THE EUMETSAT MULTI SENSOR PRECIPITATION ESTIMATE (MPE): CONCEPT AND VALIDATION

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ABSTRACT

Precipitation is the meteorological parameter affecting people in the most direct way. Forecasting the spatial and temporal distribution of rain and snow is therefore one of the major challenges for the meteorological services. Satellite remote sensing of precipitation could help to improve these forecasts. The most direct method to retrieve precipitation from spaceborne measurements is based on data from passive or active microwave sensors. These sensors are only available on low orbiting satellites up to now. In addition the spatial resolution of microwave sensors is hardly sufficient to resolve small scale precipitation events. Infrared brightness temperatures from geostationary satellites are only related indirectly to the precipitation at the ground but have a high spatial and temporal resolution. Therefore methods to combine both retrieval systems have been developed. EUMETSAT implemented such a 'blending' technique in the re-processing branch of its Meteorological Product Extraction Facility (MPEF). Rain rates derived from measurements of the Special Sensor Microwave / Imager (SSM/I) onboard of the US-DMSP satellites are combined with brightness temperatures from the Infrared channel of the MTP-METEOSAT satellites.

The basic assumptions of the Multisensor Precipitation Estimate (MPE) method is that colder clouds are more likely to produce precipitation than warmer clouds. The relation between the cloud top temperature and the surface rain rate is non-linear and depends strongly on the current weather situation. Temporally and spatially co-registrated SSM/I and METEOSAT measurements are used to derive look-up tables (LUTs) which describe the rain rate as a function of the METEOSAT IR brightness temperature. These LUTs are applied to METEOSAT images in order to derive rain rates in the full spatial and temporal resolution. Co-registered data for the LUT derivation are accumulated in geographical windows for a specified time. The size of these temporal and spatial accumulation windows must be sufficient to have enough data sets for the LUT creation but should be not too large to represent the current weather situation. We selected temporal windows of 6-12 hours and spatial windows of 5° longitude and 5° latitude.

Validation was performed with historical data sets comparing the MPE-results with rain rates derived only from SSM/I and with ground based radar data. The method performs as expected. Due to the basic assumption that cold clouds produce the most rain it is very efficient to estimate the spatial distribution and the strength of convective precipitation. This is valid for large scale tropical convection as well as for small scale convective processes and cold fronts. The precipitation at warm fronts and orographically induced precipitation is usually detected but miss-located by up to 100km.

1. INTRODUCTION

The estimation of precipitation parameters from satellite data has quite a long history (see e.g. Grose et. al., 2002). The major problem of all methods is the very in-direct relation between the precipitation on the ground and the measured satellite signal. Measurements in the microwave spectral region use the absorption of microwave radiation by liquid water or on the scattering by ice particles. One of the major difficulties here is that the amount of precipitation reaching the ground depends also on the structure of the atmospheric layer under the precipitating cloud. In addition the poor spatial resolution and the long re-visit times of microwave sensors lead to considerable sampling errors in the estimation of accumulated rainfall (Ebert et. al. 1998). The use of infrared satellite data is an even more in-direct approach. The cloud top temperature is only for convective systems directly related to the surface rainfall and even in these cases the amount of precipitation depends significantly on the stage in the life cycle of the convective system. Despite of this disadvantage the high temporal and spatial resolution of geostationary satellite data makes the use of IR brightness temperatures useful for both, the near-real estimation of precipitation in areas with a sparse radar network (e.g. Central Africa) as well as for the long-term monitoring.
The combination of both kinds of data, microwave (MW) data from polar orbiting satellites and IR data from geostationary systems is an obvious approach to overcome some of the shortcomings in the estimation of precipitation. From the different available schemes we decided to build up a system based on the Naval Research Lab algorithm (Turk et. al. 1999) because this algorithm was designed to be robust enough for an operational implementation.

2. METHOD

The applied algorithm is described in detail in Heinemann et. al., 2002. Therefore only a brief outline of the concept in respect to the validation efforts is given in this paragraph.

Like most IR algorithms the Multi-sensor Precipitation Estimate (MPE) is based on monotonic functions relating the measured IR brightness temperature to the rain rate. The coldest temperatures are associated to the highest rain rates. For temperatures above a certain threshold no precipitation is estimated. The form of this functions depends on the current weather situation. Therefore the MPE algorithm adjusts it geographically and temporarily using derived rain-rates from the passive MW measurements as calibration values. Due to the poor spatial coverage of MW measurements the adjustment cannot take place for each individual image but must be based on accumulated data over a certain time period. In practice we co-locate IR images and MW data over up to 12 hours in geographical 5°x5° boxes and derive a rain rate function for each of the geographical boxes. The matching between MW rain rates and IR brightness temperatures is done with a direct histogram matching technique starting from the coldest (rainiest) data points. The derived functions are stored in the form of lookup-tables (LUT) and can be applied to IR images taken in similar weather situations as the images which were used to derive the LUTs. Usually images taken within or shortly after the accumulation period are used.

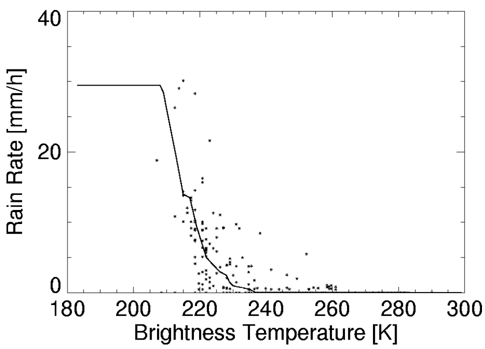

Fig. 1: *Look-up tables (LUT) derived from a 6h period on Aug. 19th, 2001 for the 5°x5° box number 229, over West Africa.*

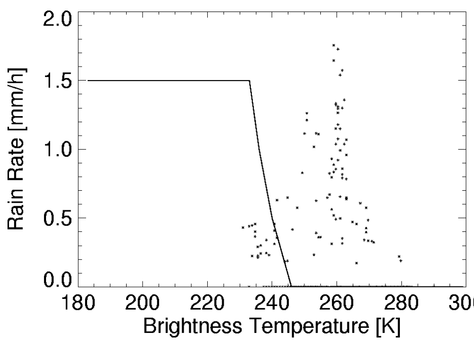

Fig. 2: *Look-up tables (LUT) derived from a 6h period on Aug. 19th, 2001 for the 5°x5° box number 15, south-west of South Africa.*

The straight lines in Fig. 1 and 2 show LUTs as they were derived from a 6 hour accumulation period for two different geographical boxes. The dots in the figures represent the accumulated data points. Since the direct histogram matching technique always assigns the coldest data points to the highest rain rates, the curve does not have to be a good representation of the points. In the 5°x5° box represented by Fig.1 large scale tropical convection was defining the weather situation. The correlation between rain-rates from MW data and measured IR brightness temperatures is quite high and the application of the LUT will produce a rather good representation of the rain field. The situation in Fig. 2 is completely different. Here the weather in the 5°x5° grid box was dominated a frontal system in the South Atlantic. According to the MW data the rain was produced mainly by the warm front. The poor correlation between the points and the curve in the figure shows the problem of the algorithm to describe this kind of 'warm rain'. Please note also the very different rain rates scales for the two figures.

3. IMPLEMENTATION

The current MPE algorithms is designed to process data from the IR channel of the METEOSAT first generation satellites. As passive MW data measurements of the Special Sensor Microwave / Imager (SSM/I) onboard of the US-DMSP satellites are used. The data are received and archived by the ECMWF and transferred from there. The conversion of microwave radiance to rain rates is performed with the operational NOAA-NESDIS scheme (Ferraro 1997).

The completely modular design of the algorithm and its implementation allows for the extension of the program to other sources of MW data or other MW to rain rate conversion algorithms. Especially the use of TRMM data is planned for the future.

The MPE algorithm is intended to be an integrated part of the Meteorological Products Extraction Facility (MPEF). The MPEF is EUMETSATs real-time processing facility for the production of meteorological products from METEOSAT data (EUMETSAT, 1996). It is located at the central facility in Darmstadt and is operated on the same high level of availability and timeliness as the rest of EUMETSATs ground system. In order to process historic METEOSAT data with the newest generation of MPEF algorithms a re-processing environment (R-MPEF) was developed which can operate the same algorithms as the operational MPEF (O-MPEF).

The implementation of MPE in the R-MPEF is completed and a data decoding routine for the GRIB2 data format was developed. Historical data can be calculated for all periods with available METEOSAT and SSM/I data. The implementation in the O-MPEF will take place in the near future and the publication of MPE rain rate images in JPEG format on the EUMETSAT web-page is planned as soon as the initial tests of the implementation are completed. After this step the digital data will be made available in GRIB2 format for download.

As far as the use of MSG data is concerned a fellowship in co-operation with the DWD was established in order to investigate the work that has been done by different groups in this field and to propose an enhanced operational algorithm for MSG.

4. VALIDATION

The major problem with the validation of instantaneous satellite precipitation products is the lack of suitable reference data. Surface rain gauge data are usually not available in an appropriate spatial and temporal resolution. Some test sites with a dense set of tipping buckets exist in the USA, South Korea and Australia but unfortunately not in the field of view of METEOSAT 7. Therefore the validation of MPE is based on the comparison with other remote sensing methods.

Since the SSM/I data are used as reference data and no one-to-one regression is performed with the brightness temperatures, a direct comparison with the SSM/I data is possible without decreasing the degree of freedom of the system. In addition to the test of the accuracy in the spatial resolution of SSM/I, the effects of the different spatial resolutions of the two sensors and the spatial form and location of precipitation pattern can be investigated in this way. As a second external data source ground based radar data were used. These data are more closely related to falling precipitation on the ground than space based observations but the relation between rain rate and radar signal has to be adjusted carefully. We used radar only for a qualitative comparison of the form of precipitation pattern. For all comparisons the possible time delay between the two data sources of up to 30 minutes should be considered in the appraisal of the results.

Three different geographical test regions were selected for the validation. Fig. 3 shows the three locations in the METEOSAT view projection. The first test area covers most of Central and Eastern Europe. In this area a cyclone caused a major flood in parts of Germany along the river Elbe, in the Czech Republic and parts of Poland in early August 2002. As a reference region an equatorial region in Central Africa was analysed for the same period. The EUMETSAT nowcasting SAF established a campaign for the validation and transfer to other climate regions of its Precipitating Clouds (PC) algorithm with data from April and May 2001. Their test area covered mainly the Iberian Peninsula. The data comparison included the Convective Rain Rate (CRR) product by the Spanish National Meteorological Institute (INM) and data from the INM radar network. In the current validation work we analysed only the radar data and compared them to MPE results.

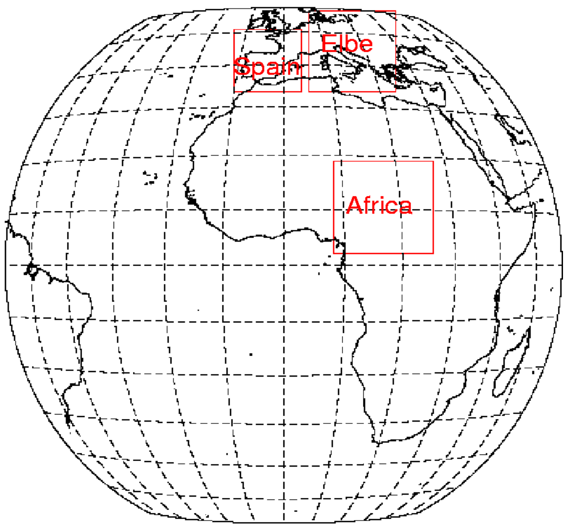

Fig. 3: *Validation regions for May 2001 (Iberian Peninsula, named: Spain) and August 2002 (Eastern Central Europe, named: Elbe, and Central Africa, named: Africa) in the satellite projection of METEOSAT 7.*

4.1. Central Africa reference case

The MPE scheme is supposed to work most effectively in regions with large scale convective precipitation events. We selected therefore a region in Central Africa (~5^0-15^0 W and ~10^0-25^0 N) as a reference case. This region is dominated by strong convective cells in the frame of the ITCZ in August. Fig.4 shows the MPE and SSM/I rain rates for a convective case. SSM/I data were mapped on the METEOSAT projection. The grey area represents the SSM/I swath with valid data and zero precipitation. We can see a good correlation, both in the precipitation values and the form and position of precipitation patches in all cases, considering the possible time delay and the rapidly developing systems. As expected MPE seems to be well suitable for this type of precipitation.

4.2 Elbe flooding case

Between 11-13 August, 2002 a cyclone moved from south (Northern Italy) to north (German-Polish border region) causing heavy flash floods. An air mass with high precipitable water vapour content moved from South to North, but on 12^{th} the direction of this air mass turned back, and because of the North direction the orographic precipitation surplus, especially in the up wind areas of the 'Erzgebirge' (mountain range at the German-Czech border), was significant. A detailed description of this case and the comparison of MPE with ground based measurements and other remote sensing methods is discussed in Berger, 2003.

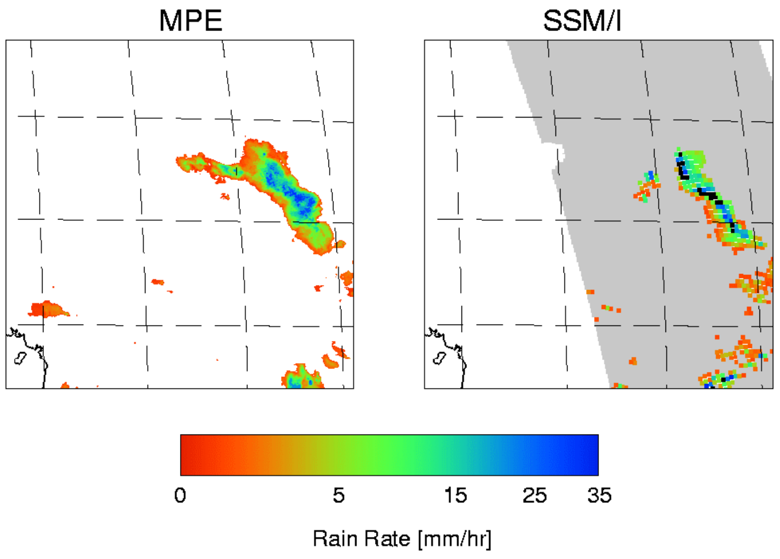

Fig. 4: *MPE and SSM/I rain rates for Central Africa (see Fig.3 for geographical location) 11/08/2002, 20:00 UTC. Strong convective systems with a large geographical extension in the frame of the ITCZ.*

For the three days of the major precipitation only three suitable SSM/I overpasses could be found. Fig. 5, 6, and 7 show examples for the MPE data compared to rain rates derived directly from SSMI measurements. On 11th at the Dinaric mountain a huge convective system developed giving high precipitation. Comparing the two kinds of data we can observe a good correlation, both in value and geographical position. A similar correlation can be observed in general in the next two figures. However, the position of the highest precipitation in Fig. 5 in the late afternoon of the 12th is not retrieved correctly. MPE could not retrieve the orographic precipitation enhancement correctly.

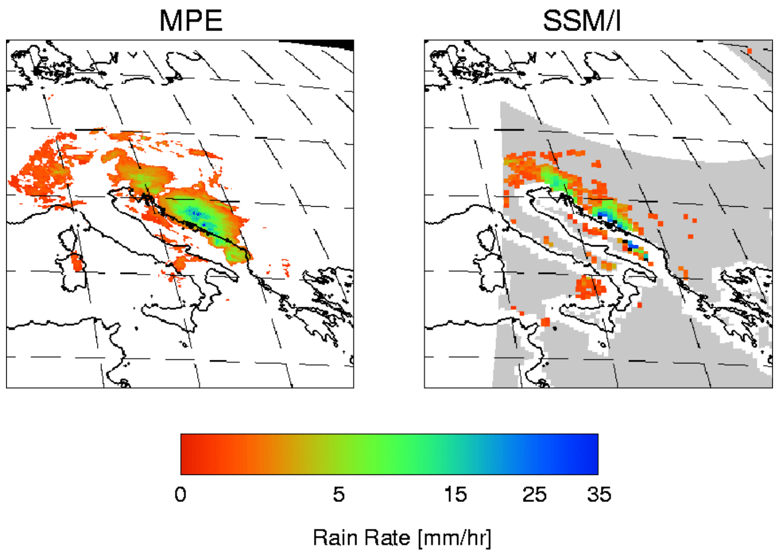

Fig. 5: *MPE and SSM/I rain rates for the Central and south-eastern Europe, 11/08/2002, 6:00 UTC. Strong precipitation at the Dalmatian coast due to landfall of the front of the northward moving Genoa cyclone.*

On 13th (Fig. 7) at the Slovak-Ukrainian border the SSMI measured 2-3 mm/hr rain, while the MPE data did not, and this difference can be seen in Byelorussia also. Again, the front is not located correctly.

As a short summary of this case we can say that the use of MPE for the retrieval of frontal precipitation is possible, but the exact position of the precipitation event may be missed by up to 100km. Orographic effects on the precipitation strength are not properly considered. The precipitation in general is strongly underestimated (Berger, 2003). The major reason for the poor performance of the algorithm for this specific case is that SSM/I data were only available for two overpasses during this episode. In addition the overpasses of the DMSP satellites did not take place during the period of the strongest precipitation. Since the algorithm used these MW data to calibrate the IR images over the whole period, no higher rain rates than those measured during the SSM/I overpasses could be reached. In addition the orographic effects of the mountains cannot be considered by the algorithm and therefore the precipitation is distributed over a larger area.

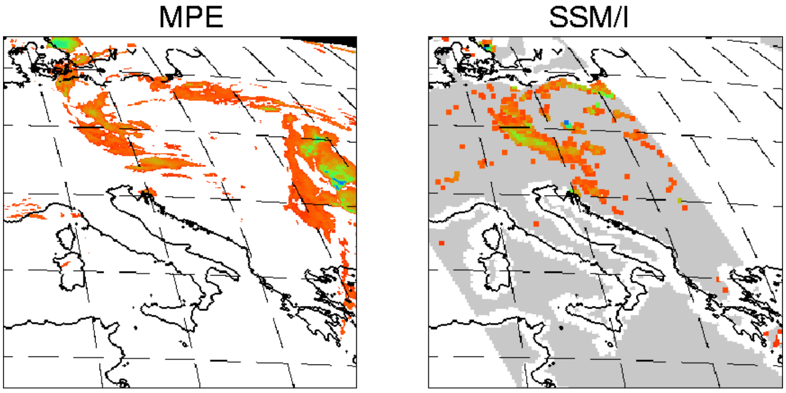

Fig. 6: *As Fig. 5 but for 08/12/2002, 17:00 UTC. The fronts changes its direction and hits the mountain region in the Czech-German border region from the North and produces heavy rainfall.*

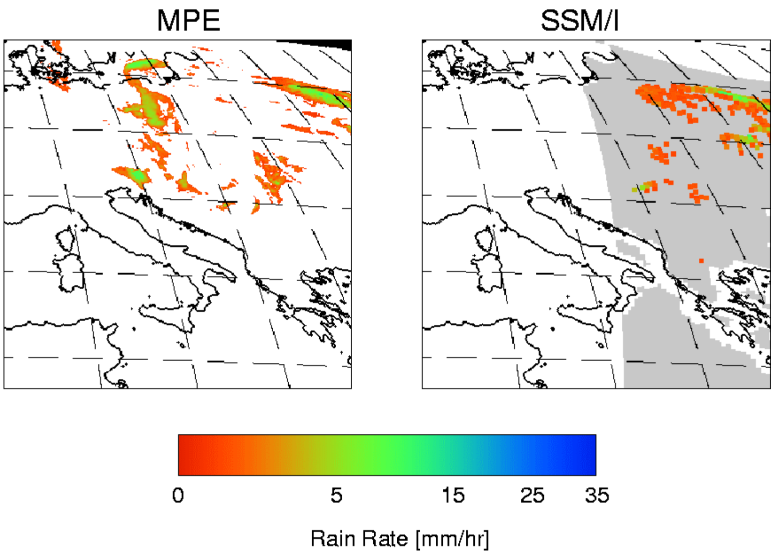

Fig. 7: *As Fig. 5 but for 13/08/2002, 5:30 UTC. The cyclone moves eastwards causing heavy precipitation in Eastern Europe.*

4.3 The Spain May, 2001 case

Radar composites over the Iberian Peninsula were provided by INM for the months April and May 2001 coincident with AMSU overpasses received by SMHI. The data provided as binary images with 13 different grey-value classes covering a range of precipitation intensity between 0 and 100 mm/hr on a roughly logarithmic scale. The data were converted from reflectivity measurements using the standard Z-R relation given by Marshall and Palmer ($Z=200R^{1.6}$) by INM. From all distances from the radar the measurements were taken at 2500 m altitude and no gauge or range adjustment was performed.
All radar data were projected on the METEOSAT IR/MPE image projection and averaged for each METEOSAT pixel.
Unfortunately during the investigated period there was only one case, May 3rd, 7:00 UTC (Fig.8), when we were able to compare all three data sets, MPE, radar and SSM/I. The MPE method identifies the location and spatial extension of the different precipitating areas quite well. An interesting aspect of the SSM/I retrieval algorithm can be observed if we compare the different precipitation fields above and South of the Pyrenees. Some convective clouds developed there and the corresponding rain is identified by all methods. But the SSM/I data show an additional strong precipitation field directly over the Pyrenees which is surely a miss-interpretation of snow on the ground.

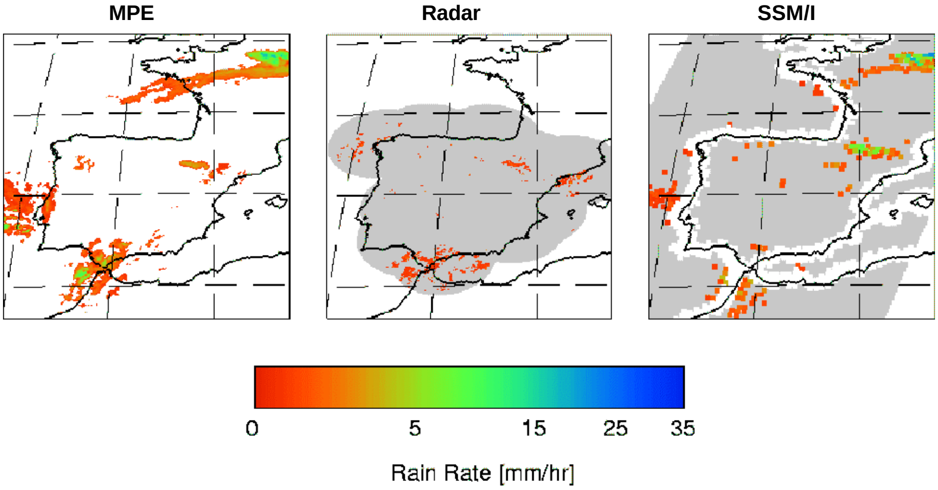

Fig. 8: *MPE, radar and SSM/I rain rates for the Iberian Peninsula for 03/05/2001, 7:00 UTC. Some convective precipitation south of the Pyrenees and a precipitation field over Gibraltar. Grey areas represent valid data sets with zero rain rates for radar and SSM/I.*

The validation cases over the Iberian Peninsula showed in general the performance of the MPE algorithm for very different weather situations. In the presence of mostly convective precipitation the algorithm is showing a good agreement with radar data. Cold fronts can be described well, but the major precipitation may be miss-located. Precipitation from relatively low clouds at warm fronts cannot be described accurately enough. Very localised precipitation is *smeared* out to a larger area by the algorithm.

5. CONCLUSION

In general the MPE algorithm seems to fulfil the expectations, in its performance as well as in its limitations. The implementation shows no major unexpected errors anymore. The method is well suited for the tropical and subtropical convection areas but can be used with the mentioned limitations also for higher latitudes. The algorithm is robust and reliable enough for the implementation in an operational environment. The additional potential of MSG for the precipitation estimation should be explored.

6. REFERENCES

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