THE EUMETSAT MULTI-SENSOR PRECIPITATION ESTIMATE (MPE)

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ABSTRACT

The combination of measurements from different satellite instruments for the estimation of precipitation is a promising way to overcome the shortcomings of measurements from a single data source. EUMETSAT realised the Multi-sensor Precipitation Estimate (MPE) in order to combine the advantages of the high temporal and comparably high spatial resolution of a geostationary IR sensor with the higher accuracy in rain rate retrieval of microwave sensors on polar orbiting satellites. IR-images from METEOSAT 7 on a geostationary orbit at 0° longitude are co-located with passive microwave data from the Special Sensor Microwave/Imager (SSM/I). The retrieval of rain rates from microwave data is based on established algorithms. A statistical matching in temporal and geographical windows is performed in order to correlate the IR brightness temperatures to the retrieved rain rates. The size of the time and space windows is selected to fit the scale of typical synoptic weather systems.

The assumption is used that cold clouds are more likely to produce precipitation than warmer clouds, in the same synoptic system. In this way the method reproduces the average rain rates according to the microwave measurements within the time and space window as well as the most likely spatial and temporal distribution of the precipitation in the full resolution of METEOSAT.

The MPE algorithm prototype is integrated in EUMETSAT's Meteorological Product Extraction Facility (MPEF) and will be validated by reprocessing METEOSAT data from the year 2000.

1. INTRODUCTION

The remote sensing of precipitation from IR-imagery of geostationary satellites has a long history. The high temporal and spatial resolution of these observations allows to study the development of clouds and their corresponding precipitation systems in detail. Even though the potential of these methods for the retrieval of monthly rainfall has been proven (Ebert and Manton 1998), the accuracy of the instantaneous precipitation estimation is limited by the indirect retrieval schemes. Most algorithms are based on thresholds with a seasonal or regional dependence using the cloud top temperature as a single indicator for the probability and amount of precipitation. This approach limits the use of these measurements to the estimation of convective rain. EUMETSAT is producing a threshold based precipitation index (PI) in the frame of its Meteorological Product Extraction Facility (MPEF) (EUMETSAT 1996) on an operational basis for the current METEOSAT satellites. EUMETSAT was approached by potential users of precipitation products in order to improve the quality of this product.

A more direct method to retrieve precipitation from satellite measurements is the use of passive microwave sensors. The absorption of microwave radiation by liquid water and its scattering by ice particles can be related to rainfall over ocean and over land (Ferraro 1997). Microwave radiometers are not available on geostationary satellites, yet and will not be for several years. The most comprehensive and in near-real time available data sets of suitable microwave measurements are currently performed by the Special Sensor Microwave Imager (SSM/I) sensors onboard the polar orbiting DMSP satellites.

An improved EUMETSAT method for the estimation of instantaneous rain rates and daily rainfall averages on the resolution of METEOSAT should make use of the additional information provided by SSM/I measurements. The primary goal of the newly developed Multi-sensor Precipitation Estimate (MPE) was therefore the combination of the advantages of both retrieval systems, the high temporal and spatial resolution of METEOSAT IR-imagery and the more accurate instantaneous rain rate retrieval from SSM/I data, in an operational environment

The production algorithm is based on previously existing retrieval schemes and programmed fully modular. This enables us to replace or extend parts of the algorithm with newly available methods. The current implementation is described here. After the construction and test of a prototype the algorithm was implemented in the operational environment.

The combination of data from polar orbiting and geostationary satellites on an operational basis will play a much more important role in the future. Especially the improved capabilities of METEOSAT second Generation (MSG) will surely enhance the need for satellite data merging. Further more the MPE implementation may also be understood as a key study for the use of data from foreign satellites in EUMETSATs Meteorological Products Extraction Facility (MPEF).

2. ALGORITHM DESCRIPTION

The role model for the MPE algorithm was the algorithm developed by Turk et. al. (1999). It had to be simplified due to technical considerations but the main features have remained unchanged. IR brightness temperatures (BBT) and rain rates from passive microwave data are co-located in time and space. A statistical matching between BBT and rain rates is performed in order to derive look-up tables. These tables describe a locally and temporarily valid data base to retrieve rain rates from BBT's in the full spatial and temporal resolution of METEOSAT.

The SSM/I data are obtained from the ECMWF archive. The conversion of microwave radiance to rain rates is performed with the operational NOAA-NESDIS scheme (Ferraro 1997).

2.1. Co-location

The implemented method represents a continuos calibration of the IR brightness temperatures against SSM/I rain rates in specific time and space windows. The size of these windows must be large enough to get a sufficient number of data for the statistical matching but should be as short as possible in order to represent the current weather situation. The space windows are currently defined by a 5°x5° geographical grid. For high observer zenith angles at the edges of the METEOSAT observation disc, the spatial resolution of the METEOSAT data is drastically reduced.

Therefore only data from within 60° of the satellite position are used (i.e. for METEOSAT-7 at 0° longitude data from +/- 60° longitude and +/-60° latitude). Because the algorithm is limited to convective rain, the tempered regions with mostly non-convective precipitation events are also clipped. Currently we are using METEOSAT data from +/-40° for the co-location with SSM/I. A METEOSAT pixel with its geographical centre in a SSM/I pixel is considered to be spatially co-located with it. The smaller size of the grid boxes compared to the original algorithm (Turk et al 1999), reduces the error due to insufficient aerial coverage of the grid box. Therefore this parameter is not monitored in the MPE-implementation.

The temporal co-location is more critical and should correspond to the window size of the spatial co-location. Typical temporal and spatial scales for convective precipitation systems are difficult to estimate and can range from several hundred meters to hundreds of kilometres and from minutes to several hours. The spatial grid size is chosen to represent large scale tropical convective cells. The corresponding lifecycle of these cells is between 6 and 12 hours. This should also be the frame for the temporal co-location window. Each SSM/I measurement taken within the 30 minutes of a METEOSAT scan is considered to be temporarily co-located with this image. Thus the maximal possible time difference between SSM/I and METEOSAT measurement is 30 minutes. The average time difference in tropical regions is about 10 minutes. In order to reduce the effect of this mismatching a temporal floating averaging of retrieved instantaneous rain rates can be applied.

Fig. 1 shows the adjustable time parameter which can be used to tune the algorithm. T_0 is the nominal time of the rain rate retrieval. The size of the temporal window for the co-location is described by ΔT_{LUT}. Δt_{eval} represents the averaging window. For real time or near real time operations is $t_e \leq T_0$ and $T_e \leq T_0$. Since there is a time delay for the reception of SSM/I data at EUMETSAT, the time for the end of the co-location T_e cannot be equal to the evaluation time T_0.

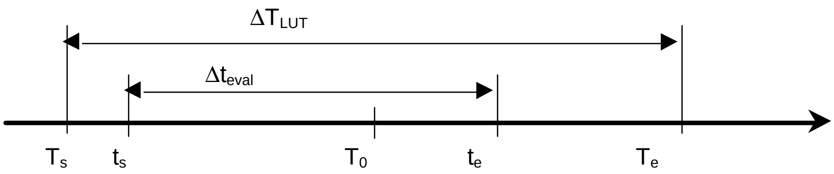

***Fig. 1**: Adjustable time parameters for the MPE algorithm on a time axis. T_0 : nominal evaluation time, t_s and t_e: start and end time of evaluation averaging, T_s and T_e : start and end time of co-location.*

The EBBT of all IR-pixels which are temporarily and spatially co-located to the same SSM/I pixel are averaged. The result is a spatial averaging according to the SSM/I pixel size. At the end of this procedure a set of co-located data for each 5°x5° grid box in the time window ΔT_{LUT} is available for a statistical regression.

2.2 Cumulative histogram matching

Two aspects are important for the matching between rain rates and EBBTs. On the one hand the total rain rate averaged over the time and space window should be equal for the SSM/I rainrates and the METEOSAT rainrates. On the other hand the most likely rain rate distribution according to the EBBT should be found. Though it is not optimal, the direct probability matching fulfils both requirements. The cumulative probability distribution of rain rates in a co-located data set is compared to the corresponding cumulative probabilities of the EBBTs. For equidistant steps of the EBBT, starting from low temperatures, the corresponding rain rates with the same value of the cumulated probability function are extracted from the histograms. In this way look-up tables (LUTs) are created for each 5°x5° box. These look-up tables are used for the evaluation of rain rates from METEOSAT IR images.

Fig. 2 shows two typical LUTs (straight lines) together with the co-located data sets (small stars). The positions of the two 5°x5° boxes are marked in Fig. 4 by arrows. On the left side a convective rain situation over West Africa is shown. High rainrates and a rather good fitting of the curves are typical features of such a case. A frontal precipitation system is covered by the area of the 5°x5° box represented by the LUT on the right side. The brightness temperatures seem to be nearly independent of the SSM/I rainrates for this area. In this case no useful information about the spatial distribution of rain rates in the grid box can be extracted from the IR data. However due to the integral conserving characteristic of the matching algorithm, the spatial and temporal average rain rate is still very near to the SSM/I temporal and spatial average.

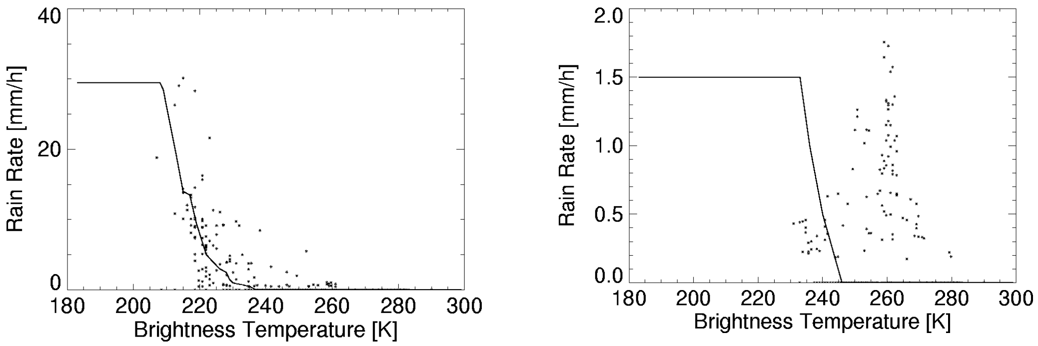

Fig. 2: *Look-up tables (LUTs) derived from a 6h period on Aug. 19th, 2001 for the 5°x5° boxes number 229, over west Africa and 15, south-west of South Africa (see arrows in Fig. 4 for approximate positions).*

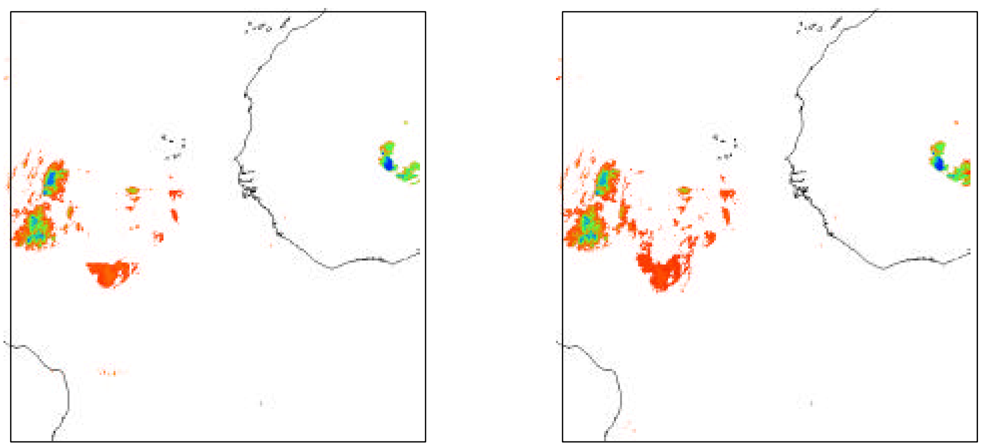

Fig. 3: *Rain rates over the Atlantic with LUTs applied only to pixels in the corresponding 5°x5° box on the left. On the right side rain rates were calculated from the weighted average of rain*

rates derived with the LUTs of the corresponding and of the adjacent boxes. Artifical edges at the grid box boudaries over the Mid Atlantic are disappearing with the averaging technique.

2.3 Application to METEOSAT images

The derived LUTs could be applied to data of the corresponding 5°x5° boxes of METEOSAT IR-images directly. However, while the time averaging introduced by the sampling window for the creation of the LUTs (ΔT_{LUT} in Fig.1) is a floating average, the spatial sampling is defined on the fixed boundaries of the 5°x5° boxes. Pixel at the edges of these boxes may be represented by the LUT of the neighbouring box as well as by the LUT of their *home box*. Therefore each pixel rain rate is calculated with the LUT of their *home box* and the LUTs of the three adjacent boxes. The weighted average of the 4 rain rates is associated to the pixel. The weighting for the adjacent boxes depends on the position of the pixel in the *home box*. It becomes 0 at the centre of the box and equal to the weighting of the *home box* at the edges of the box. Fig. 3 illustrates the effect of this spatial smoothing on a convective cell over the Mid Atlantic. On the left side the rain rates are calculated using only the *home box* LUT. On the right side the described technique is applied. The artificial edges appearing at the boundaries of the 5°x5° boxes in the left figure are smoothed out in the right figure.

3. INTEGRATION IN THE MPEF ENVIRONMENT

The Meteorological Products Extraction Facility (MPEF) is EUMETSATs operational level 2 and 3 processing environment for METEOSAT data (EUMETSAT 1996). Meteorological and climatological products like wind fields, clear sky radiance, sea surface temperature and the precipitation index are retrieved from the three channels of METEOSAT in real-time and distributed to the users, namely the national weather services and partner organisations like NOAA and ECMWF. The implementation of the MPE algorithm in the MPEF environment and its connection to the control and monitoring systems has been done during the last months. The program was constructed to allow for the replacement of single program modules by more advanced methods without changing the core of the implementation. In this way the tuning of the algorithm can be performed directly in the operational environment with the advantages of direct data access and continuous processing.
ECMWF is currently performing re-analysis of meteorological data from the last 40 years. EUMETSAT contributes to the ERA-40 program by re-processing its complete METEOSAT data archive with the current operational MPEF routines. In order to perform this task, a data driven version of the MPEF was implemented. In the re-processing MPEF (RMPEF) the time driven scheduling of product generation was replaced by a data driven system while the algorithms and their implementation were copied directly from the operational MPEF. Algorithms developed for the MPEF environment can be implemented to the RMPEF without major modifications. The re-processing environment was identified as the appropriate test and validation system for the MPE algorithm because it allows for the processing of larger data amounts in a shorter time. In addition consolidated validation data i.e. spatially averaged and interpolated rain gauge measurements and ground based radar rain rates, are usually available only after a certain time. Currently it is forseen that 1 full year (2001) of data is going to be processed in order to perform the required validation of the system.

Fig. 4 shows an example of instantaneous rain rates for a developing tropical convection at 9:00 UTC. The LUTs were created from 6 hour sampling of SSM/I - METEOSAT co-locations. No quality filter was applied to these data. In the South Atlatic two frontal systems can be clearly identified by their shape. Over the Atlantic only very little precipitation seems to be present.

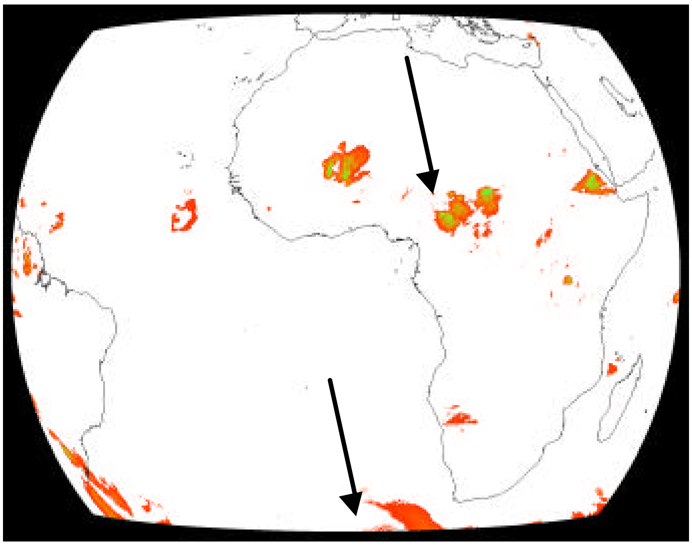

Fig. 4: *Instanteneous rain rates for August 19th 2001, 9:00 UTC derived with the MPE prototype. Sampling of co-located data for the LUTs performed between 3:00 and 9:00 UTC. Arrows indicate the aproximate position of the grid boxes of the LUTs in Fig. 2 : upper arrow corresponds to left side of Fig.2, lower arrow to right side.*

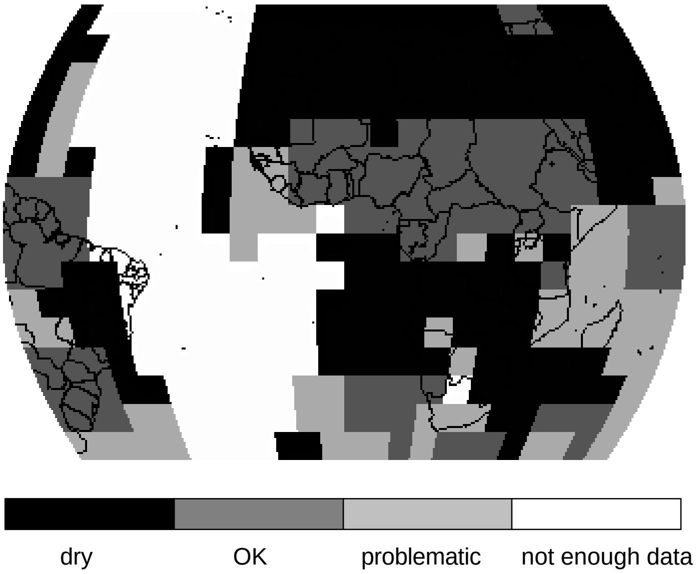

Fig. 5: *Quality indicators of the LUTs used for the evaluation in Fig. 4. Over the Atlantic the data coverage is not sufficient to derive LUTs. At the edges of this data sparse area and in the regions with obviously non-convective precipitation in the South Atlantic and Southern Indian Ocean the LUTs cannot be used to derive instantaneous rain rates.*

4. QUALITY CONTROL

In addition to careful validation and regular verification of the products an operational data processing requires a continuous automated quality control in order to flag suspicious or obviously wrong data sets. The MPE algorithm is limited to convective rain, and will therefore produce wrong results in areas with other forms of precipitation during the time of data sampling for the LUTs. The identification of these areas is based on the comparison of co-located data sets with the retrieved rain rates for the same pixel at the same time. The correlation between non-zero co-located SSM/I rain rates and the retrieved rain rates gives a good hint if this area is mainly covered with non-convective precipitation. The correlation coefficient of the 5°x5° grid box on the left side of Fig. 2 is significantly higher (correlation = 0.75) than the correlation coefficient for the obviously non-convective data set on the right side (correlation = 0.19). This value will be given as a basic quality indicator to the users. In general the time window for the sampling of co-located data sets should be selected large enough to guarantee a sufficient coverage by SSM/I overpasses for all 5°x5° boxes. If there are data missing (SSM/I or METEOSAT) data sparse areas may occur which are flagged as well. In addition a quality flag for all pixels in 5°x5° degree boxes will be raised where not enough rainy data sets were available to derive a consolidated look-up table. These areas are too dry to apply the algorithm.

In Fig. 5 the quality indicator is shown for the LUTs used for the production of Fig. 4. Dark grey areas are those with a correlation coefficient above 0.2. For black areas the *too dry* flag was raised in the light grey areas the correlation coefficient was too low. Due to insufficient data coverage no LUTs were calculated over the Mid Atlantic. Data from two SSM/I overpasses are missing in this area. The algorithm can be applied to the large-scale tropical convection over Africa and to some parts of frontal precipitation in the tempered regions.

5. CONCLUSION AND OUTLOOK

A method for retrieval of rain rates from combined data from different satellite sensors was implemented to an operational environment. An automated quality control system was applied in order to detect problematic regions from the used data sets themselves. First results indicate that the implemented method in combination with the quality control system can produce useful data of instantaneous rain rates and daily average precipitation in regions of mostly convective rainfall.

If the validation tests indicate that the MPE method is a useful contribution to the global efforts of improved precipitation monitoring, an implementation in the operational MPEF is possible. Currently the production of instantaneous rain rates and daily precipitation is discussed. Especially for African countries the MPE data may be a useful way to fill the gaps in their sparse ground based rain data sets.

Due to the modular programming technique of the MPE implementation the replacement of specific modules of the algorithm can be performed easily. The following changes are currently discussed:

1. Replacement of the direct histogram matching co-location with a functional histogram matching according to Grose et al (2002).
2. Combination of the MPE results with secondary flow deformation fields (divergence and vorticity fields) derived from the METEOSAT wind vector products

2. Improvement of the quality control using the statistic of all pixel in a grid-box instead of using only co-located data sets.
3. Use of the METEOSATs visible channel (for approaches see i.e. Inoue, 2000)

On September 28th this year the first of three satellites of METEOSAT Second Generation (MSG) was successfully launched. The improved capabilities of the new Scanning Enhanced Visible and InfraRed Imager (SEVIRI) onboard of these satellites with its 12 channels, a 15 minutes repeat cycle and an increased spatial resolution will enhance the quality of many meteorological products, namely the precipitation estimation. In order to investigate these potentials EUMETSAT established in co-operation with the German Weather Service (DWD) and the University of Bonn a fellowship with the program name Advance Multi-sensor Precipitation Estimate (AMPE).

6. REFERENCES

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