Monitor. The categories include agriculture (crops, livestock, range, and pastures), water (streamflow, snow pack, groundwater, reservoirs), and fire (wildfire - forest and range fires). Crop stress is often the earliest indicator of a developing drought situation because of the plants need for moisture and moderate temperatures during critical phases of development. On the other hand, hydrological impacts of a major drought often linger for months or even years after agricultural concerns disappear. Thus, it is essential to monitor the evolution of drought types as well as overall conditions.

Finally, as mentioned earlier, a significant key to the outstanding success of the Drought Monitor is the process of gleaning information from many experts located across the country. Their input and verification of impacts at the regional and local levels are critical in both the production of the Drought Monitor and in establishing and maintaining the credibility of the product. These experts include regional and state climatologists, agricultural, and water resource managers, hydrologists, NWS field office employees, and others. The list of expert reviewers has grown to nearly 150. A Drought Monitor Workshop is held annually to allow all participants to meet and share ideas for improvement in the process and the product. The Drought Monitor is a dynamic product that is the focus of constant searching for timely and better indicators to assist the user community. This user community ranges from a farmer to a government policymaker.

### **Operations of the Joint USDA/OCE/WAOB and MSU/DREC Agricultural Weather and Data Center**

An example of how this national cooperative effort is applied to research and extension activities at the state level is illustrated by the JAWF-DREC operation. The Mississippi State University (MSU) Delta Research and Extension Center (DREC), located in Stoneville, Mississippi, is situated on one of the largest agricultural experiment stations in the world. The crop research area covers about 1,650 acres, including approximately 200 acres of federally owned land. Field plots occupy about 1,200 acres, with soil types ranging from very fine sandy loams to heavy clays. Over fifteen governments, states, and private organizations are involved in agricultural research and production in the 18 countywide areas of the state called the Delta.

In May 1996, a Weather/GIS Data Center was established at MSU/DREC in order to meet the local demands for adequate coverage of agricultural weather information required in research and production agriculture. The main mission of the Data Center was to ensure the collection and archival of vital agricultural weather data in the Mississippi Delta. A partnership between the WAOB and DREC was established in October 1998, with the WAOB field office co-located with the DREC-Weather/GIS Data Center. The purpose of the joint Data Center is to collect, quality control, manage and disseminate agricultural weather data, and serve the local needs for agricultural weather information and services in the Delta. As a

result, WAOB partnerships with other institutions engaged in agricultural weather activities and climate services have grown to include USDA's National Resource Conservation Service (NRCS); the states of Missouri, Alabama, and Iowa; and the Regional Climate Centers (RCCs). At the same time, WAOB continues to work closely with the NWS to support the modernization of the crucial COOP Network, to ensure continuity in the national surface observation network.

- *Products and Services:* The joint DREC-WAOB Agricultural Weather Data Center provides weather and climate data, geographic queries, crop progress information, products developed using GIS, and weekly weather briefings to researchers, producers, county extension agents, and agricultural industries in the Delta. The primary mechanism used to disseminate the Delta weather data is through the DREC – Weather/GIS website, while the WAOB field office website is used to disseminate the table of regional “Weather Data for Mississippi and the Missouri Bootheel.” To date, over 350,000 users have visited the DREC website to access Delta weather data and products. The Data Center also handles numerous requests for information related to climate services, including temperature and precipitation data, wind data, average first and last frost or freeze dates, solar radiation, and pan evaporation data. Contributions to the monthly MSU-Extension Service (ES) agriculture newsletter also helps distribute data and information to users.

The DREC - Weather/GIS Data Center also produces several agro-meteorological products that are derived from weather data and prior research on crop phenology. Crop growth simulation models are available for rice and cotton. A Rice DD50 model is a program that interactively “grows” a rice crop based on accumulated heat units (derived from temperature data) that are related to the crop’s phenological development (Ramirez and Bauer, 1974). From the website, growers can choose their individual counties and varieties of rice to obtain information on stages of crop development as well as crop management recommendations. For future dates, the program uses 30-year historical norms to finish growing out the crop until a predicted harvest date. This helps farmers anticipate growth stages for planning future management decisions in order to increase revenues and/or decrease losses. Researchers and Extension personnel also use this program to complete comparative variety studies and aid in diagnosing problems in clients’ fields.

Research experiments from 1993 through 1996 resulted in a new MSU-ES recommendation being introduced into the cotton production industry in the Mississippi Delta. This MSU-ES recommendation, called the “Node Above White Flower Five Rule,” calls for the collection of DD60 heat unit data after a cotton plant reaches a certain growth stage. This recommendation requires vigilant monitoring of the cotton plants when nearing maturity by researchers and producers to identify that date at which a flower blooms on the fifth node (branch) from the top of the plant (terminal). From that date, the cotton boll that is made from that flower needs 350-Degree Day heat units based on 60 degrees Fahrenheit (DD60) to become large enough to be safe from certain insect damages. At the point in which a certain amount of heat units are accumulated, certain crop damaging pests are no longer a threat and thus no longer in need of being controlled. As a result, applications of pesticides for certain pests can be terminated (Harris, et al., 1997), thus saving the producer as well as the environment an average of two insecticide applications. Since the benefits from this recommendation require a researcher or producer to keep a vigilant watch of each field and variety, the recommendation suggests obtaining data from a nearby weather station or extension office (Cochran, et al., 1998) to aid in the determination of cotton development.

Planting recommendation reports are also available on the DREC - Weather/GIS Data Center's web page. The MSU-ES recommends time windows for planting crops. Some of their recommendations are based on weather scenarios. Planting recommendations for corn and soybeans are based on 30-year normals, and are used for the timing "trigger" as when to plant. MSU-ES's current recommendation is plant as early as a farmer wants depending on the amount of risk the farmer is willing to accept for the chance of frost or freeze each crop can withstand. Probability maps are produced ranging from 10 percent, 50 percent, and 90 percent chance of occurrence.

The cotton planting recommendation is based on soil temperature. When soil temperatures reach a certain level in the spring, producers are advised to plant cotton when there is an accumulation of fifty DD60s in the next 5 days. These calculations of future heat units are needed to ensure that soil temperatures will remain at favorable levels for seed germination. To calculate these future heat units, forecasted model output of temperature data from the National Weather Service's medium range forecast model is used for locations in Mississippi as well as surrounding states. The 5-day forecasted maximum and minimum temperatures from the model are downloaded and placed into a database. The DD60 data are calculated from the forecast temperature and stored in the database. Using Geographical Information System (GIS) software, contour maps of the DD60 data are then generated on a map of the state of Mississippi. The data are separated into three gradations, "favorable," "marginal," and "unfavorable," to plant cotton for that day. The map is re-drawn nightly and the gradations move from south to north as the temperatures increase in the spring until state-wide soil temperatures reach favorable levels for cotton planting.

### **The Essence of Agricultural Weather and Climate Services for the 21<sup>st</sup> Century**

Although many essential elements of an effective agricultural weather and climate services system exist, portions are poorly funded and others suffer from a lack of coordination. Management tools, such as GIS, powerful desktop computers, and the Internet, give us an opportunity to improve our efforts in the future. Four areas where these management tools will likely enhance agrometeorological services in the future include:

- A temporally and spatially diverse climate database that supports a wide variety of user-oriented analysis tools;
- A national, interactive climate information system that delivers a family of user-selectable products to meet customer needs via the Internet;
- A climate applications research program that provides national leadership to address climate-relevant natural resource and economic needs; and,
- An education program that provides training, educational materials, and workshops to improve the use of climatic information in all sectors of the user community.

Achieving these goals requires leadership and coordination among agricultural weather and climate service providers at the national, regional, and state levels and with the user community at all levels. From the NWS, adequate funding is essential for the maintenance of a modernized observational network that includes data needed for agricultural analysis. Further, cooperating agencies must provide recognition and support for the urgency of NWS to improve both short-term forecasts and long-range outlooks. While the accuracy of these forecasts has improved in recent years, natural disaster reduction and mitigation of extreme events in agriculture will be enhanced by further improvements.

Agricultural agencies are tasked with helping the people protect soil, water, and wildlife as well as sustain agricultural growth and development. As advances in information and biological technologies move forward, fundamental changes will likely occur through the agricultural sector in the 21<sup>st</sup> Century. The demand for weather and climate information will likely continue to expand for a wide spectrum of agricultural applications. In government, the information will be used for crop, forest, pasture and livestock conditions, irrigation reserves, crop-yield potential, and marketing outlooks. In research, the information will be used to develop model simulations (yield, physiology, pest, and irrigation management), weather-based generators, and scenario analyses in operational applications. In farming and agribusiness, the information will be used for advisories, daily farm management decisions, and long-term agricultural planning. Finally, more coordinated and integrated national policy on natural disaster reduction and mitigation of extreme events on agriculture will necessitate linkage of operational services with communities affected by these events.

In order to satisfy the user community, fundamental data observations of sufficient quality and quantity, accurate forecasts relating to episodic events affecting agriculture, and accurate long-range outlook to offer guidance for scenario analyses will be essential components of a data base system. However, it is important to recognize that many agricultural areas face limitations, not only with the type of data available but also more fundamental issues. These include: insufficient density of basic data observations in many agricultural areas; the lack of timely access to comprehensive data bases; the availability of data in no-standard formats; and, the lack of a unified climate data base with appropriate software to create products necessary for agricultural applications. These problems must be overcome before significant advancement can be made.

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# **Institutionalizing Climate Information Applications: Indonesian Case**

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## **Abstract**

At present, the use of climate (forecast) information is minimal. At Indramayu, a district vulnerable to El Niño/Southern Oscillation (ENSO) events, farmers are always suffering from drought and flood whenever El Niño and La Niña occur. Some of the reasons are that end-users (farmers) have difficulty in understanding climate forecast information that contains probability, and there is no effective dissemination system of climate forecast information to end-users. Farmers are also not aware of the economic value of climate forecast information. As a consequence, the level of farmers' adoption to climate forecast information is minimal and they have no capacity to tailor their cropping strategy to climate forecasts. To increase farmers' adoption to climate forecast information, their knowledge of climate and its application should be improved. A process called Climate Field School (CFS) is introduced to increase farmers' knowledge on climate information application. The basic concept of CFS is to disseminate climate information applications to end users by translating the information from scientific language into field language and then translating field language into farmers' language through field school. Based on the result of the evaluation, it was indicated that the CFS might be an effective way to educate farmers (end-users) on climate information application. The main challenge in the implementation of CFS is the development of modules. This paper discusses briefly the concept of CFS and its implementation at Indramayu.

## **Introduction**

Climate information systems must ensure that tailored climate information to users' needs should get into the hands of the users in a timely fashion in order to have some influence on practical decisions. There would not be much benefit for society if the results of climate applications research remain in the academic or research area. Considerable efforts are required to develop the appropriate means for the effective dissemination of the climate information to users.

Asian Disaster Preparedness Centre (ADPC) has a long experience in southern and southeastern Asia regions to institutionalize climate information application for many sectors, specifically in the agriculture sector. Observation in many countries showed that the agriculture sector has been found to be the most vulnerable sector to extreme climate events. The significant reduction in crop production was always observed whenever extreme climate events occurred. Some of the important reasons that caused this condition are: 1) end-users have difficulty understanding climate forecast information that contains probability; 2) there is no effective dissemination system of the climate information to the users; 3) there is a low capacity of users in translating climate forecast information for practical use; and, 4) the end-users (farmers) are not aware of the economic value of climate forecast information (Boer

and Setyadipratikto, 2003). In many cases, the end users will seek the information and use it when it will provide benefits.

Considering the above conditions, the production of seasonal climate forecasts should not be considered as the end results of a climate forecast system. It is only one of the early links in a long chain of tailored climate information and forecast products that should be fed into a Climate Information System (Ropelewski and Lyon, 2003). Thus, the results of the climate forecasts and other climate information should be delivered to intermediate- and end-users through a number of appropriate means and various institutional channels.

The appropriate means for disseminating climate information to users may include sophisticated technologies such as Internet or direct satellite links, and some other ways that are not required or less dependent on advanced technologies such as radio, newsletter, education materials, and local civic meetings. This paper provides a brief report of the ADPC project in Indonesia on the development of the institutional system for disseminating climate information to end-users, specifically farmers.

### **Site for Implementation of the ADPC Project**

The selection of sites for the implementation of the project is one of the important steps that may determine the success of the project. In the ADPC project, the selection of project sites was based on: 1) the level of vulnerability of the site to the extreme climate events; 2) status of incorporating climate variability concerns in agriculture planning (e.g., crop-planning cycle) and support from local government; 3) demand and acceptability of probabilistic forecast at farmer's level; 4) potential applicability of pilot project to other location; and, 5) availability of historical database and institutional arrangements at the district level to implement the project. Considering these factors, Indramayu, a district in West Java Province, has been selected for the ADPC project.

Indramayu is one of the districts in West Java Province that is very vulnerable to extreme climate events associated with ENSO. Observations from 1991-1997 showed that this district was always suffering from drought whenever El Niño occurred. The impact on the community's income was very significant. The proportion of the population under the poverty line increased significantly during El Niño years (Figure 1). Rainfall station networks are also quite good. However, the transfer of the recorded data to data analysis centers is not smooth. In addition, the local government has provided greater attention to the climate hazards even though the efforts are more responsive than preventive.

The institutional process for disseminating climate forecast information at Indramayu district follows the process presented in Figure 2. Information such as extreme climate forecast or new technology issued by related agencies is passed to the head of the districts (Bupati) or head of the district offices (Kepala Dinas) either in the coordination meeting held at the Province or directly from the source agencies such as the Bureau of Meteorology and Geophysics (BMG). In the case of extreme climate events, the Bupati issues instructions to the head of the District Agriculture Office. The head of the District Agriculture Office coordinates with other district offices to implement the instructions. The agriculture office issues an operational guidance (e.g., steps or actions that should be taken in the field) to anticipate the events. This guidance is passed to the head of the sub-districts or coordinator of the extension workers and they pass it to the heads of the village or farmer groups. In some cases, the head of the agriculture office can directly contact the head of the village for

implementing the Bupati instructions if human resources at sub-districts level are limited. The extension workers can conduct activities for farmers and farm leaders. For locations where the water becomes very limited during the El Niño events, the District Government (Pemda) through the Agriculture Office provides the farmers with a soil water pumping facility and renovates the irrigation canals.

Because most of the criteria defined above were already met in Indramayu, the district could be representative of the climate anomaly in almost the entire island of Java, and the experiences gained in this district on the use of climate information for reducing the vulnerability of rice-based farming systems to ECE could be replicated elsewhere. Therefore, this district was selected for the pilot phase (First Phase). The project specifically aimed to: 1) provide locally relevant climate information in advance to enable decision-making; 2) conduct training to enable staff of the agriculture office and extension workers to communicate probabilistic forecast information to the farmers and other end-users; 3) increase capability of the local agriculture staff and extension workers to use climate forecast information for suggesting cropping management strategies; 4) evaluate farmers' responses to climate forecast information; and, 5) refine the provision of climate information for future use by farmers and other end-users based on the evaluation.

For the second phase, the project is designed to: 1) assist local institutions, farmers, and other end users to apply climate forecast information for reducing impact of floods and droughts; and, 2) promote a sustainable institutional mechanism for application of climate information.

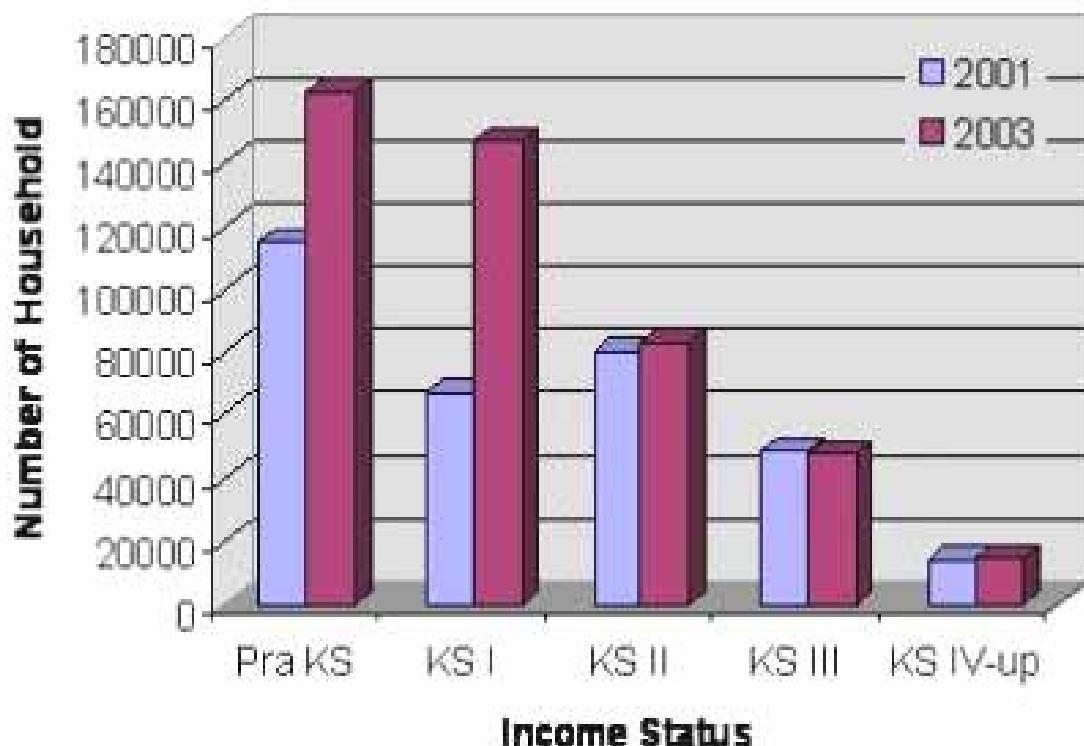


Figure 1. Number of households based on income status in non-El Niño years (01) and El Niño years (03).

(Note: Pra-KS and KS1 are households with income below the poverty line.)

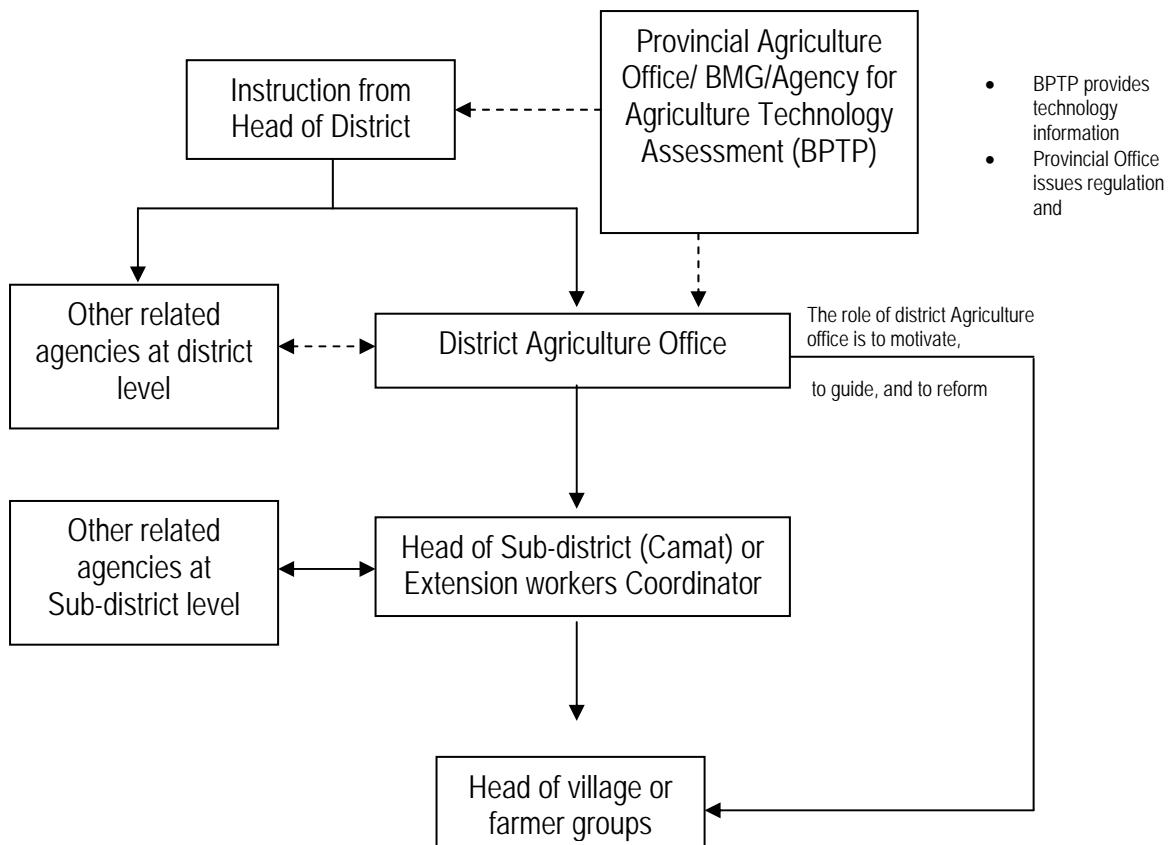


Figure 2. Flow of technologies or district instructions to farmers.

### **Implementation of the ADPC Project**

For the pilot phase, because the nature of the project is mainly research, the implementation of the project was coordinated by Bogor Agricultural University (IPB) in collaboration with the Agriculture Office of Indramayu District (IAO), BMG, and the Directorate of Plant Protection Department of Agriculture (DITLIN). As the components of the project move into the operational stage, coordination of the project will be taken over by related government agencies, namely the BMG and DITLIN.

In line with the specific objectives, the component activities of the pilot project were divided into three main activities, namely: 1) provision of climate outlook, which is the responsibility of the BMG; 2) translation of climate outlook into impact outlook and crop management strategies, which is the responsibility of IPB in collaboration with IAO and DITLIN; and, 3) dissemination of the recommended crop management strategies to farmers, as well as its evaluation, which is the responsibility of IAO. In the second phase, it is expected that the role of university and research agencies will be to provide advice on new climate information applications.

In order to increase the level of adoption by farmers to climate forecasts and its use for tailoring their cropping system, the knowledge of farmers on climate information application needs to be improved. The use of the field school approach for improving farmers' knowledge on climate information application might be effective. This approach was successful in improving Indonesian farmers' knowledge on the integrated pest management (Warsiah et al., 1999). After the implementation of this program, pest and disease outbreaks

can be reduced significantly. Therefore, a program called Climate Field School (CFS) was introduced by the project. The following section describes briefly the implementation of CFS at Indramayu.

### **Improving Farmers' Knowledge on Climate Information Application**

The idea of using the CFS approach is that the process for the dissemination of climate information to farmers should be similar to the process of introducing new technologies. Farmers should be convinced that the use of climate forecast information would benefit them and increase resilience to the extreme climate events (Boer, et al., 2003). Thus, in the CFS, all training modules are given in the form of a game or simulation. Materials used for developing the games were taken as much as possible from farmers' experiences. This is intended to relate the participants to the process of learning by practical experience. In other words, the CFS is a continuous process, i.e., getting experiences from doing, discussing, or explaining the experiences to colleagues, analyzing the experience together, formulating conclusions, and taking action (implementing) and then gaining new experiences from the action taken (Figure 3). All the processes are facilitated by Field Facilitators (extension workers or farmer leaders).

The basic concept of CFS is to disseminate climate information applications to end users by translating the information from scientific language into field language by the Field Facilitator-1 (extension worker specialists); and then translating it into farmer language by extension workers called Field Facilitator-2 in the form of a field school (for details see Boer, et al., 2003). Thus, the Field Facilitator-2 requires modules that translate climate knowledge and information into field language for guidance during the implementation of the CFS.

The development of modules will require a good understanding of developers on climate information applications, and good knowledge on agriculture systems, and climate-related problems at the sites. This will enable module developers to provide examples of simulations in the modules that are relevant to the site conditions or farmers' problems. Thus, development of the modules may require intensive discussion among module developers, the Field Facilitator-1, and local authorities. A series of modules should be developed in such a way that the final objective of the CFS could be achieved. The final objectives of the CFS is to form farmer groups that are strongly motivated to develop their own agribusiness activities where climate information is used as inputs for making plans, strategies, and decisions.

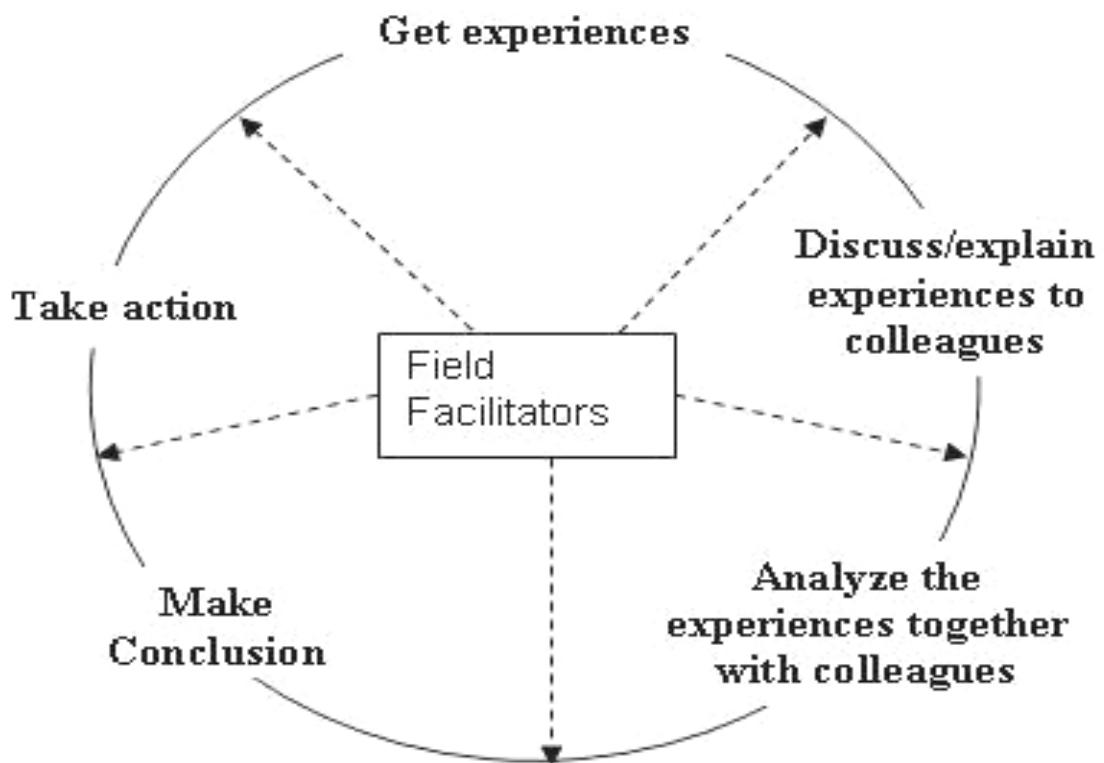


Figure 3. Process of Climate Field School (Adopted from Department Pertanian, 1998).

Based on the evaluation, it was indicated that the CFS was effective in improving farmers' understanding on climate information applications. Most of participants agreed that their knowledge on climate has increased. About 70 percent of the participants considered that their knowledge and understanding on weather and climate, their ability to use observed climatic data and climate forecast information to support farming activities, and their awareness on the importance of working in a group have significantly increased (Figure 4 and Table 1).

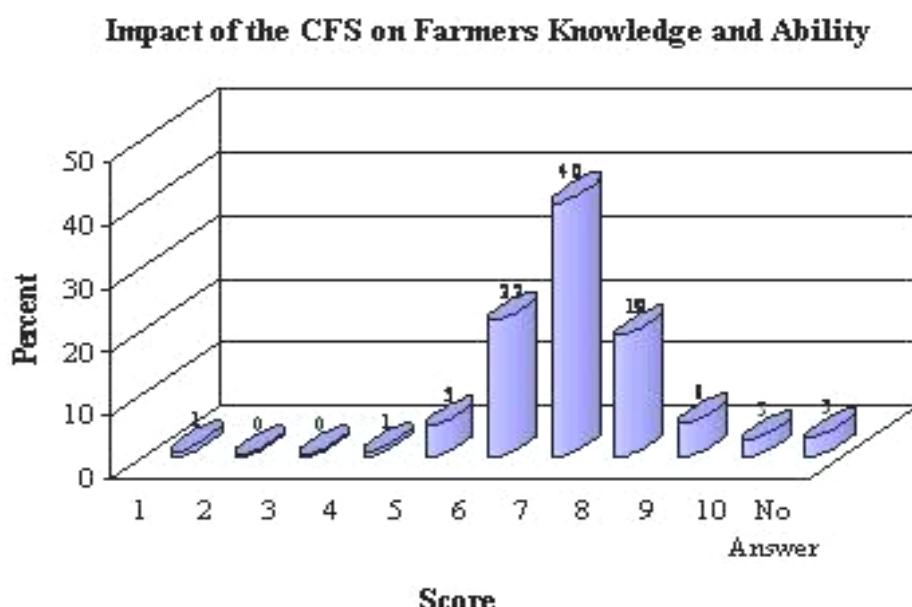


Figure 4. Result of evaluation of CFS program for improving farmers' knowledge on climate information application (ADPC, 2004).

Considering the final objective, the main challenge in the development of CFS programs is the development of modules that could cover not only climate information applications for on-farm activities but also for off-farm activities. On the other hand, how local government could also make use of climate information to support farmers' decisions and their off-farm activities is also another challenge.

Type of Ability	Score				Total
	7	8	9	10	
Knowledge and understanding about weather/climate towards agriculture	44	17	6	4	70.4
Making use of climatic data to support farming activities	31	30	7	2	70.4
Making use of results of BMG forecast to support farming activities	41	20	6	4	70.4
Making strategies to manage crops under extreme climate condition	46	7	4	2	59.3
Being aware of the role and good attitude for a group activity	41	20	6	6	72.2
Playing an effective role as a group member and being able to direct activities	37	22	7	2	68.5
Involving all the members of a group actively in activity	35	22	2	4	63.0
Giving and receiving response effectively and efficiently	44	22	2	0	68.5
Good knowledge of types of activities, facilities and methods to be applied in everyday work	41	13	11	2	66.7

Table 1. Percent of the participants that gave a score of 7-10 according to type of ability being evaluated.

Note: Score 10 is the highest, meaning the ability has improved or been well mastered.

Source: ADPC (2004). Fifty-four farmers were interviewed.

Agricultural development at Indramayu is directed at increasing and improving productivity, quality, and the production of agriculture commodities; creating more job opportunities in the villages; and increasing village community participation in private investments (agribusiness activities). The latter is aimed at enabling farmers to control off-farm systems. At present, farmers only control production systems (on-farm), while off-farm systems such as production and price of agriculture inputs and price of agriculture products are not controlled. The classic example is that farmers never receive high benefits when they have a surplus of production, since the price always decreases during peak planting seasons when the price of agricultural inputs has increased.

Considering the above conditions, policies of the government of Indramayu for agriculture development are divided into three parts (Regent of Indramayu, 2003): 1) programs to improve farm management system; 2) programs to improve agricultural institutional system; and, 3) programs to develop partnership systems for agribusiness activities.

Improvement of the farm-management system is conducted through a number of programs. The programs are: 1) technology improvements that include improvement of the dissemination system for selected and prioritized crop-management technologies to farmers through demonstration plots and farmer field schools and development of appropriate technologies (pre- and post-harvest technologies); 2) development of agroecological zones, or developing the region based on availability of agriculture facilities and resources potential; 3) crop selection system, where the selection of crops in a given season is expected to follow market condition and climate forecast.

Improvement of agricultural institutional systems at on-farm and off-farm systems consists of a number of programs. At on-farm systems, the programs aim to improve institutional

systems for disseminating agriculture technologies and market and climate information among farmers, between villages, between villages and sub-districts, and between villages, sub-districts, and the regency. At off-farm systems, the programs aim to develop and improve institutional systems that can help farmers to have good entrepreneurship either in upstream or downstream agribusiness systems. For an upstream system, the program includes development of a rural financial system and agricultural inputs businesses managed by farmers' group, etc.; and the downstream system includes development of post-harvest management systems (village ag. product storage system, etc.).

Programs for development of partnership systems for agribusiness activities are designed to achieve a number of objectives. The first objective is to increase the bargaining power of farmers though enhancing farmers' collaboration in managing their agribusiness activities. The second objective is to increase the quality of farmers' products and income through agribusiness collaboration between farmers' groups and private companies. The third objective is to enhance linkage between technology producers (universities and research agencies) and farmers' groups.

The challenge is how climate information can be applied in supporting the agricultural development at Indramayu. Figure 5 shows how climate information will be used in farm management systems, agricultural institutional systems, and partnership systems for agribusiness activities; and the roles of the government. Figure 5 implies that the role of the government in facilitating the process of improving farmers' knowledge and capacity to manage climate variability in on-farm and off-farm activities through CFS programs is still dominant, and then will gradually decrease as the program moves toward the development of a partnership system. At this stage, it is expected that farmers' groups have strong motivation and the capacity to develop their own agribusiness activities and to develop links or collaborate with the private sector. The role of local government will focus on issuing local regulations or decrees or new policies to support the farmers' agribusiness activities. The three programs could be done in sequence or in parallel depending on the condition of the villages or the sub-districts.

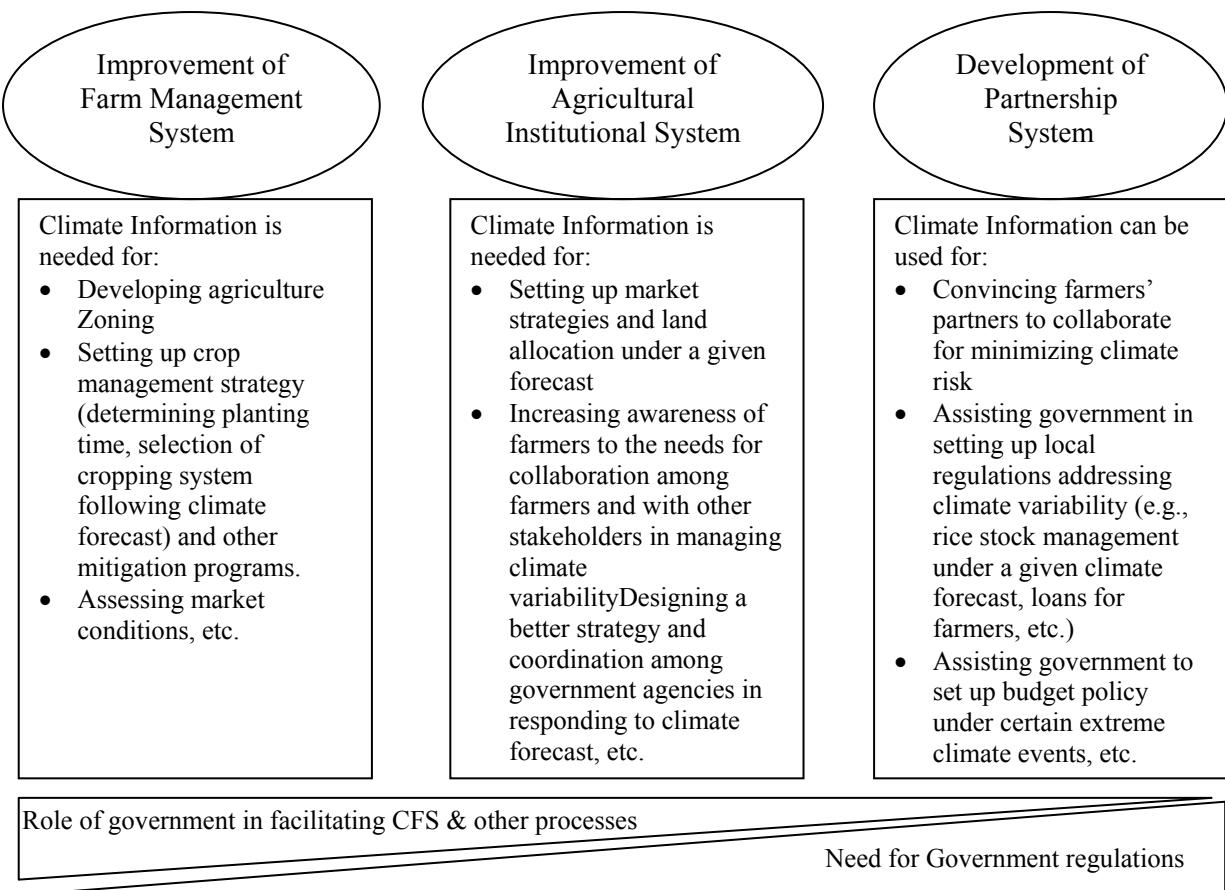


Figure 5. Climate information for agricultural development in Indramayu (Boer and Tamkani, 2003).

## Conclusion

CFS might be one of the effective ways to disseminate and educate farmers on climate information application. The main challenges are the development of modules that cover climate information application for both on-farm and off-farm activities and designing programs for capacitating staff of local government agencies in climate information application. Integrated efforts among universities, research agencies, and related government agencies are required.

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# **Operational Agrometeorological Services for Extension Needs and the Supportive Role of Agricultural Research**

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## **Abstract**

The climatic and environmental resource base of crops plays a dominant role in their survival, growth, and development. Therefore, weather and climate, crops, other parts of the resource base, and crop/weather and crop/climate relations need the continuous attention of applied research. This helps not only to protect the resource base and sustain the quality and quantity of crop yields, but it also is a basis for the farmers' income. However, to make sense, the products of science as well as forecasts and advisories must increasingly be made available to assist the farmers, through operational agrometeorological services, which range from agroclimatological characterization to management of natural resources. To explain the actual scarcity of agrometeorological services, particularly in developing countries, Stigter developed a diagnostic and conceptual framework that pictures the generation and transfer of agrometeorological information from the existing support systems to its adaptation, dispersion, and teaching at the farm level. This framework lessens the confusion between the goals and means in generating agrometeorological services. Diagnosis of current agrometeorology practices shows a need for agrometeorology to arrive at on-farm agrometeorological services. This is illustrated with ample examples from an earlier defined list of such services. It is concluded that agrometeorological in-service education of extension intermediaries is essential to train farmers in field classes, improve their income, and protect the agricultural production environment from degradation. This ultimately materializes in down to earth and to the point agrometeorological services in well-defined farming systems.

## **Introduction**

Agricultural meteorology, as an accepted term, is only about 80 years old. The aim of agricultural meteorology is to make use of the science of meteorology in the interest of food production and its security. The first half of this period saw its development in the western world, Japan, India, and in China, where it had to be completely rebuilt since the 1980s (Stigter, 2002).

In the physical environment of plants, the components may be seen as a physically unified and dynamic system called Soil – Plant – Atmosphere – Continuum (SPAC). In this system, various physical processes occur continuously and interdependently and knowledge of these processes is the basic pre-requisite for understanding the behavior of plants in relation to their environment. Agricultural production can be maximized from the soil, if all agricultural operations are planned keeping in view the physical, meteorological, climatological, and hydrological properties in relation to the physical forces and conditions in the atmosphere at optimum dynamic equilibrium, under which seeds and plants survive and remain productive (Moharir, et al., 2003).

The world is witnessing shrinking land and water resources for agriculture, increasingly varying agroclimatic conditions, and spiraling population explosions. In this scenario, judicious management of soil, water, air and other natural resources, early warning and forecasting and prevention of degradation of environment assume paramount importance. Agricultural meteorology plays an important role in understanding the underlying processes of change in the SPAC, helps in recommending proper management practices, and assists in evolving strategies to keep crop production sustainable under changing conditions. However, there is a very slow progress in the direction of taking agrometeorological products to the end users. Many suitable research findings or products based on such findings are not at all transferred to the farmer's field through extension workers (Stigter, 1999). Therefore, it is necessary to train such intermediaries to make the products more client-friendly and more tuned to actual farmers' needs. This calls for identification of the farmer's field problems with agrometeorological components that pertain to agricultural practices to guide the science of agrometeorology in more operational use (Stigter, 2001 and 2003c). Ultimately field classes will be needed to train the end users.

### **Stigter's Diagnostic and Conceptual Framework and Operational Agricultural Meteorology**

Agrometeorological services are defined here as all agrometeorological and climatological information that can be directly applied to improve or protect agricultural production (yield quality, quantity, and income obtained from yields) while protecting the agricultural resource base from degradation (Stigter, 2004).

The bottlenecks that appear in transfer of agrometeorological information through agrometeorological services are insufficient considerations of the actual conditions of the livelihood of farmers; and development of inappropriate support systems (Stigter, 2003b).

To overcome these bottlenecks, an "end to end" scheme in agrometeorology was developed by Stigter (Figure 1, e.g., Stigter, 2003c). It pictures the build-up and transfer of agrometeorological and agroclimatological information to the end users (farmers). It acts as a good guide for understanding the value of activities in the field of data, research, education/training/extension ("E, T & E"), and policies for the design of agrometeorological services to end users on an operational basis.

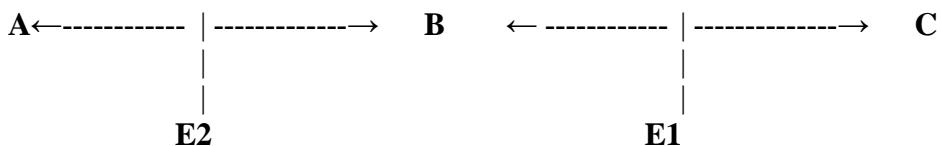


Figure 1. End to end scheme in agrometeorology

- A** = Sustainable livelihood systems.
- B** = Local adaptive strategies (knowledge pools based on traditional knowledge and indigenous technologies).
  - + Contemporary knowledge pools (based on science and technology)
  - + Appropriate policy environments (based on social concerns and environmental considerations, scientifically supported and operating through the market where appropriate).
- C** = Support systems to agrometeorological services:  
Data + research + education/training/extension + Policies.
- E1 = Agrometeorological Action Support Systems on Mitigating Impacts of Disasters.
- E2 = Agrometeorological Services Supporting Actions of Producers.

In this scheme, in the so-called “C” domain, there are support systems such as data, research, “E, T & E”, and policies. These basic support systems are of a purely supportive nature. Activities of such kinds also exist in the so called “A” (livelihood of farmers) and “B” (initial and boundary conditions for problem solving) domains. The focal guiding activities are found in the E<sub>1</sub> and E<sub>2</sub> domains (see Figure 1 and below for detailed explanations). In these operational domains and activities, the data, research, “E, T & E”, and policies are actually used/carried out in action, not in support of unproven possibilities.

Across the globe, as of now, there is a lot of work in these basic agrometeorological support systems in the “C” domain. However, there is an absolute need for such basic scientific activities to selectively support the activities in E<sub>1</sub> action support systems and E<sub>2</sub> services. In reality, too many of the products of research lay idle and will never be used supportively. Even if they are used, they are playing too much of a guiding role in technology development, which these days should be guided by social concerns and environmental considerations (Stigter, 2003b).

The four ingredients of the support systems have been intentionally used in building Action Support Systems (E<sub>1</sub>) to mitigate the impacts of disasters. Unfortunately, they have too often little to do with the real world of the livelihood of farmers (domain “A”). In this domain, the agrometeorological services should deliver support for the actions of actual producers. This support should in turn be carried out by the right mixture of the three components of the “B” domain containing the knowledge pools distinguished for use in the E<sub>2</sub> guidance and other related actions towards and in the “A” domain. From the above scheme, it can be inferred that to give more priority to the livelihood of farmers, the following issues must be considered in developing agrometeorological services:

- The local adaptive strategies of the farmers;
- Right choices in the use of contemporary science;
- The overwhelming effect of inappropriate policy environments;
- The social concerns and environmental considerations that are at stake in the “B” domain;
- The support from the focused E<sub>1</sub> guidance and the “C” domain; and,
- The understanding of what is actually possible in E<sub>2</sub> guidance and of the very conditions in the ‘A’ domain, the livelihood of farmers.

### **Examples of Operational Agrometeorological Services for Extension Needs and the Supporting Role of Agricultural Research**

Agrometeorological research as a support system particularly needs constant regional, national, and local prioritization. Based on the above scheme, the overall priorities for agrometeorological services, in many places, that were identified during a Commission for Agricultural Meteorology (CAgM) workshop in Accra (Stigter et al., 2000), a possible list of agrometeorological services (e.g., Stigter, 2004) is exemplified below. Ultimately, end users have to be involved in the development of and have to be trained in field classes in the use of successful agrometeorological services.

*The products of agrometeorological characterization, obtained with whatever methodologies.*

Murthy (1995) defined agroclimate as the combined influence of climatic elements that make possible the cultivation of crops. As the climatic characterization is meant for judicious crop planning and management, the information generated should include length of possible

cropping season, distribution of rainfall, nature of soil, evaporative demand, water availability periods, etc., of the region. A hot-season crop like sorghum, which can withstand temperatures ranging from 15°C to 40°C, performs well if water is not a severe constraint. On the other hand, regions where a mean 10-day rainfall of more than 30 millimeters (mm) is only available continuously for just 30 to 40 days are highly drought prone. For example, scientists in India advised the farmers that, under such conditions, they should grow either grasses or fodder for animals. Similarly, absence of rain continuously for 10 days necessitates soil moisture conservation techniques. Comparably, very local information on water deficiency obtained from local water balance computations were used to delineate areas and seasons with deficiency, which in turn helped to develop the probable amount of supplementary irrigation needed for recharging the soil at any given period.

All the above information and recommendations are E<sub>1</sub> research support systems (Figure 1) with good intentions. However, if agrometeorologists develop understandable maps depicting the above results on a large scale with a known accuracy, showing the vulnerability of regions for related disasters, then all of them become E<sub>2</sub> services. The same applies to any further work to get that information in a form with which extension workers can assist farmers at the field level. Only such services make a difference in the livelihood of farmers, no matter whether the scientists develop maps in a simple way or through GIS.

*Advice on above-ground and below-ground microclimate management or manipulation, such as shading, wind protection, mulching, other surface modification, drying, storage, or frost protection.*

Scientists have developed shelterbelts to protect crops and soils in different farming systems under the prevailing conditions of several regions. However, only appropriate design rules drawn from this supportive research form the actual agrometeorological services to the farmers (e.g., Stigter, et al., 1989). Two case studies follow.

In Yambawa, north of Kano in Nigeria, wind erosion coupled with wind-blown sand causes wind-driven desertification. The hot dry winds accompanied by decreasing rainfall forced the farmers to diminish crop production. A solution was found with a good intention of providing relief to the farmers through shelterbelts (Onyewotu, et. al., 2003), but it was determined from behind a desk. No pilot project had been planned; no knowledge of wind protection had been applied; and no participation of farmers in detailing the solution (choice of trees, planting pattern) had been solicited. The wrong tools were applied in analyzing the multiple shelterbelts for crop microclimate.

Supportive research found that perpendicular to the wind, the distances between belts should have been less than 100 meters (m), not between 110 and 300 m. This resulted in insufficient protection from hot winds. The expected high millet yields after the application of root pruning appeared to be much too small in the leeward protected areas. Only after proper design rules and alternatives had been derived were actual agrometeorological services partly applied.

Contrary to the above example, design rules as E<sub>2</sub> service were developed for traditional subsistence and small commercial farmers in the central clay plain of Sudan. “Pit storage” (storing grains in the underground for longer duration for food security) of annual production of sorghum in the cracking clay soils of the region helps the farmers in self-sufficiency of food throughout the year. This also helps in getting better returns as the farmers can market

their grains when the prices are high. Partly based on farmer innovations, agrometeorologists and allied scientists, through their supportive research recommended that wide shallow pits using thick chaff linings and wider above ground soil caps should be used for longer duration of storage of sorghum grains (Abdalla, et al., 2002).

Advisories can be based on the outcome of response farming exercises, from sowing window to harvesting time, using climatic variability data and statistics of recent past or simple on-line agrometeorological information. All agricultural activities from pre-sowing to post-harvest are influenced by weather. So, weather-based advisories to the farmers help them in day-to-day agricultural operations well in advance. This in turn helps to mitigate the adverse impact of weather. Response farming, a method of identifying and quantifying the seasonal rainfall variability to address the risks of the farmers at field level, is a classical example of such advisories (e.g., Stigter 2002). The hypothesis is that the solutions to farming problems may be found by improved forecasting of expected rainfall behavior in the cropping season(s). Response farming also means adapting crops to the ongoing rainy season by guidance of agronomic operations, using experiences of the past, preferably from interpretations of meteorological rainfall records, with support from traditional expert knowledge where available.

An example of research support is Ian Stewart's search for and application of forecasting some patterns of rainy seasons in Kenya, which made it possible to design advice on lowering planting density by thinning or adding fertilizer as side-dressing to improve the efficiency of resource use by the farmers.

*Establishing measures to reduce the impacts and mitigate the consequences of weather and climate related natural disasters for agricultural production.*

Much literature exists on the damage that natural disasters do to agriculture but preparedness and the related supportive research leave very much to be desired (e.g., Stigter, et al., 2003b). However, sometimes agrometeorological services have been developed from research. When temperatures at night fall below freezing point during springtime (in association with cold waves) there will be frost injury in orchards. The low temperatures irreversibly damage the flowers, and the harvest of fruits in autumn will suffer. If the occurrence of frost is well forecasted, it is good to advise sprinkler irrigation of the flowers during the previous day. Spraying the flowers with water prevents them from freezing and the blossom is safe and so are the future fruits.

*Monitoring and early warning exercises directly connected to such already established measures in agricultural production, to reduce the impacts and to mitigate the consequences of weather and climate related natural disasters for agricultural production.*

Murthy (1995) defined agricultural drought as a situation in which crops fail to mature due to insufficiency of soil moisture. Drought monitoring in case of field crops can be done using the relationship between water use and productivity. Several methods are available in literature for establishing the water use and productivity of crops. The Water Requirement Satisfaction Index (WRSI) of Frere and Popov (1979) indicates in percentage the extent to which the water requirements of an annual crop have been satisfied in a cumulative way at any stage of its growing period. The index at the end of the growing season will reflect the cumulative stress endured by the crop through excess and deficits of water and is closely

related to the final yield of the crop. Yet, this is an E<sub>1</sub> support system because advice to the farmer is lacking.

There are several ways of monitoring and forecasting drought but these exercises should always be accompanied by recommendations developed in the “B” domain, like growing a short-duration crop, thinning, in-situ moisture conservation, etc., as agrometeorological services. As long as farmers do not get validated benefits out of the above advice, monitoring and forecasts remain E<sub>1</sub> support systems only.

*Climate predictions and forecasts and meteorological forecasts for agriculture and related activities, on a variety of time scales, from years to seasons, and from a variety of sources.*

A good climate prediction is not always a good agrometeorological service. Not only the skills of the forecast count but also the absorption capacity of the target groups matter a lot. This is well illustrated in the following case study (Lemos, et al., 2002).

The seasonal climate forecasts in Cear'a, N-E Brazil, for maize/bean/manioc growers, on drought were found to be a disaster. An emerging technology “was appropriated and pressed into service of a policy making apparatus designed to reduce the impacts of severe droughts.” Policy-makers started to exaggerate the potential usefulness of the science product, “therefore creating a situation of cultural dissonance between science and local knowledge and belief systems that quickly eroded the value of the information” (Lemos, et al., 2002). The scientific product, a typical E<sub>1</sub> action support system, which did not have the right mix in the “B” domain, was not used to lead to useful E<sub>2</sub> agrometeorological services. Due to their particularly vulnerable socio-economic conditions, the farmers were unable to respond to raw climate predictions, irrespective of the quality and the precision of the forecasts.

*Development and validation of adaptation strategies to increasing climate variability and climate change and other changing conditions in the physical, social, and economic environments of livelihood of the farmers.*

Murthy (2002) defines climate change as “any long term substantial deviation from present climate because of variations in weather and climatic elements.” If supportive scientists develop with the farmers an improvement of an already existing adaptation to increasing climate variability, then the new product may be called an agrometeorological service when the policy environment is conducive to such change. In this direction two examples from India show what is basically possible to make a positive difference in the livelihood of farmers.

The first is the use of the Southern Oscillation Index (SOI) to advise farmers on growing either cotton or peanuts in parts of India. In years with positive SOI, peanuts outperformed cotton in 70 percent of years and in negative SOI years there was only small advantage in 40 percent of years. So, if farmers grow cotton in SOI negative years, the above supportive research produced an E<sub>2</sub> service.

The second example is potential advice on the seasonal rainfall probability for profitably growing of peanuts in parts of India. The supportive research results indicate that if the seasonal rainfall (July to December) is >50 centimeters (cm), the yield probability of >1.5 t/ha is 50 percent and the probability of yields <0.7 t/ha is zero. Therefore, prediction of rainfall “greater than” or “less than” 50 cm would be extremely helpful to the farmers.

However, it appears that in 87 percent of El Niño years the seasonal rainfall was <50 cm, but of the 58 years with rainfall <50 cm, only 21 were El Niño years. This shows the problems of supportive research. Still, a better forecast would be an E<sub>1</sub> activity, but could be made into an E<sub>2</sub> service if this information was reliably explained as to probabilities, and was made available in time and in a way that local farmers can absorb, and if other agrometeorological information and other inputs for crop production could be simultaneously supplied as per the required schedule.

*Specific weather forecasts for agriculture, including warnings for suitable conditions for pests and diseases and/or advice on countervailing measures.*

There is a considerable loss in the production of food grains due to occurrence of pests and diseases. Supportive studies based on the relationship between the micro/macro climate and origin, multiplication, spread, and intensity of diseases and pests may be useful to understand the environmental conditions that are congenial for their development. In supportive research Nagarajan and Hardev Singh (1976) proposed a method for predicting wheat stem rust appearance in South India based on the occurrence of synoptic conditions likely to lead to the transport deposition of spores. Even earlier, Rainey (1963) supportively identified synoptic situations associated with the migration of desert locusts. Chakravarthy and Gautam (2002) developed a forewarning theory, which has a potential as an indicator of mustard aphid population build up. Using simple parameters, this can be done as early as one month in advance. This may enable the farmers to be ready with necessary tools to combat the pest problem, if advised accordingly. Such supportive studies in the “C” domain may not have any operational utility unless they pass the “B” domain process of using the right mix of the three pools of knowledge and become an E<sub>2</sub> service in the “A” domain.

*Advise on measures reducing the contributions of agriculture production to global warming.*

The major environmental problem today is global warming, which is due to accumulation of several gases causing greenhouse effects and depletion of the ozone layer in stratosphere; finally also affecting agricultural production. However, contributions to reducing contributions to global warming should be asked from developing countries particularly in combination with measures that improve efficiencies of resource use and the health of their populations.

For example the wetland rice fields are a major source of atmospheric methane. The following measures would pertain: prevention of submergence of rice fields wherever feasible without affecting the rice productivity; increased adoption of direct seeding instead of transplanting; crop diversification in rice-based cropping systems; water management by intermittent drying and mid-season drainage in controlled water situations; growing rice cultivars having traits with low methane emission potential; use of sulfate containing fertilizer; minimizing of soil disturbance during the growing season to reduce the escape of entrapped methane; use of properly composted organic amendments. Several of these measures serve resource-use efficiency purposes.

*Proposing means of direct agrometeorological assistance to manage natural resources for development of sustainable farming systems.*

When for example knowledge from field experimentation is utilized in supportive crop simulation models, gaps between actual, attainable, and potential yield for a given

environment can be determined. Also, some opportunities for yield improvement, for example through improved sowing windows, can be asserted by using strong agrometeorological sub-routines. However, validating the predictive power of a model for the management of the natural resource base is essential for using it at an operational level. Modeling can be of immense use in high input agriculture. However, operational use of the model means making predictions on the performance of the crop and suggesting ways of managing which lead to a sound basis for the final stages of field testing prior to advising farmers ( $E_1$  support services) or to direct formulation of recommendations ( $E_2$  services). However, modeling socio-economic aspects is still too cumbersome.

## Conclusions

- The consequences of increasing climate variability/change make it necessary to urgently strengthen participatory extension in the field of agrometeorology and climatology;
- Intermediaries between general agrometeorological advisories/forecasts and agrometeorological services have to be trained for increased preparedness for new or worsening problems of farming systems, caused by climate disasters (Stigter, 2003a);
- Farmers, extension intermediaries, and agrometeorologists should much better understand needs, possibilities, limitations, and realities for/of agrometeorological services in well-defined farming systems. This is essential for successful development and implementation of actual operational agrometeorological services (Stigter, et al., 2003a);
- An independent national agrometeorological data bank has to be established in every country and liberal policies should be adopted for supply of trustable agricultural and meteorological data to the research (and extension) institutions involved in agrometeorological research (Ramana Rao, 1988);
- A database of sound and dependable supportive research results must be developed by agrometeorologists in various application fields. Ongoing research programs have to be recast by much more functionally looking into the problems and priorities for developing and organizing operational agrometeorological services for specific farming systems (examples in this paper);
- A number of in-service training programs for extension intermediaries have to be established, by and for agrometeorologists, to make them better aware of the actual needs of the farmers, with agrometeorological components, in different farming systems. Training also is needed on how to use agrometeorological products together with knowledge from neighboring disciplines for the benefits of those farmers. Their successes, failures, and experiences will have to be brought back into the curricula of agrometeorological personnel of the NMHSs and into those at vocational schools and universities, to enlighten the classical training in agrometeorology and strengthen its usefulness (Stigter, 2003a); and,
- End users must be trained accordingly in appropriately organized field classes.

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# **A Review of Agrometeorological Monitoring Tools and Methods Used in the West African Sahel**

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## **Abstract**

Agrometeorological monitoring in the Sahelian countries consists of collecting, processing, and analyzing various data and information that can affect the outcome of the agricultural season. It combines observational data from national meteorological, hydrological, agricultural extension, plant protection, and livestock breeding offices, as well as satellite data provided by the AGRHYMET Center. From May until the end of October, multidisciplinary working groups (MWGs) in each country publish dekalal and monthly bulletins. At the regional level in the AGRHYMET Center, data and information coming from the national components are combined with satellite data to elaborate regional syntheses that are published at different time steps. In these publications, the current situation is analyzed and compared with that of the previous period, the previous year, and the average. Forecasts of seasonal rainfall and crop yields, that are refined from month to month, are also given. Color maps illustrates the amounts of rainfall, sowing dates, crop water requirements, satisfaction indices, yield estimates, zones with particular pests, and the advance of the vegetation front. Hard copies and electronic versions of these publications are mailed to subscribers. They are also posted on the Center's website: [www.agrhymet.ne](http://www.agrhymet.ne).

## **Introduction**

The creation of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) has played a major role in the development of agricultural meteorology in West Africa. Indeed, it is following the catastrophic droughts of the early 1970's that seven countries (Burkina Faso, Chad, The Gambia, Mali, Mauritania, Niger, and Senegal) decided to create the CILSS. They were joined later by Cape Verde and Guinea Bissau. The AGRHYMET Center, a specialized institution of the CILSS, was created in 1974 with the mission of training personnel, providing adequate technical equipment for the meteorological and hydrological stations networks, and setting up MWGs for the monitoring of the meteorological, hydrological, and crop and pasture conditions during the rainy season. The main task of these groups was to analyze the current situation and give advice to policy-makers (national authorities and their international partners) regarding the possible outcome of the rainy season, thus allowing them to take adequate measures to prevent massive human suffering and displacement.

The AGRHYMET Center still continues to support, financially and technically, the activities conducted. Indeed, the main objective of all the new methodological developments undertaken at the Center is to transfer them to member countries. This is done through workshops and long-term training sessions attended by the staff of the different technical offices. Those offices are also assisted with equipment to be used for data collection, transmission, storage, and analysis. All this is done by the operational units of the AGRHYMET Center, in collaboration with scientific partners such as African Center for

Meteorological Applications to Development (ACMAD), Centre de cooperation Internationale en Recherche Agronomique pour le Developpement (CIRAD), Food and Agriculture Organization (FAO), Food and Agriculture Organization-Famine Early Warning System Information Network (FEWS-NET), Institute de Recherche pour le Developpement (IRD), Institute of Biometeorology-National Research Council (IBIMET), U.S. Geological Survey (USGS), and World Meteorological Organization (WMO). Financial support for these activities is provided by Danish, French, Italian, and U.S. governmental cooperation agencies and other regional and international donors.

The objective of this paper is to give an overview of agrometeorological monitoring tools and methods that are used by the nine CILSS member countries in West Africa.

### **Seasonal Forecasting**

The AGRHYMET Centre is a member of a consortium, along with the ACMAD and the Niger River Basin Authority (NBA), which issues forecasts for the July-August-September (JAS) cumulative rainfall, two to three months in advance, for the Economic Community of West African States (ECOWAS) member countries. These forecasts are based on outputs of ocean-atmosphere dynamic models coupled with outputs of national statistical models. Each year, scientists from all West and Central Africa countries delineate zones for which forecasts are made separately. For each of these zones, the seasonal forecast gives the probabilities of the JAS rainfall (Figure 1), or maximum river flow, within the lowest, middle, or top third of the available time series, usually the last 30-year standard normal period ([www.acmad.ne](http://www.acmad.ne)).

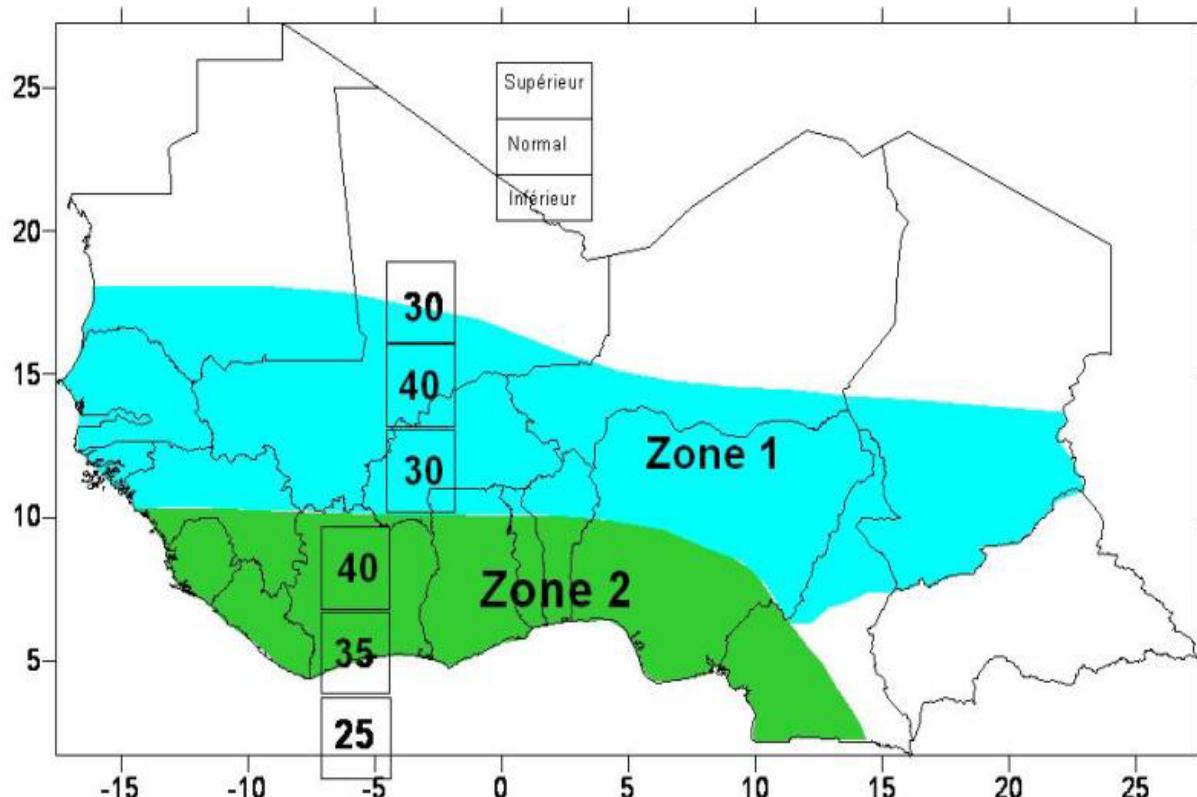


Figure 1. Seasonal forecast for the year 2003 July-August-September cumulative rainfall.  
Source ACMAD.

## Monitoring the Cropping Season and Determining Risk Zones

Most of the information generated by the AGRHYMET Center and its national components is addressed to policy makers at the government or international aid agency level. Several indicators are used throughout the rainy season to assess crop and livestock conditions and issue advisories or warnings, if necessary, to decision makers at different levels. Indicators include decadal and cumulative rainfall amounts, surface water levels and flows, estimated starting dates of the season, simulated crop satisfaction indices, status of natural vegetation, crop pests and diseases status, crops and overall biomass yield estimations, among others.

### Rainfall

The analysis of the rainfall situation consists of mapping the cumulative dekadal and seasonal amounts observed throughout the Sahel and commenting on them with regards to the average or the previous year. Rainfall data can come from the regular raingauge networks of member countries and/or estimates made using meteorological satellite (METEOSAT) infrared images. Particular attention is paid to zones with exceptional events, such as those with prolonged dry spells or flooding.

### Surface waters

Surface waters are monitored using data collected and transmitted by the national hydrological offices. Water levels and river flows are analyzed and inter-annual comparisons are made (Figure 2).

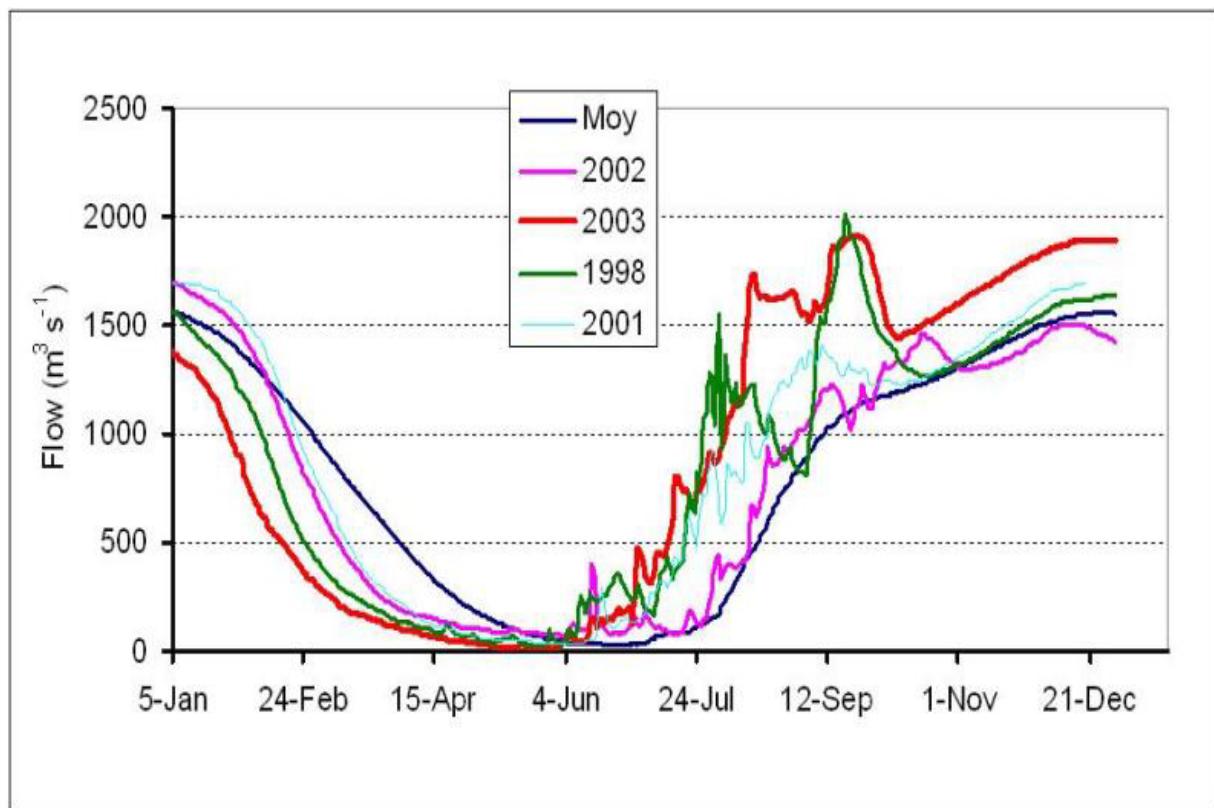


Figure 2. Evolution of Niger River flow in 2003 at Niamey, Niger.

## Start of the Season

Two models, based on slightly different methods, are used at the AGRHYMET Center to determine the start of the season. The first method, based on soil water balance simulation, is implemented using the diagnostic hydrique des cultures (DHC) model (Girard, et al., 1994; Bourneuf, et al., 1996). This model uses as input data the daily rainfall from the regular network of CILSS member countries or rainfall estimates from METEOSAT infrared images, the average dekadal values of potential evapotranspiration (PET), and the soil potential water storage above the wilting point in the first meter layer. The starting date of the rainy season, called “successful sowing date” is determined by giving a threshold of available soil moisture (10 millimeters [mm]) in the soil top layer (15 centimeters [cm]) to be reached starting from the 1<sup>st</sup> of April, and a 20-day period during which the crop water requirements satisfaction index should not fall below 50 percent (Figure 3). The “successful sowing date” may or may not be the same as the “first sowing date,” which just satisfies the first condition.

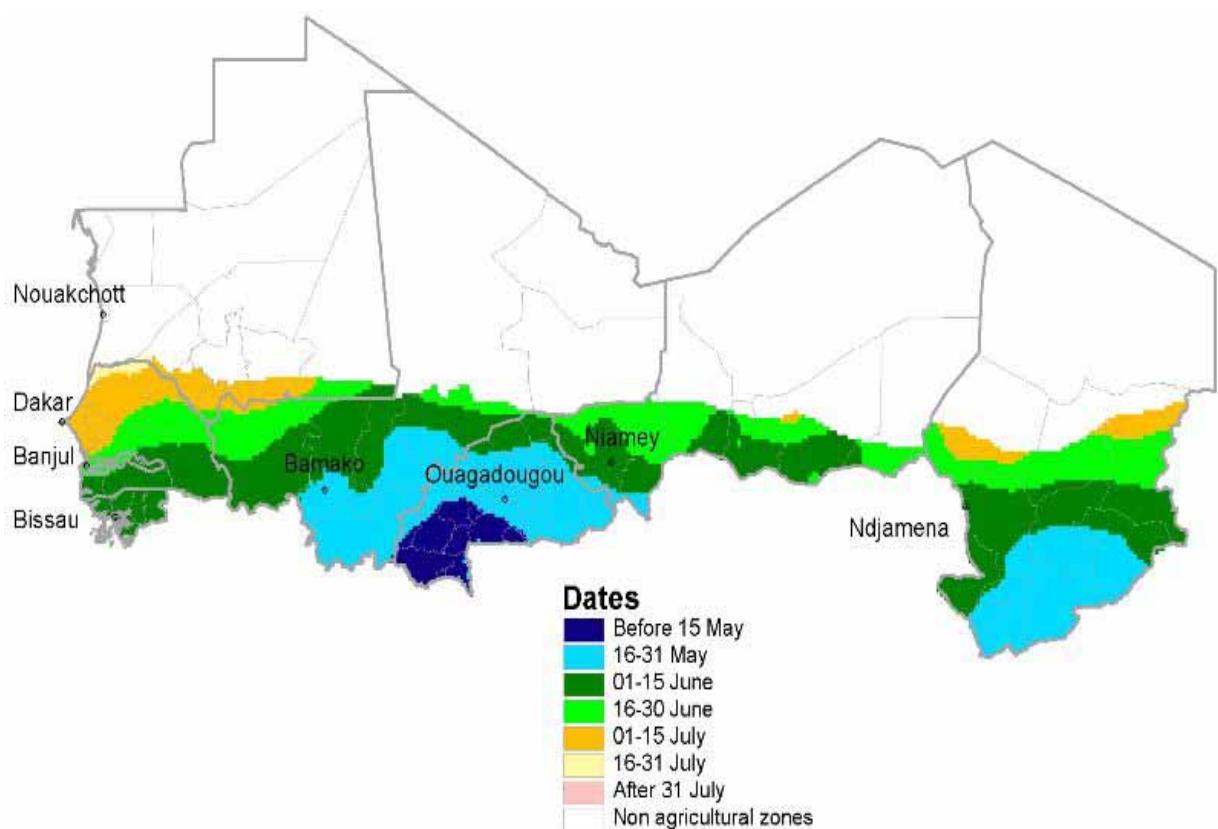


Figure 3. Year 2003 “successful” sowing dates. Source DHC.

The second method, implemented with the Zones A Risque (ZAR) model, determines the start of the season based on a rainfall threshold of 20 mm followed by a dry spell of no more than 20 days in the next 30 days using dekad METEOSAT derived rainfall estimates (AGRHYMET, 2002). In addition, the ZAR model gives areas of “failed sowings,” the potential duration of the season based on a fixed average ending date (Figure 4), and other information related to the starting date.

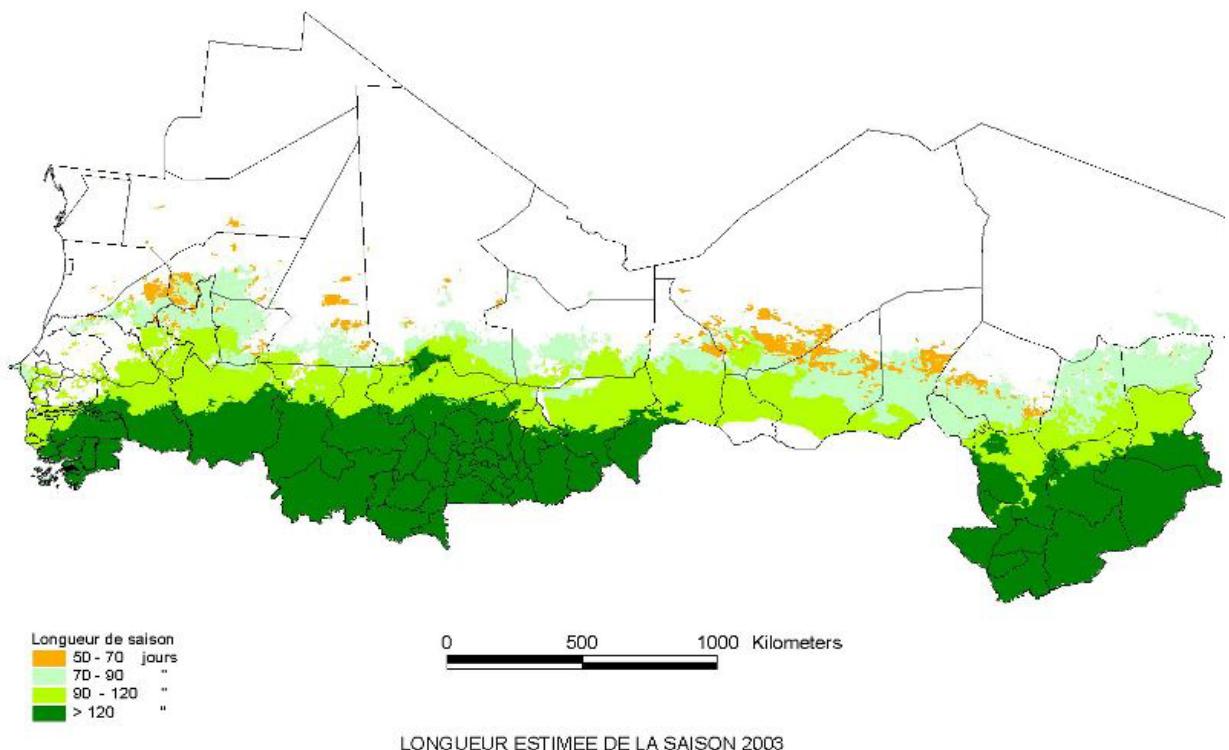


Figure 4. Potential duration of the 2003 cropping season. Source ZAR.

Both these methods use the same principle developed by Stern et al. (1981) and implemented in the INSTAT+ software, which AGRHYMET also makes available to its national components through the SIAC courses organized jointly with the University of Reading, United Kingdom. ([www.ssc.rdg.ac.uk/instat](http://www.ssc.rdg.ac.uk/instat)).

The results obtained by the two methods can be the same or differ by one to two dekads (10-20 days), depending on the location and the year. They are applied on long time series of data to calculate the “normal” starting date at a given location and to make inter-annual comparisons.

### Crop Water Requirements Satisfaction

As with the start of the season, the DHC model is used to monitor the crop water requirements status throughout the season. Once a successful planting date is determined for a given location, the potential crop cycle, the duration of the four main growth stages (initial, development, full vegetation, and maturation) and the crop water requirements for every 10-day period are determined by assuming a fixed ending date: the average date after the 1<sup>st</sup> of September on which available soil moisture in the 1-meter layer is irreversibly depleted at less than 90 percent (Bourneuf, et al., 1996). Crop water requirements are determined using a relationship between latitude and the three characteristics values of the crop coefficients (Doorenbos and Pruitt, 1977) derived from measurements on different sites throughout the Sahel (Fréteaud, et al., 1984). The crop water satisfaction index is the ratio of the actual evapotranspiration (AET) to the maximal evapotranspiration (MET) for a given dekad. AET is computed using an algorithm proposed by Eagleman (1971) that relates the water consumption of a crop to its water requirements (MET) and the relative soil moisture content, and MET is the product of the crop coefficient by the potential Penman evapotranspiration

(PET). Other assumptions on bare soil evaporation, root growth and soil drainage are made in the computation of AET (Bourneuf, et al., 1996; Dingkuhn, et al., 2003).

The DHC model gives several outputs related to crop water requirements that can be analyzed and mapped to illustrate the crop water status. These are: the water satisfaction index for the last decade; the overall water satisfaction index since the start of the season; the water requirements for the remaining of the crop cycle; and, the currently available soil moisture.

### **Crop Pests and Diseases**

Several sources of information, including regular reports from member countries, the advance of the Intertropical convergence zone (ITCZ), the occurrence of rainfall, the emergence and/or presence of vegetation detected on Normalized Difference Vegetation Index (NDVI) images are used to analyze the crops pest situation and make forecasts on the possible outbreak of the most important crop pests in the Sahelian region. These analyses are based on the knowledge of the relationship between the biology of the insects and the environmental factors such as day length, temperature, soil type and moisture content, vegetation status, wind speed and direction, and the position of ITCZ. For example, the grasshopper *Oedaleus senegalensis* is known to move gradually from south to north at the beginning of the rainy season as the environmental conditions become more and more humid. Towards the end of the season, as the vegetation dries out and the ITCZ moves back southwards, the grasshopper also follows the same direction and may cause massive damage to maturing millet and sorghum crops in the Sahelian and Sudanian zones (Launois, 1978; Lecoq, 1978).

The desert locust *Schistocerca gregaria*, on the other hand, remains mostly in desert areas and may reproduce, multiply, and migrate to agricultural zones if environmental conditions become favorable.

Several studies, including Tucker, et al., (1985); Hielkema, et al., (1981); and FAO (1997) have used remote sensing techniques to evaluate the ecological conditions in the desert locust reproduction zones. Tappan (1991) and Berges, et al., (1991) on one hand and Burt, et al., (1997) on the other hand have also demonstrated the possibility of monitoring and anticipating the outbreak of grasshoppers using NDVI and METEOSAT rainfall estimates, respectively. All these tools are used at AGRHYMET to closely monitor the ecological conditions that may be favorable for the outbreak of these pests, and if necessary, to issue warnings in the regular or special information bulletins.

### **Status of Natural Vegetation**

The analysis of the status of natural vegetation is done mostly with remote sensing data. National Oceanic & Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR) derived NDVI is used to monitor the emergence and the advance of the vegetation front throughout the season. Comparisons of the current dekad values with those of the previous one allow seeing where conditions were favorable or unfavorable to vegetation growth (Figure 5). These results are used by pastoralists and plant protection specialists to evaluate the conditions for livestock or crop pests. Towards the end of the season, the potential productivity of pasture lands throughout the Sahel is evaluated using a model that estimates biomass yield from METEOSAT rainfall estimates and soil data

(AGRHYMET, 2002). The outputs of this model, which makes simple assumptions on water infiltration, runoff, and nitrogen balance are potential dry matter yield in kilogram/hectare (Kg/ha) at the 5 x 5 km scale (Figure 6) and biomass quality based on its nitrogen content. These results are used to evaluate livestock performance in terms of potential meat and milk production (Di Vecchia, et al., 2002).

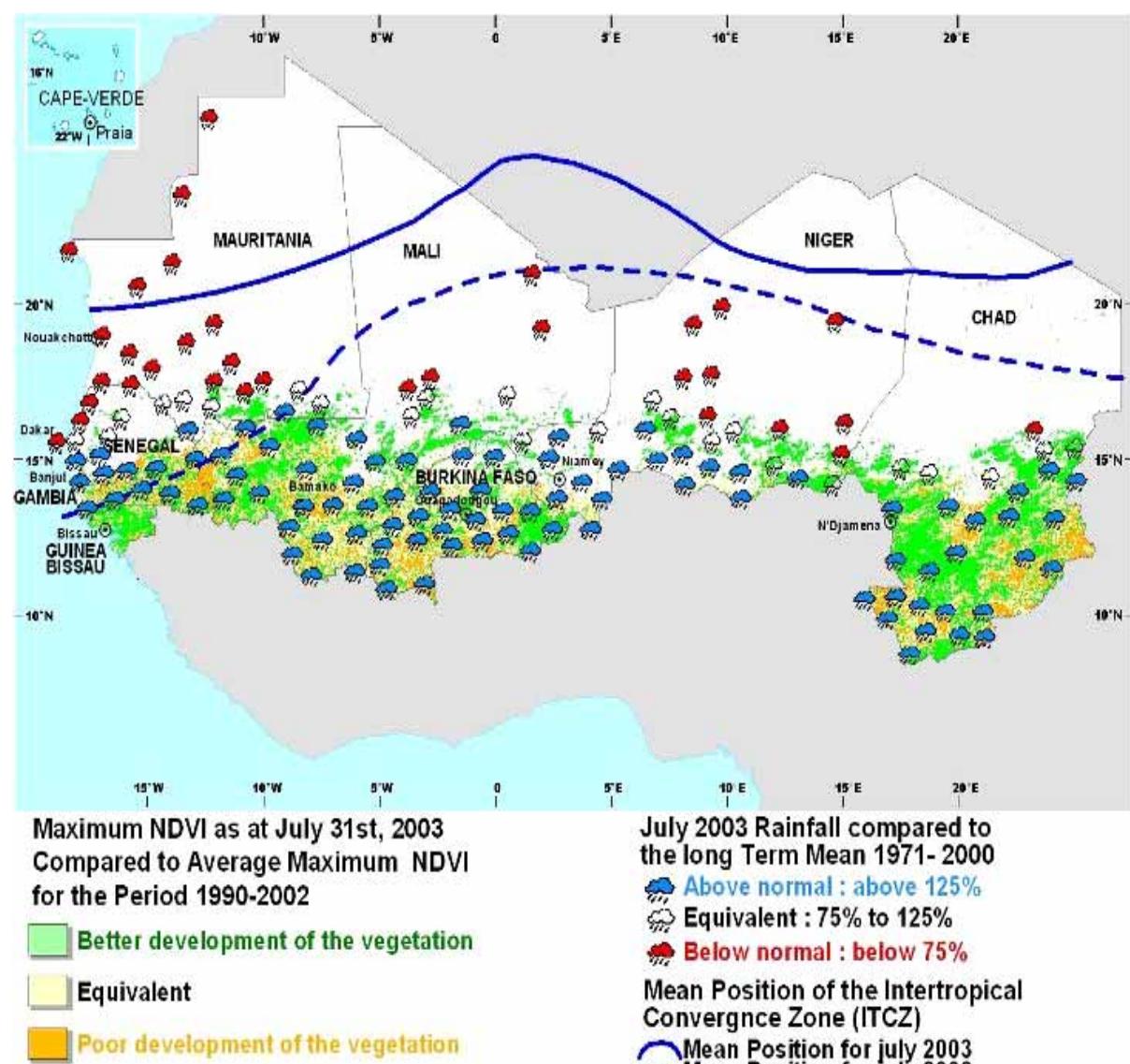


Figure 5. Average positions of ITCA, with rainfall and NDVI values of July 2003 compared with respective averages.

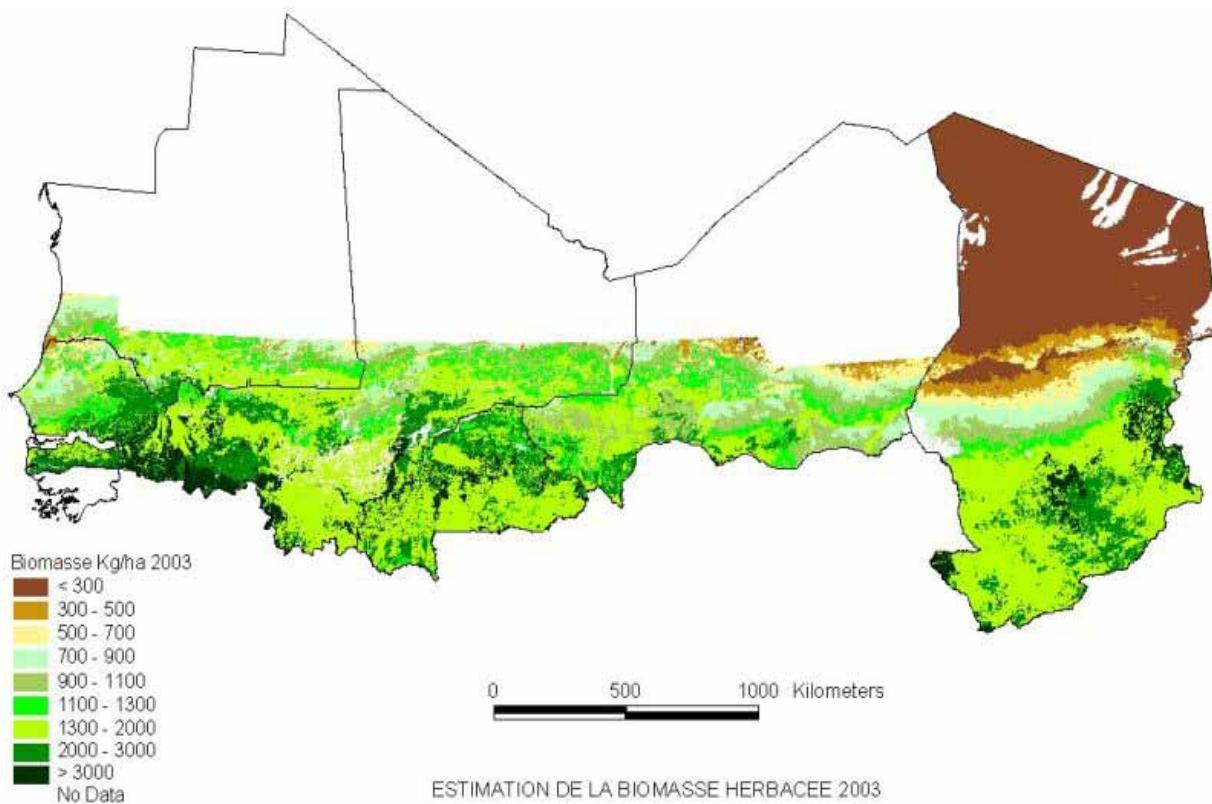


Figure 6. Potential biomass yield as of September 30, 2003.

### Crop Yield Forecasting

The main crop yield forecasting tool used at AGRHYMET and in the member countries is the DHC model (Samba, 1998). As already described, this model calculates the actual crop evapotranspiration (water use) every dekad and evaluates to what extent its water requirements have been satisfied. Following a 3-year survey in six West African countries (including Burkina Faso, Mali, Niger, and Senegal), an empirical relationship was established between millet yields observed on farmers' fields and an index derived from the outputs of the DHC model (Girard, et al., 1994; Bourneuf, et al., 1996; Samba, 1998; Dingkuhn, et al., 2003). This relationship is used in the model to predict expected millet yields throughout the Sahel. A first yield estimate is made at the end of August and updated at the end of September. The comparison with the average expected yield gives an indication of a zone being at risk or not at risk (Figure 7).

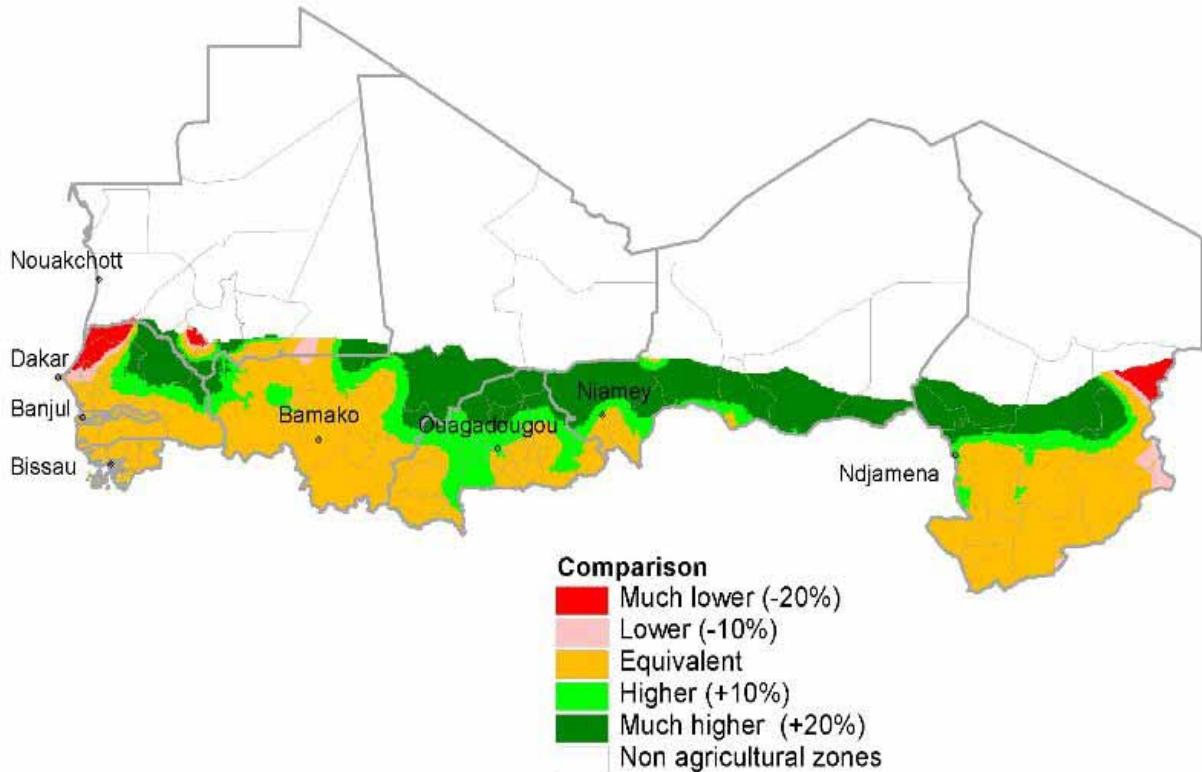


Figure 7. Year 2003 expected pearl millet yields compared with the 1971-2000 average.  
Source DHC.

### Risk Zones

All the above mentioned indicators may be used to declare a zone “at risk.” The first signal is given by a delay of more than two dekads in the current year’s starting date relative to the average (Figure 8). If that happens in a given location, this usually means that there will be less time for crops to develop and give adequate yield, because of a shortened season. This is based on the observation that the starting date of the rainy season in the Sahel is much more variable than its ending date (Sivakumar, 1988), and that a season starting late does not necessarily mean that it will also end late (Traore et al., 2000). At the AGRHYMET center, a final assessment of the starting conditions is done at the end of July and all zones with a late start are declared to be at risk (Figures 3 and 8). Once the season is installed, other indicators are used to determine risk zones, namely, if the crop water satisfaction index falls below 50 percent for two consecutive dekades, or if NDVI values regress from one dekad to the next. Important outbreaks of pests, floods, and below-average potential millet yields may also indicate that a particular zone should be considered as at risk. This gives basis for decision makers to focus their attention to those areas by closely monitoring not only rainfall conditions, but also socioeconomic activities and taking adequate measures to prevent famine.

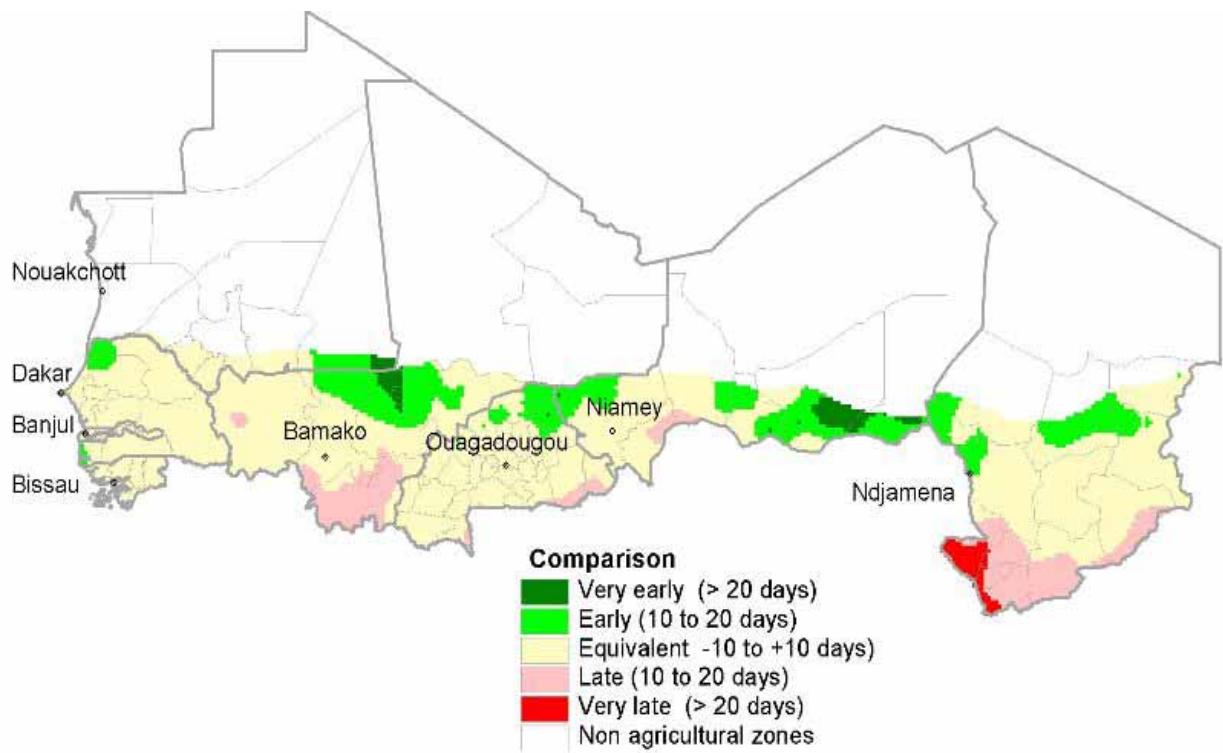


Figure 8. Year 2003 “successful” sowing dates compared with the average of the 1971-2000 period.  
Source DHC.

## Assistance to Producers

In addition to giving information to policy makers, AGRHYMET and its member countries also assist the producers so that they can enhance their production by using agrometeorological information. Indeed, in some countries and at the regional level, advisories are also given to producers allowing them to take particular actions given certain conditions. The tendency is now to develop methodologies allowing producers (farmers, livestock breeders, fishermen, etc.) to enhance their production and income based on the exploitation of appropriate agrometeorological information. These types of activities are conducted mostly within the framework of pilot projects, some of which have been conclusive and are now being extended. This is the case of the Mali agrometeorological assistance project, where farmers receive, through broadcasts on national radio and television, directives from the MWG on adequate times for sowing, fertilizer application, weeding, phytosanitary treatments, etc. In many member countries, agrometeorological bulletins give advice to herders on where to find abundant pastures and when to vaccinate their livestock if a risk of disease outbreak is sought. In this regard, AGRHYMET has recently conducted with success a pilot project in the Tahoua region of Niger, where herders were given information on where to locate good pastures every 10 days through the Radio and Internet for Communication of Hydro-Meteorological and Climate Related Information (RANET) system.

## Problems and Perspectives

In implementing all these activities, the Center and its partners face several problems, most of which relate to data acquisition in member countries, their timely transmission, and the small number of observation points. Since the late 1980s, the Center has considered the use of

satellite imagery to compensate for the lack of sufficient and timely acquisition of ground data. This has prompted the development of a spatial version of the water balance simulation and yield forecasting model, DHC-CP that uses rainfall estimates from METEOSAT images (Samba, 1998). The ZAR and the BIOMASS models also use METEOSAT rainfall estimates to calculate the starting date and the potential length of the growing season on one hand, and the potential biomass productivity of pastures, on the other hand.

Activities are currently underway to upgrade the crop monitoring and yield forecasting model, so that it simulates not only crop water balance, but also crop growth and development using solar radiation and air temperature data. The new model, called SARRA\_H (Dingkuhn, et al., 2003), was developed in collaboration with CIRAD and CERAAS, and is now being tested for Sahelian farming conditions. The new functionalities of the model should allow the yield forecasting to be extended to other crops and agroclimatic situations for which water is not the main limiting factor. This is in accordance with the new mandate of the Center to cover all ECOWAS member countries. In the process of upgrading the new crop model, the new procedures proposed by the FAO (Allen, et al., 1998) will be implemented, namely, calculating crop and reference evapotranspiration using the Penman-Monteith method. AGRHYMET operational units are also preparing for the arrival of the new METEOSAT Second Generation receiving station, which should allow the derivation of climatic variables to feed the different models in use at the Center at better time and spatial resolutions.

With regards to agrometeorological assistance to producers, discussions are currently underway with Niamey area vegetable growers in Niger, and with farmer associations in the Senegal River valley on how to assist them to better manage their irrigation water and obtain good quality products.

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# **Advising Growers on Conditions for Sugarcane Burning in Cauca Valley (Colombia) Using Data Obtained From an Automated Weather Network**

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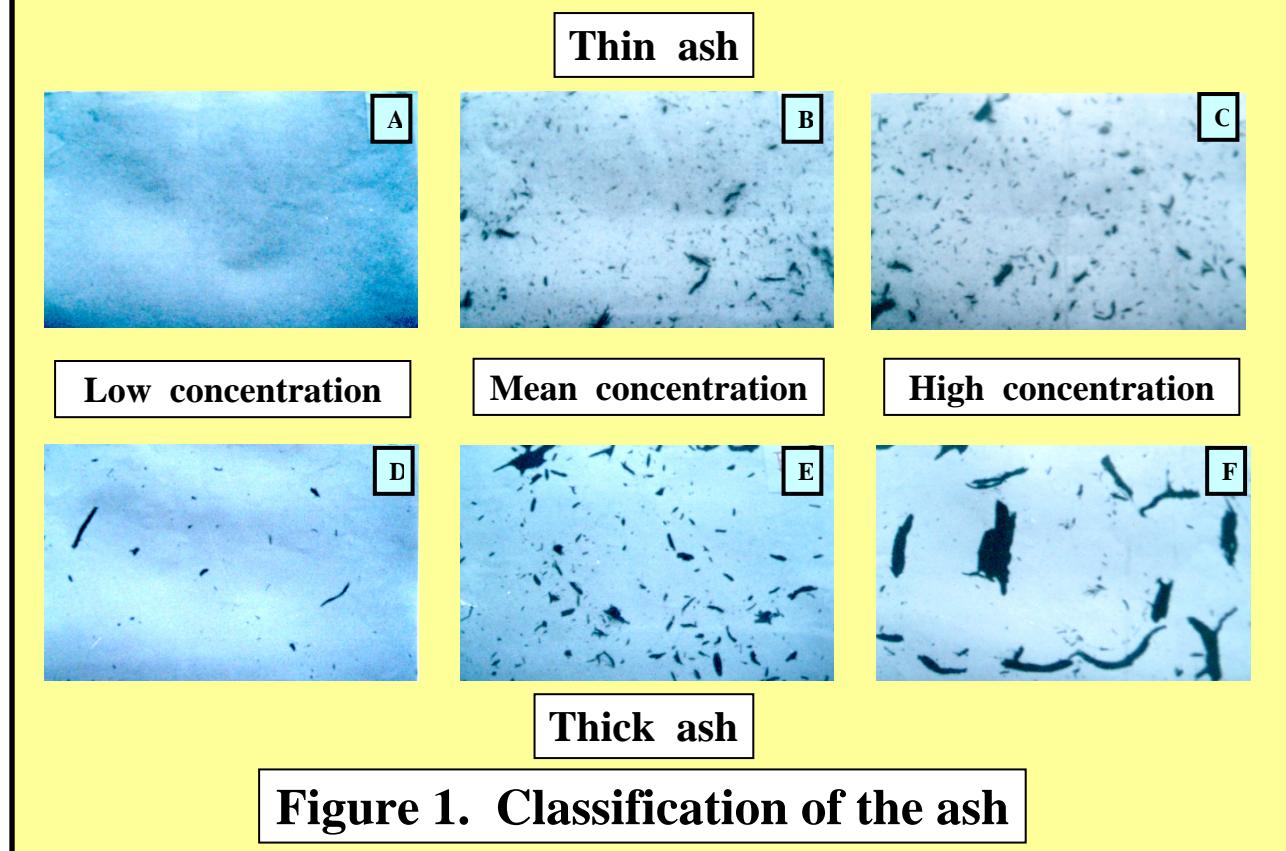
## **Abstract**

The application of meteorological and climatological information obtained through the Colombian sugarcane industry's automated weather network is discussed. A primary concern is to minimize the number of cases when the ash and smoke from sugarcane burning causes annoyances to the residents of population centers of the Cauca Valley in Colombia. The most important topics related to this agricultural practice that are presented include: the technology, the different types of information required, the climatological and statistical data on the wind's behavior, the procedures to obtain all this information, and the steps to apply it.

## **Introduction**

For the last 30 years, since the Colombian sugar industry began the practice of burning the sugarcane prior to harvesting, the "sweet" sector of the Colombian economy has been facing an environmental and social problem. The burning of the cane harvest results in pieces of ash being dispersed and transported in the air by the wind and then falling to the ground, causing annoyances to the residents of the population centers in the Cauca Valley (Figure 1). Wind-blown smoke further complicated this problem in population centers.

## **Classification of the ash**



**Figure 1. Classification of the ash**

Figure 1. Wind-blown smoke in the Cauca Valley.

In view of the need to solve this problem, the Colombian sugar industry, located in the Valley of the Cauca River, acquired and installed an Automated Weather Network (AWN), which the Colombian Sugarcane Research Centre (CENICAÑA) has operated and administered since September 1993. At present there are 28 weather stations. The most immediate objective of this network, aside from the usual meteorological observations in the short-, intermediate-, and long-term, is to use the system as a technological tool to minimize the negative effect of the ash fallout in the population centers located in the area of influence of the sugarcane crop.

In order to accomplish that goal, CENICAÑA designed a set of procedures for managing the cane burning, based on using different kinds of information: geographical, climatological and meteorological. CENICAÑA has implemented several training events on such procedures for sugar mill employees. These procedures have been called "Meteorological monitoring of sugarcane burning."

### **Meteorological Monitoring of Sugarcane Burning**

This monitoring consists of programming steps and carrying out the burning of the sugarcane in accordance with the appropriate atmospheric conditions, both climate and weather. Thus, if either climate or weather conditions are not conducive for burning, appropriate adjustments are made and the decision to burn is delayed.

This should be obvious, considering that practically everything involved in a burn is found or occurs in the atmosphere: the crop, the ignition, the combustion, the appearance of by-products of this last process (pieces of ash, smoke, some gases, and particulate matter), the rising into the air and later dispersion, transportation, and suspension or fallout of such products. Consequently, these conditions are the primary determinants of the form, size, quantity and other properties, as well as, the behavior and course that the generated products take during or after the burning.

The main objective of the meteorological monitoring of the sugarcane burn is to minimize, whenever possible, the number of events in which the ash fallout occurs on urban centers and other protected areas, to prevent annoyances for the residents of these centers as well as complaints to the environmental authorities.

### **Pilot Project for Management of Sugarcane Burning**

In order to learn from experience and to improve everything related to the meteorological monitoring of sugarcane burning, CENICAÑA and the Colombian Sugarcane Growers Association (ASOCANA) entered into an agreement with the Regional Development Corporation for the Cauca Valley (CVC). The agreement was to implement a pilot project for managing the sugarcane burns by the mills in the area of Palmira, Rozo, and the regional International Airport, using information supplied by the stations of the Colombian sugar industry's AWN.

This pilot project began in July of 1996 under the supervision of a "burns inspector," contracted by the sugar industry. After four months, the information collected to date was analyzed. Two studies were conducted. First, the total number of controlled sugarcane burns was analyzed. These were programmed and carried out in the pilot project zone during that period, using the meteorological monitoring scheme (1,094 events). In the second study, the total number of sugarcane fires was reviewed. These were accidental burns and thus not programmed or controlled meteorologically, which occurred in the same area during the same period (124 events). The number of times that the controlled burns produced ash fallout in the urban areas of Palmira, Rozo, or on the grounds of the regional International Airport (54 events), and the number of times that fires or "accidental burns" produced the same effect (16 events) were also compared (Figure 2).

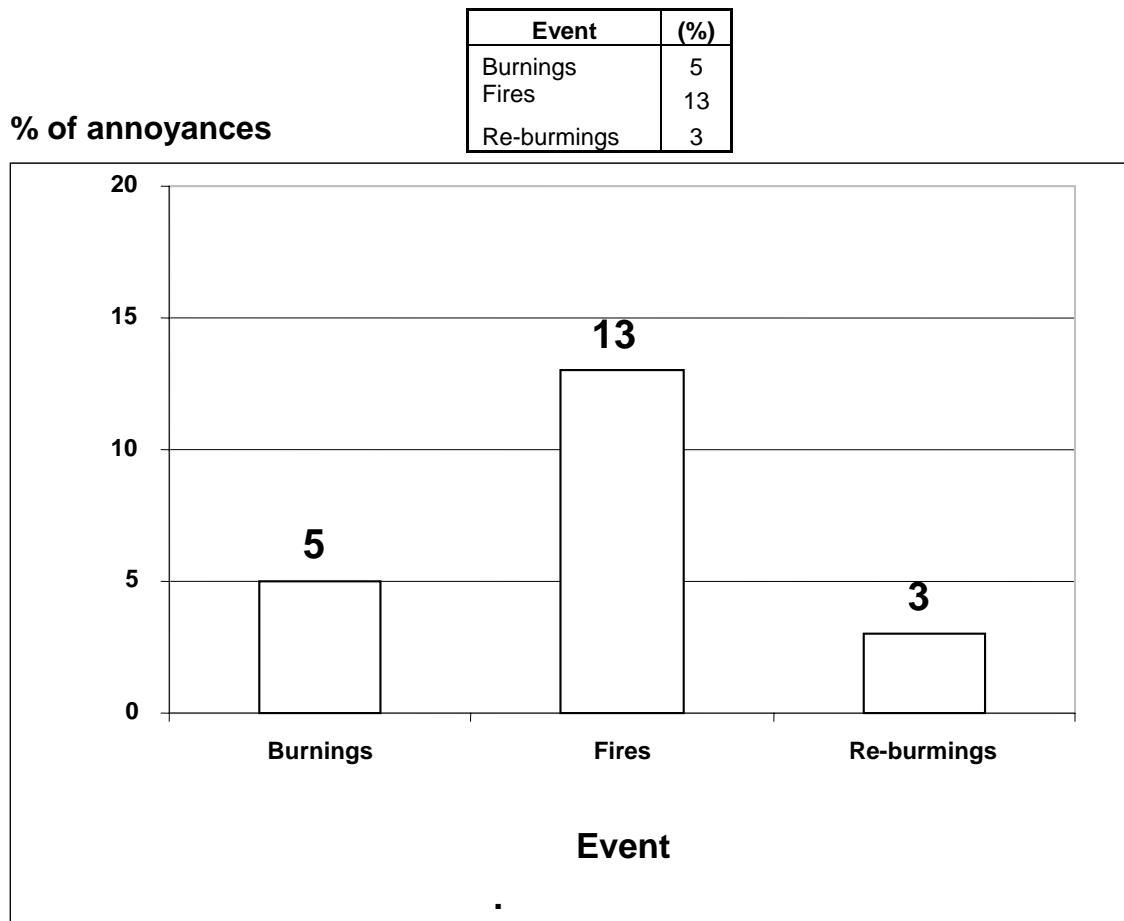


Figure 2. Percent of annoyances generated by different events.

This figure shows that of all the controlled sugarcane burns that occurred in the pilot project area during those 4 months, ashes fell in zones to be protected in only 5 percent of the cases, while in the case of fires or accidental burns (uncontrolled), the same effect was produced in 13 percent of the cases. The percentage of annoyances caused due to ash fallout originating in controlled burns constituted less than 40 percent of the annoyances caused by fires or accidental burns (uncontrolled).

There was a significant decrease in the number of annoyances caused by controlled sugarcane burns as compared to the number caused by accidental fires or uncontrolled burns. This decrease of more than 60 percent is evidently related to the use of climatological and meteorological information for programming and carrying out the burns.

In order to carry out the meteorological monitoring, three factors are required: 1) properly trained technicians, who must have good knowledge of the surrounding areas, as well as the matter of burning; 2) an adequate technology that responds to specific technical requirements; and, 3) geographical, climatological, and meteorological information.

## **Technology**

The appropriate technology for meteorological monitoring is provided by the AWN of the Colombian sugar industry. The AWN operates in the flatlands of the Cauca River Valley in southwestern Colombia. It covers an area of about 400,000 hectares, of which some 200,000 are planted to sugarcane. The AWN began operating in September 1993. Initially, there were 12 meteorological stations, 2 radio frequency-repeating stations, and 1 base station, located at CENICAÑA. There have been four expansions. Since November 2001, there are 29 meteorological stations, each of which has a given area of influence (Figures 3 and 4).



Figure 3. Automated weather station.

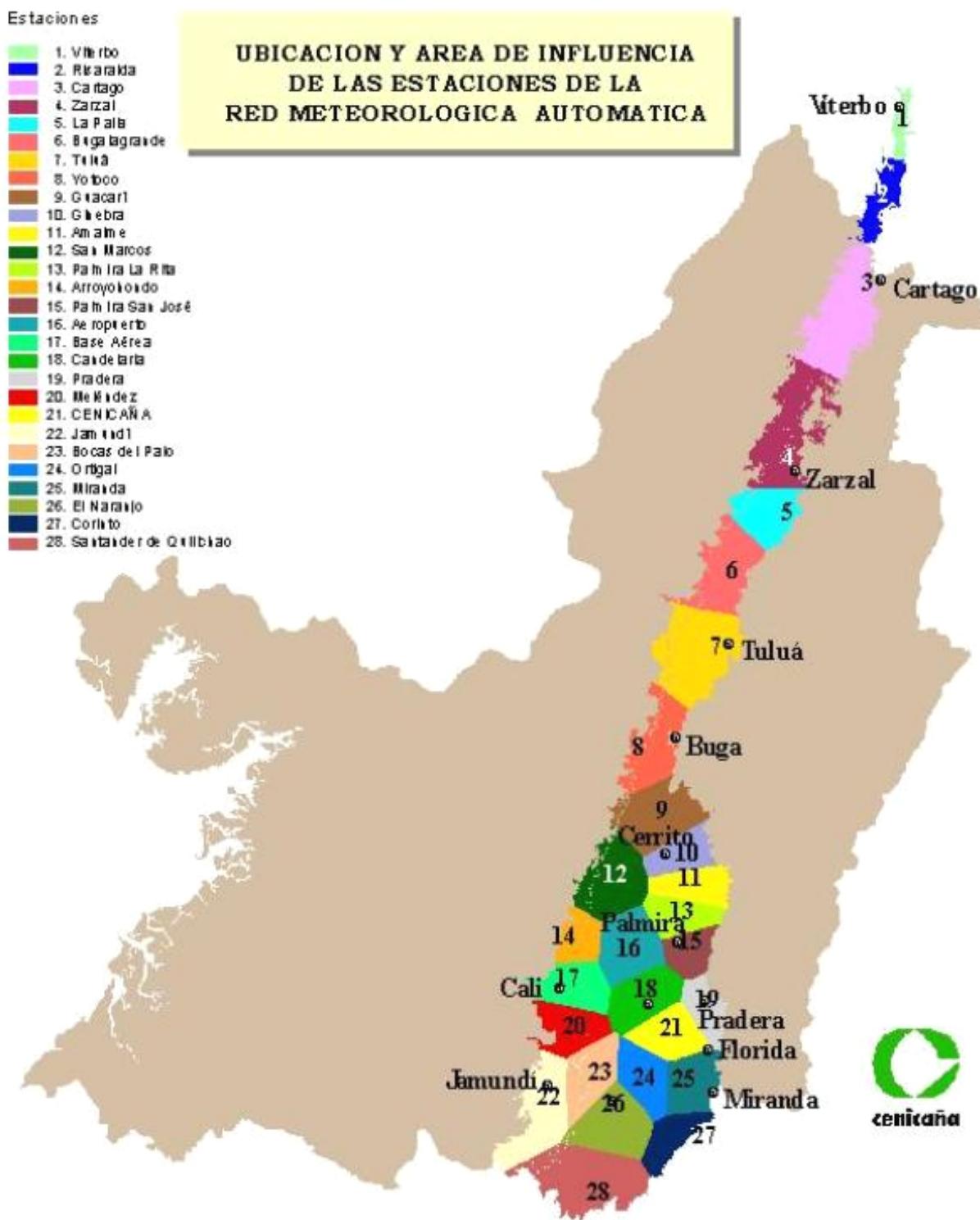


Figure 4. Map of the 29 automated weather stations in Cauca Valley.

CENICAÑA administers, operates, and maintains the AWN on behalf of the Colombian sugar industry. In addition, it provides technical support on the use of this technology and on the management and interpretation of the information that is supplied. The owners of the AWN are the sugar mills in the region, which, together with the cane growers, constitute the principal users of the data generated by the Network. In addition to these users, the information is widely used, generally through bilateral agreements, by universities, governmental entities, and individuals as well.

The AWN is cutting-edge technology, which in comparison to conventional networks has remarkable advantages. For example, the AWN has the very high frequency and precision of the measurements, and is easy to install, operate, and maintain. AWN is highly resistant to harsh weather and universally compatible with many instruments and equipment.

Nevertheless, the most outstanding advantage of this technology for the Colombian sugar industry lies in the fact that data in real time (instantaneous) can be obtained and used through the system of telemetry and radio communications, which is a requisite of the technology to be used to carry out the meteorological monitoring of the burnings.

All the meteorological stations of the AWN measure the following atmospheric variables: temperatures of the air (minimum, mean, maximum); fluctuation of the temperature; relative moisture; rainfall; solar radiation; wind direction and speed; maximum winds or gusts; and, variability of wind direction. For each of these variables records are generated hourly and daily. Sunshine is also recorded at four stations with automated electronic sensors.

It is worth highlighting the Network's capacity for the permanent measurement and recording of the two atmospheric variables, wind and solar radiation, on an hourly and daily basis by all the AWN stations, given that these data are rarely recorded in the region or in the country, as well as in many parts of the world.

Given their configuration, programming and operation, all the AWN stations have the capacity to supply at any time, via radio, instantaneous meteorological data for any atmospheric variable. Naturally, these are raw data that have not been processed or verified, having been obtained directly from the meteorological stations.

## **Geographical Information**

The geographical information used for this monitoring can be found in a wide range of maps and plans, which are available to the mills and cane plantations. This information is practically invariable unless new lands are put under cane production or are withdrawn from this activity. These documents show the location where the cane plantations and mill lots, cities and population centers, airports and main roads, as well as the weather stations of the sugar industry's AWN. For purposes of the meteorological monitoring of the sugarcane burns, what most matters is the *relative location* between plantations or lots, population centers, airports and roads, and weather stations.

The geographical information is basically used for two purposes: 1) to determine from which meteorological station(s) the data should be obtained for monitoring sugarcane burns in a given plantation, lot, or group of lots; and, 2) to determine the "favorable" ("permitted"), "unfavorable" ("forbidden"), and "risky" ("requiring precautions") wind directions for each plantation, lot, or group of lots with respect to the possibility of ash fallout or the presence of smoke in population centers, airports, and roads, if a burning is to be done in those places.

## **Climatological information**

The climatological information can be found by consulting the database of the automated weather network or in different publications and studies of a climatological type. This information, which is primarily statistical in nature, contains the trends or patterns of behavior for the different atmospheric variables in the long term for each of the areas of

influence of the weather stations in the network and is represented by means of climatic variables. Given their nature, these data vary only slightly on a time scale of at least tens or even hundreds of years.

In the meteorological monitoring of sugarcane burning, basically the climatological data on the behavior of the winds are used, which can be obtained in the Detailed Study of the Wind in the Cauca Valley, which CENICAÑA has been carrying out and maintaining up to date. Thus, for the area of influence of each station of the sugar industry's AWN, data can be obtained on the most and least frequent wind directions for every hour of the day ("prevalent winds"), average wind speed hour by hour during the day, maximum periods and the variability of the wind direction, how these same three parameters behave under different wind directions, as well as the compass card or wind rose (percent distribution of the occurrence of the different wind directions in the long term).

The climatological information, in particular that of the wind, is used to program the burns of the cane crop, seeking to adjust the trends in different zones in order to carry out the burns effectively (without having to change the decision to do so) and without affecting the protected areas with ash fallout.

### **Detailed Study of the Winds for Cauca Valley**

To ensure that the monitoring of the sugarcane burning is an effective tool in the task of minimizing the social and environmental impact, it is necessary to know the specifics of the wind's behavior in each site susceptible to burning as well as in the surrounding zone. Such knowledge includes the long-term trends of wind direction and speed (climatic information), as well as its variation in real time (meteorological information). Only then can the principal objective of such monitoring be achieved.

The main objective of this study was to determine the climatic regime of the wind; that is, the long-term trends and other details of wind behavior in the sugarcane-growing area of influence. Another general objective of this research was to supply the Colombian sugar industry with data, information, and analyses on the behavior of the wind, which, when applied to the management of the cane crop, can improve its productivity, profitability, and competitiveness

In this research, for each of the 28 weather stations involved, the following products, that constitute climatological information, were obtained:

- Most and least frequent winds for each hour of the day;
- Compass Card (Wind Rose) for each hour of the day (Figure 5);
- Periods of 6 and 3 continuous hours of greatest and least occurrence of the different wind directions during the day;
- Hourly frequency of incidence of each of the wind directions (16) (Figure 6);
- Distribution by hours of the mean wind speed, the maximum wind speed (gusts), and the mean variability of wind direction;
- Distribution by directions of the mean wind speed, the maximum wind speed (gusts) and the mean variability of wind direction; and,
- Overall Compass Card (Wind Rose) for the entire period analyzed (Figure 7).

CENICAÑA AUTOMATED WEATHER NETWORK OF THE COLOMBIAN SUGAR INDUSTRY			DETAILED STUDY OF THE WIND CAUCA VALLEY - COLOMBIA							FOR THE	
			STATION : RISARALDA			LATITUD : 04° 54' 43" N LONGITUD : 75° 54' 07" W					
			PERIOD : SEP/93 - ABR/97			ALTITUD : 900 m s n m					
LESS FREQUENT WINDS					MORE FREQUENT WINDS						
HOUR	BLOWING FROM	FREQ. ( % )	MEAN DIRECTION	TURN	HOUR	BLOWING FROM	FREQ. ( % )	MEAN DIRECTION	TURN		
00 - 01	SW - NW	14	W	1	00 - 01	NNW - ENE	63	NNE		1	
01 - 02	SW - NW	12	W		01 - 02	NNW - ENE	67	NNE			
02 - 03	SW - NW	14	W		02 - 03	NNW - ENE	66	NNE			
03 - 04	SW - NW	14	W		03 - 04	NNW - ENE	66	NNE			
04 - 05	SW - NW	14	W		04 - 05	NNW - ENE	65	NNE			
05 - 06	SW - NW	11	W		05 - 06	NNW - ENE	69	NNE			
06 - 07	SW - NW	12	W		06 - 07	NNW - ENE	66	NNE			
07 - 08	SW - NW	6	W		07 - 08	N - E	70	NE	2		
08 - 09	SW - NW	6	W		08 - 09	NNE - ESE	62	ENE	3		
09 - 10	WSW - NNW	6	WNW	2	09 - 10	E - S	51	SE	4		
10 - 11	WSW - NNW	7	WNW		10 - 11	ESE - SSW	62	SSE	5		
11 - 12	WSW - NNW	7	WNW		11 - 12	ESE - SSW	63	SSE			
12 - 13	WSW - NNW	7	WNW		12 - 13	ESE - SSW	66	SSE			
13 - 14	WSW - NNW	9	WNW		13 - 14	ESE - SSW	64	SSE			
14 - 15	WSW - NNW	10	WNW		14 - 15	ESE - SSW	64	SSE			
15 - 16	WSW - NNW	13	WNW		15 - 16	SE - SW	56	S	6		
16 - 17	WSW - NNW	20	WNW		16 - 17	SE - SW	46	S			
17 - 18	ENE - SSE	15	ESE	3	17 - 18	NW - NE	53	N	7		
18 - 19	ENE - SSE	13	ESE		18 - 19	NW - NE	64	N			
19 - 20	ENE - SSE	14	ESE		19 - 20	NW - NE	63	N			
20 - 21	ENE - SSE	12	ESE		20 - 21	NW - NE	58	N			
21 - 22	ENE - SSE	15	ESE		21 - 22	NW - NE	58	N			
22 - 23	SW - NW	20	W	1	22 - 23	NNW - ENE	56	NNE		1	
23 - 00	SW - NW	14	W		23 - 00	NNW - ENE	63	NNE			

Table 1. Detailed study of the wind for the Cauca Valley – Colombia.

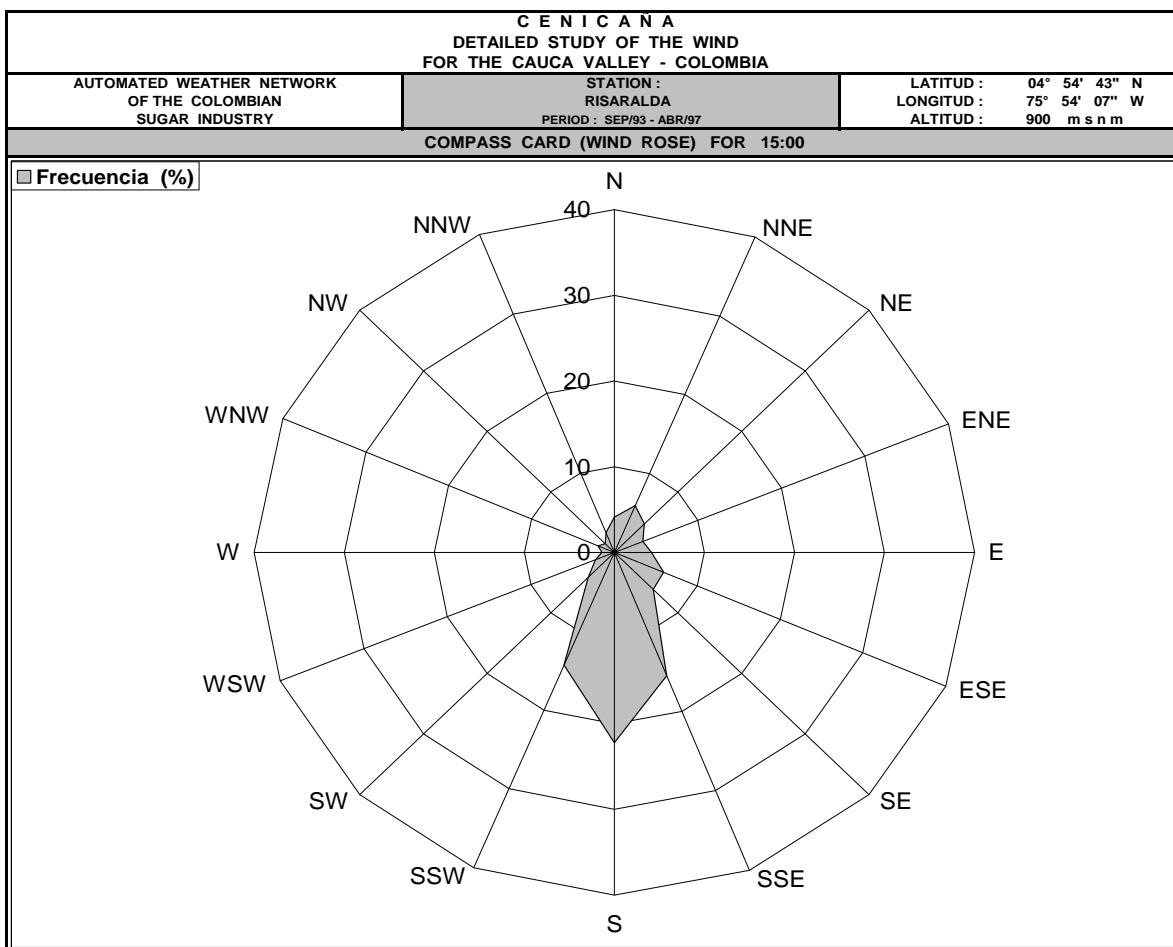


Figure 5. CENICAÑA – Automated weather network.

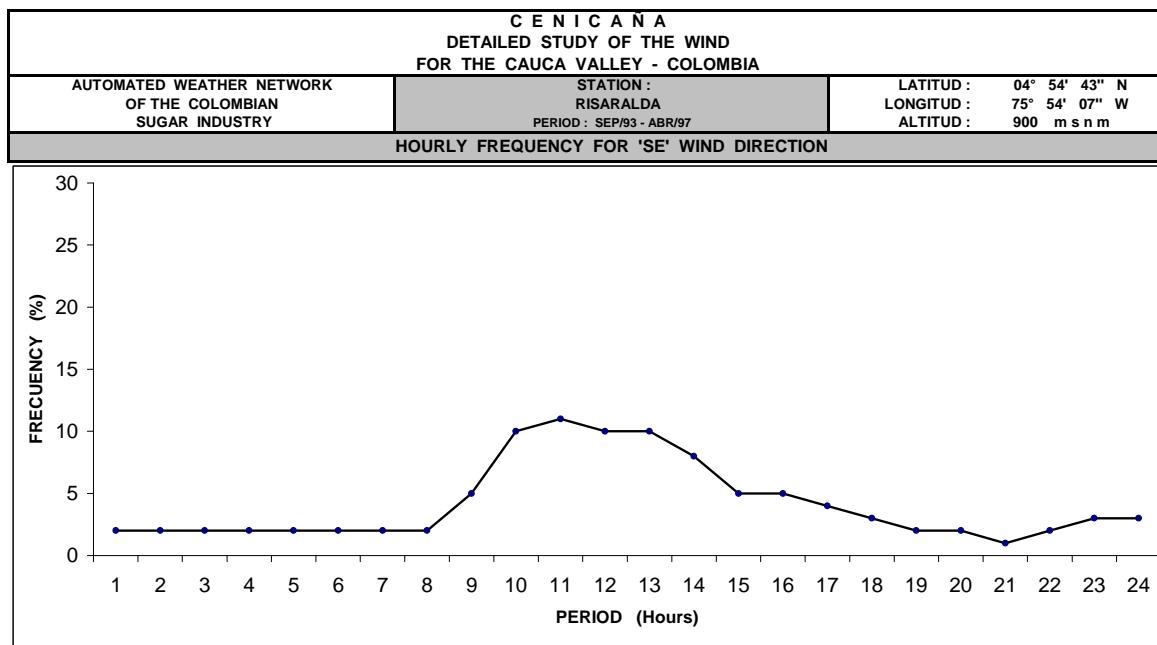


Figure 6. Hourly frequency for SE wind direction.

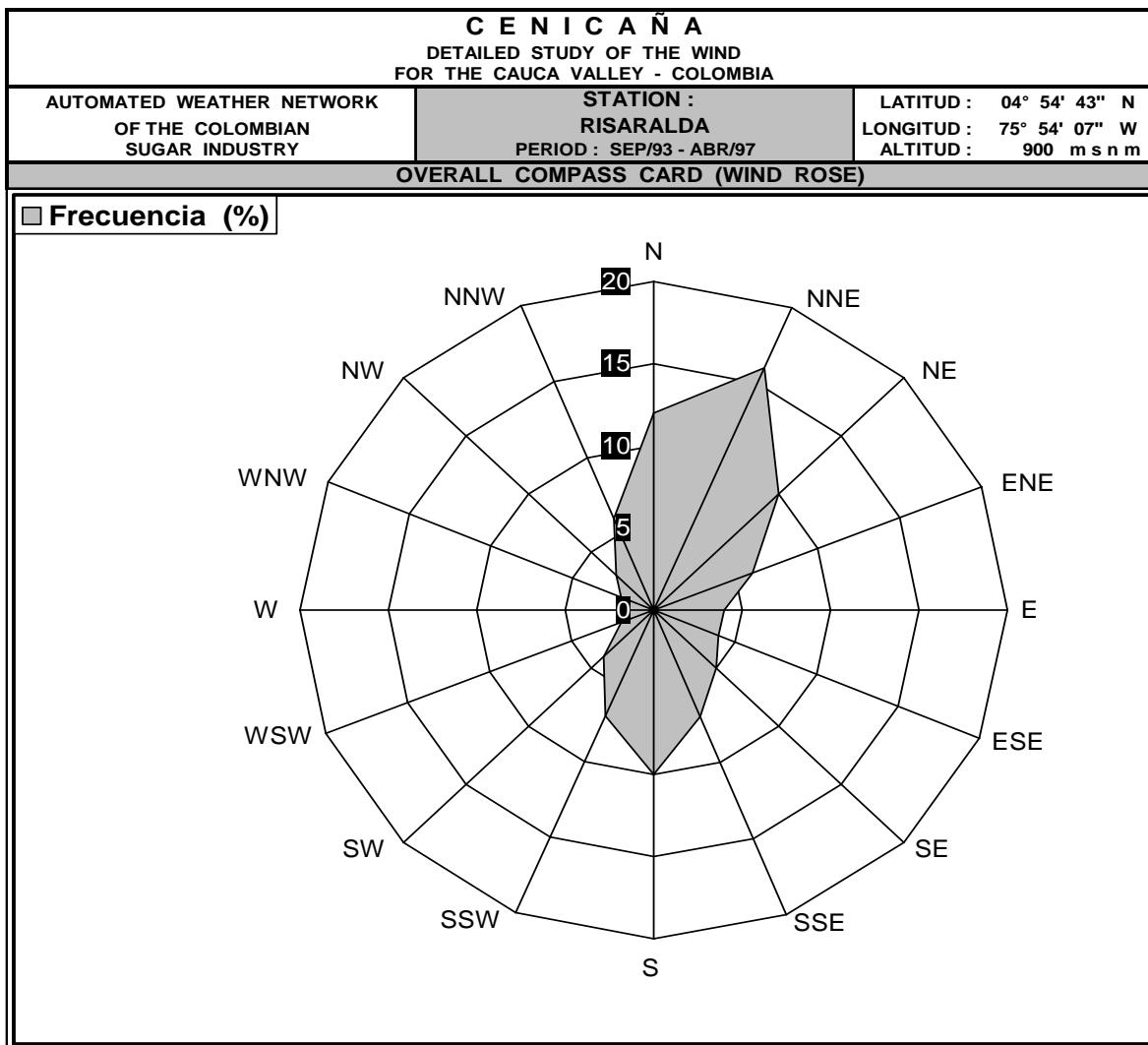


Figure 7. Overall compass card (wind rose).

### Meteorological Information

Meteorological information can be obtained by three different routes: 1) by consulting in the database of the automated weather network hourly and/or daily data; 2) through "direct" communication with the weather station(s) via radio in order to find out the current atmospheric conditions in the zone where the burning is going to be done; and, 3) by measuring, with the help of portable sensors, the wind's direction, speed, gustiness, and variability directly at the burning site.

All of the means provide the meteorological information in real time. Given the nature of this information, there is great variability as the data are practically instantaneous.

### Conclusion

The application of meteorological information for monitoring sugarcane burns makes it possible to decide whether to burn or not, depending upon whether the prevailing conditions in the place at the time foreseen for the burning so permit, without affecting the areas that are to be protected from ash fallout or smoke presence.

## Glossary

*Protected areas or areas to be protected* are zones where ash fallout or the presence of smoke coming from the sugarcane burning is to be prevented. These areas are primarily cities and population centers in general, airports, and main intercity highways.

*Restricted areas* are those zones where the burns are permitted, but there are some conditions or restrictions (about time, for instance) on carrying out a burn.

*Prohibited areas or areas of no burning* are the zones where legal provisions explicitly prohibit burning. These are essentially the zones adjacent to urban perimeters, the most important being the airports and the intercity highways.

*A favorable or permitted wind direction* is one in which burning can be done at a particular site with only a slight probability of ash fallout in a given area that is to be protected precisely against this event.

*An unfavorable or prohibited wind direction* is one in which, if the cane is burned in a certain place, there is a high probability of affecting a protected area with ash fallout.

*A risky wind direction or a direction requiring precautions is a direction* in which, at first glance, there may appear to be no major risk of causing ash fallout in a protected zone, but due to normal changes (not sudden and abrupt) in the direction of the wind, ash fallout could occur.

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## **Workshop Evaluation**

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### **Introduction**

The Inter-Regional Workshop on Strengthening Operational Agrometeorological Services was co-sponsored by the World Meteorological Organization (WMO), the Food and Agriculture Organization (FAO), and the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

The Thirteenth Session of the Commission for Agricultural Meteorology (CAgM-XIII) of WMO held in October 2002 in Slovenia considered the need to improve agrometeorological services to increase agricultural production and to conserve the environment and identified this aspect as one of three priority areas to be addressed during 2004-2007. This Inter-Regional Workshop was organized in response to the recommendation of CAgM-XIII with the objective of evaluating how the National Meteorological and Hydrological Services (NMHSs) provide operational agrometeorological services to the various user communities at the national levels, identifying shortcomings and limitations, assessing how the organizational structures of the National Services and their links with other government agencies can be adopted in the most cost-effective manner to serve the needs of the customers, and formulating an effective strategy to build the capacity of the NMHSs in the different WMO regions to strengthen their operational agrometeorological services.

Twenty eight participants from 19 countries, including 4 from the Philippines, attended the workshop.

### **Format for the Inter-Regional Workshop**

The workshop programme consisted of eight technical sessions. The first three sessions presented perspectives on operational agrometeorological services currently being provided at the national and regional levels and the international perspectives. This was followed by two sessions focusing on a critical review of strengthening operational agrometeorological services and needs from the agricultural sector.

The final three sessions of the workshop were devoted to three brainstorming sessions involving all the participants in a target-oriented interactive session format. In the first session, the critical issues in strengthening operational agrometeorological services were identified. This was followed by an interactive session in prioritizing the issues. Finally, recommendations were drawn on addressing the priority issues.

### **Workshop evaluation**

In order to facilitate the evaluation of the workshop and help obtain feedback from the participants, an evaluation form was circulated on the final day. A summary of participant evaluation of the workshop is shown in the following table. About 90 percent of the participants felt that the program met the expressed objectives of the workshop. The quality of the workshop program was rated by 100 percent of the participants as being very good to good. Forty-five percent of the participants rated the workshop as excellent, while 50 percent rated it as very successful.

**Summary of Workshop Evaluation**  
**(Responses given in percentage of the total participants (20)**  
**responding to the evaluation form)**

QUESTION	Very well met/very relevant/very good/excellent	Fully met/relevant/good/very successful	Nearly met/adequate/successful	Yes/fair	No/not met/inadequate/poor	No response
1. Did the programme meet the expressed objectives?	70	20	10	-	0	0
2. Will the knowledge acquired help you contribute more effectively to your Service?	-	-	-	100	0	0
3. How relevant was the programme to your work?	65	35	0	-	0	0
4. Did you receive advice relevant to your work?	-	-	-	90	10	0
5. Did you have any language difficulties?	-	-	-	30	70	0
6. Quality of pre-workshop information?	50	50	0	-	0	0
7. Quality of service received from UNDP/WMO regarding the travel arrangements?	60	20	15	-	5	0
8. Quality of WMO assistance?	75	25	0	-	0	0
9. Quality of assistance received on arrival in Manila	65	25	10	-	0	0
10. Quality of workshop programme?	85	15	0	-	0	0
11. Was duration of programme adequate?	-	-	-	95	5	0
12. Do you have any suggestions for future workshops of this nature?	-	-	-	35	60	5
13. How would you rate the overall events?	45	50	5	-	0	0
14. Did you encounter any problems with regard to travel arrangements, stipend payments, accommodation arrangements, etc.?	-	-	-	30	70	0

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