

# Meteorological Products Generation Using Combined Analysis of NOAA AVHRR and ATOVS Data.

***Izabela Dyras, Danuta Serafin-Rek, Zofia Adamczyk***

*Institute of Meteorology and Water Management,*

*P. Borowego 14, 30-215 Kraków, Poland*

## **Abstract**

The satellite observations in different spectral ranges provide the important information on the state of the atmosphere that is used for weather analysis and forecast. Combining these data into one system encounters problems due to the data various range as well as temporal and spatial resolution. The Geographical Information System (GIS) methods can be a useful tool for the data analysis and presentation.

The paper presents the progress in the cloud analysis on NOAA AVHRR images as well as in algorithms allowing the retrieval of various parameters from NOAA AMSU data in the Satellite Research Department, Institute of Meteorology and Water Management in Poland.

The meteorological products prepared for the Polish meteorological service include several thematic layers such as precipitation intensity and range, convective clouds' detection, and total precipitable water estimation. The combined analysis maps are created and then disseminated via Intranet to the regional forecasting offices. Such satellite maps enhance the ability to diagnose the precipitation using satellite imagery.

The GIS technology is used for preparation and visualisation of the products derived from various sources including additional overlays such as geographical data and administrative boundaries.

The AMSU data have been processed using the Advanced ATOVS Processing Package (AAPP ver.3.7) and visualized using ER Mapper 6.3 software.

## **Introduction**

The satellite observations, ground measurements and numerical weather prediction (NWP) models provide continuous information on the state of the atmosphere that are used for weather analysis and forecast. Combining these data into one system encounters problems due to the data various range as well as temporal and spatial resolution, however, GIS can provide the useful tool for the data analysis and presentation.

Since their launch the satellites NOAA-15, 16 and 17 are equipped with microwave radiometers (AMSU) that are very useful for atmosphere sounding i.e. evaluation of precipitable water and ice crystal distribution. There has been significant progress in developing methods using microwave information over the sea and oceans. However, the methods of sounding from the microwave spectrum over land are still inadequate and these problems are researched in several centres in the world.

## Data and software

A summary of the data used in this work is presented in the Table 1, which demonstrates the potential problems caused by different spatial resolution, frequency, temporal resolution and scale. 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 was used from SYNOP at 12.00 GMT (precipitation sum for the last 6 hours). Vertical profiles of temperature, dew point and geopotential height from TEMP data were used to calculate air relative humidity and cloud water content. Water vapour mixing ratio, relative humidity and liquid water contents and consequently - cloud liquid water path (LWP) were calculated at the standard pressure levels.

Data Type	Range	Resolution	Frequency	Scale
SYNOP KLIMAT	Europe Poland	synoptic/ climatic stations	1 h 3 h 6 h/12 h/24 h	regional regional
AEROLOGICAL SOUNDING	Poland/Europe	aerological stations	1x -4x /day	global
NOAA AVHRR NOAA AMSU NOAA HIRS	Central Europe	1.1 km 17/40 km 10 km	6/day	regional regional regional
SAFIR	Poland	1 km	1 min	regional
NUMERICAL WEATHER PREDICTION MODEL	Central Europe	13 km	6/12 h	mesoscale

Table 1: Meteorological and climatological data.

Satellite data was introduced into the present system come from the polar orbiting NOAA satellite system. The Advanced Very High Resolution Radiometer (AVHRR/3) is a multipurpose imaging instrument used for global measurement providing the characteristics of cloud cover, sea surface temperature, ice, snow and vegetation cover. AVHRR has 6 channels in the visible and infra-red between 0.63 and 12.0 micrometers, with a resolution of 1.1 km at the sub-satellite point [NESDIS, 1998]. The Advanced Microwave Sounding (AMSU) sounder consists of 3 radiometers. The first two radiometers AMSU-A1 and AMSU-A2 provide measurements in 15 channels with 40 km resolution in sub-satellite point, in the range of 23.8 GHz to 89 GHz. The third - AMSU-B provides data in 5 channels; in frequencies 89GHz, 150 GHz and 183 GHz with 16 km resolution. Passive microwave instruments provide information about precipitation, since precipitation directly influences the radiation field. The drawback of passive microwave instruments is their low spatial resolution.

Figure 1 shows a good example of combining different information. In the background there is a False Colour Composite (FCC-channels 321) from the AVHRR/3 radiometer on board the polar orbiting meteorological satellite - NOAA 16. The clouds appear in white to blue colours, sea in black and land in shades of green and brown. Several different thematic layers are laid on top of the FCC; the locations of the SYNOP stations in Europe and Poland are shown as blue and yellow dots, respectively. Yellow dots show the marked SYNOP stations with the

recorded precipitation over 1 mm. The labels show the recorded precipitation. The recorded lightning from Safir system is shown in red.

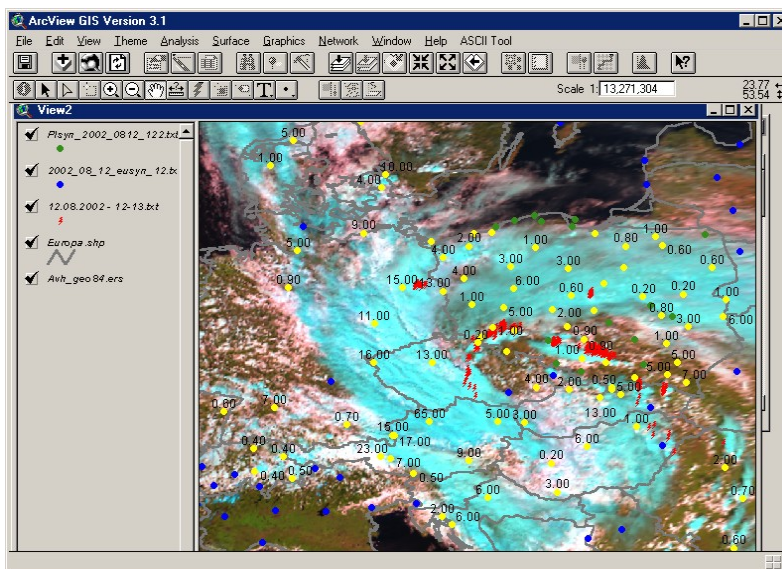


Fig. 1: Satellite data with the SYNOP stations overlay, 12.08.2002 (ArcView).

Several specialized 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, 1997; AAPP Documentation, 1999a, 1999b; Renshaw and English, 1998]. Received AVHRR and ATOVS data are transformed to the AAPP level 1d format i.e. all necessary decommutation, calibration, geo-referencing and identification of cloud contamination are performed by the package. Specially designed routines allow the automatic control of the AAPP package for the current satellite pass of NOAA 15, 16 and 17. The output data sets are in the form of an ASCII (x,y,z), where x – longitude, y – latitude and z – albedo or brightness temperature. The separate files are created for AVHRR and AMSU data with some auxiliary information such as logistic Crosby test, precipitation probability, satellite and sun angles, land cover type, etc.

ER Mapper is the commercial software package used for the raster images processing and visualization. It also allows presenting raster data with the vector layers. ArcView 3.1 and ARCGIS 8.3 packages are used in order to combine the ground data with the satellite-derived parameters.

## Products generation

Precipitation is a highly variable parameter with time and space therefore the use of satellite data allows obtaining the global information. The measurements in microwave channels are a particularly interesting source of information concerning the humidity of the atmosphere [Muller, 1994].

The microwave humidity products are made available as Microwave Sounding Service and TOVS Sounding Service. They are based on the regression algorithms described in previous works [Dyras I. and D. Serafin-Rek, 2001a, 2001b, 2002a, 2002b].

## Rain Rate

The maps of precipitation intensity - Rain Rate (RR) are created for the current satellite pass of the polar orbiting satellites NOAA 15, 16 and 17. Fig. 2 shows the three classes of light, moderate and high precipitation intensity. The Rain Rate was calculated according to the regression algorithm 1.

$$RR = 47,75 - 0,096*TB(50)+0,123*TB(89)-0,158*TB(150)-0,037*TB(183.7)) \text{ [ mm/h ]} \quad (1)$$

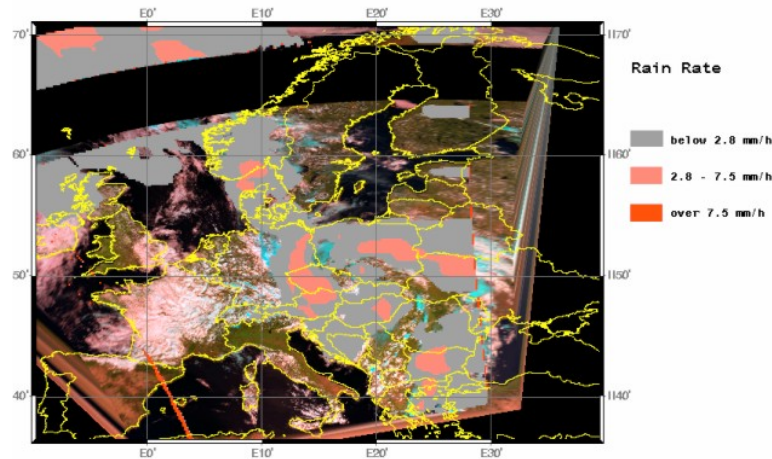


Fig. 2: Precipitation Intensity map from AMSU data; NOAA 16, 12.08.2002, 12:24 GMT. Intensity is broken into 3 classes – light, moderate and high.

## Scattering Index

Microwave data NOAA/AMSU is valuable for the recognition of extreme situations such as convective cloud systems or extended storm clouds. The results of testing and verification of the precipitation detection versus ground measurements for the summer-autumn season in 2002 is shown in Table 2. It was observed that the majority of precipitation occurred when the value of  $SI_{land}$  was greater than 3.

SATELLITE SYNOP	PRECIPITATION $SI_{land} \geq 3$	NO PRECIPITATION $SI_{land} < 3$
PRECIPITATION	338	2
NO PRECIPITATION	27	4

Table 2: The results of precipitation detection using scattering index – comparison of the results obtained from AMSU data vs. SYNOP for the summer-autumn season in 2002 (371 cases).

$$SI_{land} = 42.72+TB(89)-TB(150) \quad (2)$$

Scattering Index (SI), used for convective clouds detection ( $SI_{land}$ ), is calculated according to the regression algorithm 2. It is assumed that the precipitation occurs if  $SI_{land} \geq 3$ . The horizontal size of the cloud is important – big systems are recognised better than small that sometimes are ignored. Fig. 3 shows the detected convective systems over the Central Europe.

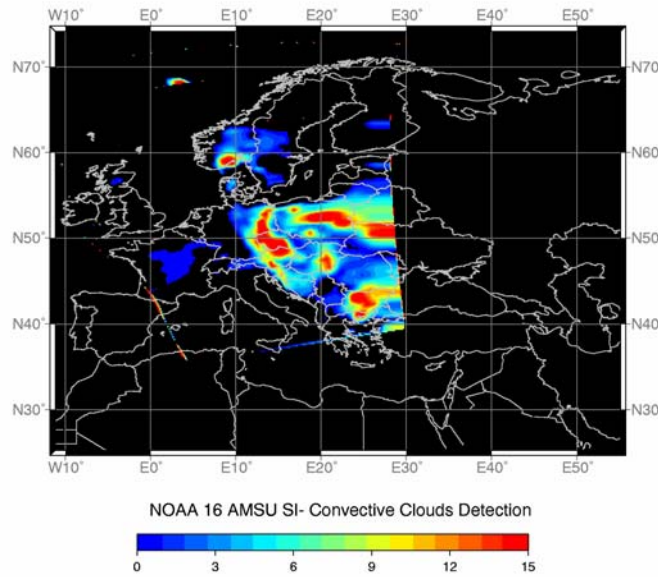


Fig. 3: Scattering Index over land map – areas of detected convection from AMSU, NOAA 16, 12.08.2002, 12:24 GMT.

### Total Precipitable Water

Total Precipitable Water (TPW) as described by formula (3) allows estimating the water vapour content in the air over the land. The obtained regression fitting index  $R^2 = 0.59$  with standard deviation  $\pm 4.6$  mm, for 618 cases. Table 3 contains the results of regression analysis.

$$TPW = -26,94 + 0,32 * TB(50) + 1,0198 * TB(89) - 0,404 * TB(150) - 0,789 * TB(183 \pm 7) \quad [mm] \quad (3)$$

STATISTICA MULTIPLE REGRESSION	Regression Summary for Dependent Variable: <b>TPW</b> R= 0,76699883 <b>R<sup>2</sup> = 0,58828720</b> Adjusted R <sup>2</sup> = 0,58560066 F(4,613)=218,98 p<0,0000 <b>Std. Error of estimate: 4,5781</b>						
	N=618	BETA	St. Err. of BETA	<b>B</b>	St. Err. of B	t(613)	p-level
<b>Intercept</b>				<b>-26,9441</b>	13,23545	-2,03576	0,042204
<b>T50_3</b>	0,238232	0,096127	<b>0,3202</b>	0,12921	2,47831	0,013469	
<b>T89_0</b>	0,918632	0,165788	<b>1,0198</b>	0,18404	5,54101	0,000000	
<b>T150</b>	-0,444990	0,140871	<b>-0,4043</b>	0,12798	-3,15886	0,001662	
<b>T183_7</b>	-0,667865	0,067999	<b>-0,7887</b>	0,08030	-9,82171	0,000000	

Table 3: The results of the regression analysis obtained for Total Precipitable Water (STATISTICA).

The case of very intense rain causing flooding in the Czech Republic in August 2002 was chosen to visualize the usefulness of microwave TPW sounding. The map on Fig. 4 shows the example of TPW product created for the NOAA16 pass on 12.08.2002 and it shows the high TPW content over Central Europe. The highest TPW values are shown in red. Fig. 5 presents the spread between TPW values from radiosonde data (on axis Y) and TPW values determined from the combination of brightness temperatures of AMSU channels (on axis X) as calculated by a STATISTICA program.

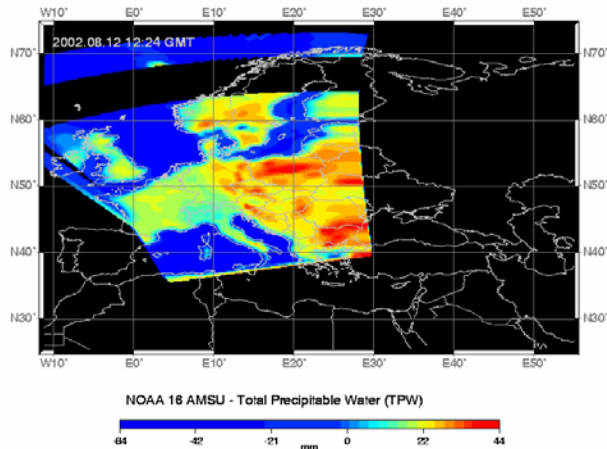


Fig. 4: Total Precipitable Water ( $\text{kg}/\text{m}^2$ ), calculated from microwave AMSU data, NOAA 16 12.08.2002; 12:24 GMT.

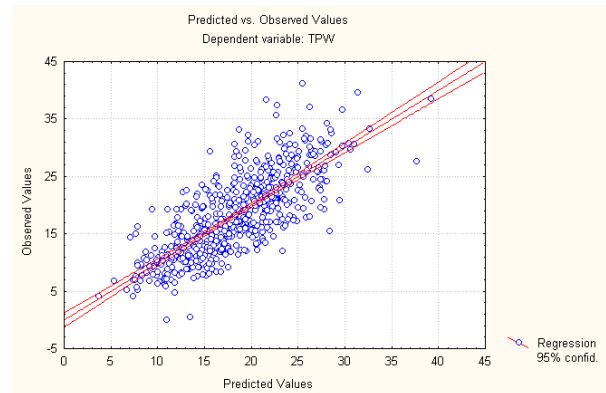


Fig. 5: The spread between TPW values calculated from radiosonde data – axis Y and TPW values determined from combination of brightness temperature of AMSU channels– axis X.

The location of the low and system of fronts shown on the surface analysis map (Fig. 6) has a good representation on the satellite image. The microwave algorithms adequately define the areas of the high humidity values, rain rate intensities as well as ranges.

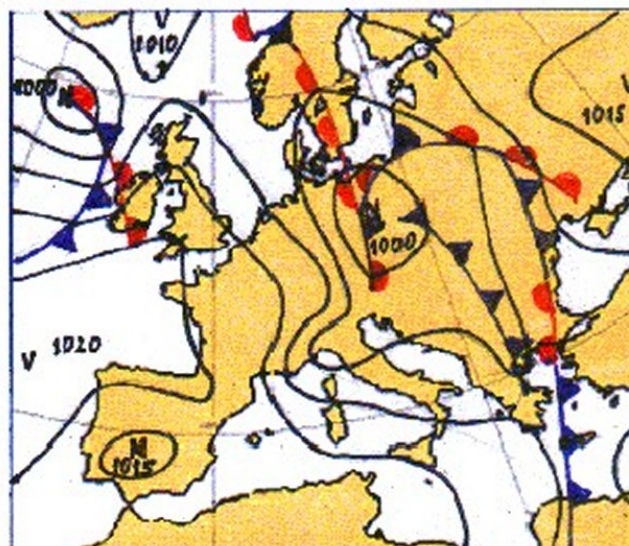


Fig. 6: Meteorological situation on 12.08.2002, analysis at the surface.  
(source:<http://www.chmi.cz/hydro/pov02/flood.htm>)

## Composite Images

Creating a False Colour Composite (FCC) is very simple technique for cloud cover enhancement (Fig. 8). It simultaneously combines satellite images from three channels of AVHRR data into one colour image product. Discrimination between low clouds and fog, thin and thick cirrus, cloud free land ocean, and thick non-precipitating clouds from nimbostratus can be performed more successfully and more confidently when using multi-spectral infrared and visible colour imagery in conjunction in one another. Convective clouds are in blue, low clouds in pink. More advanced techniques – supervised or unsupervised classification can also be applied as shown on the Fig. 9.

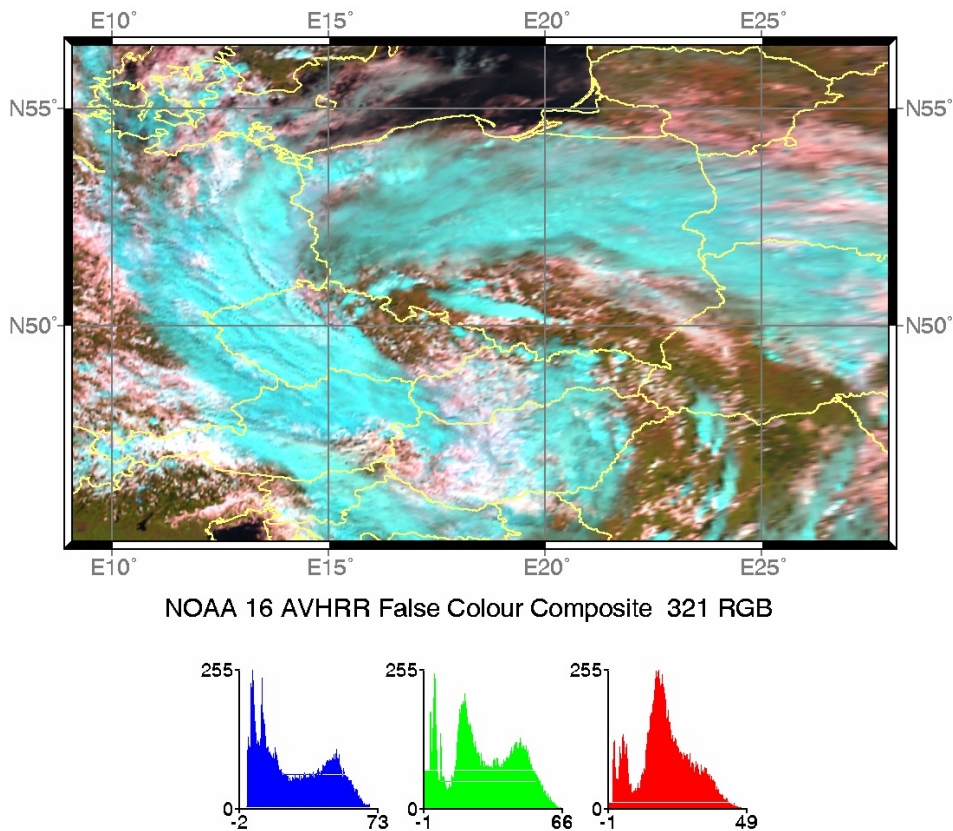


Fig. 8: False Colour Composite (NOAA / AVHRR - RGB) - of channels 3<sub>A</sub>21;  
NOAA16, 12.08.2002; 12:24 GMT.

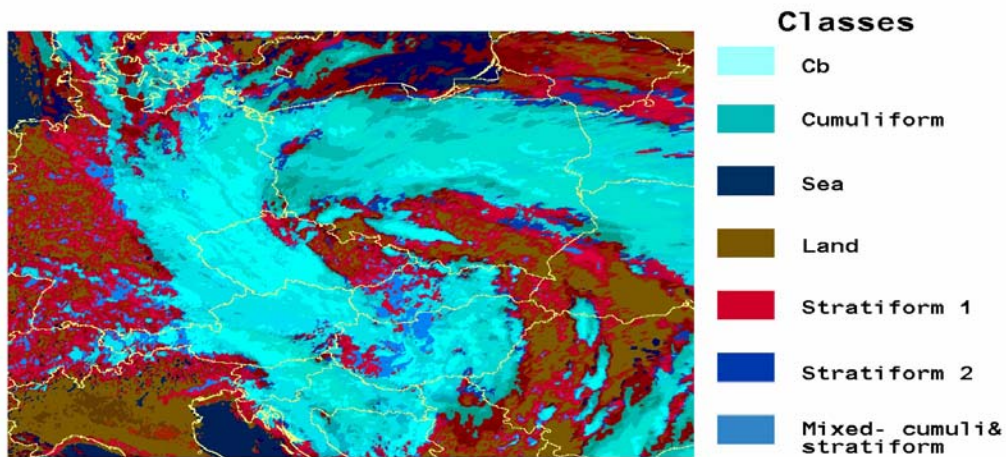


Fig. 9: Satellite cloud cover classification based on NOAA/AVHRR data.

### Numerical Weather Prediction Model Fields

Temperature and precipitation forecast fields imported in order to create the thematic layers are shown in Fig. 10 and in Fig. 11, respectively.. Temperature at 7 pressure levels (surface, 925, 850, 700, 550, 450, 300 hPa) and the forecasted precipitation at +03h and +06h (stratiform, convective) were rasterised using a gridding procedure and rectified by triangulation using ER Mapper 6.3 software.

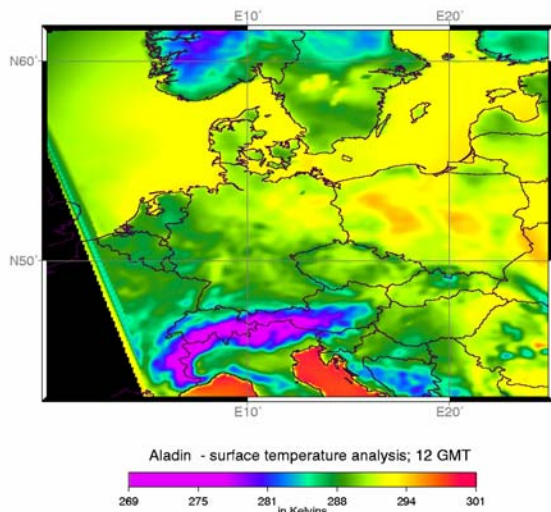


Fig. 10: Temperature field at the surface– from numerical model Aladin.

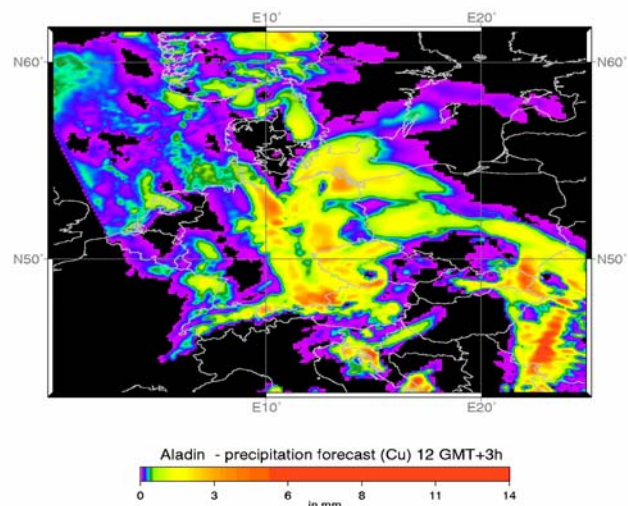


Fig. 11: Convective precipitation forecast (Aladin) on 12.08.2002, 12.00 GMT + 3 h.



## Conclusions

Geographical Information System (GIS) methods and tools proved very useful for joint analysis and presentation of satellite as well as meteorological data.

GIS used for the joint analysis and presentation of satellite and meteorological data allow the preparation of:

- Maps of the integrated information from all satellite sensors (AVHRR, HIRS and AMSU) such as TPW, RR, SI.
- Classification and visualisation of the multi-spectral data with the vector overlays (i.e. geographic or administrative boundaries)
- Development, testing and verification of the suitable algorithms for various meteorological parameters;

GIS methods allow presenting the integrated information from NOAA satellite sensors (AVHRR and AMSU) transformed to a suitable projection; creating composite images using different spectral channels and overlaying with the vector data (geographic and administrative boundaries); developing the suitable algorithms for various meteorological parameters calculation, testing and verification. Finally, these methods allow combining different data (raster and vector) into one thematic layer for their Internet distribution. The Intranet service for NOAA Microwave sounding products was created. It consisted of maps for convective clouds detection, precipitation probability, Liquid Water Path, Total Precipitable Water and Rain Rate respectively prepared for the NOAA passes.

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