

THE USE OF ANCILLARY SURFACE DATA PRODUCTS IN THE MET OFFICE SEVIRI CLOUD MASK

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Abstract

Accurate identification of cloudy pixels in satellite imagery is a prerequisite for carrying out quantitative analysis of cloud properties, and for the screening of cloud-contaminated data prior to the assimilation of clear-sky radiances into Numerical Weather Prediction (NWP) models.

Cloud detection over land presents a considerable challenge as a result of the heterogeneity of surface characteristics. Improvements have been made to the Met Office cloud screening algorithms applied to Spinning Enhanced Visible and Infrared Imager (SEVIRI) imagery through the use of ancillary surface data. In the first instance the EUMETSAT clear-sky reflectance map (CRM) product is used to generate dynamic thresholds for cloud screening under daylight conditions. Secondly the EUMETSAT surface emissivity dataset is supplied as input to radiative transfer simulations which are subsequently used to derive thresholds for a variety of cloud screening tests. We present results showing the impact of using these data on the operational cloud mask.

INTRODUCTION

Quantitative imagery products derived from the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) are used for forecaster guidance and form an important input to Nimrod (Golding, 1998), the Met Office nowcasting system. Furthermore, clear-sky SEVIRI radiances over the North Atlantic and European region are assimilated into the Met Office Numerical Weather Prediction (NWP) system (Kelly and Francis 2008). A key pre-processing step for both of these tasks is the accurate identification of cloud-contaminated pixels.

In common with many operational cloud detection algorithms, the Met Office SEVIRI mask is based on a series of threshold cloud tests. The thresholds for the tests are derived principally from two sources: radiative transfer simulations of clear-sky brightness temperatures (BTs) based on recent NWP model forecast fields, and various ancillary datasets (see Saunders *et al.* 2006 for more details). This paper describes the use of two such datasets in improving cloud detection over land surfaces. The EUMETSAT clear-sky reflectance map (CRM) product allows dynamic thresholds to be generated for cloud tests over land surfaces in the day time. The EUMETSAT land surface emissivity (LSE) atlas may be used as input to the radiative transfer simulations to improve their accuracy and hence allow for more efficient cloud detection over land surfaces in both day and night.

CLEAR-SKY REFLECTANCE MAP

The CRM product (EUMETSAT, 2008) is disseminated daily via the EUMETCast system. The nominal product time is 1200Z and the data consist of average clear-sky reflectances in each of the SEVIRI visible and near-IR channels taken over the previous seven days from the two slots closest to the product time. Where no clear-sky data are available for a pixel, the data are relaxed towards a climatology by linear combination of the previous week's CRM value and the climatological reflectance.

Application of the data

Clouds are frequently observed to have higher reflectances than the underlying surface. Before the CRM data were used in the Met Office SEVIRI mask, a simple visible threshold test was applied with static thresholds over land surfaces. The CRM data allow the thresholds to be dynamically generated increasing the efficiency of the test substantially. Pixels are flagged as cloud-contaminated if:

$$R_{(0.6)}^{ob} > R_{(0.6)}^{CRM} + \Delta R_{(0.6)}$$

where $R_{(0.6)}^{ob}$ is the observed reflectance at 0.6 μm , $R_{(0.6)}^{CRM}$ is the corresponding CRM reflectance, and $\Delta R_{(0.6)}$ is a pre-defined offset.

Even though the CRM data are based on reflectances around 12Z, they can usefully be applied throughout much of the day for the purposes of cloud detection. Under some circumstances higher reflectances are observed, for example due to enhanced forward scattering at high illumination angles. To avoid flagging clear pixels as cloudy (henceforth referred to as false positives), a higher offset is used for slots before 0600Z and after 1800Z, and for high solar zenith angles (above 70° in the northern hemisphere winter, and above 60° for the rest of the year). There are also cases for which the CRM data are unsuitable and in these cases fixed thresholds (independent of the CRM data) are used. These include slots before 0400Z in winter and 0500Z for the rest of the year, and certain geographical regions (seasonally-dependent) which are prone to increased observed reflectances, especially at high illumination angles. Finally, the CRM data are not used if the CRM reflectance exceeds 0.60 as this often indicates either cloud- or snow-contamination in the CRM dataset. Despite these various conditions, the CRM data are used over a wide range of slots each day and over much of the Earth disc.

Results

The Nowcasting Satellite Applications Facility (SAFNWC) also generates a SEVIRI cloud mask based on a series of threshold tests (Derrien and Le Gléau 2005). Although the SAFNWC and Met Office masks have a number of cloud tests in common, an important difference between the masks lies in how the test thresholds are derived. The SAFNWC mask employs pre-calculated look-up tables based on large numbers of off-line radiative transfer simulations. The tables are indexed by geometrical variables such as solar and satellite zenith angles, NWP fields such as surface temperature and total column water vapour, and other ancillary data such as elevation and climatological data.

To provide a quantitative idea of the impact of the CRM data on the cloud mask a comparison with the SAFNWC cloud mask was carried out. The comparison dataset consists of the hourly slots from 04Z-19Z (covering the range of slots for which the CRM data are used) on 13th June 2008. Table 1 shows the proportion of day time land pixels which were cloudy in the SAFNWC mask that were flagged as cloud in the Met Office mask (“% cloudy correct”), and likewise for SAFNWC clear pixels.

	% cloudy correct	% clear correct
Without CRM	82.52 %	94.84 %
With CRM	85.99 %	94.63 %
Difference	+3.47 %	-0.21 %

Table 1: Illustrating the impact of the CRM data on the Met Office cloud mask as compared to the SAFNWC cloud mask. Figures are taken over day time land pixels only. ‘% cloudy correct’ refers to the proportion of SAFNWC cloudy pixels flagged as cloudy in the Met Office mask. ‘% clear correct’ is the proportion of SAFNWC clear pixels flagged as clear in the Met Office mask.

The introduction of the CRM shows a substantial increase (3.47%) in the proportion of SAFNWC cloud flagged in the Met Office mask with only a small reduction (0.21%) in the proportion of SAFNWC clear pixels which were clear in the Met Office mask. This suggests that comparatively few false positives are being introduced with the use of the CRM data as compared against the SAFNWC mask. Figure 1 shows an example of the improvement in the cloud mask with the introduction of the CRM data.

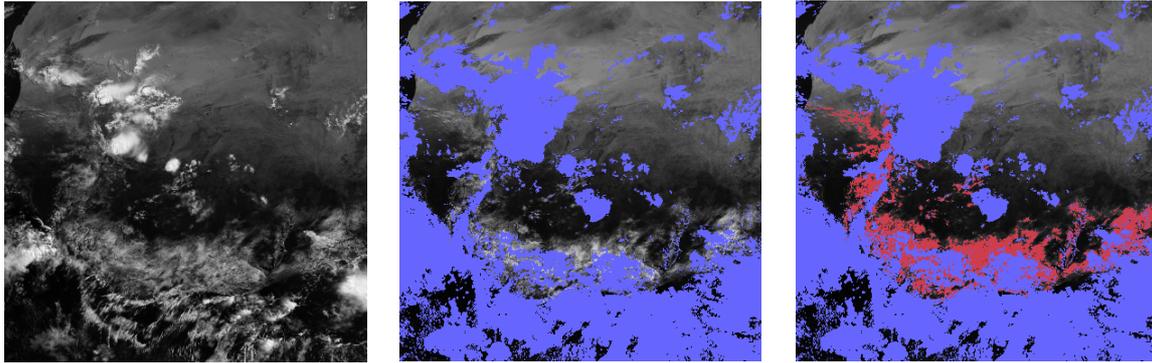


Figure 1: A case from 3rd July 2008 at 1015Z showing the additional cloud detected as a result of using the CRM data. The image on the left shows 0.6 μm channel. The central image has the pre-CRM cloud mask overlaid in blue. The image on the right shows the extra cloud flagged as a result of using the CRM data in red.

LAND SURFACE EMISSIVITY ATLAS

EUMETSAT have created a land surface emissivity (LSE) atlas (Lutz and König 2008) from the University of Wisconsin (UW) – CIMSS high resolution emissivity atlas (Seemann *et al.* 2008) which in turn is derived from MODerate-resolution Imaging Spectro-radiometer (MODIS) land surface emissivity retrievals. The data consist of SEVIRI pixel-resolution LSE values in each SEVIRI thermal infrared channel.

As mentioned above, thresholds for certain cloud tests are based on simulated clear-sky BTs. These tests are listed in Table 2, in which $T_{B(\lambda)}^{ob}$ represents the observed BT at wavelength λ μm , $T_{B(\lambda)}^b$ is the corresponding simulated BT, and the ΔT_B are pre-defined positive offsets which may vary with surface type. The tests themselves mostly originate from cloud detection algorithms applied to AVHRR imagery (for example Saunders and Kriebel 1988) and they are common to a number of operational SEVIRI cloud masks (for example Derrien and Le Gléau 2005, EUMETSAT 2007). The simulations are carried out using RTTOV-9 (Saunders *et al.* 1999) based on recent NWP model forecast fields. By default, RTTOV uses a fixed land surface emissivity of 0.98 which is somewhat high, particularly for barren surface types. The gross test is particularly affected by this: if the LSE is too high then the clear-sky BT will also be too high, thus increasing the risk of erroneously flagging cloud. The use of a LSE atlas can improve the accuracy of the simulated BTs, resulting in more efficient thresholds.

Gross	$T_{B(10.8)}^{ob} < T_{B(10.8)}^b - \Delta T_{B(10.8)}^{gross}$
Thin cirrus	$T_{B(10.8)}^{ob} - T_{B(12.0)}^{ob} < T_{B(10.8)}^b - T_{B(12.0)}^b + \Delta T_{B(10.8-12.0)}^{thin-cirrus}$
Mixed scenes	$T_{B(3.9)}^{ob} - T_{B(12.0)}^{ob} < T_{B(3.9)}^b - T_{B(12.0)}^b + \Delta T_{B(3.9-12.0)}^{mixed-scenes}$
Fog/low cloud 3.9	$T_{B(10.8)}^{ob} - T_{B(3.9)}^{ob} < T_{B(10.8)}^b - T_{B(3.9)}^b + \Delta T_{B(10.8-3.9)}^{fog\ 3.9}$
Fog/low cloud 8.7	$T_{B(10.8)}^{ob} - T_{B(8.7)}^{ob} < T_{B(10.8)}^b - T_{B(8.7)}^b + \Delta T_{B(10.8-8.7)}^{fog\ 8.7}$

Table 2: Cloud tests in the Met Office mask whose thresholds are based on simulated clear-sky brightness temperatures (with ‘b’ as superscript). Pixels are flagged as cloudy if the condition is satisfied.

Application of the data

Two methods for using the LSE atlas were investigated. The first was to average the pixel emissivity values over the NWP model grid points and use the resulting emissivity as input to the existing RTTOV simulations. The second method involved making use of the emissivity data on a per-pixel

basis. For the purposes of testing the effect on the cloud mask, RTTOV simulations were carried out individually for each pixel over sub-sets of the SEVIRI Earth disc. In practice a more sophisticated scheme would have been required if this were implemented operationally, but in fact it was found not to be necessary.

Figure 2 shows the differences between the clear-sky simulated and observed BTs (the observations were screened using the operational cloud mask which did not use the LSE atlas). The data were taken from an area over North Africa at 2230Z on 13th June 2008. These are largely barren surface types for which we observe the largest differences between the emissivities in the atlas and the RTTOV default emissivity.

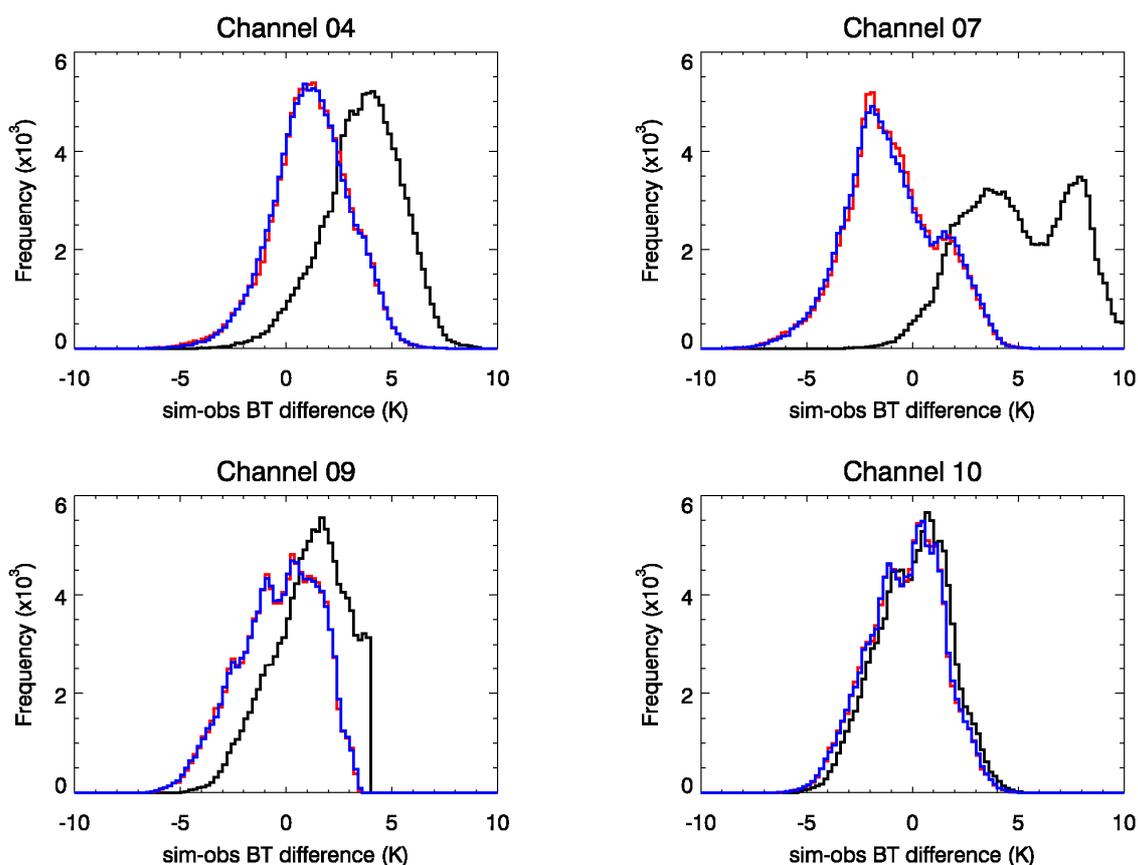


Figure 2: Histograms of simulated minus observed clear-sky BTs in each SEVIRI channel used for cloud detection. The black lines show the simulated BTs without the LSE atlas. The red lines show simulated BTs with pixel emissivity values averaged over NWP model grid points. The blue lines show simulated BTs calculated for each pixel using individual pixel emissivity values. Data is taken from a region over North Africa at 2230Z on 13th June 2008. The sharp cut-off at +4K in the channel 9 histogram without LSE data is due to the gross test: pixels more than 4K colder than the simulated BT were flagged as cloudy and hence excluded from this analysis.

As to be expected it is generally observed that biases are reduced in each channel with the LSE atlas. The spread of the differences is not reduced (with the exception of channel 7) since the dominating error lies in the model land surface temperatures. The two methods of using the emissivity data exhibit very little difference in these plots and this was borne out in the resulting cloud masks which also showed minimal differences. For this reason it was decided to use the less computationally intensive method of averaging the emissivity atlas over model grid points and only doing the radiative transfer calculations on the model grid.

Results

To illustrate the impact of the LSE data, a comparison has again been carried out against the SAFNWC mask over the hourly slots 01Z-23Z from 13th June 2008. The results of the comparison are summarised in Table 3. The statistics are presented for land pixels only and are analogous to those in Table 1.

	Without LSE atlas		With LSE atlas	
	% cloudy correct	% clear correct	% cloudy correct	% clear correct
Night	93.87 %	79.33 %	93.37 %	82.87 %
Day	86.31 %	94.08 %	87.09 %	93.91 %
Overall	89.71 %	87.05 %	89.99 %	88.52 %

Table 3: Illustrating the impact of the LSE atlas on the Met Office cloud mask as compared to the SAFNWC cloud mask. Figures are taken over land pixels only. '% cloudy correct' refers to the proportion of SAFNWC cloudy pixels flagged as cloudy in the Met Office mask. '% clear correct' is the proportion of SAFNWC clear pixels flagged as clear in the Met Office mask.

The LSE atlas has the largest impact on the gross test. NWP models often fail to capture land surface temperature extremes, typically over-estimating at night and under-estimating during the day. The result is that the gross test sometimes introduces false positives into the cloud mask at night, and is more likely to miss cloud in the day time. The effect of the LSE data at night is to reduce the bias in the simulated BTs making them colder, and hence eliminating some of the false positives in the cloud mask.

This is borne out in Table 3: for night time pixels, the LSE data results in an increase of 3.54% in the proportion of SAFNWC clear pixels identified as clear in the Met Office mask. This indicates a substantial decrease in false positives. This compares with a drop of 0.50% in the proportion of SAFNWC cloud correctly identified.

For day time pixels the situation is reversed, with an increase of 0.78% in the SAFNWC cloudy pixels flagged as cloud, and a reduction of 0.17% in SAFNWC clear pixels flagged as clear by the Met Office mask. The principal benefit of the LSE atlas in day time is in allowing more efficient thresholds to be used, which enable more cloud to be detected.

The effect of the LSE atlas for all pixels is a modest increase (0.28%) in the proportion of cloudy pixels flagged by the Met Office mask, and a larger increase (1.47%) in the proportion of clear pixels flagged correctly. This indicates that overall the LSE atlas is beneficial to the cloud mask, with the greatest impact being a reduction of false positives.

RTTOV land surface emissivity atlas

A new emissivity atlas is being developed within the RTTOV software (Borbás *et al.* 2009). This atlas is also based on the UW-CIMSS dataset, though the RTTOV atlas uses emissivity data from 2006 while the EUMETSAT atlas is based on the 2005 dataset. Since the RTTOV atlas is work in progress, only an initial comparison has been made with the EUMETSAT atlas. An example is shown in Figure 3 which shows differences between simulated and observed clear-sky BTs for a case over North Africa. The largest differences between the atlases are observed over barren surface types. It appears that the RTTOV atlas has smaller bias in channels 4 and 7, but a slightly larger bias in channel 10 compared to the EUMETSAT atlas. A substantial inter-annual variability has been observed in the underlying MODIS emissivity datasets which is the probable explanation for these differences.

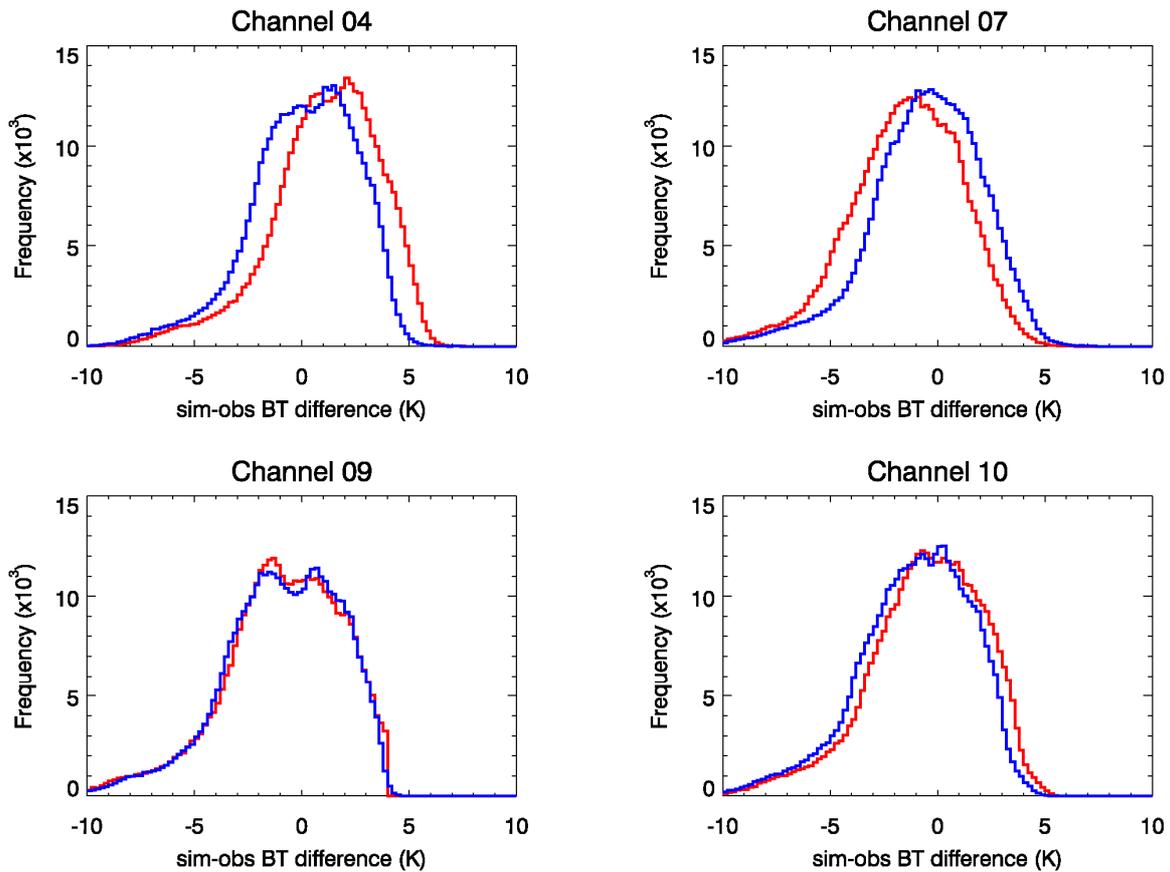


Figure 3: Histograms of simulated minus observed clear-sky BTs in each SEVIRI channel used for cloud detection. The red lines show the results using the EUMETSAT LSE atlas. The blue lines show the results using the RTTOV LSE atlas. Data is taken from a region over North Africa from 0400Z on 12th December 2008.

SUMMARY AND FUTURE WORK

This paper has described the use of two ancillary land surface data products in the Met Office SEVIRI cloud mask. The EUMETSAT clear-sky reflectance map product is used to improve day time cloud detection over land using visible data. The EUMETSAT emissivity atlas is used as input to RTTOV simulations which in turn are used to derive thresholds for a number of cloud tests. Use of the LSE atlas reduces false positives in the cloud mask and can allow more cloud to be correctly identified.

EUMETSAT produce a two-hourly CRM product internally, valid at 0400Z, 0600Z, up to 2000Z. This product captures variations in clear-sky reflectances due to changing illumination conditions and so should improve the performance of the visible threshold test further. It is hoped to make use of these data once they are disseminated.

Work is underway to provide a LSE atlas within RTTOV. This atlas is also based on the UW-CIMSS high-resolution atlas, but a number of differences are observed between the RTTOV and EUMETSAT atlases. Once work on the RTTOV atlas is complete it is planned to make a comparison of the impact of the two datasets on the cloud mask.

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