1 INTRODUCTION

The EUMETSAT multi-sensor precipitation estimate (MPE) has been developed in order to derive instantaneous rain rates from MTP METEOSAT data. A detailed algorithm description can be found in DOCSopen #40339 (paper for IPWG meeting, Madrid 2001).

The method is based on the blending of brightness temperatures of the METEOSAT IR channel with rain rates derived from the Special Sensor Microwave/Imager (SSM/I). The basic assumption is that colder pixels represent higher reaching clouds and that those are more likely to produce precipitation than warmer clouds. The rain rates from the SSM/I sensor are used as reference. A co-location is performed between the SSM/I pixels and the METEOSAT data. Within specified geographical and temporal windows, look-up tables (LUT) are created describing the relation between rain rate and IR brightness temperature. The matching between the two data sets is done using a direct histogram matching technique, starting at the highest SSM/I rain rate and the lowest METEOSAT IR-temperature. That means the associated rain rates decreases monotonically with increasing temperatures. Figure 1 shows an example of co-located data sets in a temporal and spatial window and the corresponding curve of the LUT values. These LUT are applied to METEOSAT images in order to derive rain rates in the full spatial and temporal resolution of METEOSAT.

The algorithm was developed in a prototype version and later on implemented in the reprocessing MPEF (RMPEF) environment. The results of both versions are identical within the numerical accuracy of the two different computer systems. The results in this report are mainly based on the RMPEF version.

MPE data are created for a geographical region of +/-60° latitude and longitude from the sub-satellite point. The spatial windows for the LUT are defined on a fixed 5x5° grid. Co-located data sets are co-located for the LUT are collected for 18 hours.
2 DIRECT INTERNAL QUALITY CONTROL

The major limitation of the retrieval scheme is a result of the basic assumption that rain rate and cloud temperature show a negative correlation. This assumption can be considered valid for mainly convective precipitation but is only partly true for frontal or orographic cloud systems. Especially for warm fronts the rain is usually not associated with the highest clouds but occurs much earlier.

![Fig.1: Co-located data sets of METEOSAT IR brightness temperature and SSM/I rain rates for a 5x5° box over West-central Africa on Aug. 19th, 2001 (dots) and the LUT derived from these data sets (straight line).](image)

![Fig.2: As Fig. 1 but for a grid box in the South Pacific with a frontal weather system.](image)

The applied histogram matching technique to derive LUT tables is always defining a monotonic relation between rain rate and brightness temperature, even if there is no correlation between SSM/I rain rate and METEOSAT IR brightness temperature. Fig. 1 and Fig. 2 show LUT curves and the co-located data points which were used to derive them. Fig. 1 represents a region over Central Africa with large scale convective precipitation and Fig. 2 represents a grid box in the South Atlantic with a warm front. Obviously the correlation assumption is not valid in the second case. Therefore the used approach will lead to mis-locations of precipitation fields in this non-convective weather situation.

A simple and direct check of the applicability of the method on a specific weather situation can be done by re-applying the derived LUT to the brightness temperatures of the co-located data sets. The derived rain rates can be compared to the original SSM/I rain rates. The correlation between both sets of rain rates represents a measure for the possible accuracy of the retrieval algorithm for this specific case. For the Fig. 1 and 2 the correlation coefficients are 0.75 and 0.19, respectively. In addition to its functionality as a quality control mechanism, the correlation coefficient can be seen as a first direct validation. The method seems to deliver useful results for convective weather systems. Fig. 3 shows the quality control parameter for all LUT. All data with a correlation coefficient below 0.3 are marked problematic. In many areas not enough precipitation was found to calculate a reliable correlation coefficient. Most equatorial regions show high correlation coefficients, while the correlation in the tempered regions of the South Atlantic are usually below the applied threshold. But there are also regions in this area where useful rain rates can be derived.
In general the quality control parameters show that the method can be applied at all latitudes, but especially at higher latitudes the quality of the data will depend very much on the current weather situation.

![Quality indicators of the LUT. Over the Atlantic the data coverage was not sufficient to derive LUT. At the edges of this data sparse area and in the regions with obviously non-convective precipitation in the South Atlantic and Southern Indian Ocean the LUT will not produce reliable rain rates.](image)

### 3 VALIDATION WITH EXTERNAL DATA SETS

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. This comparison is similar to the internal quality control as described in the previous section. But 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. 4 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 state we analysed only the radar data and compared them to MPE results.

Fig. 4: 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.
3.1 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°W-15°W and ~10°N-25°N) as a reference case. This region is dominated by strong convective cells in the frame of the ITCZ in August. Fig. 7., and 9., show the MPE and SSM/I rain rates for two convective cases. 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.

![MPE and SSM/I rain rates for Central Africa](image)

**Fig. 5:** MPE and SSM/I rain rates for Central Africa (see Fig.4 for geographical location) 11/08/2002, 20:00 UTC. Strong convective systems with a large geographical extension in the frame of the ITCZ.
Fig. 6: As Fig. 5 but for 12/08/2002, 17:00 UTC.
3.2 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. Fig. 7 shows the front system and the warm, moist conveyor belt at 11\textsuperscript{th} August 2002, 12 UTC and 12\textsuperscript{th} August 2002, 12 UTC. We can see, that an air mass with high precipitable water vapour content moved from South to North, but on 12\textsuperscript{th} the direction of this air mass turned back, and because of the north direction the orographic precipitation surplus, especially in the luv of the Erzgebirge at the German-Czech border, was significant.

In Fig. 8 the corresponding precipitation estimated by MPE for this period is shown. The two major rainfall events can be observed on the 11\textsuperscript{th} and in the early morning of the 13\textsuperscript{th}.

![Fig. 7: Weather situation at 11. August, 2002, 12 UTC and 12. August, 2002, 12 UTC](image)

For the three days of the major precipitation only three suitable SSM/I overpasses could be found. Fig. 9, 10, and 11 show examples for the MPE data compared to rain rates derived directly from SSMI measurements. On 11\textsuperscript{th} at the Dinaric mountain a huge convective system developed giving high precipitation. Comparing the two kinds of data we can 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. 8 in the late afternoon of the 12\textsuperscript{th} is not retrieved correctly. MPE could not retrieve the orographic precipitation enhancement correctly.

On 13\textsuperscript{th} (Fig. 11) 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 validation work on this case will continue in co-operation with partners from the University of Dresden. It is planned to perform comparisons with the new US-NRL algorithm by J. Turk which includes orographic effects, algorithms considering the temporal development of a precipitation system, developed by the Universities of Marburg and Dresden, and an improved passive microwave algorithm, developed by the University of Cologne.
Fig. 8: Weather situation on July 11th to July 13th, 2001 over Central Europe for 0:30, 8:00 and 16:00 UTC. A Genoa-cyclone is moving northwards and produces heavy precipitation especially when the air mass is orographically lifted at the Erzgebirge on the Czech-German border.
Fig. 9: 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.

Fig. 10: As Fig. 9 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. 11: As Fig. 9 but for 13/08/2002, 5:30 UTC. The cyclone moves eastwards causing heavy precipitation in Eastern Europe.

### 3.3 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 greyvalue 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. 12.), 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.
Later that day (Fig. 13) the precipitation field over Gibraltar has moved north-west and can still be identified by the MPE. Scattered convection is observed over most of Spain by both retrieval methods. The cold front moving in from the Gulf of Biscay, producing only light precipitation, is also identified by MPE.

A completely different picture shows Fig. 14 one day earlier when the corresponding warm front passed the Spanish and Portuguese North-coast. The major precipitation pattern of MPE and radar look quite different. MPE shows considerable precipitation at the warm front which is strong enough to be picked up by the radar. But almost no precipitation can be seen in this area in the radar images. The substantial problem of MPE at warm fronts becomes obvious in this case.

On May 18th (Fig. 15) a mostly convective weather pattern was present. Again the spatial distribution and extension of the precipitation fields of MPE and radar is very similar. A general tendency of MPE to distribute precipitation events over a larger area by coinciding reduction of the maximal strength (smearing) can be illustrated by this image. The localised very strong radar echoes at the Portuguese-Spanish border are corresponding to much larger but weaker precipitation field in the MPE data. The same feature can be observed (less clearly) in the Africa cases (Fig. 5 and 6).

As a next step the comparison of MPE with the nowcasting-SAF PC product and the INM-CRR should be performed in order to get a broader data basis for the validation.

The validation cases over the Iberian Peninsula showed 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.

4 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. Continuation of work on the current algorithm implementation is therefore desirable.
Fig. 12: 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.

Fig. 13: MPE and SSM/I data for the Iberian Peninsula for 03/05/2001, 15:00 UTC.
Fig. 14: As Fig. 13 but for 02/05/2001, 0:30 UTC.

Fig. 15: As Fig. 13 but for 18/05/2001, 14:00 UTC.