METEOSAT-8: FROM TEMPERATURE TO RAINFALL

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ABSTRACT:

Given the new distribution policy of Eumetsat (free access to the data for open research and education), combined with the possibility to receive the data using a low cost ground receiving station, on a continuous basis Meteosat data is currently received and archived. To handle the enormous amount of data, software tools are developed facilitating storage, easy import and radiometric – geometric calibration of the images. All Meteosat-8 data (for the whole field of view / all spectral channels) is available online for further processing. Here the 10.8 micron channel of the SEVIRI instrument onboard of Meteosat-8, recording the long wave thermal infrared part of the electromagnetic spectrum, is used to get a more accurate idea of the spatial and temporal variation of the precipitation over a selected region in Africa. A blending technique is applied using TRMM derived rainfall intensity to calibrate the Meteosat image. To account for collocation problems (for direct relation of passive microwave and thermal infrared observations on a per-pixel basis), such as spatial and timing offsets, an averaging procedure has to be incorporated. In literature approaches are described using larger areas (resampling of the IR data to account for spatial offset) or averaging two IR data acquisitions to compensate for timing offset. Here a slightly different procedure is proposed: the TRMM assigned rainfall pixels with corresponding rainfall intensities are averaged based on MSG–IR pixels having equal temperature (in classes of 0.5 or 1 degree Kelvin). This results in a temperature range, e.g. from 180 to 260 Kelvin, having for each temperature class interval a certain averaged corresponding rainfall intensity. These two variables are then used to determine the correlation and when satisfied a suitable regression function can be used for regionalization using the IR image as well as a short term IR time series of 15 minutes interval images (in the case of MSG). The rainfall images can be aggregated to obtain the total daily rainfall. Initial results show a good correlation between the Meteosat 10.8 channel and the TRMM obtained rainfall intensity. Synoptic observations have to be used to evaluate if these IR obtained rainfall intensities also represent actual measured precipitation at the ground. Next to this a better cloud differentiation has to be adopted, e.g. to differentiate family C and D types of clouds. Different regression functions for different cloud families can be derived which might improve the overall results.

1. INTRODUCTION

1.1 Meteorological satellite observations for African Basin Water Resources Management

Water resources management calls for an informed participation of different stakeholders concerned with sustainable development. Timely, accurate and comprehensive information about water resources forms the basis of effective water resources management. It is now widely recognized that the monitoring and assessment of water resources, in terms of both quantity and quality, require adequate meteorological, hydrological and other related data. Satellite observations can assist in enhancing the observation capabilities by providing additional data and variables (rainfall, evaporation, soil moisture, altimetry, etc) complementing and integrating ground observations. Especially the new Meteosat programme, using the Spinning Enhanced Visible and Infrared Imager (SEVIRI), could play a major role in this respect. Stationed over Africa this satellite provides a continuous "eye in the sky" and from the recordings provided the relevant (dynamic) meteorological and hydrological variables can be retrieved to assess the actual conditions of the natural resources. This article describes the effort conducted at ITC to receive this data using a low cost ground station, the online archiving system that has been developed to store a huge amount of data, the import routines for the images as well as a rainfall retrieval application utilizing the data archive to demonstrate the enhanced ILWIS RS/GIS functionality (shareware) for time series analysis. Such a system is a very efficient tool to assist Basin Authorities in Africa to prepare Integrated Water Resource Management and water efficiency plans as part of their contribution to national and trans-boundary development plans.

1.2 SEVIRI radiometer on MSG

MSG-1 was launched on the 28th of August 2002. On January 29, 2004, the satellite commenced routine operations and was renamed Meteosat-8. The advanced SEVIRI radiometer aboard the MSG series will enable the Earth to be scanned in 12 spectral channels from visible to thermal infrared (including water vapour, ozone and carbon dioxide channels) at 15 minutes intervals. Meteosat-8 data is received via the EUMETSAT Multicast Distribution System (EUMETCast). The EUMETCast system has been established to provide an alternative reception system after the failure of one of the on board power amplifiers of MSG-1. On the 21st of December

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2005, MSG-2 was successfully launched and commissioning test are currently under way. This will ensure a continuous data stream for the next decade.

From its geostationary orbit at 0º N, 3.4º W, Meteosat-8 continuously scans the Earth surface and transmits the data to the EUMETSAT Primary Ground Station in Germany (Darmstadt). The received data is pre-processed and rectified into a so called Level 1.5 data-format; furthermore the data is compressed and split in small data-packages. These packages are send to the uplink station in Usingen (Germany) and are subsequently transmitted to the Hotbird-6 satellite. At ITC, using a satellite dish directed towards the Hotbird-6 satellite, the DVB (digital video broadcasting) signal can be received. The DVB-PCI card in the computer demodulates and decodes the continuous DVB data-stream. Meteosat-8 transmits the data in a Low Rate Image Transmission (LRIT) and High Rate Image Transmission (HRIT) mode. After central ground processing at EUMETSAT, images in full resolution are transmitted in HRIT mode, within five minutes of observation. EUMETCast provides a continuous stream of data from different platforms ranging from Meteosat 5, 7 and 8 to NOAA and GMS allowing near global coverage (at three hours intervals). At ITC all EUMETCast data is received but only the high rate information transmission (HRIT) data is archived. This data set is about 85 % of the total data stream. ITC is receiving the images under license from the Royal Dutch Meteorological Institute (KNMI) as METEOSAT's national point of contact. For education-research institutes no additional costs for data receiving applies as the data is requested for educational and open research usage.

1.3 Software and archive development

After an initial test period at ITC combined with some software development a Meteosat data archive is under construction. Currently every 15 minutes the high resolution and 11 low resolution channels are received. The high resolution channel consists of 24 segments stored as separate files, the low resolution channels consist of 8 segments. All segments are stored in their original lossless wavelet compressed file format. This results in the smallest demand for storage space, coupled with no further user interference (fully automated, only a provisional system check once a day). Over 11.000 files, equivalent to 7.5 Gigabyte, are stored per day. A software tool has been developed to move the relevant data, based on the acquisition date and time, to specific folders. It also creates entries in a log file if data is missing and optionally it can send warning emails if large problems, like system failures, may occur. The data is stored on high capacity disks of 1 Terabyte to provide easy access and retrieval. These disks are connected to a system that shares the disks online over a network.

The problem with MSG data is that the file format is not standard. None of the commonly used remote sensing packages is able to open or process the raw compressed images. It was decided that the solution with the most future prospects was to implement a driver for reading the images in Geospatial Data Abstraction Library (GDAL, http://www.gdal.org). GDAL is a translation library for raster geospatial data formats that is released under an MIT style Open Source license. All source code is in C++, and great effort is put into keeping the code platform-independent. Drivers for writing files in popular RS formats (e.g. ENVI, ERDAS, ILWIS, GeoTiff) but also picture formats like JPEG, GIF and BMP have already been implemented by the community, so appending a driver for

reading MSG image files to this driver seemed to be the most appropriate. Through the user interface all relevant parameters can be adjusted and a time series can be easily constructed. The figure below shows the data retriever / time series generator.
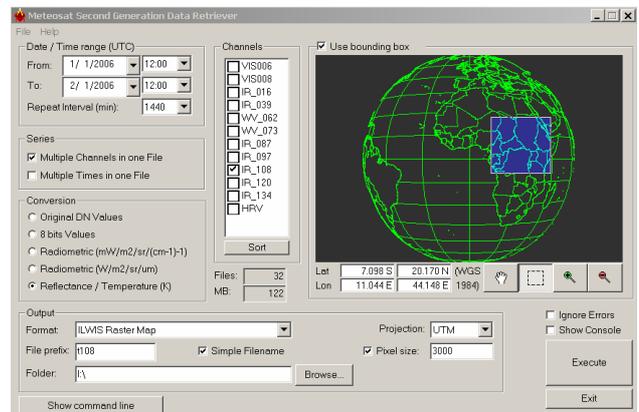

Figure 1: MSG data retriever / time series generator

In the example provided in figure 1, for a specific region in central Africa, the 10.8 micron channel is retrieved and converted to temperature for the 12.00 hr UTC image from the 1st of January to the 1st of February and is exported to the ILWIS data format, resampled to UTM at a 3 km. pixel resolution. The visible channels can be converted to reflectance, allowing easy computation of NDVI or other related vegetation indices.

On top of the existing ILWIS capability additional functionality for time series data analysis and visualization has been implemented. This enhanced ILWIS capability to handle and analyse time series, together with the MSG-Data Retriever tool developed, can provide a low cost alternative to the "non-traditional meteorological" user community in e.g. the African continent, applying the Meteosat data to a multitude of potential earth science related applications given the new and enhanced MSG sensor capabilities and current favourable data distribution policy of EUMETSAT. With the construction of an online MSG archive (currently consisting already of over 4 TB of compressed data), coupled with easy data retrieval and Top of Atmosphere radiometric and geometric calibration the main bottleneck for effective data analysis has been well taken care of.

2. SATELLITE BASED RAINFALL ESTIMATION

2.1 Passive microwave and infrared satellite observations for rainfall estimation

A longstanding promise of meteorological satellites is the improved identification and quantification of precipitation at time scales consistent with the nature and development of cloud rain bands (Levizzani et al, 2002). Meteorological satellites expand the coverage and time span of conventional ground-based rainfall data. The primary scope of satellite rainfall monitoring is to provide information on rainfall occurrence, amount and distribution over e.g. the African continent. The problem of using satellite remote sensing to retrieve rainfall is still complicated since there is not a single spaceborne platform which is carrying all the suitable instruments for monitoring the properties related to rainfall occurrence. Geostationary weather satellite visible (VIS) and infrared (IR) imagers provide the

rapid temporal update cycle needed to capture the growth and decay of precipitating clouds. The Low Earth Orbit satellites have the potential to use microwave sensors but due to the swath widths of satellites in tropical orbit such as the Tropical Rainfall Measuring Mission (TRMM) (Kummerow et al., 1998) and of sensors in polar orbits like the Special Sensor Microwave Imager (SSM/I) series, substantial gaps, both temporally and spatially, still occur.

Clouds are opaque in the VIS and IR spectral range and precipitation is inferred only from the cloud top structure. At passive MW frequencies precipitation particles are the main source of attenuation of the upwelling radiation. Microwave radiometers can detect cloud structure and rain rate since the MW brightness temperatures are sensitive to liquid and ice hydrometeors (Ferraro, 1997). MW techniques are thus physically more direct than those based on VIS/IR radiation. Precipitation drops strongly interact with MW radiation and are detected by radiometers without the IR strong biases derived from the cloud top only.

As microwave and infrared observations are clearly complementary to monitor a highly variable phenomenon like precipitation, an easy to implement and simple statistical integration of both sources, might already considerably improve the monitoring capability of the National Hydrological Services in the African countries, supplementing their ground based network observations. The example presented here is based on rainfall intensities obtained from the TRMM archive, which incorporated also some ground validation sites over Africa.

2.2 Statistical integration of IR and MW observations

To transform brightness temperature of Meteosat-8 into rainfall intensity the rain rates as obtained from TRMM's Microwave Imager are used (available from: http://disc.sci.gsfc.nasa.gov/). A selection of the relevant orbit can be made for the 2A12 Hydrometeor Profile image products at a 5 km horizontal resolution, in ascending or descending mode and subsequently the data can be downloaded from the TRMM FTP site. Using the Orbit Viewer software package provided the selected data, in this case SurfaceRain, can be visualized and a sub-scene can be extracted as an Ascii table for import into a GIS for both the rainfall intensity as well as the location. The extracted tables can be merged at a later stage to obtain a latitude-longitude point file with rainfall intensities. The Orbit Viewer also provides the time of recording which is important for selection of the Meteosat-8 image for collocation to obtain an appropriate statistical correlation. Here use is made of the TMI-file 2A12.050908.44534.6.HDF (providing information about the surface rain (mm/hr) at 05:17:49 on September 08 2005 using version 6 of the TRMM rainfall estimation algorithm for Eastern Africa, see also figure 2).

Using the MSG data retriever / time series generator the 10.8 micron channel data for Meteosat-8 was retrieved on a 15 minutes basis and converted to brightness temperature for the same day. The 05.15 hr UTC image is crossed with the TMI rasterized point map and from the cross table obtained, having the temperature column from Meteosat and the rainfall column from TRMM for each location, the correlation was determined. A correlation coefficient of -0.445 was obtained, showing a weak overall correlation indicating that decreasing temperatures results in increased rainfall intensity. Turk et al (2003) indicated some common sources of low correlation due to spatial and temporal offsets. In literature approaches are described (e.g.

EUMETSAT's Multi-Sensor Precipitation Estimate) using larger areas (resampling of the IR data to account for spatial offset) or averaging two IR data acquisitions to compensate for timing offset. Here a slightly different procedure is adopted: the TRMM assigned rainfall pixels with corresponding rainfall intensities are averaged based on MSG–IR pixels having equal temperature (in classes of 0.5 or 1 degree Kelvin). This results in a temperature range, e.g. from 180 to 260 Kelvin, having for each temperature class interval a certain averaged corresponding rainfall intensity. These two variables are then used to determine a new correlation coefficient and when satisfied a suitable regression function can be determined using the 05.15 UTC IR image. The regression can also be used for a short IR time series of 15 minutes interval images (in the case of MSG) to obtain the total daily rainfall. Having a daily calibration possibility using TRMM, the procedure can be easily repeated and a new regression can be adopted for a new time series.
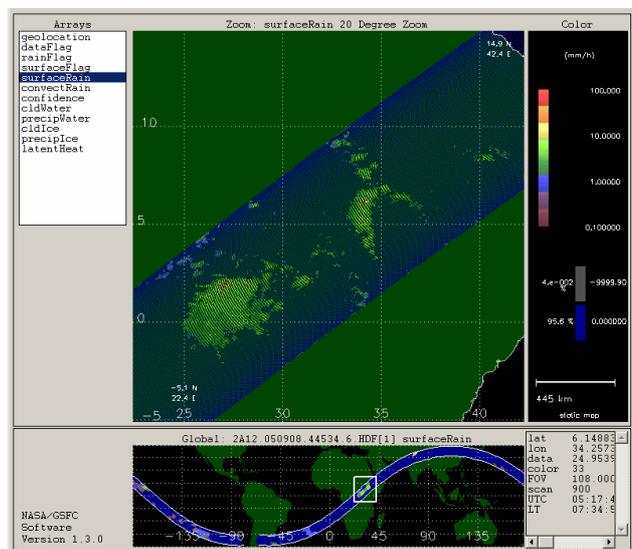

Figure 2: Orbit Viewer showing area selected

The new cross table with average rainfall intensities, aggregated per 1 degree Kelvin, showed an increased correlation coefficient (-0.651) which was subsequently used to determine a modified exponential fit ($y = ae^{b/x}$, a = 4.3505278e-005 and b = 2550.0127), with a standard error of 2.44 and a correlation coefficient of 0.87. Figure 3 shows the results obtained graphically.
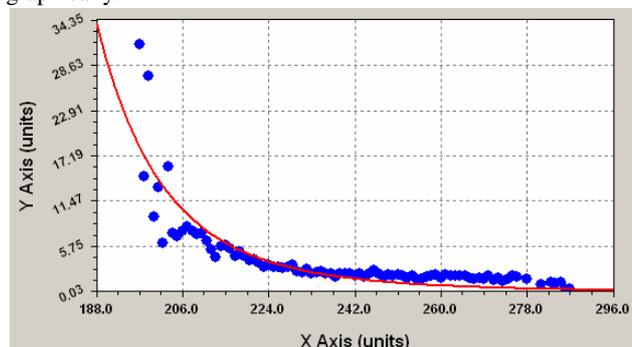

Figure 3: Modified exponential fit, X=temperature, Y=rain

To convert the thermal image to a rainfall intensity image use is made of the ILWIS map calculator, using a threshold of 260 Kelvin, as the upper cloud temperature limit at which rainfall occurs.

The resulting rainfall map obtained for this 05.15 UTC image is presented in figure 4 and the rainfall intensity over the whole time series extracted and processed (in cm. / hr. for the centre of the storm event in the SE of Uganda for every 15 minutes) is presented in figure 5.
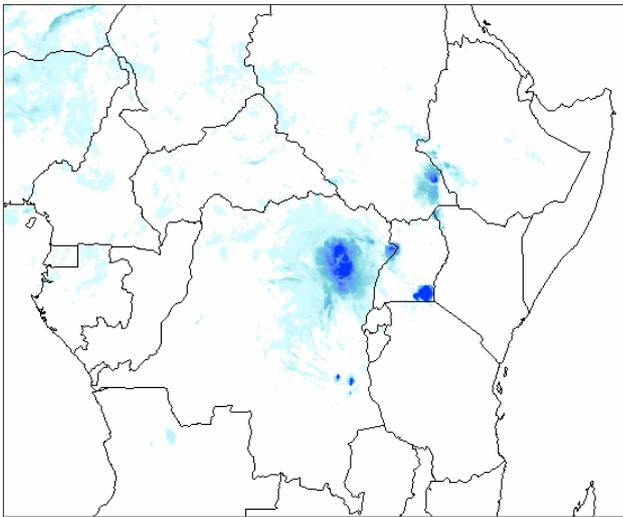

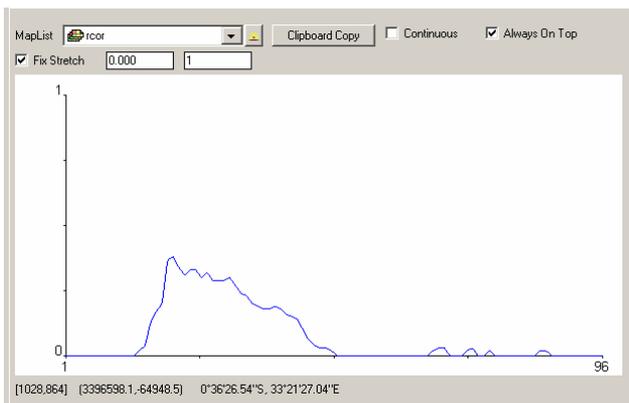Figure 4: Rainfall estimation over Central Africa

Figure 5: Temporal rainfall distribution over a pixel in SE Uganda (cm/hr)

Figure 6 shows the overall daily rainfall, processed for the 8th of September from 00.00 to 23.45 UTC aggregating all the 96 images.
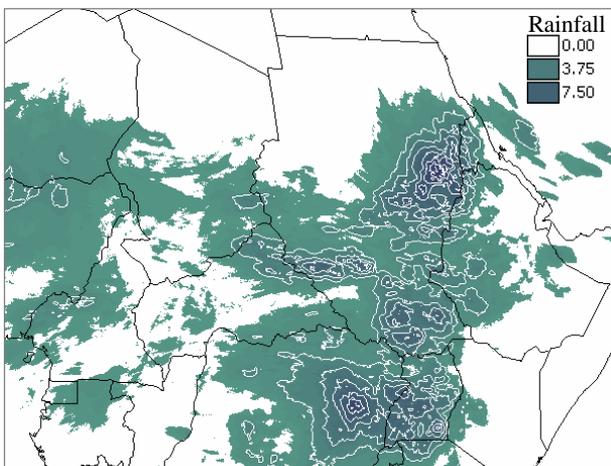

Figure 6: Total daily rainfall

2.3 Discussion on results presented

The results presented here indicate that the 10.8 micron channel can be used for a first approximation of the rainfall, using an averaging method to obtain a reasonable correlation with the TRMM measurements. Also other tests from different dates and over other basins in Africa, following the same averaging approach, showed a reasonable correlation between the TRMM averaged rainfall per 1 Kelvin temperature class. Given the high temporal frequency (1 image per 15 minutes) a good idea is obtained with respect to the intensity of the rainfall over time, something which is currently only available if tipping bucket measurements are used (but only representative for a small area). If these measurements are available they can also be incorporated to validate the final rainfall intensities obtained. Here all rainfall samples of TRMM of a selected subset are used that have produced rainfall, irrespective of the type of cloud. As can be seen from figure 3 the regression shown has a larger bias for low and high intensity rainfall amounts which are due to the different type of clouds (e.g. nimbostratus or cumulonimbus). A cloud mask and type determination as proposed by Derrien and Le Gléau (2005) could further improve the results presented here. The implication is that additional processing is required as well as the incorporation of additional parameters from a Numerical Weather Prediction model. It is likely to be out of the scope of a National Hydrological Service, provided that these can be easily integrated into the GIS used and the computations can be automated or batch processed. It is expected that a better correlation can be obtained between the TRMM rain rates for different cloud types. Regressions developed for each of these cloud types can than be applied to transform the IR images into rainfall intensity in a similar way as presented here. Further effort to develop the necessary (automated) processing in a GIS environment is envisaged.

3. CONCLUSION

Multispectral data have long since been available both from polar orbiting and geostationary satellite sensors and used for retrieving cloud properties. The relevant channels for cloud characterization were part of the payload of the polar satellites, while the sensors at geosynchronous altitude were almost exclusively devoted to VIS-IR operational monitoring of precipitation system displacements. This has considerably changed in the past few years since more and more sophisticated sensors have been conceived for the GEO orbits that will allow for real-time cloud characterization. It is in this changed framework that new applications are possible that will considerably improve rainfall estimations from space assisting the National Hydrological Services in Africa to provide information on the status and trends of their water resources. The changed (near real-time) data distribution of EUMETSAT, the low cost receiving station and data archiving system, in combination with the (shareware) software developed, allows effective data processing. If near real-time applications are necessary initial calibration of the IR channel can be done using onsite rainfall observations (e.g. tipping bucket) as there is a short time gap when TMI derived rainfall information is available through the TRMM-FTP library. Linkage with e.g. hydrological models provides the Hydrological Services with the tools to come to flood forecasting and other models might assist in a better drought warning, processes that have an important economical and social impact for the concerned societies in Africa.

4. REFERENCES

Derrien, M. and Le Gléau, H., 2005. MSG/SEVIRI cloud mask and type from SAFNWC. *Int. J. of Remote Sensing*, Vol 26, No. 21, 10 Nov. 2005, pp 4707-4732.

Ferraro, R.R., 1997. SSM/I derived global rainfall estimates for climatological applications. *J. Geophysical Research*, 102, pp 715-16.

Kummerow, C., Barnes, W., Kozu, T., Shiue, J., Simpson, J., 1998. The tropical rainfall measuring mission (TRMM) sensor package. *J. Atmos. Oceanic Technol.*, 15, pp. 809-817.

Levizzani, V., Amorati, R., Meneguzzo, F., 2002. MUSIC – MUltiple-Sensor Precipitation Measurements, Integration, Calibration and Flood Forecasting. A Review of Satellite-based Rainfall Estimation Methods. Istituto di Scienze dell'Atmosfera e del Clima-CNR, Bologna, Italy. http://www.isao.bo.cnr.it/ ~meteosat/ (accessed 07 Feb. 2006)

Turk, F. J., Ebert, E.E., Oh, H.J., Sohn, B.J., Levizzani, V., Smith, E.A., Ferraro, R., 2003: Validation of an operational global precipitation analysis at short time scales. *Proc. 1st IPWG Workshop*, Madrid, 23-27 Sept. 2003, pp.217-240.