The combination of SEVIRI and GERB on Meteosat-8 provides a powerful new tool for detecting aerosols and estimating their radiative effect at high temporal and spatial resolution. However, at present no specific aerosol detection is performed in the GERB processing chain which can result in dust plumes being incorrectly identified as clouds. This has the potential to bias the derived top of the atmosphere reflected short wave flux due to the selection of an incorrect radiances to flux angular model. In this paper a technique is described which uses selected longwave SEVIRI channels to detect dust aerosol and simultaneously provides a crude estimate of the aerosol optical depth. Preliminary comparisons with MODIS aerosol retrievals made during a particular dust event are also performed.

1. INTRODUCTION

Quantifying the both the direct and indirect radiative impact of aerosols is one of the major challenges facing climate scientists today. Uncertainties in concentrations and the radiative and chemical properties of the various aerosol types hinder estimates of their direct radiative effect, while their strong interaction with the hydrological cycle make untangling their indirect impact extremely difficult. In addition, the relatively short lifetimes and complex geographical distributions put stringent requirements on the sampling rate and coverage required to monitor their presence effectively. The synergy of SEVIRI and GERB on Meteosat-8 should provide an excellent opportunity to study the radiative effect of aerosols at high temporal and spatial resolution. The region monitored by the satellite is ideal for studying the interaction between aerosols and the climate system, with around 20% of the global biomass burning budget released via African savanna burning. In addition, Africa is a rich source of mineral dust. Dust plumes are regularly seen in satellite imagery extending off the west coast of Africa and can also strongly affect conditions in the Mediterranean. Although monthly mean climatologies of aerosol optical depth do exist for the area, these are based on data from polar orbiting platforms and therefore suffer from the poor diurnal sampling associated with this type of orbit. GERB data will provide the first opportunity to measure the effect that short-term aerosol variability has on the Earth’s radiation budget over the entire African region.

Currently however the GERB processing chain does not include a specific aerosol detection algorithm. This can result in dust plumes being incorrectly identified as cloud (Figure 1) and the selection of an inappropriate angular dependency model for the conversion of the measured radiance to flux. Several authors (e.g. Ackerman, 1997, Wald et al., 1998) have attempted to use the spectral signature of dust aerosol in the outgoing longwave radiation (OLR) to detect dust outbreaks with limited success. This may be due in part to inadequacies in the dust model used to predict the spectral response. This paper describes a technique based upon multiple linear regression which could be employed to detect dust outbreaks using selected
infra-red SEVIRI channels, and tests its sensitivity to four different dust representations. The ability of the technique to quantify the dust optical depth is also discussed.

Figure 1. (a) Dust plume off the African coast at 1400 UTC on 05/03/04 as seen by MODIS on AQUA. (b) Corresponding GERB cloud flag: white hatching indicates that cloud has been detected.

2. DETECTION METHODOLOGY

Using a subset of 207 tropical atmospheres from the TIGR-3 (TOVS Initial Guess Retrieval) dataset as input to the MODTRAN-4 radiative transfer code (Berk et al., 2003), simulated longwave SEVIRI channel brightness temperatures (\(T_B\)) were obtained for both clear-sky conditions, and varying dust optical depths. The aerosol contaminated runs were repeated for four aerosol representations using refractive indices after Volz, Fouquart, the World Meteorological Organisation (WMO), and the Optical Properties of Aerosol and Clouds (OPAC) dataset (Highwood et al., 2003, Hess et al., 1998). Optical properties were calculated assuming Mie theory and a multi-modal log-normal size distribution, with, for the Volz, Fouquart and WMO indices 5 modes included (Jim Haywood, personal communication), and for the OPAC indices, 4 modes. The resulting extinction coefficients and single-scatter albedos are shown in Figure 2. Note that because of uncertainties involved in ‘stitching’ the refractive indices between the longwave and shortwave regions of the spectrum the 3.8 µm channel results are not utilised here.

Figure 2. Longwave optical properties of the four aerosol representations used. (a) Extinction coefficient (normalised to 0.55 µm). (b) Single-scattering albedo.

Early analysis focused on the possible development of a tri-spectral approach similar to that used to detect cirrus cloud, looking at the relationship between \(T_{10.8} - T_{12.0} (\Delta T_1)\) and \(T_{8.7} - T_{10.8} (\Delta T_2)\) (Figure 3). Three of
the aerosol representations show a similar pattern of behaviour, but the fourth, due to Fouquart, is substantially different, and is incompatible with SEVIRI observations made during identified dust events. Given this further analysis was confined to the remaining three aerosol representations.

![Figure 3. Scatter plot of $T_{B8.7}-T_{B10.8}$ against $T_{B10.8}-T_{B12.0}$ for the four aerosol representations.](image)

Although the tri-spectral approach shows some promise, without ancillary information (e.g. water vapour content, lapse rate) accurate thresholding between clear and aerosol contaminated conditions is problematic. In principle, the required information should be present in the outgoing spectrum so, in an attempt to include information from the water vapour and temperature sounding channels, for each remaining aerosol representation a multiple linear least-squares regression fit was calculated with the channel $T_{B8}$ as predictors and the 0.55 $\mu$m optical depth ($\tau_{0.55}$) as the outcome. Backward stepwise regression was performed in order to identify the significant predictor variables, using an assessment of the overall goodness of fit of the model. In terms of model fit, for all of the aerosol representations the smallest residuals were seen when all of the channels were included. However, upon application of the models to SEVIRI data it was found that the inclusion of the 13.4 $\mu$m channel led to poor aerosol/cloud discrimination, possibly due to an inadequate representation of CO$_2$ line mixing in MODTRAN-4, so the analysis was repeated with this predictor removed. Table 1 gives an example of the final fits obtained.

<table>
<thead>
<tr>
<th>Dust model</th>
<th>Volz Coefficient</th>
<th>Std Error</th>
<th>OPAC Coefficient</th>
<th>Std Error</th>
<th>WMO Coefficient</th>
<th>Std Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-1.03945</td>
<td>-</td>
<td>4.72125</td>
<td>-</td>
<td>3.82918</td>
<td>-</td>
</tr>
<tr>
<td>6.2 $\mu$m</td>
<td>-0.02040</td>
<td>0.01540</td>
<td>0.00080</td>
<td>0.01687</td>
<td>0.02523</td>
<td>0.0149</td>
</tr>
<tr>
<td>7.3 $\mu$m</td>
<td>-0.04288</td>
<td>0.02442</td>
<td>-0.10040</td>
<td>0.03156</td>
<td>-0.16211</td>
<td>0.0242</td>
</tr>
<tr>
<td>8.7 $\mu$m</td>
<td>1.60404</td>
<td>0.12142</td>
<td>1.91104</td>
<td>0.10918</td>
<td>2.16170</td>
<td>0.1276</td>
</tr>
<tr>
<td>9.7 $\mu$m</td>
<td>-0.02447</td>
<td>0.01056</td>
<td>-0.03972</td>
<td>0.01025</td>
<td>-0.04896</td>
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<tr>
<td>10.8 $\mu$m</td>
<td>-2.51864</td>
<td>0.1338</td>
<td>-3.35229</td>
<td>0.20339</td>
<td>-3.70665</td>
<td>0.1706</td>
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<tr>
<td>12.0 $\mu$m</td>
<td>1.00853</td>
<td>0.06421</td>
<td>1.56765</td>
<td>0.15324</td>
<td>1.72103</td>
<td>0.0793</td>
</tr>
</tbody>
</table>

Table 1. Multiple regression coefficients, standard errors, and the associated residual standard deviations at a viewing zenith angle of 0° for the Volz, OPAC and WMO dust representations.

### 3. APPLICATION TO SEVIRI DATA

Application of the WMO regression model to the observed SEVIRI channel $T_{B8}$ corresponding to the time slot shown in figure 1 results in the dust detection pattern indicated in Figure 4(a). Clearly the model locates the main dust plume but incorrectly flags several cloud clusters as cloud (compare Figure 4(a) to Figure 1(a)). To circumvent this problem, additional thresholds were applied to the SEVIRI window channels (8.7,
10.8 and 12.0 µm) and to $\Delta T_{B1}$ and $\Delta T_{B2}$. Using the simulations, thresholds were calculated for each aerosol representation fitting firstly the minimum expected $T_B$ in each window channel, and secondly the maximum expected values of $\Delta T_{B1}$ and $\Delta T_{B2}$, as a function of $T_{0.55}$ and viewing zenith angle. Finally, a spatial consistency test was defined in order to contrast the generally smooth characteristics of dust plumes with those of more broken cloud fields. Figure 4(b) indicates the resulting detection on the 1400 UTC field.

4. QUANTIFICATION OF DUST OPTICAL DEPTH

In addition to detecting a dust outbreak, the regression algorithm also provides an estimate of the aerosol optical depth. Given the residual standard deviations associated with the method (Table 1) the estimates are expected to be rather crude but as a first look, Figures 5 and 6 indicate the optical depths obtained for two time-slots within the dust outbreak highlighted throughout this paper. Optical depth retrievals from the MODIS instrument on TERRA (Figure 5(d)) and AQUA (Figure 6(d)) for the nearest available times and locations are shown for comparison.
In both cases the inter-plume variability given by all three of the regression models is similar, as expected from the regression coefficients (Table 1). However, the absolute values are substantially different, with the Volz dust representation giving the lowest values of $\tau_{0.55}$, through to the highest being seen in the WMO case. This is linked to the larger contrast in channel 10.8 $\mu$m absorption relative to that seen in channel 12.0 $\mu$m for a given optical depth for the latter case (Figures 2 and 3). Although the MODIS retrievals are not available over the whole of the study domain, at both times they appear to give best agreement with the regression fits from the OPAC representation at latitudes north of approximately 25°N. Nearer the African coast the regression results tend to underestimate $\tau_{0.55}$ compared to the MODIS results. This may be due to the assumption of a constant dust profile extending from 0.5 to 5 km in the MODTRAN-4 simulations. It might be expected that nearer the coast the dust plume is less lofted than further out over the ocean such that the depression and contrast in channel TBs due to the dust presence will be reduced.

5. FUTURE WORK

Clearly the technique described in this paper is at a very preliminary stage. The results thus far are encouraging but further testing on quantifiable dust outbreak events is required to demonstrate the robustness of the method. One particular avenue of research will involve the development of a more conventional aerosol detection and quantification technique utilising the visible and near-infrared SEVIRI channels in order to test the longwave approach, and to permit the identification of other important aerosol types. Suitable radiance to flux conversion models will then be applied to the GERB observations and the radiative effect of these aerosols quantified.

6. REFERENCES


7. ACKNOWLEDGEMENTS

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