EVALUATION OF SEVIRI-DERIVED RAIN RATES AND ACCUMULATED RAINFALL WITH TRMM-TMI AND RAIN GAUGE DATA OVER WEST-AFRICA

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ABSTRACT

Clouds are of paramount importance to the hydrological cycle, as they influence the surface energy balance, thereby constraining the amount of energy available for evaporation, and their contribution through precipitation. Especially in regions where water availability is critical, such as in West-Africa, accurate determination of the various terms of the hydrological cycle is warranted. At the Royal Netherlands Meteorological Institute (KNMI), an algorithm to retrieve Cloud Physical Properties (CPP) from mainly visible and near-infrared spectral channel radiances from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard Meteosat-8 and -9 has been developed. Recently, this algorithm has been extended with a rain rate retrieval method. Evaluation of this geophysical quantity has been done with rain radar data over the Netherlands.

This paper presents the first results of this rain rate retrieval over West-Africa for June 2006. In addition, the added value of the high temporal and spatial resolution of the SEVIRI instrument is shown. Over land, retrievals are compared with rain gauge observations performed during the African Monsoon Multidisciplinary Analyses (AMMA) project and with a kriged dataset of the Comité Inter-Etate pour la Lutte contre la Sécheresse au Sahel (CILSS) rain gauge network, whereas rain rate retrievals over ocean are evaluated using Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI) data.

1 INTRODUCTION

Precipitation can be considered the most crucial link between the atmosphere and the surface in weather and climate processes. Quantitative precipitation estimates on high spatial and temporal resolutions are of increasing importance for water resource management, for improving the precipitation prediction scores in numerical weather prediction (NWP) models, and for monitoring seasonal to interannual climate variability. Although operational networks of weather radars are expanding over Europe and North America, large areas remain where information on the occurrence and intensity of rainfall are missing. For example, over certain regions in West-Africa only a few rain gauges per 1000 km^2 can be found. Especially this region is susceptible to year-to-year changes in precipitation, which can have large impact on both ecology and local economy. It is therefore of crucial importance to obtain accurate rainfall estimates for this region at a high temporal and spatial resolution. The SEVIRI instrument, with its 3x3-km^2 spatial and 15-minute temporal resolution, has the potential to cover the lack of rain gauges to estimate rainfall in West-Africa.

2 DATA AND METHODS

2.1 SEVIRI rainfall retrieval algorithm

The SEVIRI rainfall retrieval (hereafter referenced as RR) algorithm has been developed at KNMI by modifying an existing rainfall retrieval algorithm for the Special Sensor Microwave/Imager (SSMI, Wentz and Spencer, 1998) using the Cloud Physical Properties (CPP) retrieval algorithm. In the CPP algorithm, the cloud optical thickness (τ), effective radius (r_e), Cloud water path (CWP), and cloud phase (CPH) are retrieved from 0.6- and 1.6-µm SEVIRI reflectances by using a Lookup Table (LUT) approach (Roebeling et al., 2006). CWP is obtained using (Stephens, 1978):

$$CWP = 2/3 * \tau * r_e$$

The CWP and CPH retrievals have been extensively evaluated against ground-based observations over Western Europe (Roebeling et al, 2008, Wolters et al., 2008), while the optical thickness has been used as input for the calculation of the Shortwave Solar Incoming radiation (SSI), which was subsequently validated against pyranometer data (Deneke et al, 2008).

The logical flow of the RR retrieval algorithm is presented in Figure 1.

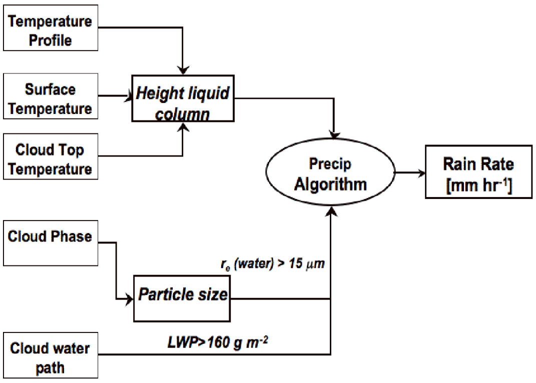

Figure 1: Flowchart of the RR retrieval algorithm.

The Cloud Top Temperature (CTT) is obtained from the SEVIRI 10.8 µm spectral channel and is corrected for cloud emissivity < 1 following a procedure of Minnis et al. (1998). The height of the raining column is calculated as the difference between the actual pixel CTT and the CTT of the warmest cloud within a 100x100 pixel area around the actual pixel. Note that for the warmest pixel a HLC of 600 m is assumed (Roebeling and Holleman, 2009).

Clouds are assumed to produce precipitation if the CWP exceeds a threshold of 160 g m^{-2}, which is close to the SSM/I threshold of 180 g m^{-2} originally applied by Wentz and Spencer (1998). Water clouds are required to have at least an r_e of 15 µm, conform findings of Rosenfeld and Gutman (1994), whereas for ice clouds no r_e threshold is applied. In order to avoid unrealistically high rain rates, a cutoff of 40 mm h^{-1} has been set. The RR algorithm has been extensively evaluated against rain radar observations over the Netherlands (Roebeling and Holleman, 2009).

2.2 TRMM-TMI

The Tropical Rainfall Measurement Mission (TRMM) Microwave Instrument (TMI) is a passive microwave instrument onboard the TRMM satellite (Kummerow et al., 1998). The instrument is a nine-channel passive microwave, based on the SSM/I. The most important differences with respect to the latter instrument are an additional pair of 10.7-GHz channels with horizontal and vertical polarizations and a frequency change of the water vapor channel from 22.235 to 21.3 GHz. The change off the water vapor line avoids saturation due to water vapor in the tropics. The spectral resolution of the nine channels ranges from 7x5 km at 85.5 GHz to 63x37 km at 10.7 GHz. The TMI instrument scans the Earth surface at a maximum viewing angle of 53°, which results in a swath width of ~715 km.

2.3 Rain gauge data

Rain gauge observations are sparsely distributed over West-Africa, with in some regions only as few as 30 gauges over 16000 km^2 (Ali et al, 2005a). Within the African Monsoon Multidisciplinary Analysis project (AMMA, Redelsperger et al., 2006), for 2006 several rain gauge observations were temporarily added to the existing rain gauge network. Here we use 5-minute rainfall observations from the stations of Samadey (13.59°N, 2.70°E) and Nangatchouri (9.65°N, 1.74°E), which were aggregated to 15-minute rain rates to make it comparable to the SEVIRI-derived rain rates.

In addition to the AMMA rain gauges, we used daily rain amounts as obtained from the Comité Inter-Etate pour la Lutte contre la Sécheresse au Sahel (CILSS) rain gauge network maintained and operated by the Centre Regional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationnelle (AGRHYMET). These daily rainfall amounts are available on a 0.5°x0.5° grid and are calculated using a kriging procedure to minimize the error (Ali et al., 2005a; Ali et al., 2005b).

3 RESULTS

3.1 SEVIRI vs TRMM-TMI rain rates

Figure 2 shows the rain rates as obtained for SEVIRI and TRMM-TMI for 1-13 June 2006 over ocean surface outside West-Africa. The SEVIRI rain rates have been aggregated to 0.5°x0.5° grid to match the resolution of the TRMM-TMI rain rates. It can be seen that SEVIRI underestimates rain rates < 0.5 mm h $^{-1}$ compared to TMI, which changes into an overestimation for 0.5 and 3.0 mm h^{-1}. From 3 mm h^{-1}, differences between SEVIRI and TRMM-TMI are only a few percent. Overall, SEVIRI retrieves a higher rain rate than TRMM-TMI, with median rain rates of 1.1 mm h^{-1} and 0.7 mm h^{-1}, respectively.

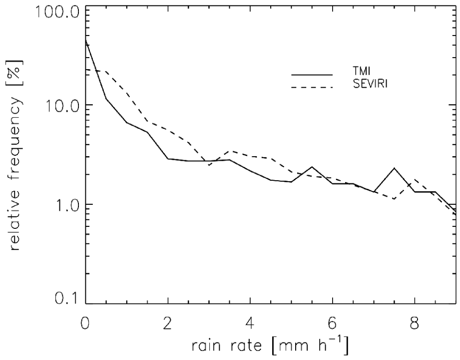

Figure 2: frequency distributions of TRMM-TMI- (solid line) and SEVIRI-derived rain rates over ocean surface outside West-Africa for 1-13 June 2006.

3.2 SEVIRI rain rates and accumulated rain versus AMMA rain gauge observations

Figure 3 shows the comparison of SEVIRI rain rates for 9 June 2006 with rain gauge observations for the station of Samadey, Niger, in the left panel. The right panel shows the accumulated rain. The SEVIRI rain rate for the pixel with the geolocation closest to the Samadey geoloation was used. The 5-minute rain rate observations were aggregated over 15 minutes to match the SEVIRI time resolution. Although the individual rain peaks are not that well matched by SEVIRI, it can be seen that the accumuated rain agrees fairly (gauge total=6.0 mm, SEVIRI=6.8 mm).

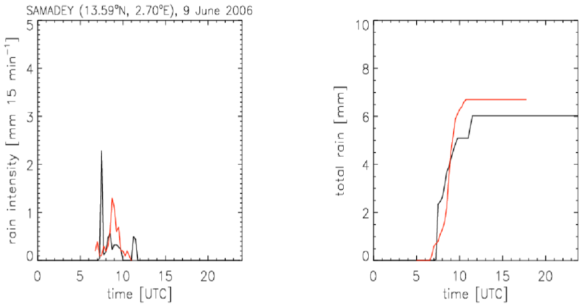

Figure 3: (left panel) Rain rates (in mm 15 min^{-1}) as obtained from SEVIRI (red line) and rain gauge (black line) and (right panel) accumulated rainfall from SEVIRI and rain gauge for Samadey, Niger, 9 June 2009.

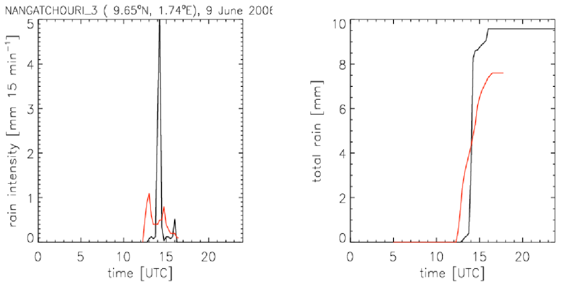

Figure 4: (left panel) Rain rates (in mm 15 min^{-1}) as obtained from SEVIRI (red line) and rain gauge (black line) and (right panel) accumulated rainfall from SEVIRI and rain gauge for Nangatchouri, Benin, 9 June 2009.

A similar comparison for 9 June 2006 has been performed for the station of Nangatchouri, Benin, which is located ~500 km SW of Samadey, hence it is located closer to the current position of the Inter Tropical Convergence Zone (ITCZ).

The instantaneous rain rates indicate that a short, heavy shower passed over the station at about 1445 UTC (1545 local time), with ~5 mm of rain in 15 minutes, whereas from SEVIRI a rain rate of ~1 mm 15 min^{-1} is retrieved. It is noted that due to the aggregation of the 5-minute rain rate to 15 minutes this amount of rain rate might have fallen in just 5 minutes, being equivalent to ~ 60 mm h^{-1}. It is likely that due to the nearest neighbor approach a pixel with heavy rainfall is missed. Using a method in which the trajectory of convective systems is taken into account would probably result in a better agreement of the instantaneous SEVIRI-derived rain rates to those of rain gauges. Furthermore, the SEVIRI rain rate is retrieved over an area of ~3x3 km^2, so heavy rains occurring over a smaller area are smeared out. The obtained accumulated rain from SEVIRI underestimates the rain gauge total by ~20%.

3.3 SEVIRI versus CILSS accumulated rain

SEVIRI rain rate observations have been accumulated for an area covering 12°-16°N, 0°-4°E for 9 June 2006. The results are shown in Figure 5.

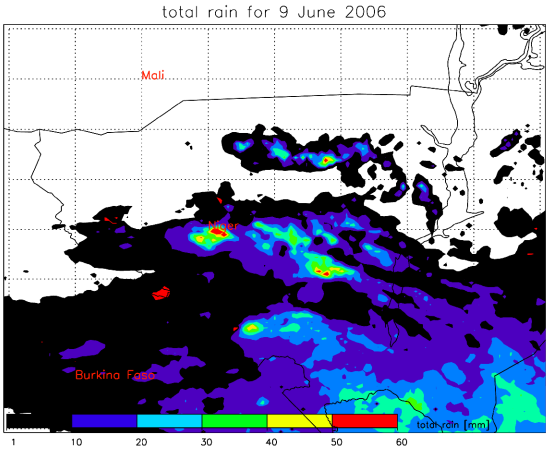

Figure 5: Accumulated rain from SEVIRI for the region 12°16°N, 0°-4°E for 9 June 2009. Contouring intervals are at 1, 10, 20, 30, 40, 50, and 60 mm.

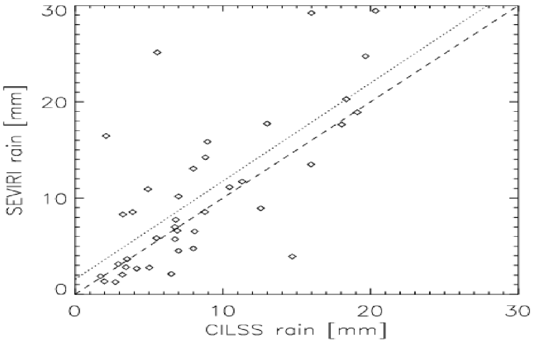

Figure 6: Daily rain totals for 9 June 2006 of kriged CILSS observations versus SEVIRI for 12°-16°N, 0°-4°E using a 0.5°x0.5° grid. The dashed line indicates the 1:1 relationship; the dotted line denotes a linear fit through the observations.

It can be seen that in the southern part of the area, rain totals are generally in the range of 10-30 mm, with a few locations having rain totals >50 mm. Going from south to north, the rain totals gradually decrease, as the ITCZ has not proceeded that far north at the beginning of June.

The SEVIRI rain totals for 9 June 2006 have been aggregated to a 0.5°x0.5° grid to make it comparable with the kriged rain observation dataset of CILSS. The results are shown in Figure 6. Apart from some outliers, the agreement between SEVIRI and CILSS rain totals is very promising, bearing in mind that SEVIRI daily totals were obtained from visible/near-infrared reflectance. For West-Africa this implies that retrievals could be done for about 50% of a day. The correlation coefficient is 0.71. A linear fit through the observations yields the relation SEVIRI = 1.55 + 1.02 * CILSS.

4 SUMMARY AND OUTLOOK

In this paper, we presented a rain rate retrieval algorithm using visible and near-infrared reflectance from SEVIRI onboard Meteosat-8 and -9 and applied it over West-Africa for June 2006. Rain rate retrievals and accumulated rain have been compared with TRMM-TMI data and rain gauge observations from AMMA and CILSS. First results indicate that over ocean, agreement between SEVIRI and TRMM-TMI is promising, although SEVIRI tends to overestimate rain rates. We note that a microwave imager is sensitive to different parts of clouds and rain, whereas the rain rates from SEVIRI are estimated from cloud-top properties. Over land, SEVIRI is reasonably capable of retrieving rain rates for individual stations, although some mismatches in both timing and intensity occur. Part of this is probably due to the rather simple nearest neighbor approach for SEVIRI in this study, while another part might be the result of small-scale heavy precipitation occurring at a scale smaller than the SEVIRI sampling resolution. Daily totals of rain for individual stations agree to within ~20%, while daily totals compare well to the kriged CILSS rain totals, with a correlation of 0.71. In the near future, the comparison with TRMM-TMI and rain gauge observations will be extended by 1) including more rain gauge stations from the AMMA project, and 2) extending the comparison to the entire monsoon season (May – August). In addition, more emphasis will be put on the diurnal cycle of convection over the continent. Finally, we will investigate the two-way interaction between soil moisture and the initiation and duration of the monsoon convection.

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