Meteorol. Appl. 12, 69–75 (2005) doi:10.1017/S135048270400146X

The application of GIS technology for precipitation mapping

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Precipitation is one of the most variable meteorological parameters in time and space. The standard surface measurement network provides very localised information about the precipitation. The satellite and radar observations and Numerical Weather Prediction (NWP) models provide continuous information on the state of the atmosphere, but at much lower resolution.

This paper presents work undertaken in central Europe on stratiform and convective precipitation estimated from satellite microwave data. The results of analysis are prepared in the form of precipitation intensity and range maps. The data available from an Advanced Microwave Sounding Unit (AMSU) on board NOAA-15, 16 and 17 satellites enhanced the scope of the work by providing access to new meteorological precipitation-related products. These products, such as Rain Rate (RR), Scattering Index (SI), Total Precipitation Water (TPW), Precipitation Probability (PP) and Liquid Water Path (LWP), were prepared using the regression algorithms. The data from spring and summer seasons in 2001 and 2002 were used for analysis.

The temperature and precipitation thematic layers are created from the NWP model grid data. Also SYNOP (Surface Synoptic Observations) and TEMP (Sonde air temperature) data are converted into thematic coverages. Progress in GIS technology application for NOAA/AMSU microwave-derived products preparation and visualisation in the Satellite Research Department in Poland was achieved. The developed system allows the display of the rain field forecast by the NWP model Aladin and the precipitation observed with the satellite data and other ancillary information. The maps of precipitation with additional geographical data and administrative boundaries are available for weather forecasting units via the Intranet. It is also planned to make images available on the web for external customers.

1. Introduction

Agriculture, weather forecasting and water management require appropriate estimation of precipitation. The hydro-meteorological network is the main source of information concerning precipitation. As the precipitation is highly variable in time and space, satellite data are an important additional source.

The second generation of the NOAA satellites (NOAA-15, 16 and 17) are equipped with the microwave radiometers – Advanced Microwave Sounding Unit (AMSU). These radiometers are very useful for atmosphere sounding to provide precipitable water evaluation and ice crystal distribution. There are established methods using microwave information over the sea and oceans (Ferraro, Grody et al. 1998; Ferraro, Smith et al. 1998; Grody et al. 1999). However, the methods of sounding using the microwave spectrum over land are still inadequate and several research centres are working on this around the world. The research on the algorithms that allow use of microwave soundings from satellite measurements for precipitation characteristics has been under way in the Satellite Research Department of the Institute of Meteorology and Water Management in Kraków since 2000.

This paper focuses on developing GIS with different atmospheric layers, such as precipitation and other parameters, derived from satellite data, Numerical Weather Prediction (NWP) models as well as hydro-meteorological data. Such an approach allows us to combine different thematic layers for analysis and enables us to visualise the meteorological products. These products are then available via the Intranet to meteorological offices in the form of maps showing the distribution of each parameter. It is planned in the future that all thematic layers will be available for analysis via the GIS web server.

Several data types, such as radiosondes, synoptic data, numerical model data and soundings in visible, infrared

Table 1. *Meteorological and climatological data*

Data Type	Range	Resolution	Frequency	Scale
SYNOP	EUROPE	Synoptic/	1 h	regional
KLIMAT	POLAND	Climatic Stations	3 h	regional
			6 h/12 h/24 h	regional
AEROLOGICAL SOUNDING	Poland/Europe	Aerological Stations	1x–4x/day	global
VISTEL	Upper Vistula basin	irregular	10 min	regional
RADAR	100–200 km	0.5 deg	10 min	regional
NUMERICAL WEATHER PREDICTION MODEL	Central Europe	13 km	6/12 h	mezoscale

and microwave spectral ranges from the NOA-15, 16 and 17 satellites were used in this analysis in order to evaluate and validate the rate and range of the precipitation.

2. Meteorological data

Water vapour mixing ratio, relative humidity and liquid water content and, consequently, cloud liquid water path (LWP) were calculated at the standard pressure levels. Vertical profiles of temperature, dew point as well as geopotential height from TEMP were used to calculate air relative humidity and cloud water content. SYNOP data provided information concerning temperature, dew temperature at the surface, as well as present and past weather, cloud cover and cloud type. Precipitation data were used from SYNOP at 12.00 GMT (precipitation sum for the last 6 hours).

Table 1 shows the variety of data used and the potential problems caused by different spatial resolutions, frequency, temporal resolutions and scale. KLIMAT is a climatic data format whereas VISTEL is the network of automatic stations for precipitation data collection in the Upper Vistula basin.

3. Satellite data – NOAA

The Advanced Very High Resolution Radiometer (AVHRR/3) is a multi-purpose imaging instrument used for global measurement of cloud cover, sea surface temperature, ice, snow and vegetation cover and characteristics. AVHRR has five channels in the visible and infrared between 0.63 and 12.0 micrometers, with a resolution of 1.1 km at the sub-satellite point. The squared instantaneous field of view has a size of 1.1 km at nadir (NOAA-KLM, NESDIS 1998).

Figure 1 shows a good example of combining different information. In the background there is a False Colour Composite (FCC – channels 321) from the Very High Resolution Radiometer (AVHRR) on board the polar orbiting meteorological satellite NOAA 16. The clouds appear as white/blue, the sea in black and the land in shades of green and brown. Several different thematic layers are laid on top of the FCC; the locations of the

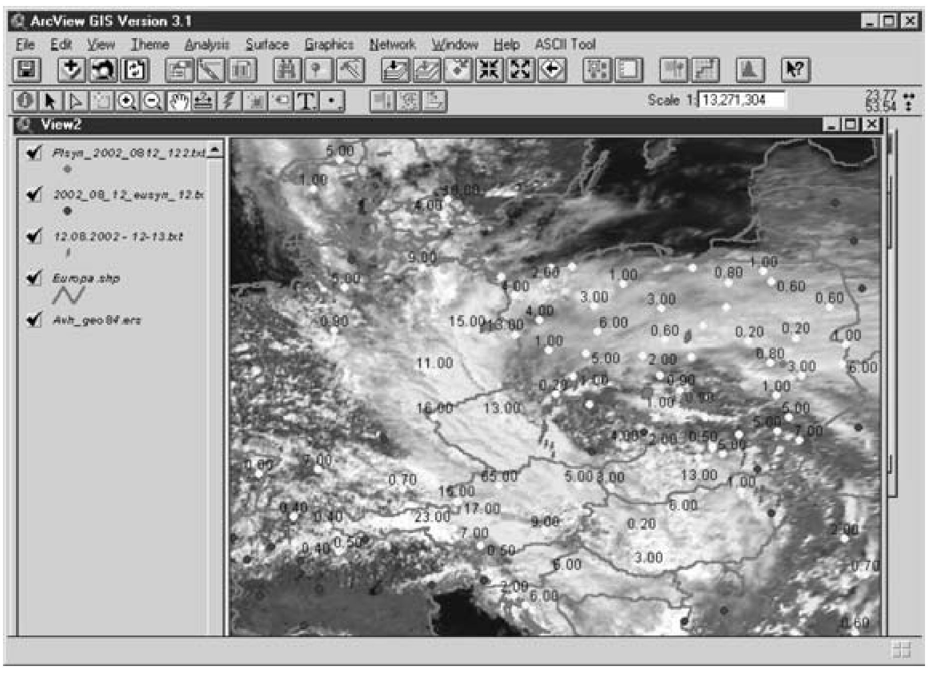

Figure 1. *Satellite data with the SYNOP stations overlay, 12 August 2002 (arcview).*

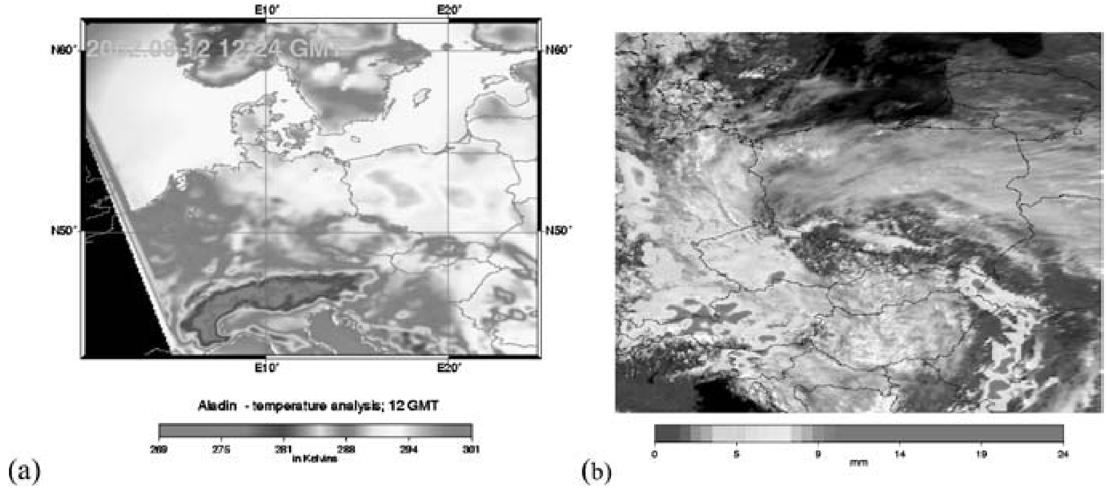

Figure 2. *Numerical weather prediction model Aladin, 12 August 2002 at 12:00 GMT (a) Temperature field analysis; (b) Convective precipitation forecast (+3h) in mm.*

SYNOP stations in Europe and Poland are shown as blue and green dots, respectively. Yellow dots show the marked SYNOP stations with the recorded precipitation over 1 mm. The labels show the recorded precipitation. Recorded lightning from the Safir system (Polish lightning detection network) is shown in red. This figure shows some of the layers described in Table 1.

The High InfraRed Sounder (HIRS/3) on board NOAA-15, 16 and 17 satellites sounds the temperature and humidity in 20 infrared channels. The different weighting functions of each radiometer with their maximum at different pressure levels allow the derivation of temperature and humidity profiles, temperature of the earth, and total ozone content. The resolution is approx. 10 km in all channels. The width of the scanning swathe is 2160 km.

The Advanced Microwave Sounding (AMSU) sounder consists of three radiometers: AMSU-A1, AMSU-A2 and AMSU-B. The first two radiometers provide measurements in 15 channels with 40 km resolution at the sub-satellite point, in the range of 23.8 GHz to 89 GHz. The third one provides data in five channels; at frequencies of 89 GHz, 150 GHz and 183 GHz with 16 km resolution. The swathe is approximately 2343 km wide. Passive microwave instruments provide a more direct measure of precipitation, since precipitation directly influences the radiation field. The drawback of passive microwave instruments is their low spatial resolution. Both HIRS and AMSU sounders are part of Advanced Tiros Operational Vertical Sounder (ATOVS).

4. Numerical weather prediction data from the Aladin model

The thematic layers – temperature distribution at seven pressure levels (surface, 925, 850, 700, 550, 450, 300 hPa) – were created using the Aladin model output in ASCII format. In addition, the forecasted precipitation at +03 h and +06 h (stratiform, convective) were imported from ASCII grid and rasterised using gridding procedure. Figures 2a and 2b present the results of the visualisation procedure for surface temperature and precipitation. This allows for the joint analysis of satellite data and regional Numerical Weather Prediction Model Aladin fields as in Figure 2b the satellite data is overlaid with the precipitation forecast layer drawn from the numeric model. Both images also have the vector data layer showing the international boundaries and coast.

5. Software

Several specialised software packages are used in order to process different types of data. Initially, the satellite data are processed using the Advanced ATOVS Processing Package (AAPP) created and distributed by the EUMETSAT (AAPP Module Design 1997; Renshaw & English 1998; AAPP Documentation 1999a). Received AVHRR and ATOVS data are transformed to the AAPP v.3.4 level 1d format. This means that all necessary decommutation, calibration, georeferencing and identification of cloud contamination are performed by the package. The obtained albedo and brightness temperatures of AVHRR, HIRS and AMSU data are also mapped to HIRS grid. ER Mapper is the commercial software package used for the raster images processing and visualisation. It also allows raster data to be presented with the vector layers. ArcView 3.1 and ARCGIS 8.3 packages are used in order to combine the ground data and the satellite-derived parameters (Figure 1).

AAPP has been implemented on an Alpha DEC workstation with the Digital UNIX system. Specially designed routines allow the automatic control of the AAPP package control for the current satellite pass of NOAA-15, 16 and 17. Finally, all datasets are in the form of an ASCII (x,y,z), where x = longitude, y = latitude

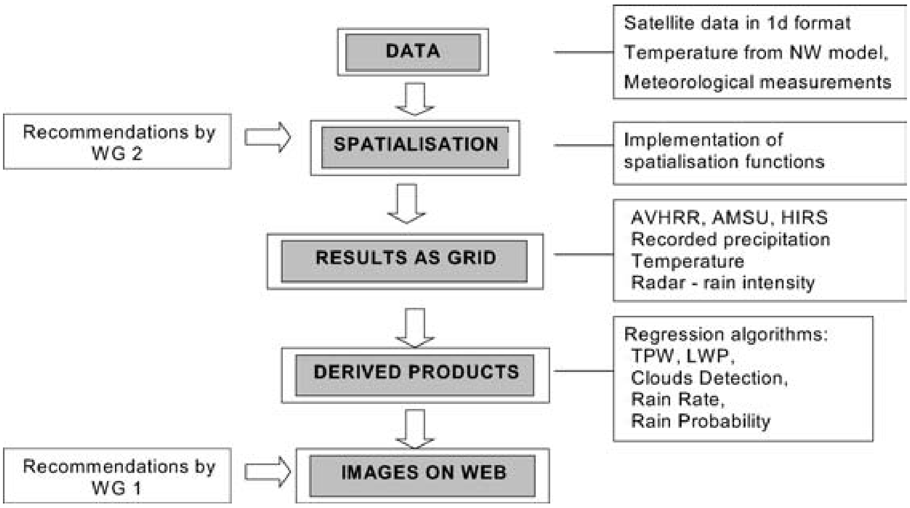

Figure 3. *Processing workflow.*

and z = albedo or brightness temperature. The separate files are created for AVHRR, HIRS and AMSU data with some auxiliary information such as logistic Crosby test, precipitation probability, satellite angles, land cover type, etc.

The Inverted Coupled Imager package (ICI) (Lavanant 1999, 2001; Lavanant & Brunel 2000) allows the retrieval of vertical temperature and humidity as well as the total water vapour and ozone content. The ICI package has been developed by the NWP Satellite Application Facility (SAF) responsible for developing the software and numerical weather prediction models. It is very closely related to the AAPP package and uses the level 1d data. Similarly, the AAPP the package has been implemented on an Alpha DEC workstation and the output datasets have the same ASCII formats.

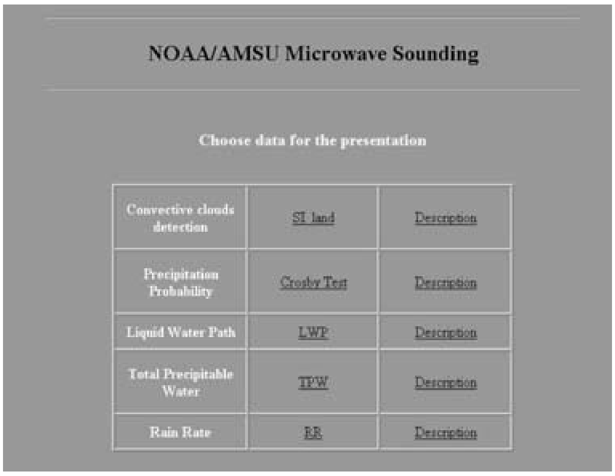

Figure 4. *Microwave Sounding Service Intranet.*

6. The use of Geographical Information Systems (GIS) methods

An analysis of the data types and characteristics are first performed in order to evaluate the efficiency of each thematic layer created. In the analysis the size, spatial, spectral and temporal data analysis was accounted for the different satellite radiometers. The next step was to define the consistent and homogeneous processing system for the satellite data (Figure 1) and the numeric data (Figure 2) data. This included definition of the projection (geographic) allowing the merging of the different thematic layers of raster and vector data.

Figure 3 presents the processing scheme. The initial data from satellite, NWP and measurements undergo the spatialisation procedure. Once transformed into a regular grid, the regression algorithms are applied. Finally the products are made available on the web page in the form of maps. Two important recommendation inputs are envisaged. The recommendations are the expected input from Working Groups 1 and 2 of the COST 719 Action (http://www.knmi.nl/samenw/cost719). The WG1 input refers to the data standards, formats and metadata definitions. WG2 expected input should provide the recommendation for the spatialisation methods relevant to the data type.

Based on the regression algorithms described in previous works (Dyras & Serafin-Rek 2001a, 2001b, 2002a, 2002b), the products are made available via the Microwave Sounding Service (see Figure 4). The maps of Liquid Water Path (LWP), Total Precipitable Water (TPW), Scattering Index (SI) used for detection of convective cloud systems, Precipitation Probability (PP) and precipitation intensity or Rain Rate (RR) are created for the current satellite pass of the polar orbiting satellites NOAA-15, 16 and 17. Figures 5, 6, 7, 8 and 9 show examples of these products created for the NOAA-16 pass on 12 August 2002. Each product has an option called ‘Description’ which provides information on the algorithm, the formulas used and bibliographic sources.

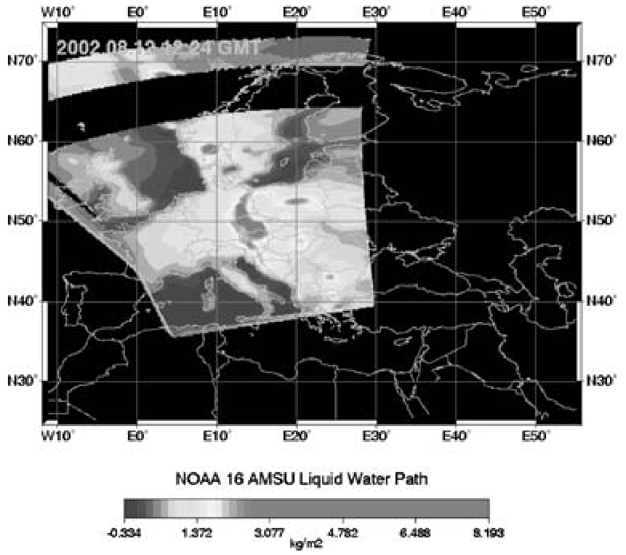

Figure 5. *LWP – Liquid Water Path, NOAA-16, 12 August 2002, 12:24 GMT.*

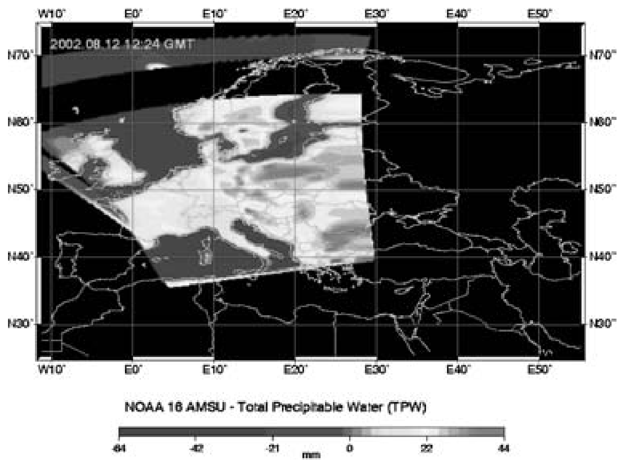

Figure 6. *TPW – Total Precipitable Water, NOAA-16, 12:24 GMT.*

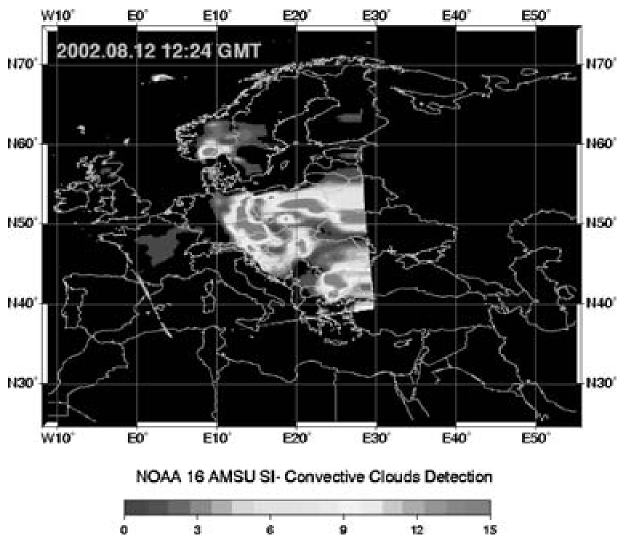

Figure 7. *SI – Convective cloud systems detection NOAA-16, 12 August 2002, 12:24 GMT.*

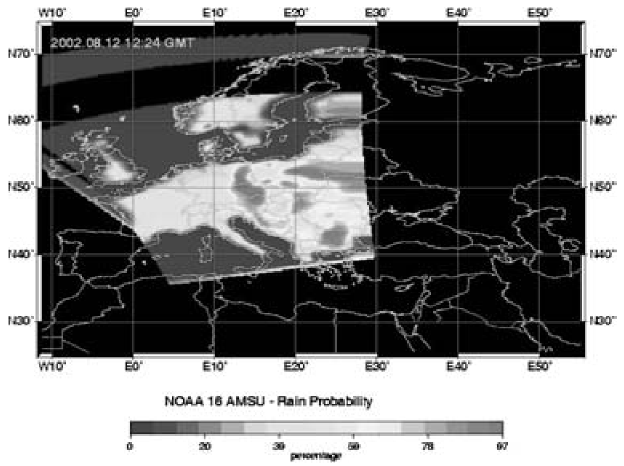

Figure 8. *PP – Precipitation probability NOAA-16, 12 August 2002, 12:24 GMT.*

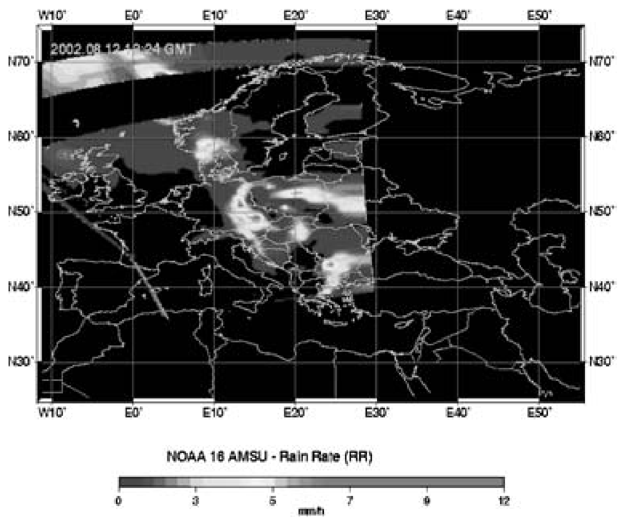

Figure 9. *Rain Rate – RR, calculated from the satellite microwave data (AMSU), NOAA-16; 12:24 GMT.*

There was a deep low-pressure centre over central Europe with cloud systems over eastern Germany and the Czech Republic bringing very intensive rainfall that caused flooding (Figure 1). The synoptic stations recorded rainfall of 30 mm/6h, in some places as much as 60 mm/6h. The convective cloud systems were correctly identified on microwave images (see Figure 7); LWP was very high at over 2.5 kg/m^2 (see Figure 5).

The simple PP, RR data classification allowed the overlay of rainfall probability (Figure 10) and rain rate (Figure 11) on the satellite image of clouds. It shows the potential of the system for presenting the analysed data, reducing the amount of information that is distributed through the network in operational situations.

7. Conclusions and future work

The humidity and temperature fields from microwave data provide important supplementary information for the standard radiosondes network. The spatial resolution of microwave data is better while the temporal

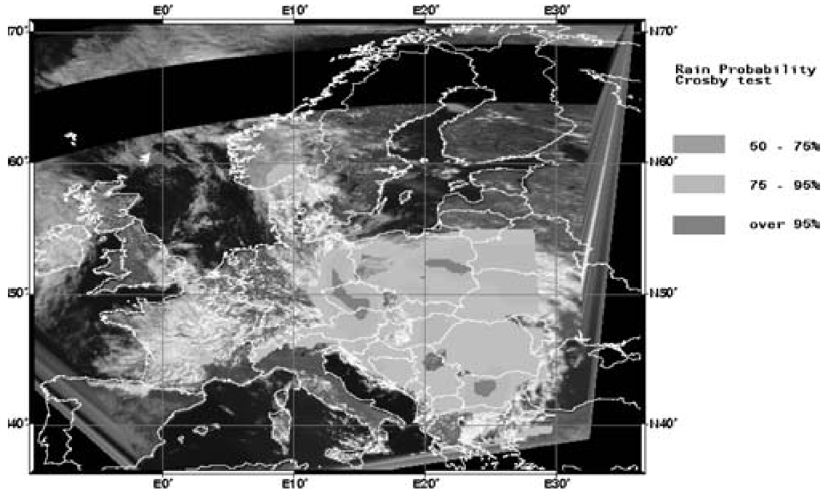

Figure 10. *Rain probability classes overlaid on the False Colour Composite.*

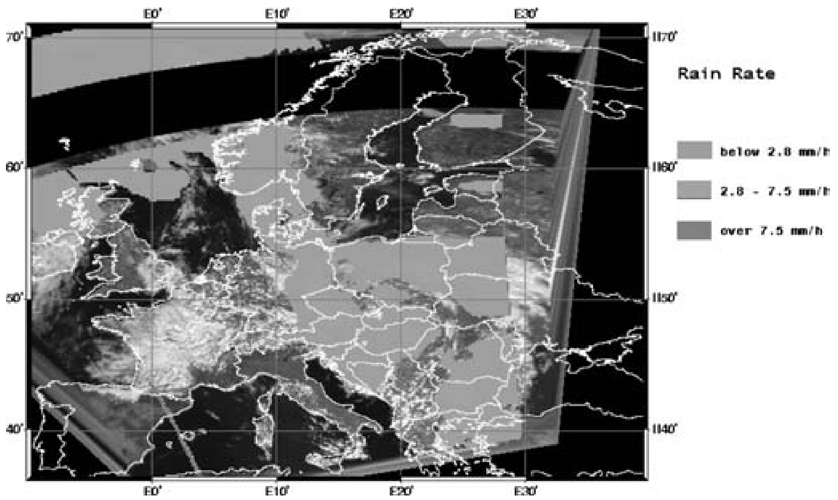

Figure 11. *Rain Rate – precipitation intensity and range in three classes.*

resolution depends on the number of satellite passes (six a day). The algorithms for the identification of convective clouds are very useful in extreme situations. They still require quantitative analysis over longer periods and verification against radar data. It is clear that the derived system for the joint visualisation and analysis of meteorological data from different sources plays an important role in performing these tasks. Presenting concise analyses of the abundant data is an especially important operational service.

The microwave data from AMSU/NOAA radiometers has a low spatial resolution so it is very important to pay attention to the geographical rectification and coastal effects.

In future it is planned to focus on the operational implementation of the ICI package and automation of the vertical profiles production. The verification of Rain Rate algorithms against the radar network is of great importance. They should be developed using the network of hydro-meteorological or radar stations, and surface emissivity has to be accounted for. The algorithms also need to be tested in different seasons, as only the summer season has been tested here. In winter, snow and ice-covered areas would have to be screened, and microwave data analysis in wintertime (the impact of snow and ice) will need detailed investigation.

Acknowledgements

The work was supported by the Polish Committee for Scientific Research (KBN) with Grant No. 618/E-217/SPUB-M/COST/P-04/DZ 245/2001–2003.

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