RAINFALL ESTIMATION OVER AFRICA USING MSG

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Abstract

Africa has a vital need for rainfall estimates, as many areas are extremely vulnerable to excesses and deficits of rain. Satellite rainfall estimates have the potential to be fed into crop yield and hydrological models, and can be used to predict flooding and drought in Africa. Due to financial and infrastructural constraints, rain-gauge and precipitation radar networks are currently extremely sparse over most of Africa. There is a particular shortage of rain-gauge data that is available in real time. Satellite-based rainfall monitoring provides a method of producing rainfall estimates for the entire continent, without the need for extensive real time surface observations.

The UK Met Office and the University of Reading are running a project to produce and validate rainfall estimates over Africa using Meteosat Second Generation (MSG) data, calibrated with European radar data. This is based on a product already used operationally by the Met Office over Europe, calibrated with the European radar network.

The African rainfall estimates used a similar algorithm to the European estimates, and were calibrated in the same way using European radar data. These estimates were validated against African rain-gauge data in the Sahel region where there is a dense network of gauges. The MSG estimates were also compared with rainfall estimates produced by the University of Reading’s TAMSAT African rainfall estimation algorithm, to see if there is any improvement in accuracy over the basic TAMSAT model. The initial validation used historical MSG, European radar and rain-gauge data from a period in mid 2004. The results of this show the Met Office scheme performs less well than the TAMSAT scheme, so changes to the Met Office scheme will be necessary before the product can be disseminated to users in Africa.

MOTIVATION FOR DEVELOPMENT OF A NEW SATELLITE RAINFALL ALGORITHM FOR AFRICA

Accurate precipitation estimates are necessary in Africa for agricultural, humanitarian and hydrological applications. The dependence of much of the population on rain-fed agriculture, and the scarcity and large temporal and spatial variation of rainfall over much of the continent means that dependable, near real-time rainfall estimates are vital for agricultural decision making and famine early warning systems. Precipitation radar networks are extremely rare in Africa, and rain-gauge networks are often sparse, with the data from many gauges collected only on a monthly or seasonal basis. Over the last 15 years the African rain-gauge network has actually degraded (Ali et al ’05), and there is little sign of this improving in the near future. Satellite-based rainfall estimates provide one method to fill this information gap.

Several different types of satellite rainfall estimation (rfe) algorithms exist. The main types are:

- Algorithms that primarily use infra-red (IR) data
- Algorithms that primarily use passive microwave (PM) data
- Algorithms that use a combination of IR and PM data
Many algorithms also assimilate available real-time gauge data, and some now utilise data from the precipitation radar (PR) onboard the TRMM (Tropical Rainfall Monitoring Mission) satellite.

The University of Reading’s TAMSAT (Tropical Applications of Meteorology using SATellite data) algorithm, which uses data from a single thermal infrared Meteosat channel and is calibrated regionally using historical gauge data, produces operational ten day (dekadal) rainfall estimates for Africa. A detailed description of the TAMSAT methodology can be found in Grimes et al ‘99. Two recent satellite rfe inter-comparison studies over Africa (Dinku et al ’07 for Ethiopia and Chopin et al (unpublished) for the Sahel region) have shown that TAMSAT rainfall estimates perform as well as, and often better than more sophisticated algorithms when validated using rain-gauge data.

These inter-comparisons and others (Nicholson et al ’03), found that in general for Africa, algorithms primarily based on PM data (e.g. SSM/I rain product) produce large overestimates of rainfall. Possible reasons for this include the poor temporal sampling of the polar orbiting satellites that carry the PM sensing instruments, and the fact that rain droplet absorption channels do not give useful information on rainfall over land due to high surface emissivity. In contrast, IR data from instruments onboard geostationary satellites is available at high spatial and temporal resolution. Several algorithms (e.g. GPCP products, CMORPH, CMAP) have attempted to combine the benefits of the high temporal resolution provided by IR data with the presumed superior rain-detection properties of PM data. However the benefits of this approach are doubtful over Africa, where PM data does not appear to give accurate rainfall estimates.

The SEVIRI instrument on board MSG (Meteosat Second Generation) records data from several visible, near IR and thermal IR channels, and a combination of these channels should provide more information on rainfall than the single channel used by TAMSAT. Therefore it should be possible to develop an improved rainfall estimation algorithm for Africa based on data from a combination of channels from SEVIRI.

**MET OFFICE RAIN-RATE ESTIMATION IN EUROPE AND EXTENSION TO AFRICA**

The Met Office has an existing scheme in place for estimating precipitation amounts over Europe. This was written by Pete Francis. It involves correlating MSG data with data from the UK and European rainfall radar.

The radar rain rate files are re-projected onto MSG pixels for analysis. Initially the satellite area that is in the area of radar coverage (ARC) is looked at. A statistical analysis is carried out which looks at each rain rate in turn (0.0 mm/hour, 0.125 mm/hour, 0.5 mm/hour and 2.0 mm/hour) to classify rain-rates.

The MSG data are binned into a number of discrete classes, 32 for the infrared channels and 16 for the solar. A finite number of satellite classes are obtained, having 4, 3 or 2 dimensions depending on the number of MSG channels used for each rain rate, the satellite classes are compared with the radar data for the corresponding pixels, in order to determine the probability of precipitation for each satellite class with the radar measurements used as truth. Figure 1 shows how this would look in two dimensions.

![Figure 1: Example 2D correlation table.](image-url)
Each pixel is assigned as being "wet" or "dry" depending upon whether the radar rain-rate for that pixel is above or below the current threshold. These counts are accumulated for all pixels in each satellite class. The counts are expressed as a percentage of the total in each class. If this percentage is above a certain critical value (which gives the closest match between the total number of wet pixels computed for each rain-rate class within the ARC and that given by the radar data) then all satellite pixels in this class are assigned as having rain at that particular rain-rate.

After repeating the process for each rain-rate threshold, the resulting rain/no-rain assignments can be applied to MSG pixels outside the radar coverage area. Figure 2 shows how calibrating the satellite with the radar gives a realistic analysis of rainfall outside of the ARC.

![Figure 2: Example from 11th April 2006 showing how the satellite rain-rate estimate is used to supplement the radar data to produce a surface rain-rate estimate (Francis et al. 2006)](image)

This scheme has been performing well over Europe. Best results have been achieved by using 4D correlation information with the 0.8, 1.6, 3.9 (reflectance component) and 10.8μm channels during the day, and a 3D correlation using the 3.9 (brightness component), 10.8 and 12.0μm channels during the night. There is a transitional period between solar zenith angles of 75 and 88 degrees, when various other combinations of channels are used in order to produce a smooth boundary between day and night. The additional channels have been shown to have a positive impact on the Met Office rainfall estimation product, when compared to the previous 1D/2D correlation products based on Meteosat 7 products.

It was decided to test the scheme over Africa to discover whether it could, still using European radar for calibration, give realistic rainfall estimates for Africa. Changes were made to the European code to allow it to provide rainfall estimates over Africa. Six additional rain-rate classes were added to the procedure to account for the higher tropical rainfall rates which occur over Africa. The top bin in the European scheme was >2mm/hr. Rainfall rates in Africa can be very high and can easily be far greater than 2mm/hr so to accurately represent this, a larger range of rainfall classes is needed. A 10 bin scheme was introduced with the highest bin being >128mm/hr.

For the validation exercise a region was selected from the Equator to 30° north and from 20° west to 60° east. This covers most of Northern Africa and the Arabian peninsula. The hourly rainfall amounts were binned and then accumulated by assigning a rainfall value to each bin and adding these over 24 hour and dekadal (10 day) periods. As well as MSG pixel resolution, the rainfall estimate is also averaged to 0.5°, 1.0° and 2.5° resolutions for comparison with different rain gauge data sets. The rainfall accumulations can be plotted as in figure 3.
COMPARISON OF MET OFFICE AFRICAN RAINFALL ESTIMATES WITH TAMSAT ESTIMATES AND RAIN GAUGE DATA OVER THE SAHEL REGION OF WEST AFRICA

Rain-gauge data from the Sahel region of West Africa for the rainy season of May – August 2004 was used to validate Met office algorithm estimates at 0.5 by 0.5 degree and 1 by 1 degree spatial aggregations, and at dekadal (10 day) and monthly time scales. The geographical extent of the validation domain is shown in figure 6. Rainfall estimates produced using the TAMSAT algorithm for the same region and period were used as a baseline against which to compare the accuracy of the Met office algorithm estimates, as TAMSAT has been shown to produce reliable estimates for this region.

Table 1 shows the results of this validation at 0.5 by 0.5 degree spatial and dekadal temporal aggregation. Validation at the other time and space scales mentioned above did not produce qualitatively different results, and so are not shown here. The Met office algorithm (shown on the table as the ‘Met office mid-bin’ estimates) is outperformed by the TAMSAT algorithm.

In order to try and reduce the large bias in the original Met office estimates, a small alteration was made to the algorithm and the estimates computed again for the same region and time period. In the original algorithm, when pixels are assigned to a rain-rate bin, the actual rain-rate value is assigned to be the mean rain-rate within this bin. For example a pixel assigned to the 16 – 32 mm/hr bin would actually be given the value 24mm/hr. This original scheme is referred to from here on as the Met office mid-bin scheme. The alteration to the algorithm involved instead assigning each pixel to the lowest rain-rate value in its assigned rain-rate bin, e.g. a pixel assigned to the 16 – 32mm/hr bin would be given a value of 16mm/hr. This altered algorithm will be referred to as the Met office low-bin scheme.

As can be seen from table 1, the low-bin scheme does have a significantly lower bias and RMSE than the mid-bin scheme, but is still outperformed by the TAMSAT algorithm. The larger spread of the Met office estimates compared to TAMSAT estimates can be seen in figures 4 and 5. As an example, a plot showing the comparison of the algorithm outputs with gauge data for July dekad 2 2004 is shown in figure 6. In general, throughout the season, TAMSAT estimates are higher than Met office low-bin estimates in the western coastal region, Met office low-bin estimates are higher in the south-central and eastern regions, and the estimates agree well in the dry north-east region.

The Met office algorithm performs relatively well in May and June, but does particularly poorly in August, which is the month with the most rainfall. The large positive bias appears to be due to overestimation of the amount of rainfall at high rain-rates, which is why the low-bin algorithm performs better than the mid-bin as it goes some way towards correcting for this.
Table 1: Statistics for the comparison of Met office mid and low-bin and TAMSAT estimates against AMMA gauge data, at 0.5 degree spatial and ten day temporal aggregations.

<table>
<thead>
<tr>
<th></th>
<th>Met office mid-bin estimates</th>
<th>Met office low-bin estimates</th>
<th>TAMSAT estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bias</td>
<td>RMSE</td>
<td>$R^2$</td>
</tr>
<tr>
<td>May</td>
<td>12.3</td>
<td>25.1</td>
<td>0.57</td>
</tr>
<tr>
<td>June</td>
<td>25.2</td>
<td>41.4</td>
<td>0.42</td>
</tr>
<tr>
<td>July</td>
<td>62.2</td>
<td>95.5</td>
<td>0.56</td>
</tr>
<tr>
<td>August</td>
<td>77.5</td>
<td>104.5</td>
<td>0.25</td>
</tr>
<tr>
<td>September</td>
<td>11.5</td>
<td>43.0</td>
<td>0.25</td>
</tr>
<tr>
<td>All months</td>
<td>37.7</td>
<td>59.7</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Fig. 4: Met office low-bin dekadal estimates plotted against rain-gauge estimates.

Fig. 5: TAMSAT dekadal estimates plotted against rain-gauge estimates.
**CONCLUSIONS AND DISCUSSION**

The Met office algorithm does show some skill at capturing the pattern of rainfall over the Sahel. However statistically it does not perform as well as the TAMSAT algorithm when compared against gauge data, even when a ‘low-bin’ bias correction is applied to the Met office scheme. Possible reasons for this include the non-local nature of the calibration, lack of sufficient calibration data for high rain-rates, and the inherent difficulty of estimating rainfall from satellite estimates at every 15 minute time interval, rather than the more time-averaged approach used by the TAMSAT algorithm.

The simple extension of a European rainfall estimation method to Africa that has been used here makes this result fairly unsurprising, and work is ongoing to produce an improved algorithm incorporating local calibration data. This could then be disseminated to users in Africa in real time via EUMETCAST.

**REFERENCES**


Francis, P et al. (2006) Improving the Nimrod nowcasting system’s satellite precipitation estimates by introducing the new SEVIRI channels. EUMETSAT conference proceedings, Helsinki, 12-16 June 2006
