Available online at www.sciencedirect.com

ScienceDirect

Procedia Environmental Sciences 1 (2010) 37–54

Procedia Environmental Sciences

Health and climate – opportunities

D.P. Rogers[a,*], M.A. Shapiro[b], G. Brunet[c], J-C. Cohen[d], S.J. Connor[e], A.A. Diallo[f], W. Elliott[g], K. Haidong[h], S. Hales[i], D. Hemming[g], I. Jeanne[j], M. Lafaye[k], Z. Mumba[f], N. Raholijao[l], F. Rakotomanana[m], H. Teka[n], J. Trtanj[o], and P.-Y. Whung[p]

[a] *Health and Climate Foundation, Washington DC, United States*
[b] *National Center for Atmospheric Research, Boulder, Colorado, United States*
[c] *Environnement Canada, Dorval, Québec, Canada*
[d] *Météo France, Paris, France*
[e] *International Research Institute for Climate and Society, Palisades, New York, United States*
[f] *African Centre for Meteorological Applications for Development, Niamey, Niger*
[g] *Met Office, Exeter, United Kingdom*
[h] *School of Public Health, Fudan University, Shanghai, China*
[i] *World Health Organization, Geneva, Switzerland*
[j] *Formerly Centre de Recherche Médicale et Sanitaire, Niamey, Niger*
[k] *Centre National D'Etudes Spatiales, Toulouse, France*
[l] *National Meteorological Office, Antanarivo, Madagascar*
[m] *Unité Epidémiologie, Institut Pasteur, Antanarivo, Madagascar*
[n] *Climate and Health Working Group, Addis Ababa, Ethiopia*
[o] *National Ocean Service, NOAA, Silver Spring, Maryland, United States*
[p] *US Environmental Protection Agency, Washington DC, United States*

Abstract

While Hippocrates recognized that health is influenced by the external environment, it is only recently that the relationship between health and climate has become a focus of community and public health services. Advances in understanding of weather and climate sciences on the one hand and human health on the other are providing new opportunities for early detection, prediction and prevention of the adverse health effects of hazards as diverse as tropical cyclones, floods, heatwaves and cold spells, air quality, wildfires, droughts and disease epidemics. Early warning of disease outbreaks and a timely response makes prevention possible. For some climate-sensitive diseases, our understanding is sufficient to make health forecasting possible; for others, the relationship between the disease and any causal environmental effect remains unclear, and the focus of active research programs. Institutional changes are also taking place to improve operational and research cooperation between the health sector and the weather and climate communities, ranging from joint service delivery platforms to combined research and development programs.

Keywords: Weather and climate prediction; observations; climate anomalies; heat, health and air quality warnings; public service platform

1. Introduction

Good health is one of the primary aspirations of human social development. Consequently, health indicators are key components of human development indices – for example, in the United Nations Millennium Development Goals (MDGs), by which we measure progress toward sustainable development [1]. Health is influenced by environmental, seasonal and climatic conditions. While Hippocrates recognized this, it is only recently that climate and health interactions have become a focus of community and public health services.

The international community is now exploring and advocating for strategies to address the climate risks to health as a means to protect and further development gains. This was recognized by the World Health Organization (WHO) in the 2008 World Health Day "Protecting Health from Climate Change" [2], and in the recent resolution on climate and health of the sixty-first World Health Assembly [3]. This resolution built on previous efforts, including that of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report and a growing collection of documentation commissioned by WHO, the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the Food and Agriculture Organization of the United Nations (FAO) [4][5][6][7].

* Corresponding author. Tel: +41-22-3682103
E-mail address: drogers@bluewin.ch

doi:10.1016/j.proenv.2010.09.005

Climate influences health through a number of mechanisms. This impact may be direct, through cold or heat stress, or indirect via impacts on natural systems. Climate and weather extremes cause floods, drought, food insecurity, social disruption and population displacement, and favour communicable diseases [8]. The World Health Organization identifies 14 major climate-sensitive communicable diseases, including malaria, meningitis, cholera and dengue, and acknowledges that many non-communicable coronary and respiratory diseases are also climate-sensitive.

The World Health Organization advocates the development of climate-informed early warning systems for certain climate-related health hazards. Improving routine health surveillance and detection is essential, and the opportunities now exist to create more effective partnerships to integrate climate factors effectively. Achieving this depends on the explicit involvement of WHO in global initiatives aimed at improving the well-being of societies through improved access to climate information and services, and in particular in the opportunity to develop further global, regional and national climate services for the public health sector.

This paper describes advances and selected critical uncertainties in weather and climate prediction relevant to the health sector. New opportunities exist for public health professionals to integrate weather and climate-related information into local and regional risk management plans to reduce the detrimental health effects of hazards, including hazards as diverse as tropical cyclones, floods, heatwaves and cold spells, smog, wildfires, droughts and communicable disease epidemics [9][10]. In addition, tele-epidemiology, a new conceptual approach using remote sensing, is an opportunity to provide users with innovative and tailored products [11].

On the national level, public service platforms for early warning can encourage cross-sectoral interaction. At the same time, research and training opportunities exist across all relevant disciplines. Taking advantage of these opportunities will make climate and other environmental information more accessible and operationally useful within public health services.

2. Relevance of climate information for the health sector

There are three primary timescales of interest for decision-making by the health sector: short- to medium-term (<10 days); seasonal; and interannual to decadal.

On a timescale of hours to a few days, decision-making is mostly limited to emergency responses to current and pending near-term disasters that impact the health system infrastructure and its capacity to cope with large numbers of casualties. Here, the health care system can inform those susceptible to aeroallergens, heatwaves and poor air quality to take preventative measures, and can manage hospital and outpatient care effectively. On a timescale of weeks to seasons, predictions provide outlooks for climate-sensitive diseases that are linked to changing environmental conditions, such as vector-borne diseases like malaria and dengue fever, or diseases that increase in severity with the onset of dust in the dry season, such as meningococcal meningitis, and end with the start of the rainy season. This provides an opportunity to plan interventions, such as mobilizing community health workers to raise awareness of health risks in vulnerable communities and to increase the readiness of the health care system to respond to epidemic outbreaks.

Over longer timescales, there is the opportunity to understand how a public health threat may be affected by anticipated climate conditions, and what actions are required to prevent these, while enhancing ecological sustainability. The recognition that climate change, over the long term, increasingly threatens the fundamental prerequisites for health (including food, water and shelter) requires an equally fundamental intersectoral response over decadal time frames.

3. Recent advances and current limitations in weather and climate prediction relevant to the health sector

In the past few decades, we have witnessed major advances in the observation, analysis and prediction of high-impact weather and climate [12][13][14]. Notable improvements have occurred in monitoring and predicting short-term weather hazards, climate variability and change. For example, the accuracy of global five-day forecasts is comparable with that of 2-day forecasts of 25 years ago [12]. Significant advances have also been made on longer timescales and a greater understanding of forecast uncertainties permits more useful seasonal predictions because the user can be informed as to how reliable the forecasts are likely to be [15]. The distinction between weather and climate is also disappearing (Box 1).

3.1. Observations

Reliable, continuous meteorological observations allow farmers to maximize their productivity, improving food security and reducing the risk of malnutrition. Real-time observations improve assessment of climate-sensitive disease risk and allow more timely interventions. They also provide the initial conditions and boundary conditions needed for reliable short- and long-range forecasts. For example, in Ethiopia rainfall and temperature data are beginning to be used routinely to estimate malaria risk [18][19].

Box 1. Seamless prediction: weather and climate boundaries

The traditional distinction between weather and climate is not based on physical boundaries [12][16]. Hurrell et al. [17] show that there is evidence that natural climate variations, such as the El Niño–Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) significantly alter the intensity, track and frequency of hazardous weather, such as extra-tropical and tropical cyclones and associated high-impact weather. Longer-term regional variations have been observed, such as decadal variability in tropical cyclones and multidecadal drought in the Sahel region.

Conversely, small-scale processes have significant up-scale effects on the evolution of the large-scale circulation and the interactions among the components of the global system. A challenge is to improve the prediction of the spatial-temporal continuum of the interactions between weather and climate, bridging the gap between forecasting high-impact events at daily-to-seasonal timescales [16].

These data are obtained from a combination of complementary atmosphere-, terrestrial-, ocean- and space-based observing systems, which contribute to the Global Climate Observing System and partner observing networks, including experimental sensing systems developed for specific climate objectives.

Although many countries have separate weather and climate observing networks, most of the world cannot afford this distinction and depends on a common observing network of basic meteorological parameters. This provides information on real-time changes in the environment and from which longer-term climate trends and anomalies can be detected. It is particularly important to have access to information to guide regional and local climate-sensitive decisions, whether for seasonal malaria outlooks for certain districts or for the likely impacts of floods on certain communities.

Many parts of the world have inadequate ground-based observing networks, despite their importance. The problem is particularly acute in Africa, where the need for an additional 4 000–5 000 basic meteorological observations for specific sector applications (see, for example, IRI, 2007) has been taken up through several related initiatives. For example, the African Union, through Climate for Development in Africa (ClimDev Africa), sponsored jointly by the African Bank for Development, the Commission of the African Union and the United Nations Economic Commission for Africa [20][21] is addressing climate observations, climate services, climate risk management and climate policy needs. In response and in support of the overall objectives of ClimDev Africa, new public–private partnerships have emerged recognizing the synergy between the capacity of the private sector and the information needs of both the public and private sectors. One approach, in its second phase of implementation, is the Weather Info for All (WIFA) initiative. A joint venture of the telecommunications industry, Non-governmental organizations and WMO Members, WIFA aims to fill the gaps in the surface observing network by installing automatic weather stations on cellular phone towers across Africa [22].

Elsewhere, the World Bank, through its Global Facility for Disaster Reduction and Recovery, is developing and implementing initiatives to enhance national observing networks and to improve the services provided by National Meteorological and Hydrological Services.

As we will see in the following sections, where data have been easily exchanged between climate and health practitioners, it is evident that better climate-informed health decisions are possible. However, neither health data nor meteorological observations are always freely available for a variety of reasons, including explicit individual government rules that regulate the exchange of these data.

3.2. Seasonal climate anomalies

The physical basis for seasonal climate prediction lies in the slowly varying components of climate compared with weather events [15]. El Niño is the best known phenomenon with predictability on the seasonal timescale.

Modelling and predicting seasonal climate anomalies requires a realistic representation of the sea-surface temperature (SST), sea ice, snow, soil wetness, vegetation, stratospheric processes and chemical composition, as they are major forcing processes at seasonal and longer timescales. Sub-seasonal and seasonal predictions must also capture statistical characteristics of day-to-day weather fluctuations.

Current operational predictions of the El Niño Southern Oscillation (ENSO) indicate that coupled models give useful guidance as to the future evolution of SST up to six months in advance. However, there are important gaps due in part to large systematic errors, most notably in the equatorial Atlantic. Semi-empirical approaches, which compensate for model imperfections in Ensemble Prediction Systems (EPSs) and Multi-model Ensemble Prediction Systems (MEPSs), are used to improve the individual parameterizations ([17]; Box 2).

Box 2. Ensemble prediction systems

Ensemble prediction systems (EPSs) combine multiple simulations for specific verification times beyond one week. Multi-model Ensemble Prediction Systems (MEPSs) provide the most robust predictions. This is particularly relevant for seasonal climate predictions, because of the uncertainty in the model equations themselves, where the process of parameterizing sub-grid scale motions in weather and climate models is not precise.

It is not a trivial task to post-process model output because of the complexity of weather, air quality and climate systems. Efforts have mostly focused on Model Output Systems (MOS) that are very useful, but limited because the skill and uncertainty of weather, air quality and climate forecasts are highly dependent on space and timescale.

Ensemble Prediction Systems are widely used for weather and climate prediction by operational services because they offer an estimate of the most probable future state of the system and provide an estimate of a range of possible outcomes. The latter is particularly useful from the viewpoint of decision-making, where minimizing risk is more often related to the quantitative estimates of occurrence of high impact events than with the most probable future state.

It is clear that advances in predictability must be intrinsically linked with the applications for which the forecasts are made [15]. Assessing whether predictability exists or not is inherently linked to the applications for which the forecasts are being used. This implies that prediction systems should be developed for particular applications.

Using the European Union-funded project entitled "Development of a European Multimodel Ensemble system for seasonal to inTERannual prediction" (DEMETER), a multimodel EPS experiment of the European Centre for Medium-Range Weather Forecasts (ECMWF) Palmer et al. [23] and Thomson et al. [24] demonstrated the potential of providing reliable seasonal forecasts of malaria prevalence, an effort that may pave the way for additional routine forecasts that have utility for health decisions. This forecast system was successfully applied to the prediction of malaria in Botswana, where links between malaria and seasonal climate variability are well established, adding up to four months lead time over malaria warnings issued with observed precipitation and having a high level of probabilistic skill. This skill has been further developed in the European Union ENSEMBLES project, which has developed an ensemble prediction system for climate change using high-resolution global and regional earth system models [25]. Seasonal forecasts derived from ENSEMBLES are produced at the Southern African Development Communities Drought Monitoring Centre and made available to the Ministry of Health and the WHO Inter-country Support Team for East and Southern Africa for Malaria Control.

3.3. Weather and climate predictions in the tropics

The skill of weather and climate prediction in the tropics continues to be limited because of the present inability to realistically represent the life cycle of equatorial waves and organized convection. These inadequacies compromise the skill of forecasts on timescales of days to weeks and beyond, including projections of climate change. Work is in hand that will improve the representation of organized convection, which in turn will improve the representation of tropical-extra-tropical interactions, which will lead to more skillful prediction of regional-to-global weather and climate [16]. In turn, these advances should translate into improvements in weather and climate information services including health early warning systems in both extra-tropical and tropical latitudes. The latter may be particularly significant because of the preponderance of neglected climate-sensitive tropical diseases.

3.4. Technological advances

Short-term forecast skill has advanced largely because of the capability to assimilate satellite data in numerical models, which, because of the improved global analyses based on these high spectral resolution observations, allows models to provide useful predictions up to ten days ahead [26]. The incorporation of earth observations from space into operational environmental analyses and prediction models is improving the accuracy and utility of weather forecasts and warnings, and improving seasonal-to-interannual climate forecasts. Direct monitoring from space is also important. New capabilities to measure changes in air and water quality, and to map population movements and animal behaviour may have an impact on human health. For example, satellite information is used to track likely plague outbreaks based on surveillance of rodent burrows [27].

Advanced remote-sensing technologies and improved communication infrastructure, coupled with technical training, could significantly improve the capacity of developing countries to access and use advanced tools for environmental analysis and prediction. This will depend on resources for technology transfer and training. It will also depend on developing the necessary organizational structure to integrate the climate service within the relevant user group, in this case, the health sector.

In the past decade, tele-epidemiology, a new approach to monitoring and studying the spread of human and animal infectious diseases, has developed. By combining satellite-originated data on vegetation (SPOT), meteorology (Meteosat, TTRMM), oceanography (Topex/Poseidon, ENVISAT, JASON) and hydrology data, with clinical data from humans and animals, it is now possible to construct predictive mathematical models [28][29].

An example of this approach is the French Ministry of Research Earth-Space Network, a sentinel pilot network of 44 stations, which was deployed by the Centre Recherche Médicale et Sanitaire (CERMES) on behalf of the Ministry of Health of Niger and by the Ministry of Health of Burkina Faso and Institut de Recherche en Sciences de la Santé (IRSS) in Burkina Faso to monitor infectious diseases. In Niger, this system was operational for five years and provided an unprecedented sentinel network. Epidemiological and hydrometeorological data collected weekly permitted outbreaks to be tracked and enabled a large knowledge base to be built. Combined with human and entomological field data for one part and with remote-sensing data for the other part, this database is enabling research on new bioclimatic areas of malaria patterns, which is the first step before being able to use climate forecasts to predict and then hopefully prevent malaria epidemics.

This integrated and multidisciplinary approach of tele-epidemiology includes the monitoring and assembling of multidisciplinary in situ datasets to extract and identify physical mechanisms. Remote sensing enables the monitoring of the climate and environment, which can be linked to epidemics through factors such as rainfall, vegetation, hydrology, and population dynamics and the use of bio-mathematical models for epidemics dynamics, vectors aggressiveness and associated risks.

4. Predictive modelling of health

Over recent years there have been significant developments in understanding and then predicting the impacts of weather and climate on human health. These developments are very different from the more traditional type of weather warnings that are issued by the national weather services such as heatwave warnings through the media and Websites. The pressure to broaden and enhance the offering of health warnings comes from:

(a) The need for policymakers to understand future changes to the environment and the impact of these changes;

(b) The need to make health care systems more effective and efficient, particularly against the backdrop of the rising cost of health care provision;

(c) The move to inform and therefore better protect populations from the impacts of the environment;

(d) The prospect of a rapidly changing climate.

The move has been assisted by the availability of detailed health information, enabling the use of statistical techniques to correlate with weather and other environmental data. Cross-referencing general practitioner and hospital admission data with environmental factors such as the weather, allows the impact of these factors on human health to be examined and better understood. Another important factor is the emergence of technologies to deliver information at the right time to the right people.

Hence there is increased awareness of the role modelling and prediction can play in improving health care systems and even the health of individuals. By better understanding the requirements of individuals and knowing how health care can be tailored to suit these groups, we can move away from standard provision of health care to a more customized approach. Understanding the risks that certain groups within a population (for example, older people, the young or those with defined conditions) are exposed to at certain times, we can help keep people well and reduce their need for health care.

Predictive modelling has traditionally focused on large-scale models across populations to achieve better organization and distribution of health care. More recently, significant improvements have been made to models and techniques that downscale weather and climate predictions to local scales that are more appropriate for adaptation planning. Furthermore, certain groups are developing rule-based models that can provide more explicit exposure to risk for individuals.

Over the last five years, the Met Office has worked with the United Kingdom National Health Service to develop a "Health Forecasting Service". The project has developed and now delivers bespoke health forecasts to health care providers and individuals with certain conditions such as chronic obstructive pulmonary disease (COPD) and seasonal affective disorder. These forecasts have as their basis the relationship between certain weather conditions and their effects on human health. The service predicts periods of increased risk to the individual and, using appropriate channels of communication, targets the individual at the right time to elicit a response. Simple, anticipatory care measures such as gentle exercise, monitoring and keeping rooms at the right temperature, the use of light boxes and other simple measures help keep the individual well and reduce the need to access expensive health care. There are several applications of these techniques and enthusiasm among the clinical community is growing swiftly.

In terms of longer-term health planning, the Met Office Hadley Centre is conducting research to understand the impacts that climate change is likely to have on key aspects of human health worldwide, including changing risks of heat stress, air pollution, wild fires and extreme climate events such as floods, droughts and storms. Decision tools are also being developed to help health planners choose suitable options to adapt to and mitigate changes in health risks over the next decades. Figure 1 is a schematic of one such tool, a ”Bayesian network” model, which has been developed to model the complex interactions between key factors influencing COPD admissions to specific United Kingdom hospitals. Decision-makers can use these tools to explore the relative merits of different planning options in order to optimize the use of available resources.

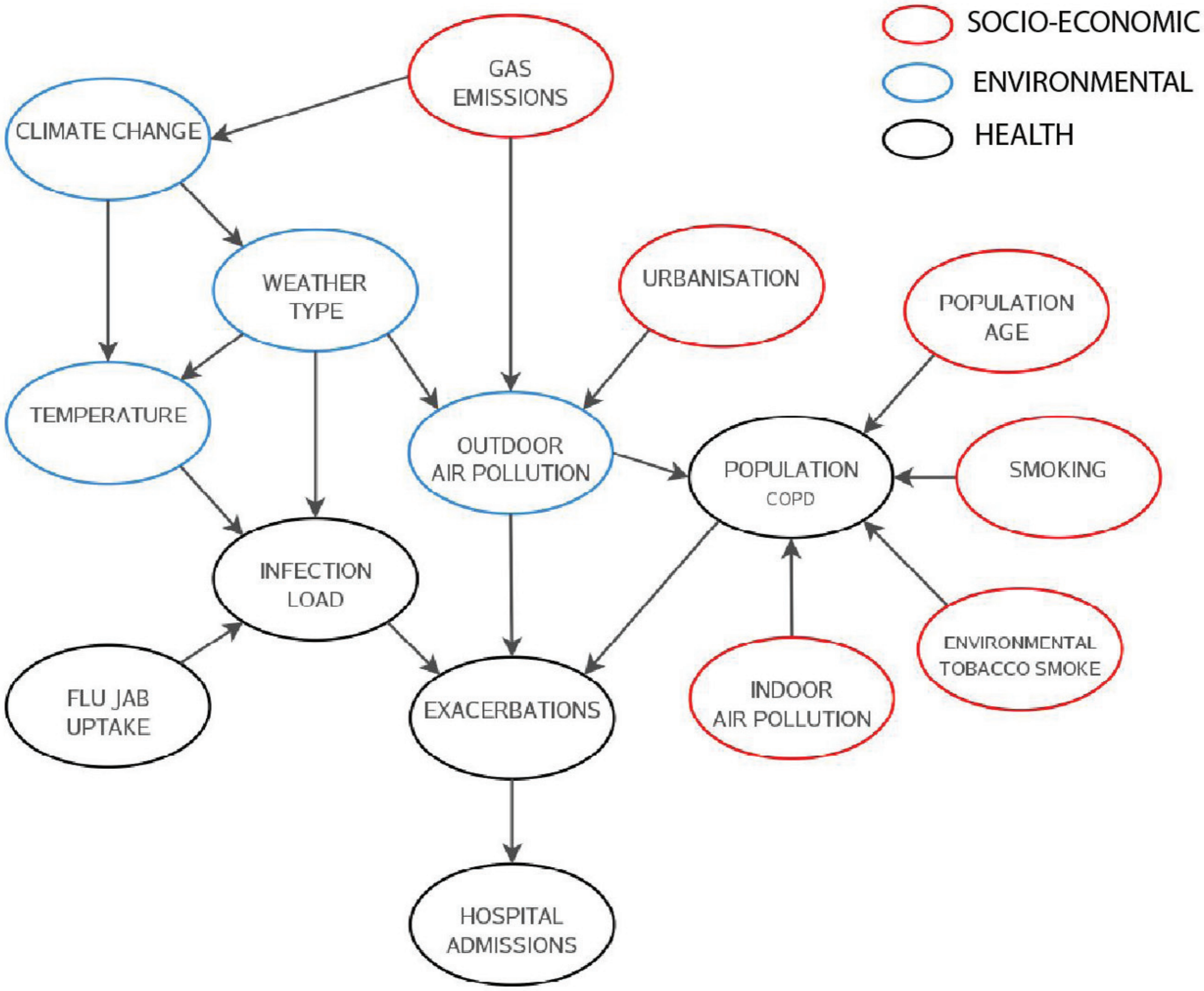

Figure 1. A schematic representation of possible factors influencing COPD patients in the United Kingdom

The information in Figure 1 can be encoded in a Bayesian network, a statistical model that allows testing of the relative importance of each factor, as well as predictions of the health implications of changes in any factor.

5. The evolution of warning systems

5.1. From climate outlooks to health warnings

The Climate Information and Prediction Services (CLIPS), a component of the WMO World Climate Programme, working together with World Climate Research Program experts, has been a driving force for developing seasonal climate prediction in Africa. One of the most significant results of these efforts is the establishment of the Regional Climate Outlook Forums (RCOFs), the first of which took place in 1996 in Zimbabwe and has now spread beyond Africa to other regions [30].

At the RCOFs, representatives of the national meteorological services are involved in developing an authoritative seasonal outlook for the region using a predominantly consensus-based approach, which they disseminate within their own countries. The concerned governmental agencies and other decision-makers then make use of the outlooks nationally and locally, particularly in the agriculture, water, energy and health sectors.

Regional Climate Centers are a relatively new component in the development of regional climate predictions, which are responsible for providing support to National Meteorological and Hydrological Services (NMHSs) to strengthen their climate information and prediction services. These will also be able to support Regional Climate Outlook Forums.

The use of climate information for predicting outbreaks of infectious diseases dates back to the 1920s, when Gill [31] developed an early warning system for malaria based on rainfall, economic conditions, epidemic potential and the prevalence of enlarged spleens [10]. Formal assessment of this prediction system for the period 1923–1942 indicated that its accuracy was significantly better than would have been obtained by climatological statistics alone [32]. Associations between temperature, rainfall, humidity and winds, and the incidence of pneumonia, smallpox, leprosy and tuberculosis were used to forecast epidemics in India and elsewhere [33][34][35], but were never implemented widely.

Health sector early warning systems remain relatively untried in contrast to other sectors, such as the famine earlier warning systems (FEWS) [36]. Notable exceptions are malaria early warning systems (MEWS). Guidelines to establish and implement long-range forecasting, MEWS and early detection were developed in 2001 [37][38][39]. These guidelines provide the concepts, indicators and planning required for the continuum of activities that monitor the escalation of the malaria situation towards a possible epidemic, and provide increasing lead times and decreasing accuracy and spatial resolution of prediction. Long-range forecasting is based on ENSO indices and climate forecasting [38]. For those areas, where future climates can be predicted, such measurements can broadly forecast malaria epidemic risk many months in advance, allowing countries time to ensure the availability of resources in the event that an epidemic occurs in the coming season. Early warning is based on monitoring of climatic indicators, population vulnerability factors and operational and environmental factors in order to detect when conditions suitable for an epidemic have already appeared at a given time and place. It has the potential of predicting epidemics weeks to months in advance, allowing for enhanced surveillance and preventive and control measures directed to specific geographic areas. The purpose of early detection is to detect the beginning stages of an epidemic by measuring changes in the incidence of malaria cases. Although at least eight African countries are developing a malaria early warning system [40], at present long-range forecasting remains predominately research-based.

The establishment of the Malaria Outlook Forum (MALOF) represents an important evolution of climate outlook forums, with a primary mission to establish an operational early warning system for malaria. It has been held since 2004 in Southern Africa, and since 2007 in the East Africa-Greater Horn of Africa region [41]. This effort reinforces the importance of the user community driving the process of which climate information is an important component. Joint MALOF and RCOF sessions enable the experts from the national meteorological services to interact with the representatives from the health sectors and together they jointly develop malaria detection and response products best suited to various sectors, spatial and temporal scales.

An important step in the improvement of warning systems is recognizing that these systems must form an integral part of the operational decision-making process in the public health sector. Failure to do so risks attributing disease variations incorrectly to climate [10]. Key steps to improving health early warning systems are summarized by WHO [10] and include the following:

(a) Maintain and strengthen disease surveillance systems. Lack of disease data is more common than a lack of climate information;

(b) Begin widespread introduction of GIS tools that increase the accessibility of surveillance data and may enable integration of all information into a single system to facilitate data access and compatibility;

(c) Develop methods to assess the predictive accuracy of the system;

(d) Measure all relevant factors for which information is available to create an accurate predictive model, (not only climatic influences);

(e) Include health policymakers in all stages of system design and implementation;

(f) Implement early warning systems based on cost-effectiveness of including climate and non-climate information.

(Note that in some countries, particularly in Africa, there is also a lack of climate information because of too few meteorological stations. Even where both disease data and climate data exist, they are not obtained from the same locations or at coherent scales, thus making analysis difficult.)

Such an approach can support ambitious initiatives, such as the Global Malaria Action Plan (see, for example, Coll-Seck [42]), which aims to eliminate malaria from Southern African Development Community (SADC) countries. Strengthening health systems and cross-border collaboration are critical to elimination. At this stage, the control program requires a rigorous surveillance system with rapid reporting, and effective information systems that can reduce the incidence rate to less than 1 per 1 000 people at risk. Once the surveillance system shows a reduction of locally acquired cases to zero, the control program enters the phase of “prevention of reintroduction” of malaria. Because the environment and climate continue to provide favourable conditions for the reintroduction of the vector and parasite, it is important that the epidemiological surveillance system continues to monitor areas with high potential for malaria. It is particularly important to monitor changing land use, changing population characteristics (behaviours, activities and migration), climate variability and climate change that could create favourable conditions for the reintroduction of the vector and parasites and increase the risk for human-to-vector contact. This is an opportunity for cooperation between the health and climate communities in surveillance and early warning.

5.2. Heat, health and air quality warnings

There are numerous studies linking atmospheric air quality and airborne particulate matter (airborne particulate matter less than 10 micrometres in size [PM_{10}]) to the worsening of cardiac and respiratory diseases [43][44]. High levels of airborne particulate matter are associated with increases in emergency room visits, hospital admissions and fatalities. Children, the elderly and people with existing cardio-respiratory disorders are particularly susceptible. Meteorological services are able to provide routine information to help address this problem. For example, the Canadian Meteorological Service produces a daily air quality forecast. Air quality is expressed using an Air Quality Index. Air Quality Advisories are issued when the air pollution levels exceed national standards. They are issued in partnership with provincial and municipal environment and health authorities, and contain advice on action that can be taken to protect health and the environment. A cornerstone of this process is the development of relevant and timely health messages that allow Canadians to safeguard their own health, as well as the health of those in their care by avoiding exposure to unhealthy air, and ensuring immediate access to prescription medication. These messages also motivate change in improving air quality in Canadian communities over the medium- to longer-term. Similar activities are taking place across the border in the United States, as well as in Europe.

In the United States, for example, the National Weather Service and the Environmental Protection Agency (EPA) are collaborating to provide air quality forecasts. Air quality has a significant impact on public health. In the United States, the Environmental Protection Agency and its partners have developed a comprehensive air quality forecasting system linked to national air quality standards designed to protect public health [45]. While most of the information presented by AIRNow, publisher of the Air Quality Index and other air quality guides, is based on observations only, EPA and the National Oceanic and Atmospheric Administration (NOAA) National Weather Service have developed an Air Quality Forecast System for the prediction of ozone as guidance to state and local air quality forecasters. The aim of the system is to provide the United States with ozone, particulate matter and other pollutant forecasts with enough accuracy and advance notice to take action to prevent or reduce adverse health effects. This development builds on advances in numerical forecasting that incorporate chemical and weather forecasts. Within a decade it is expected to be able to provide reliable air quality forecast guidance beyond two days at a spatial resolution of 2.5 km.

There is increasing evidence that high ozone and high PM_{10} accompanying heatwaves increase the risk of mortality, and that future studies of heatwaves need to consider the effects of air pollutants [8].

Meteo-France has pioneered the development of early warning systems for meteorological hazards using vigilance charts with colour-coded hazards according to severity for each of the 100 French departments (administrative regions). However, despite having a good forecast of the extreme heatwave that struck Europe, and France in particular, during August 2003, the health care system was ill prepared and there were major public health consequences. Overall, 50 000 to 70 000 extra deaths during a 16-day period were estimated throughout Europe, with 15 000 of these occurring in France alone, corresponding to a 60 per cent increase in expected mortality in France [46]. This led the French Institute for Public Health Surveillance (InVS), in close cooperation with Meteo-France, to define and implement a heat health watch warning system based on biometeorological indicators.

The warning system operates from 1 June to 31 August (level 1, seasonal surveillance period). When the alert criteria are fulfilled, the departments declare a new action level (level 2). A third level, which results in maximum mobilization, is implemented if the impacts of the heatwave overwhelm the health system or include power cuts, drought, management problems in funeral centres or heavy air pollution [47]. The alert system aims to give the public authorities three days' prior warning that a heatwave may occur in order for the National Heat Wave Plan (NHWP) measures to be put into operation [48]. The preventive measures are aimed at modifying the behavior of people, health institutions and health authorities with regard to high summer temperatures. They include television and radio spots, special assistance to people at risk (many of them being previously registered at their town halls), or facilities to access clinical information on recent morbidity or mortality.

This level of cooperation between the health and meteorological services, led by the health sector and where the meteorological warning works as a trigger for local action, is a good example of the way that the health sector can work effectively with the climate community to support operational warning and response systems. The impact of this National Heat Wave Plan was evaluated during the July 2006 heatwave, which happened to be the second hottest month in France (since 1950) only three years after August 2003 absolute records. During these 18 days of heat, the NHWP was exercised fully, including local care to elderly or sick people and daily health advice in all media. Two thousand extra deaths were observed, showing that excess death cannot be fully eradicated. Nevertheless, the detrimental effect of the heatwave was reduced significantly when compared with the effects of previous similar events such as 1976 (9 000 extra deaths).

An estimate of the number of deaths avoided is important to determine the overall benefit of the interventions. A forecast model of extra deaths based on a regional 10-day running temperature mean has been tested and validated by the French National Institute of Health and Medical Research (Inserm) in collaboration with Meteo-France. This suggests that about 4 000 premature deaths were avoided during the 2006 event, most of which were probably due to public awareness and the NWHP [49].

By 2006 there were Heat-Health Warning Systems (HHWS) operational in 16 countries. The absence of a common definition of a heat event or heatwave, however, has led to different methods of defining and indentifying such situations. While some have demonstrated success, the overall effectiveness of the systems has not been determined. A Euro-HEAT analysis showed that poor communication between the meteorological service and the health agency can prevent the implementation of an effective system [8].

A Web-based climate information decision-support tool, developed by the NMHS of Germany (Deutscher Wetterdienst) provides probabilistic information about the imminent heat situation for the next 9 (14) days at the regional level [50]. The medium-range heat information is based on the ensemble prediction system of ECMWF. On the Website http://euroheat-project.org/dwd/index.php, the region-specific probabilities for a heatwave for lead times from 0 (current day) to 14 days are displayed. In this system a heatwave is defined by 2m temperature exceeding a variable threshold that depends on the weighted mean of the temperatures during the last 30 days. In addition to the forecast issued at the actual day (this becomes available at 10:40 UTC), the forecasts issued over the last 10 days can be displayed [8][51].

Medium-range heat information with lead times of 3-10 (15) days can be a useful complement to HHWS for decision-makers to give the health system more time to prepare for an imminent heatwave and to monitor the situations in neighbouring regions. The target group for this tool are health professionals who are involved in the national-local HHWS and heat action plan rather than the public. As there are links to the Websites of the national HHWS in Europe the user has quick access to heat warnings issued by other countries. For countries that have no heat warning system or for which the Website of the system could not be identified, the Websites of the National Meteorological Services are linked, so that the user can at least access the respective weather forecasts.

Analysis of this tool by health professions indicate that it is important that the climate information tool aims to avoid triggering false alarms as these can lower the interest and the responsiveness of the actors, health professionals and the public over time. The different variables of the tool should not have different accuracy. The stakeholders within the health system would have to define the kind of information that has proven useful to them [8].

5.3. Health Interactive System: The Redgems Example

Health information systems are critical components of the successful inclusion and use of environmental information in health applications. One example is the interactive health information system, Re-Emergent Diseases Global Environment Monitoring from Space (RedGems). Tele-epidemiology is used to facilitate real-time monitoring of human and animal health (that is, epidemiology, clinical data and entomological data). The primary purposes of RedGems (http://www.redgems.org/) are to contribute to the implementation of Early Warning Systems (EWS) for infectious diseases and to the three main actions of tele-epidemiology. The main objective is to attempt predicting and mitigating public health impacts from epidemic, endemic and pandemic diseases.

6. Organizational change

Influencing health outcomes requires a close relationship and alignment between the provider and user of services. The importance of collaboration between producers and users of weather and climate services cannot be overestimated. This cooperation ensures value is added to make sure that relevant environmental information is properly considered and acted upon by the health sector [52].

While it is not possible to be prescriptive about specific climate services that meet the health sector's needs in a particular country, there are a number of commonalities [21]. How do we make climate information accessible and useful to the health sector? Where do we go to access reliable climate forecasts and outlooks? How do we integrate this information within the health sector? How can the health sector communicate easily with the meteorological community?

At the regional level, health and climate units have been implemented by WMO regional centres. One example of this is the climate and health unit of African Centre of Meteorological Application for Development (ACMAD)

6.1. ACMAD, climate and health

Initiated in 2007, ACMAD launched a project to operationally link the health sector to the meteorological community. The effort focuses on:

(a) Producing and disseminating a climate news bulletin (with a monthly analysis of the most influential climate parameters) for the health sector on a routine basis with the aim of providing support for early warning of specific diseases;

(b) Developing training materials on climate for health and applying this training within a single case study;

(c) Setting up a demonstration in two or three countries in cooperation with national or local health committees to ease communication and to promote joint activities on health and climate (including the collection and dissemination of local information);

(d) Developing an information platform on health and climate;

(e) Supporting the climate information needs of organizations such as the United Nations Children's Fund (UNICEF) and the International Federation of the Red Cross and Red Crescent Societies (IFRC) through the subregional climate outlook forums.

This support for the health sector was further developed in 2008 with the establishment of a Health and Climate Unit at ACMAD aimed at building capacity within the health and climate communities to work together towards improving health outcomes through greater knowledge of disease transmission dynamics, improved climate monitoring and forecasting and the creation of operational health-related climate products. In West Africa, the focus is on malaria and meningitis. Since July 2008, the Health and Climate Unit has produced and disseminated an experimental monthly health bulletin in cooperation with health organizations. The Health and Climate Unit includes epidemiologists and climate scientists working closely with other international organizations, such as the World Health Organization Multi-Disease Surveillance Centre, Centre de Recherche Médicale et Sanitaire and UNICEF. The Health and Climate Unit is also linked to the WMO Sand and Dust project, which aims to support the provision of sand and dust storm warnings and advisories.

6.2. Climate and health working groups

At the national level, a framework to improve communication and join planning between ministries of health and national meteorological services are being developed in Africa. Pioneered by the Federal Ministry of Health Ethiopia and the National Meteorological Services Agency of Ethiopia, the Climate and Health Working Group is a focal point for climate and health issues. Its aim is to engender a self-reliant, healthy and productive population through the proper use of climate information to improve health outcomes. Its goal is to create a climate-informed health sector and beneficiary communities that routinely request and use appropriate climate information to improve the effectiveness of health interventions [53]. The objectives of the Working Group are to create awareness of the impact of weather and climate on health; to develop effective and functional means for the health sectors and beneficiary communities to use appropriate climate information routinely; and to estimate populations at risk from climate-sensitive diseases. Among other functions, the Working Group helps formulate institutional data sharing systems among the sectors and other relevant institutions; fosters research on climate and health; organizes workshops; identifies gaps and bottlenecks which constrain the routine use of climate information by the health sector, and identifies and pursues the means to overcome these problems; and helps build the capacity of national and local community-based organizations to widen and strengthen their services.

The health ministries and meteorological services in Madagascar, Kenya and west Africa have furthered this development. Madagascar has created a climate and health working group through a ministerial agreement between the Ministry of Health and Family Planning and the ministry responsible for meteorology to increase cooperation to reduce the burden of climate-sensitive diseases, focusing on malaria, plague and Rift Valley fever. The health sector in Madagascar can use climate information in warning systems for epidemics. Seasonal forecasts of temperature and precipitation are useful indicators of the probable occurrence of malaria, which can trigger more intensive surveillance within the epidemic intervention program. Real-time observations of temperature and precipitation can be used to launch selective interventions and help in the early detection of the disease.

Climate change adaptation is also a priority for Madagascar and other vulnerable developing countries. The climate and health working group studies' focus on the three diseases in question is one step in the routine use of climate information in health planning. The emergence of arboviruses such as Chikungunya in the Indian Ocean region in recent years confirms the interest of the integration of climate information in the monitoring of these diseases [54]. Climate information helps to strengthen the existing monitoring system for early detection of vector-borne diseases with high epidemic potential. The cooperation between the meteorological and health services increases the capacity of the latter to minimize the impact of climate-related disease outbreaks associated with climate change. It is also recognized that this requires broader cooperation with other sectors, such as agriculture, transportation and energy, the strategies of which may increase or decrease the burden of disease, particularly on poorer, disadvantaged people.

These climate and health working groups are a first step towards developing an integrated public service platform that provides operational support to the health sector. They will continue to bridge the gaps between health and climate communities and will play an increasingly important role in helping to transition research to the operational services, and in addressing the research needs of the operational services.

Through its program on Public Weather Services, WMO promotes and supports such initiatives and helps the African NMHSs to implement efficient and effective cooperation with the health sector.

6.3. Public service platform

There are very many sources of climate information, some sector-specific and others providing general climate and environmental information. These include multiple government agencies, university departments and institutions, private companies and national, regional and international organizations. The diversity of sources of information reflects both the growing need for climate information and the absence of a defined structure to support climate services in most countries [21]. This situation is improving with the development of regional climate centres, which help NMHSs develop advanced climate predictions and outlooks.

Concurrently, a critical step forward would be for the service provider to understand the language of the user [55]. In the past the decision-makers were knowledgeable users of weather and climate information with applications limited to agriculture, aviation and shipping, often with a well-developed requirements process for weather and climate information. Today, the potential user of climate services is more uncertain of the value of the services because the core activities are far removed from consideration of any environmental factors that may influence decisions. Furthermore, there are only a few opportunities for education and training within the health and climate professions to bridge this gap. Overcoming this is a necessary step to more effective use of climate information in the health sector.

A climate service for the health sector involves a broad partnership of producer and user organizations, climate scientists, health service providers, health economists and social scientists. It provides an opportunity to interlink global, national and regional information systems; to provide comprehensive modelling and analytical capability to address problems at regional and local scales; and to provide for a distributed decision-relevant research and development capability [21]. It is the latter that sets this service apart from the traditional, exclusively science-based weather forecasting service. The climate service for the health sector must focus on collaborative problem solving. It a service that fully engages with the health community to produce mutually defined climate information that is most useful for individual applications. The climate service relevant to health would be integral to a ministry of health and health services in the same way that climate service for development, for example, would be integral to a ministry of finance or planning [21].

Implicitly, although climate services may be part of NMHSs, they are partnerships between environmental and social organizations. Accordingly, we recommend that countries seize the opportunity to create a public service platform that brings together the operational capacity of providers and users of climate information and services for the health sector. The benefit to the health sector would be an observational network that evolves to meet the specific needs of public health, offers forecast systems targeted to health decisions and provides an integrated system that aligns climate and environmental information with social, economic and medical information. A public service platform would provide the opportunity to focus on strengthening ground-based observation systems, strengthening health surveillance and creating integrated early warning systems.

An example of such a public service platform is found in the Shanghai Meteorological Bureau, which has developed a platform for fast, efficient and unified meteorological service delivery [56]. As a follow-up to the 2007 International Conference on Secure and Sustainable Living action plan concerning the social and economic benefits of weather, climate and water services, the China Meteorological Administration strengthened collaboration with many other organizations. These include the Ministries of Agriculture; Health; Transportation; Environmental Protection; National Land Resources; and Industry and Information Technology, as well as the Forestry and Tourism Administrations. The aim has been to realize tangible and quantifiable benefits for the community by exploiting new operating partnerships between users and providers to share responsibility for effective delivery of services. This has included the development of new tools and methods to strengthen dialogue and collaboration between provider and user, especially the implementation of more interactive early warning systems, which are integrated into every level of governance from the community level to the national infrastructure.

Separating the service platform from product delivery places emphasis on information sharing, joint information dissemination, joint research and training and joint product development between the meteorological and hydrological service and the user. In addition to information generated by the NMHS, the platform also integrates data from outside partners, both national and international so that users have access to all relevant information through a single source with which they can work directly.

A general application of this concept is an opportunity to provide an interactive platform for the health sector to collaborate with NMHSs and other service partners to deliver optimum climate-informed health decisions. The approach also provides the capacity to interact with other sectors, including water, agriculture, energy and transportation, each of which has a major indirect impact on health outcomes.

7. Future research and applications

The Earth-System Prediction Initiative for the 21st Century [12][57] identifies the importance of evolving a unified seamless approach to weather and climate prediction from days to decades and beyond [58][59] alongside user-defined decision systems. From the health perspective, this future system will provide timely weather, ocean, climate and Earth-system information to assist decision-making processes for risk reduction and adaptation. It provides an opportunity to engage users of environmental information in assessing and incorporating their requirements as a requisite to exploiting advances in a) forecasts of short-term physical and chemical weather hazards; b) observations and analyses of changes that have occurred in the physical, chemical, biological and socio-economic components of the Earth-system; c) predictions of climate variability and change at the regional and local scale, with consideration of the inherent uncertainties, and including predictions of the climatology of extreme events, such as tropical cyclones, winter storms, regional floods, droughts heatwaves and poor air quality; and d) impact assessment tools that use environmental, economic and social information to predict societal and environmental outcomes [12].

For weather, climate and Earth-system information to have timely and beneficial socio-economic impacts, the following elements must be attained:

(a) Content: sufficient accuracy and precision in space and time for the users, including a quantified estimate of its accuracy, and probability of occurrence of particular events;

(b) Distribution: product dissemination on spatial and temporal scales sufficient for action;

(c) Communication: product formats that users can comprehend and interpret;

(d) Recognition: recognition by users that the information has value;

(e) Integration: incorporating information into user-supported decision support systems;

(f) Response: actions taken by users in response to the information [12].

The primary rationale for pursuing a seamless prediction process (across all relevant timescales) is that the resulting information will influence decisions that contribute to the achievement of societal objectives including: protection of life and property; enhancement of socio-economic well-being; improvement of the quality of life; and ecological sustainability. Such objectives are embodied in the broad mandates, missions, and visions of national governments or international organizations [52]. Weather and climate predictions have already made significant, albeit variable, contributions to a wide range of economic sectors and public policy issues, including agriculture, water resources and the natural environment; human health; tourism and human welfare; energy, transport and communications; urban settlement and sustainable development; and economics and financial services [60].

Weather forecasts have proven useful for decision-making in these sectors and the number of applications to longer-term operational and planning decisions – including those related to climate change – is growing. However, there is considerable evidence of underutilization of weather and climate information that may be rooted as much in a lack of understanding of the decision-making context and requirements of users as in the precision or accuracy of atmospheric predictions. A variety of constraints make it difficult for decision-makers to benefit fully from scientific information and for the science to satisfy users' needs [61][62][63]. A seamless prediction process provides an opportunity to help resolve this problem [16].

Using the example of public health, Brunet et al. [16] selected decisions covering a wide range of temporal scales (Figure 2) that are influenced by weather and climate variability predictions, and even multi-decadal climate change projections. These predictions (and projections) are integrated with other pieces of information (for example, expected disease outbreak patterns and available medical supplies and resources) that more directly relate to important health outcomes of interest to decision-makers. These examples go beyond the realm of atmospheric predictions to include consideration of biophysical and socio-economic factors that are pertinent to successful decision-making and outcomes from the user's perspective.

Potential benefits of accelerated research and its applications will be greatest in poor nations, especially in Africa where weather and climate-sensitive diseases pose a major threat to the lives and livelihoods of millions of people. For malaria, for example, the response time to a particular outbreak or epidemic is greater than one week and often much longer, depending on the time it takes to identify cases and integrate the information from different clinics [65]. This makes this issue ideal for atmospheric observations and prediction applications at seasonal and sub-seasonal timescales, the key integrating period for weather and climate prediction.

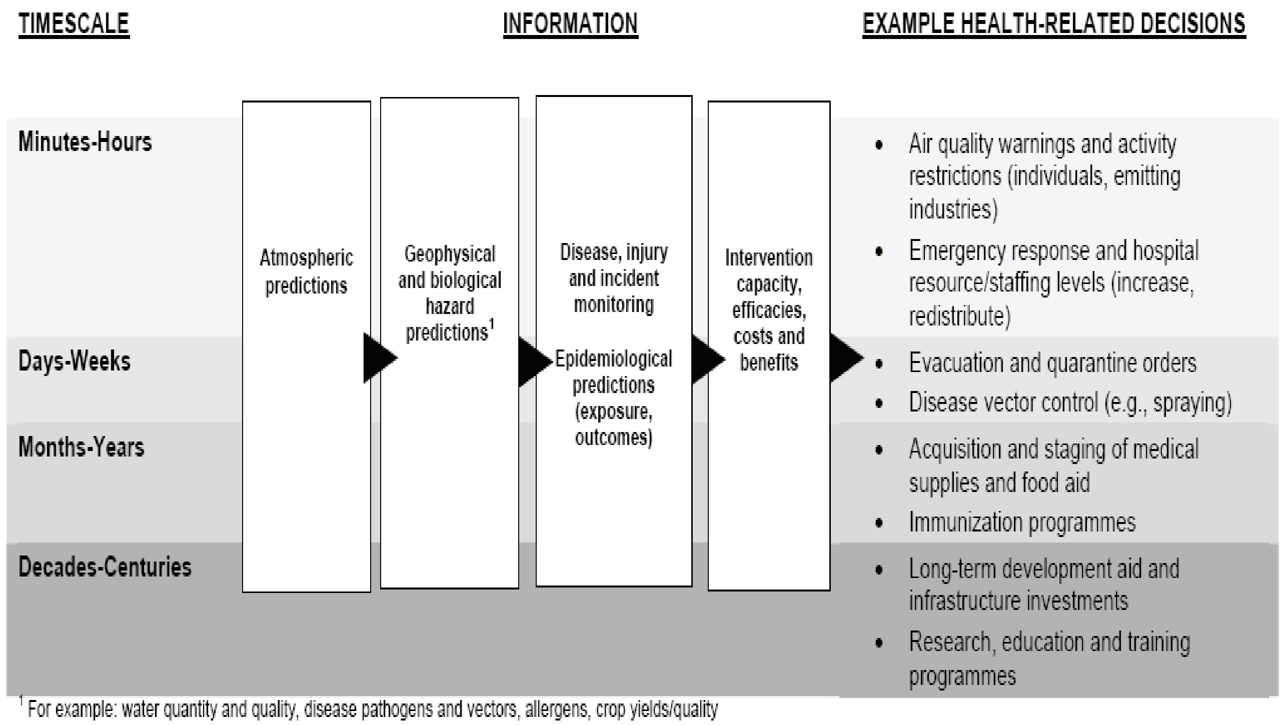

Figure 2. Simplified set of public health-related decisions and supporting information (After Brunet et al. [16])

To address the various user needs, the specific type of research will depend on the weather- or climate-sensitive issue, geographic area and decision context, as well as the most appropriate disciplinary expertise and methodologies. Priority projects may be selected based on their potential contribution to priority health objectives or where existing programmes, activities and interdisciplinary collaboration can be leveraged.

Examples of such programmes include the Meningitis Environmental Risk Information Technologies (MERIT) project; the Hydrological Ensemble Prediction Experiment (HEPEX), an international project to advance technologies for hydrological forecasting comprised primarily of researchers, forecasters, water managers, and users; and the Global Environmental Change and Human Health Initiative, one of four joint projects of the Earth System Science Partnership (ESSP) geared to quantifying and modelling health impacts and vulnerability and evaluating adaptation measures.

Building on existing research opportunities, the strategy of the WMO weather and climate research programmes should be to have greater collaboration with health researchers. In particular, the programmes should:

(a) Promote an integrated approach to the application of sub-seasonal and seasonal predictions through the active involvement of health science researchers, service providers and users;

(b) Develop a pool of interdisciplinary scientists and representatives of decision-makers in the health sectors;

(c) Identify areas that have the greatest potential health contribution, then help articulate requirements and specific projects;

(d) Leverage existing research programmes;

(e) Provide sub-seasonal and seasonal predictions in a form easily accessible to non- atmospheric scientists, user health groups and intermediaries who understand both the scientific and socio-economic issues.

8. Summary and recommendations

Based on the opportunities presented in this paper, we have three recommendations. The first is related to the opportunity for greater international cooperation between the World Health Organization and other international organizations; the second is related to the opportunities for a climate service for health; and the third is related to the opportunities for research and training that have already been developed and can be extended.

Overall recommendations for the World Climate Conference-3 (WCC-3) based on identified opportunities are:

(a) Full engagement of the health community, through WHO, in follow-up of the WCC-3 conference to establish an appropriate structure within the international community to deliver climate services for the health sector. This should include:

  (1) Co-sharing the responsibility for any follow-on task force with representatives of other sectors;

  (2) Establishing new mechanisms to engage the climate, environment and remote-sensing technologies communities as part of the public health community, serving to protect, promote and restore the health status of societies;

(b) Creation of a climate service for public health based on the public service platform developed by some WMO Member institutions, to encourage cross-sectoral interaction with the health sector including the cooperation on the establishment of observing networks, the development of decision-support tools and systems, and the development of advisory services for the health sector. This should be structured to include:

  (1) Building on existing capabilities of WMO and WHO Members;

  (2) Strengthening the ground-based observing systems in support of improving health outcomes, especially for climate services where deficiencies are greatest, such as in Africa;

  (3) Using knowledge management systems to facilitate the capture and sharing of climate risk management knowledge to the concerned communities;

  (4) Strengthening health surveillance and response systems in accordance with needs identified in the IPCC Fourth Assessment Report;

(c) Assessment, research and training opportunities developed through collaboration across all disciplines relevant to improving health outcomes. This should include:

  (1) Building on existing initiatives to integrate weather and climate science to continue to create a prediction system applicable to all decision-making timescales, and working with researchers from other disciplines to create tools relevant to health decisions;

  (2) Building on existing initiatives to enhance and encourage health research integrating climatic and environmental data;

  (3) Establishing the equivalent of an independent expert process for assessing the evidence of health–climate linkages for policy development and decision-making using the example of the Cochrane and Campbell reviews processes.

9. Conclusions

It has been known for a long time that many diseases are sensitive to the climate and that climate variability and change have a significant effect on health outcomes and the delivery of health services. The devastating consequences of European heatwaves, epidemics of malaria in Africa and malnutrition associated with food insecurity are examples of just how sensitive our health is to changes in the environment.

Advances in environmental observations and forecasting on all timescales, coupled with better access to medical records and demographic information, are improving health surveillance, early detection and early warning of disease outbreaks as well as helping to improve the delivery of health care. Much still needs to be done to create the tools to help prevent disease outbreaks. However, the greater cooperation between the health and climate communities, and a common understanding of the problem are advancing our knowledge of climate-sensitive diseases and providing the basis for improved climate-related health outcomes.

References

[1] United Nations, The Millennium Development Goals Report 2006. New York, United Nations, 2006. http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2006/MDGReport 2006.pdf

[2] World Health Organization (WHO), World Health Day 2008: Protecting health from Climate Change, 2009. http://www.who.int /world-health-day/previous/2008/en/.

[3] World Health Organization (WHO), Sixty-first World Health Assembly, 2008. http://apps.who.int/gb/or/e/e_wha61r3.html

[4] World Health Organization (WHO), Ecosystems and human well-being: Health synthesis (C. Corvalan, S. Hales and A. McMichael), WHO, Geneva, 2005.

[5] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contributions of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (M. Parry, O. Canziani, J. Palutikof, P. van der Linden and C. Hanson, eds). IPCC, Geneva, 2007.

[6] Menne, B. and K. Ebi (eds), Climate Change Adaptation Strategies for Human Health. Heidelberg, Springer, 2006.

[7] World Health Organization (WHO), Our Planet, Our Health: Report of the WHO Commission on Health and Environment. WHO, Geneva, 1992.

[8] World Health Organization (WHO), Protecting health in Europe from climate change (B. Menne, F. Apfel, S. Kovats and F. Racioppi, eds), WHO, Geneva, 2008.

[9] Ebi, K.L. and J.K. Schmier, A stitch in time: Improving public health early warning systems for extreme weather events. Epidemiologic Reviews. 27 (2005) 115–121.

[10] World Health Organization (WHO), Using Climate to Predict Disease Outbreaks: a Review (K. Kuhn, D. Campbell-Lendrum, A. Haines and J. Cox). WHO, Geneva, 2004.

[11] Vignolles C., J.-P. Lacaux, Y.M. Tourre, G. Bigeard, J.-A. Ndione and M. Lafaye, Rift Valley fever in a zone potentially occupied by Aedes vexans in Senegal: Dynamics and risk mapping, Geospatial Health. 3 (2009) 211–220.

[12] Shapiro, M., J. Shukla, M. Béland, J. Church, K. Trenberth, B. Hoskins, G. Brasseur, M. Wallace, G. McBean, A. Busalacchi, G. Asrar, D. Rogers, G. Brunet, L. Barrie, D. Parsons, D. Burridge, T. Nakazawa, M. Miller, P. Bougeault, R. Anthes, Z. Toth, J. Meehl, R. Dole, M. Moncrieff, H. Le Treut, A. Troccoli, T. Palmer, J. Marotzke, J. Mitchell, A. Simmons, B. Mills, Ø. Hov, H. Olafsson and J. Caughey, An Earth-System Prediction Initiative for the 21st Century. Bulletin of American Meteorological Society (in press). (2010).

[13] National Research Council (NRC), Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. Washington, National Academies Press, 2007.

[14] National Research Council (NRC), Earth Observations from Space: The First 50 Years of Scientific Achievements. Washington, National Academies Press, 2008.

[15] Palmer, T.N., Progress towards reliable and useful seasonal and interannual climate predictions. WMO Bulletin. 53 (2004) 325–332.

[16] Brunet, G., M. Shapiro, B. Hoskins, M. Moncrieff, R. Dole, G. Kiladis, B. Kirtman, A. Lorenc, B. Mills, R. Morss, S. Polavarapu, D. Rogers, J. Schaake, J. Shukla, Toward a seamless process for the prediction of weather and climate: The advancement of sub-seasonal to seasonal prediction. Bulletin of American Meteorological Society (in press). (2010).

[17] Hurrell, J., G.A. Meehl, D. Bader, T. Delworth, B. Kirtman and B. Wielicki, A unified modelling approach to climate system prediction. Bulletin of American Meteorological Society. 90 (2009) 1819–1832.

[18] Grover-Kopec E.K., M.B. Blumenthal, P. Ceccato, T. Dinku, J.A. Omumbo and S.J. Connor, Web-based climate information resources for malaria control in Africa. Malaria Journal. 5 (2006) 38.

[19] Connor, S.J., T. Dinku, T. Wolde-Georgis, E. Bekele and D. Jima, A collaborative epidemic early warning and response initiative in Ethiopia. In: Proceedings of International Symposium on PWS: A Key to Service Delivery, 3-5 December 2007, WMO, Geneva, 2008.
http://www.wmo.int/ pages/prog/amp/pwsp/documents/Symposium_Proceedings_Final.pdf.

[20] African Partnership Forum (APF), Climate Change and Africa. Paper presented to the 8th Meeting of the Africa Partnership Forum, Berlin, 2007.

[21] Rogers, D.P., M.S. Boulahya, M.A. Thompson, S.J. Connor, T. Dinku, K.B. Johm, H.R. Shalaby, B. Ahmadu and A. Niang, National climate and environmental services for development. In: Proceedings of International Symposium on PWS: A Key to Service Delivery. 3-5 December 2007, WMO, Geneva. 2008.
http://www.wmo.int/pages/prog/amp/pwsp/documents/Symposium_Proceedings _Final.pdf.

[22] Global Humanitarian Forum, Weather Information for All Initiative 2008–2012, Geneva, Switzerland, 2009.

[23] Palmer, T.N., A. Alessandri, U. Andersen, P. Cantelaube, M. Davey, P. Délécluse, M. Déqué, E. Díez, F.J. Doblas-Reyes, H. Feddersen, R. Graham. S. Gualdi, J.-F. Guérémy, R. Hagedorn, M. Hoshen, N. Keenlyside, M. Latif, A. Lazar, E. Maisonnave, V. Marletto, A.P. Morse, B. Orfila, P. Rogel, J.-M. Terres and M.C. Thomson, Development of a European multimodel ensemble system for seasonal-to-interannual prediction (DEMETER). Bulletin of American. Meteorological Society. 85 (2004) 853–872.

[24] Thomson, M.C., F.J. Doblas-Reyes, S.J. Mason, R. Hagedorn, S.J. Connor, T. Phindela, A.P. Morse and T.N. Palmer, Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. Nature. 439 (2006) 576–579.

[25] van der Linden, P.J., The ENSEMBLES climate change project. In: *AGRIDEMA*. New York, Nova Publishing Ltd, 2008.

[26] Le Marshall, J., J.G. Yoe, P. Phoebus and L.-P. Riishojgaard, Advanced technologies: Opportunities and challenges for developing countries. WMO Bulletin. 56 (2007) 189–195.

[27] Beck, L.R., B.M. Lobitz and B.L. Wood, Remote sensing and human health: New sensors and new opportunities. Emerging Infectious Diseases. 6 (2000) 217–226.

[28] Ndione, J.-A., J.-P. Lacaux, Y.M. Tourre, C. Vignolles, D. Fontannaz and M. Lafaye, Mares temporaires et risques sanitaires au Ferlo : contribution de la télédétection pour l'étude de la fièvre de la vallée du Rift entre août 2003 et janvier 2004, Sécheresse. 20 (2009) 153–160.

[29] Tourre, Y.M., J.-P. Lacaux, C. Vignolles and M. Lafaye, Climate impacts on environmental risks evaluated from space: A conceptual approach to the case of Rift Valley Fever in Senegal. Global Health Action, Volume 2 (2009). http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2799327/.

[30] Ogallo, L., P. Bessemoulin, J.-P. Ceron, S. Mason and S.J. Connor, Adapting to climate variability and change: the Climate Outlook Forum process. WMO Bulletin. 57 (2008) 93–102.

[31] Gill, C.A., The prediction of malaria epidemics. Indian Journal of Medical Research. 10 (1923) 1136–1143.

[32] Swaroop, S., Forecasting of epidemic malaria in the Punjab, India. *American* Journal of Tropical Medicine. 29 (1949) 1–17.

[33] Rogers, L., The world incidence of leprosy in relation to meteorological conditions and its bearings on the probable mode of transmission. Transactions of the Royal Society of Tropical Medicine and Hygiene. 16 (1923) 440–464.

[34] Rogers, L., Climate and disease incidence in India with special reference to leprosy, phthisis, pneumonia and smallpox. Journal of State Medicine**.** 33 (1925) 501–510.

[35] Rogers, L., Small-pox and climate in India: Forecasting of epidemics. *Medical* Research Council Reports. 101 (1926) 2–22.

[36] Davies, S., M. Buchanan-Smith, R. Lambert, Early warning in the Sahel and Horn of Africa: The state of the art. A review of the literature. Volume One. Brighton, Institute of Development Studies, University of Sussex, 1991.

[37] Connor, S.J., M.C. Thomson and D.H. Molyneux, Forecasting and prevention of epidemic malaria: New perspectives on an old problem. In: The Malaria Challenge after one hundred years of malariology. Parassitologia. 41(1999) 439–448.

[38] World Health Organization (WHO), Malaria early warning systems: Concepts, indicators and partners. A framework for field research in Africa. Geneva, World Health Organization, (WHO/CDS/RBM/2001.32), 2001.

[39] Thomson, M.C. and S.J. Connor, The development of malaria early warning systems for Africa. Trends in Parasitology, 17 (2001) 438–445.

[40] World Health Organization (WHO), The World Malaria Report. WHO, Geneva, 2005.

[41] DaSilva, J., B. Garanganga, V. Teveredzi, S.M. Marx, S.J. Mason and S.J. Connor, Improving epidemic malaria planning, preparedness and response in Southern Africa. Malaria Journal. 3 (2004) 37.

[42] Coll-Seck, A.M., Malaria Elimination in Africa. On the occasion of the Ministerial Meeting on Elimination in Eight SADC Countries, Windhoek, Namibia, 2 March 2009.
http://www. rollbackmalaria.org/docs/official/RBM_EXD_2009_STATE_2%20_2.pdf.

[43] World Health Organization-Europe, Regional Priority Goal 3: Respiratory diseases and air pollution. Second high-level preparatory meeting Madrid, Spain, 22-24 October 2008. Towards the Fifth Ministerial Conference on Environment and Health, Italy 2009. (26th session of the European Environment and Health Committee). WHO-Europe, Copenhagen, 2008.
http://www.euro.who.int/ document/eehc/26th_eehc_madrid_edoc06rev1.pdf.

[44] World Health Organization (WHO) Improving Public Health Responses to Extreme Weather/Heat Waves – EuroHEAT. Meeting Report, Bonn, Germany, 22-23 March 2007. WHO-Europe, Copenhagen, 2008.
http://www.euro.who.int/ Document/ E91350.pdf.

[45] Environmental Protection Agency (EPA), Air Quality Index: A guide to air quality and your health. Washington, USEPA Air and Radiation, EPA-454/K-03-002. 2003.
http://www.epa.gov/airnow/ aqi_cl.pdf.

[46] Fouillet A, G. Rey, F. Laurent, G. Pavillon, S. Bellec, C. Guihenneuc-Jouyaux, J. Clavel, E. Jougla and D. Hémon, Excess mortality related to the August 2003 heat wave in France. International Archives Occupational. Environmental. Health. 80 (2006) 16–24.

[47] Josseran, L., N. Caillère, D. Brun-Ney, J. Rottner, L. Filleul, G. Brucker and P. Astagneau, Syndromic surveillance and heat wave morbidity: A pilot study based on emergency departments in France. BMC Medical Informatics and Decision Making. 9 (2009) 14.

[48] Pascal, M., K. Laaidi, M. Ledrans, E. Baffert, C. Caserio-Schönemann, A. Le Tertre, J. Manach, S. Medina, J. Rudant and P. Empereur-Bissonnet, France's heat health watch warning system**.** International Journal of. Biometeorology 50 (2006) 144–153.

[49] Fouillet A., G. Rey, E. Jougla, D. Hémon, Estimation de la surmortalité observée et attendue au cours de la vague de chaleur du mois de juillet *2006*. Rapport à l'InVS. 2006.

[50] Koppe C, P. Becker and G. McGregor, Development of a medium-range climate information decision support tool for heat. In: Preparedness and response to heat-waves in Europe, from evidence to action. Public health response

to extreme weather events (F. Matthies and B. Menne, eds). Copenhagen, WHO Regional Office for Europe. (in press) 2010.

[51] World Health Organization-Europe, Improving public health responses to extreme weather/heat waves – EuroHEAT (B. Menne and F. Mathies, eds) Copenhagen, WHO Regional Office for Europe. 2009. http://www.euro.who.int/__data/assets/pdf_file/0010/95914/E92474.pdf.

[52] Rogers, D.P., S. Clark, S.J. Connor, P. Dexter, L. Dubus, J. Guddal, A.I. Korshunov, J.K. Lazo, M.I. Smetanina, B. Stewart, T. Xu, V.V. Tsirkunov, S.I. Ulatov, P. Whung and D.A. Whilite, Deriving societal and economic benefits from meteorological and hydrological services. WMO Bulletin. 56 (2007) 15–22.

[53] Ghebreyesus, T.A., Z. Tadese, D. Jima, E. Bekele, A. Mihretie, Y.Y. Yihdego, T. Dinku, S.J. Connor and D.P. Rogers, Public health services and public weather services: Increasing the usefulness of climate information in the health sector. WMO Bulletin. 57 (2008) 256–261.

[54] Chretien, J.-P., A. Anyamba, S.A. Bedno, R.F. Breiman, R. Sang, K. Sergon, A.M. Powers, C.O. Onyango, J. Small, C.J. Tucker and K.J. Linthicum, Drought-associated chikungunya emergence along costal East Africa. American. Journal of Tropical Medicine and Hygiene. 76 (2007) 405–407.

[55] World Meteorological Organization (WMO), *Compendium of Lecture Notes for Training Personnel in the Applications of Meteorology to Economic and Social Development* (E.A. Bernard). CD-ROM; 1976. Education and Training Programme Publications of blue series – Volume I (1955–1984), 1976.

[56] Tang, X., Partnership Practices in Public Weather Services. PowerPoint Presentation. 2009.

[57] Shapiro, M., J. Shukla, B. Hoskins, J. Church, K. Trenberth, M. Béland, G. Brasseur, M.. Wallace, G. McBean, J. Caughey, D. Rogers,, G. Brunet, L. Barrie, A. Henderson-Sellers, D. Burridge, T. Nakazawa, M. Miller, P. Bougeault, R. Anthes, Z. Toth and T. Palmer, The socio-economic and environmental benefits of a revolution in weather, climate and Earth-system analysis and prediction. In: The Full Picture. Geneva, Tudor Rose on behalf of Group on Earth Observations, 2007.

[58] Moncrieff, M.W., M.A. Shapiro, J.M. Slingo and F. Molteni, Collaborative research at the intersection of weather and climate. WMO Bulletin. 56 (2007) 204–211.

[59] Palmer, T.N., F.J. Doblas-Reyes, A. Weisheimer and M.J. Rodwell, Toward seamless prediction: Calibration of climate change projections using seasonal forecasts. Bulletin of. American. Meteorological Society. 89 (2008) 459–470.

[60] World Meteorological Organization (WMO), Towards secure and sustainable living: Outcomes of the WMO international conference. WMO Bulletin. 56 (2007) 158–161.

[61] Jasanoff, S. and B. Wynne, Science and decisionmaking. In: Human Choice and Climate Change (S. Rayner and E. L. Malone, eds), Washington, Battelle Press, 1998.

[62] Morss, R.E., O.V. Wilhelmi, M.W. Downton and E. Gruntfest, Flood risk, uncertainty, and scientific information for decision-making: Lessons from an interdisciplinary project. Bulletin of. American Meteorological Society 86 (2005) 1593–1601.

[63] Rayner, S., H. Ingram and D. Lach, Weather forecasts are for wimps: Why water resource managers do not use climate forecasts. Climatic Change. 69 (2005) 197–227.

[64] Connor, S.J. and M.C. Thomson, Epidemic malaria: Preparing for the unexpected. SciDevNet dossier on malaria. Policy Brief, 2005. http://www.scidev.net/en/policy-briefs/epidemic-malaria-preparing-for-the-unexpected.html.