SINERGEE: SIMULATION AND EXPLOITATION OF DATA FROM METEOSAT-8 USING AN NWP MODEL

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ABSTRACT

Preliminary results will be presented from the SINERGEE project, which combines simulations from the Met Office numerical weather prediction (NWP) model with data from the Geostationary Earth Radiation Budget (GERB) instrument on Meteosat-8. Initial comparisons of broad-band outgoing longwave radiation (OLR) and albedo show good agreement between GERB and the model, particularly over middle latitudes where the moisture fields, and hence the diagnosed clouds, are well constrained by the assimilation of data by the model. Despite initial problems with the GERB data, for example relating to geolocation uncertainty, errors in model fields are identified. These include: (i) too much convective cloud over tropical Africa at mid-day, (ii) lack of organisation of convective cloud, (ii) positional errors for the inter-tropical convergence zone, (iv) underestimates in albedo over the Sahara and (v) overestimates in OLR by up to 50 Wm^{-2} over parts of the Sahara.

GERB fluxes, produced by the Royal Meteorological Institute of Belgium (RMIB), initially used Meteosat-7 data to define the radiance to flux conversion models. We will present updated comparisons utilising GERB fluxes from RMIB that use the SEVIRI high-resolution imager in the radiance to flux conversions, which avoids the angular mis-match encountered between Meteosat–8 and Meteosat–7 viewing. In addition it is planned to conduct additional simulations at the Met Office of selected channels from the SEVIRI imager. The combination of information on the surface and atmospheric state from the model, together with the simulations and observations of the broad-band fluxes from GERB and narrow-band radiances from SEVIRI, enables research in several areas to be followed:

1) Understanding the Earth's radiation budget including the radiative impact and feedbacks from cloud, water vapour and aerosols,
2) Evaluation of the NWP model analyses and forecasts and climate models using data from METEOSAT-8,
3) Monitoring and evaluation of the satellite instruments,
4) Interaction with field programmes.

Many of these applications are enhanced by the near-real time nature of the comparisons.

1. INTRODUCTION

There are two primary motivations for using Earth Observation data to evaluate the radiation budget in general circulation models. Firstly, radiative processes are crucial in determining the forcing and feedbacks operating on a variety of time-scales and therefore make a key contribution both to synoptic scale evolution and climate change (Houghton et al. 2001). Secondly, the radiative energy emitted and reflected by the Earth-atmosphere system provides a wealth of diagnostic information pertaining to the properties of the atmosphere (e.g. clouds, water vapour and aerosol) and the surface. High quality measurements of the Earth's radiative energy balance therefore enable the accuracy of physical processes represented in climate and numerical weather prediction (NWP) models to be scrutinised and improved (e.g. Soden et. al. 2002).

Measurements of the Earth's top of atmosphere (TOA) radiation budget from satellites in low Earth orbit (LEO) are commonly used to test the realism of clouds, water vapour and the energy budget in climate models. Such analyses are often confined to long-term means (e.g. monthly to decadal) and over coarse grids, in part because of the limitations of time and space sampling imposed by the orbit (e.g. Wielicki et al. 1996). This can lead to problems in understanding the reasons for differences between models and data due to the disparate sampling (Allan and Ringer 2003) and also because the radiative interactions that determine how physical processes operate occur on much shorter time-scales (e.g. hours to days) than those usually considered. To avoid some of these limitations, one approach is to exploit the data from geostationary satellites which, over the portion of the earth visible from the satellite, do not suffer from the spatio-temporal sampling problems of LEO satellites (e.g., Slingo et al. 2004).

While both geostationary and LEO satellite data are utilised extensively through data assimilation to provide the initial conditions for NWP models, less use has been made of the data in evaluating these models. However, the potential for this application is considerable, since data that have not been used to initialise the forecast have a valuable role to play in verification. This is particularly important for clouds, information on which can readily be retrieved from satellite imagery, although methods for including this information in the data assimilation process are still under development. Satellites can therefore provide an independent source of data for evaluating the representation of clouds in NWP models. The nature of such an evaluation can be quite distinct from that employed when testing a climate model; in NWP, it is possible to perform a series of instantaneous comparisons for specific times and thereby to examine the high frequency behaviour of the model, as opposed to the time-averaged comparisons typically performed with climate models. Nevertheless, the similarity between the physical parametrizations now employed in the two classes of model ensures that lessons learned with one version are relevant to the other. The advantage of performing such an evaluation with an NWP model is that the model's analysis provides an optimum initial atmospheric state, so to some extent the performance of the cloud parametrization can be assessed independently of other model errors, the effect of which become evident in the model forecasts as they evolve away from the initial state.

Motivated by the above reasoning, we have initiated a project to compare simulations from the Met Office NWP model with data from the new Meteosat−8 (formerly MSG−1) geostationary meteorological satellite (Schmetz et al. 2002). Comparisons are undertaken on a near real-time basis (e.g. within 1 day), which allows timely feedback on the quality of both the satellite data and the model simulations in relation to the current synoptic situation. The project has the acronym SINERGEE (SImulations from an Nwp model to Exploit Radiation data from a new Geostationary satellite, Explore radiative processes and Evaluate models). The acronym reflects the intention to enhance the synergy between the models used for numerical weather and climate prediction and Earth Observation satellite data. Applications include observational studies of the physical processes important for accurate simulations of weather and climate, evaluation of the performance of the NWP model and the potential for contributing to the calibration and validation of the satellite instruments. In this paper, simulations from the Met Office NWP model are compared with broad-band radiation budget data from the Geostationary Earth Radiation Budget (GERB) instrument on Meteosat-8 (Harries et al. 2004). This is the first such instrument to be flown in geostationary orbit, providing unprecedented temporal sampling of the radiation budget. The emphasis here is on the exploitation of the comparisons to reveal the strengths and weaknesses of the model simulations.

2. NWP MODEL

The version of the Met Office operational global NWP model used here was introduced in August 2002 (cycle G27). The horizontal resolution is 0.833° longitude and 0.556° latitude, equivalent to about 60km at mid-latitudes. There are 38 vertical levels with a top at 3hPa. The model is based around a new dynamical core, which is non-hydrostatic and uses a two time-level, semi-implicit, semi-Lagrangian formulation. The basic time step is 20 minutes. In the vertical, a Charney-Phillips grid staggering is used (potential temperature and vertical velocity are on the same half-levels, whereas pressure and wind components are on the full model levels). The vertical coordinate is height, but a hybrid approach provides the usual terrainfollowing grid near the surface. In the horizontal, the Arakawa C grid staggering is used. Further details of the model and the background for this approach are discussed by Bell et al. (2002).

3. GERB DATA

The GERB instrument was launched onboard Meteosat−8 in August 2002. GERB measures the total and shortwave broadband radiances emitted and reflected from the Earth; longwave radiances are calculated by subtraction of the shortwave from the total. The measurements are internally calibrated on the satellite using a black body source and an integrating sphere illuminated by the sun. Two complete spectral images of the Earth are produced every 600 seconds; these data are averaged to produce a time resolution of 15 minutes for the shortwave and longwave radiance products. The approximate spatial resolution at the sub-satellite point is 50 km. The radiances are converted to radiative fluxes at the top of the atmosphere using angular models that depend on the scene type, identified by high-resolution imager data. The processing system for GERB is designed to use data from the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI), the primary operational meteorological instrument on Meteosat−8, in the radiance to flux conversion process (Ipe et al. 2004). However, for much of 2003 there was limited availability of the SEVIRI data, as the instrument had not yet become operational. Imager data from the Meteosat−7 satellite (MS7A) were therefore used. This aspect of the data processing is performed at the Royal Meteorological Institute of Belgium (RMIB). For further details of the instrument and processing system see Harries et al. (2004).

4. METHODOLOGY

The NWP model is initialised using three dimensional variational assimilation to produce analyses four times each day, from which forecasts are integrated. These operational forecasts are produced to a stringent schedule that does not allow the provision of expensive additional diagnostics, since these could delay the forecast process. A solution employed here and in other diagnostic projects at the Met Office is to run additional single-time step integrations independently of the main forecast model run, using the operational analyses as initial conditions. Thus, extra diagnostics are obtained without impeding the forecast process.

At ESSC, the model diagnostics are acquired automatically from the Met Office. In parallel, data from GERB corresponding to the time of the model data are transferred from RMIB. In the present study we use the standard flux products (ARG) unless stated. Also available are the BARG products, which are binned in space and time using the imager data. The most recent GERB data available are ingested and interpolated to the model grid. The model and GERB outgoing longwave radiation and albedo fields are then compared (see http://www.nerc-essc.ac.uk/~rpa/GERB/gerb.html) and the images stored. The co-located model and satellite gridded data are also stored for future use. With the preliminary version of the GERB data, this includes manual corrections for erroneous data due to data drop-out and poor geolocation. Figure 1 shows an example comparison of GERB and model OLR and albedo for the 31st March 2004 at 1200 UTC. This illustrates the generally good agreement between model and GERB data over middle latitudes. Here, the moisture fields, and hence the diagnosed clouds, are well constrained by the assimilation of data by the model. At lower latitudes there are a number of differences, many of which are likely to relate to model errors, as will be discussed in Sections 6 and 7. However, it is important first to establish the validity of the GERB data before conclusions are drawn about model deficiencies.

5. DATA VALIDATION

The current GERB data are preliminary and validation of the flux products is ongoing (Harries et al. 2004). While one of the main purpose of the present study is to exploit data from GERB in the evaluation of the NWP model, there is also an opportunity to contribute to the verification of the GERB data quality. This is possible by considering aspects of the model in which there is the most confidence, for example clear-sky fluxes over the oceans. Figure 2 shows comparisons between clear-sky OLR and albedo over the ocean for June-August (JJA) 2003 and December-February (DJF) 2003/4. We consider only grid-points where co-located model simulated and satellite estimated cloud cover is zero. The satellite cloud cover product, described in Ipe et al. (2003), is derived from visible channels of SEVIRI from December 2004 and from Meteosat−7 before. The clear-sky flux comparisons are restricted to the 1200 UTC data, which allows complete coverage of the GERB field of view by the visible narrow-band channels.

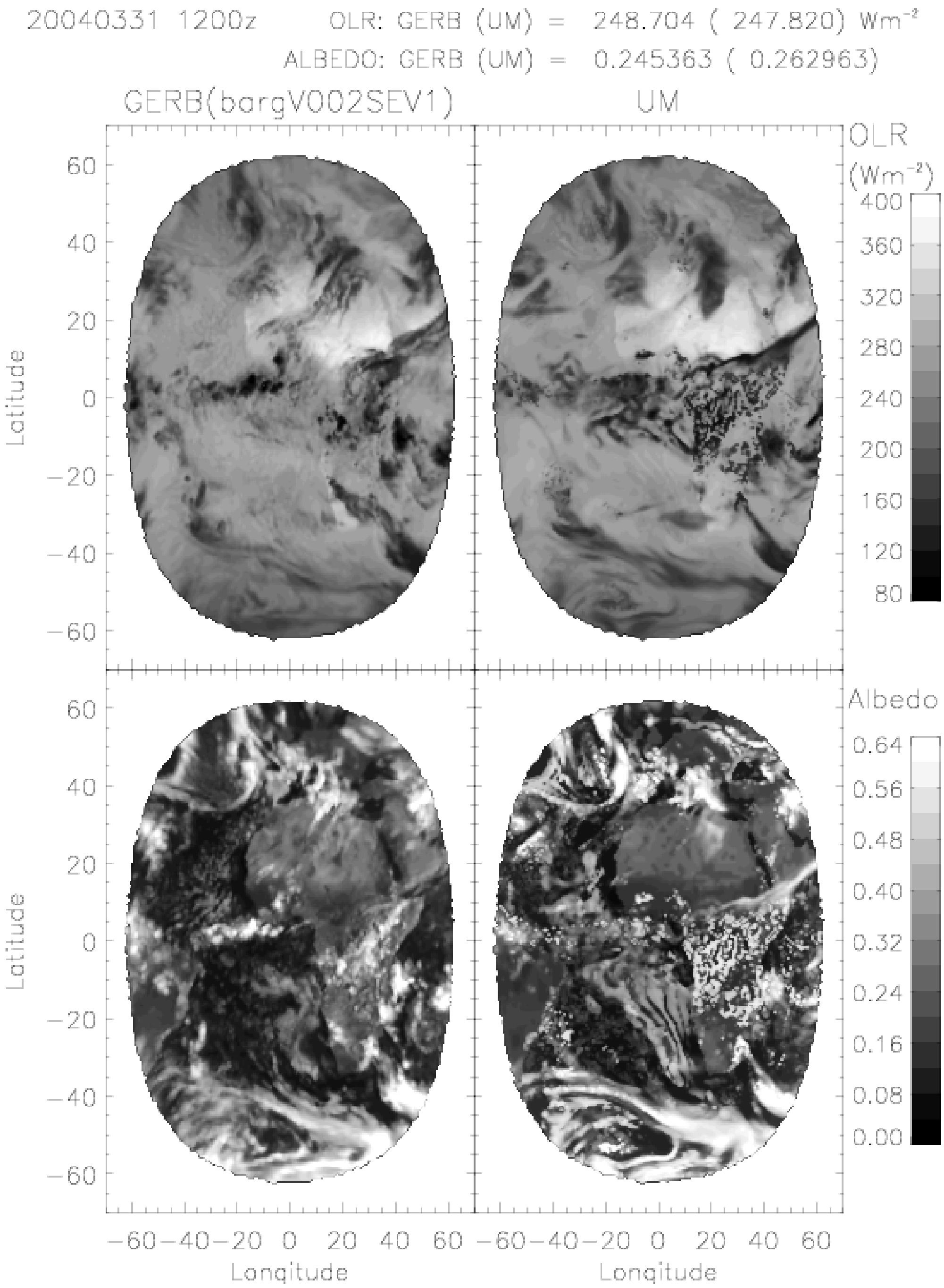

Figure 1: Example comparison of OLR (top) and albedo (bottom) between GERB BARG data (left) and the NWP model (right) for 31st March 2004 at 1200 UTC

The RMS difference between GERB and model clear-sky OLR over the ocean for DJF 1200 UTC (Figure 2c) is less than 5 Wm^{-2} (about 2% of tropical mean OLR). For the albedo (Figure 2d) there is a larger scatter with a RMS difference over the ocean of 0.018 (nearly 10% of the tropical mean albedo). Some of the scatter in the oceanic albedo comparisons is likely to be related to remaining errors in geolocation, for example the coastal regions of the Red Sea. The RMS difference for JJA over the ocean is 9.1 Wm^{-2} for clear-sky OLR and 0.049 for clear-sky albedo. The differences are significantly larger than for DJF and are likely to relate to larger errors in the GERB data due to inferior geolocation and radiance to flux conversion. However, because the model simulated clear-sky OLR over the ocean is likely to be of high quality, the excellent agreement between GERB and the model for DJF suggest that the recent GERB data are of high quality.

Regions of the open ocean between 20 and 30°W are highlighted by symbols in Figure 2. The North Atlantic is sampled between 20-30°N, the South Atlantic between 20-30°S and the Equatorial Atlantic between 5°S and 5°N. These regions do not suffer from mis-classification of scene type due to geolocation errors and generally give RMS errors of about 5 Wm^{-2} in clear-sky OLR for JJA and DJF. However, there is marked improvement in clear-sky albedo comparisons between JJA and DJF even for the open ocean regions. The large scatter in clear-sky albedo for JJA (Figure 2b) are in part explained by geolocation errors.

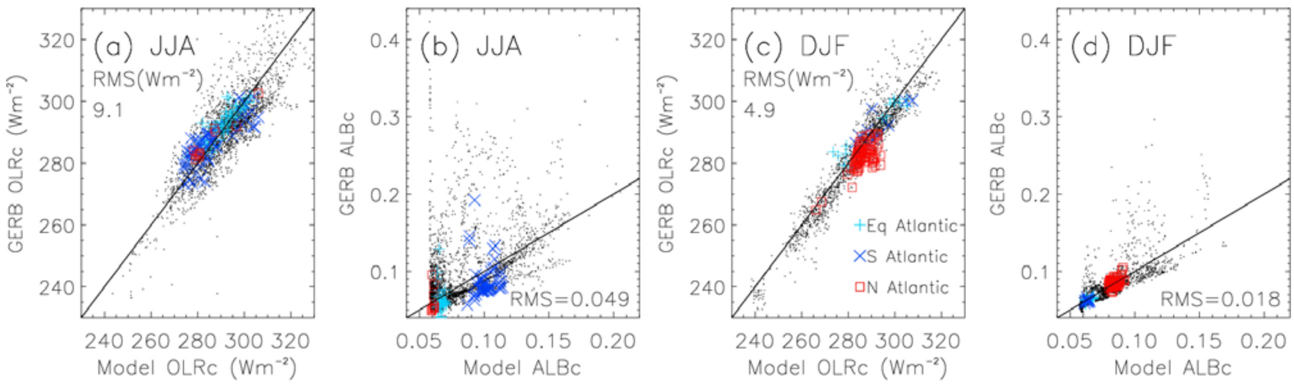

Figure 2: Scatter plot of GERB and model clear-sky OLR and clear-sky albedo for JJA 2003 and DJF 2003/4 over the oceans (dots). Selected regions over the open ocean are highlighted by symbols

Some of the differences in the clear-sky flux comparisons between JJA and DJF may relate to the change from MS7A to SEVIRI processing of radiances to fluxes implemented in December 2003. Analysis of the GERB fluxes in December 2003 for 1200 UTC using either MS7A or SEVIRI imager data for processing suggest that differences are small within 30° of the Greenwich meridian. Model minus GERB OLR and albedo differences are reduced when using SEVIRI processing compared to MS7A processing, in particular further than 30° from the Greenwich meridian. Longwave fluxes using MS7A processing are overestimated by about 5-10 Wm^{-2} further west than 30°W and over the Indian ocean compared to those using the SEVIRI imager processing. For 1200 UTC data, albedo is underestimated by up to 0.1 further west than 30°W and over eastern Europe. Albedo differences are larger when considering low solar zenith angles. In Section 6 we concentrate on Version 2 GERB data using SEVIRI processing from DJF 2003/4 because of the problems with variable geolocation quality and occasional mis-registration of data prior to November 2003.

6. SEASONAL MEANS

Instantaneous radiative flux comparisons such as presented in Figure 1 can highlight a variety of interesting model-observation differences. It is also instructive to consider seasonal mean differences in order to identify potential problems with the model or data. Figure 3 shows the DJF 2003/4 mean OLR and albedo for the model and GERB and the GERB minus model difference fields. The instantaneous GERB missing data mask is applied to the model data to ensure consistency in sampling. The data are averaged separately for each analysis time and then the mean of the four analysis times is computed at each grid point to form monthly means. The DJF mean is constructed from these monthly means.

The distribution of OLR and albedo estimated by GERB are well represented by the model although there are some notable discrepancies that are highlighted in the difference fields. GERB albedo is up to 0.1 larger than model values over the Sahara. The spatial signature of the albedo differences remains when only clear-sky scenes are sampled and appears to be robust for other months not shown here. This suggests that the magnitude and spatial variation of surface albedo is unrealistic in the model. Small positive GERB minus model OLR differences, also prevailing for clear-sky conditions, may relate to these albedo differences or from surface emissivity errors. However, model minus GERB clear-sky OLR differences of up to 50 Wm^{-2} over the western Sahara during July 2003, thought to relate to mineral dust aerosol (Haywood et al. 2004), are not present for the DJF comparison in Figure 3c.

Many of the OLR and albedo differences for DJF shown in Figure 3 do not correspond with differences identified when clear-sky screening is applied and are therefore likely to be related to differences in model and GERB cloud properties. The negative GERB minus model OLR differences and positive albedo differences over Brazil and southern Africa suggest an underestimation in deep convective cloud in the model. Differences of opposite sign over eastern equatorial Africa are consistent with an overestimation in deep cloud, consistent with the comparison for July 2003 (not shown). Also consistent with the July 2003 comparison is the apparent overestimation of model albedo over much of the ocean, especially for the marine stratocumulus regions. OLR and albedo over the tropical Atlantic are higher in the GERB data than the model; this may relate to deficiencies in the model representation of the ITCZ. Some of these discrepancies are revisited in the following section.

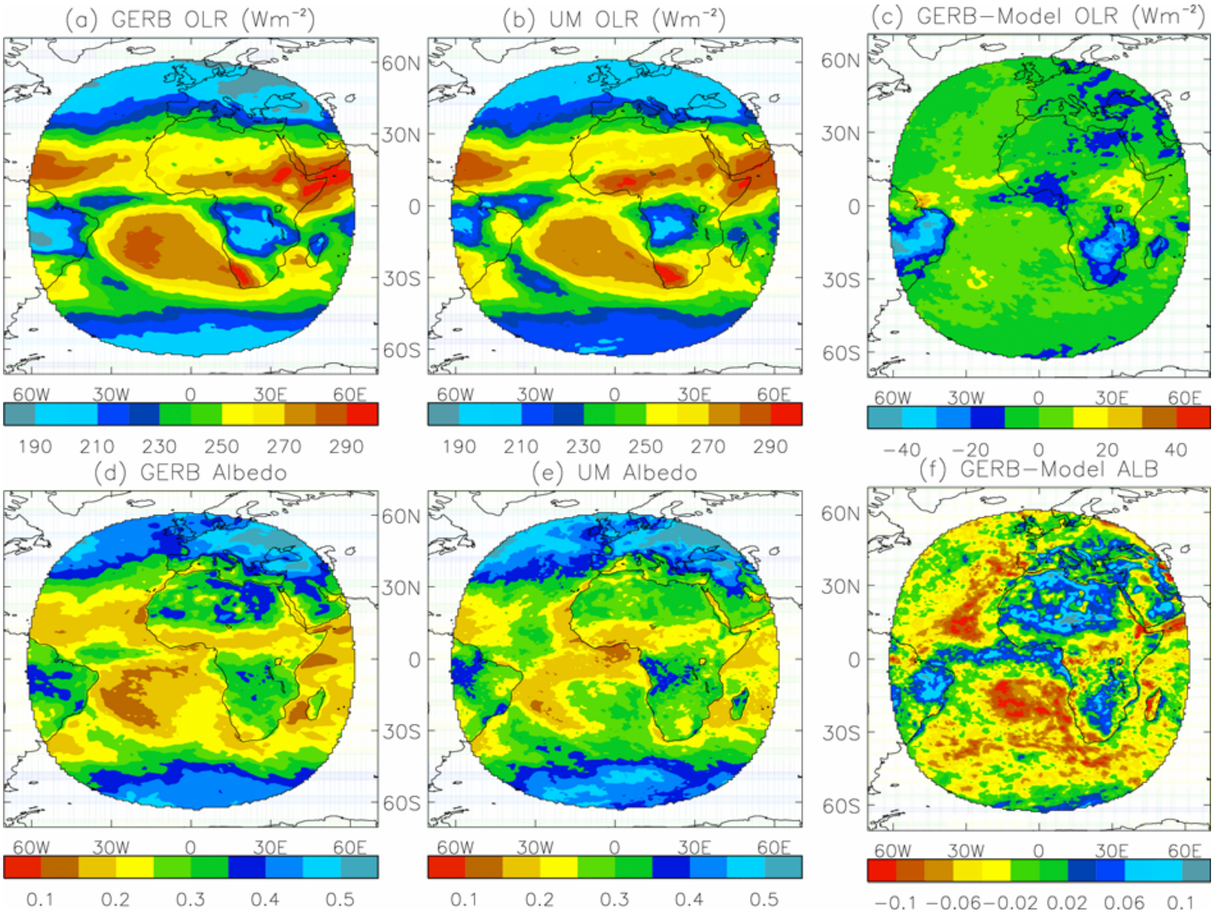

Figure 3: Mean OLR and albedo from GERB and the model and the GERB-model differences (DJF 2003/4)

7. REGIONAL COMPARISONS

We now present preliminary and ongoing analyses of the model and GERB data over selected regions.

Marine Stratocumulus

Analysing the albedo comparison shown in Figure 1 shows the model to overestimate the reflectivity and the spatial heterogeneity of marine stratocumulus at around 20°S, 0°E which merits further analysis. In Figure 4 we assess whether differences in reflectivity are related to differences in cloud fraction for July 2003 data. While the model albedo is greater than GERB by about 0.1 (compare shading in Figure 4a-b), the cloud faction (shown as contours) is similar between the model and Meteosat data. The zonal mean model minus GERB differences in albedo are uncorrelated with the Meteosat minus model cloud fraction differences suggesting that the model clouds are too bright rather than too extensive.

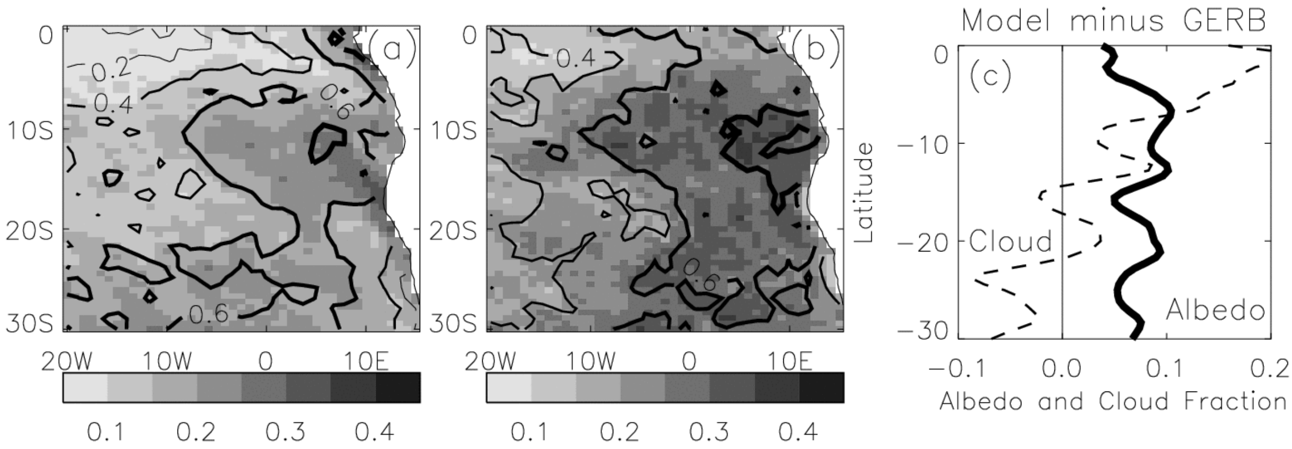

Figure 4: Albedo (shading) and cloud fraction (contours) for (a) GERB and (b) model for 1200 UTC July mean data. Zonal mean model minus GERB albedo and cloud fraction differences are given in (c)

Equatorial Atlantic

While agreement between model and GERB tropical mean OLR is generally excellent, on a number of occasions the model underestimates tropical OLR by up to 10 Wm^{-2} compared to GERB. Considering one such occasion (1 July 2003) we plot equatorial OLR as shading and contours of 500 hPa vertical motion (Figure 5). A region of low OLR at 5-10°N coincides with strong ascent in both the model and GERB suggesting deep convective cloud. However a region of OLR<260 Wm^{-2} extending south from this convective region in the model is not present in the GERB data indicating errors in the cirrus outflow from the convective region. A similar feature is also present on 31 March 2004 in Figure 1. Differences between model and NCEP vertical motion may help to explain these differences.

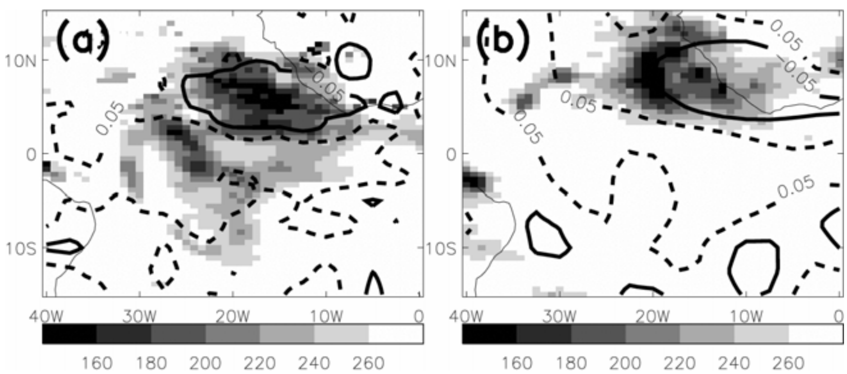

Figure 5: OLR (shading) and 500 hPa vertical motion (contours) for 1 July 2003 at 1200UTC for (a) model and (b) GERB/NCEP. Solid contours indicate ascending motion while dashed contours indicate descent

Convection over Africa

It has long been realised that the Met Office model initiates convection over land too early in the day (e.g. Slingo et al. 2004). This is evident for the 1200 UTC comparison in Figure 1 over eastern tropical Africa. Here, the model produces an extensive area of high albedo and low OLR, symptomatic of deep convective cloud, which is not present in the GERB data. It is also apparent that the spatial pattern of the high albedo deep convective cloud is highly heterogeneous compared to convective regions in the GERB data. In Figure 6 we analyse frequency distributions of albedo and vertical motion for July 2003 data at 1200 UTC for the tropical convective region of Africa. There is a peak in frequency of model albedo=0.55 corresponding to deep convection which is not present in the GERB data. The model also contains a larger number of low-albedo points than the GERB data which produces a single peak at albedo=0.25 and a long tail for higher albedo. These differences likely relate to the timing and the spatial structure of convection in the model, both of which appear unrealistic. The model vertical motion frequency distribution is skewed towards positive values (descent) with a long tail for negative values (ascent) while NCEP gives a normal distribution with a peak in frequency for neutral conditions.

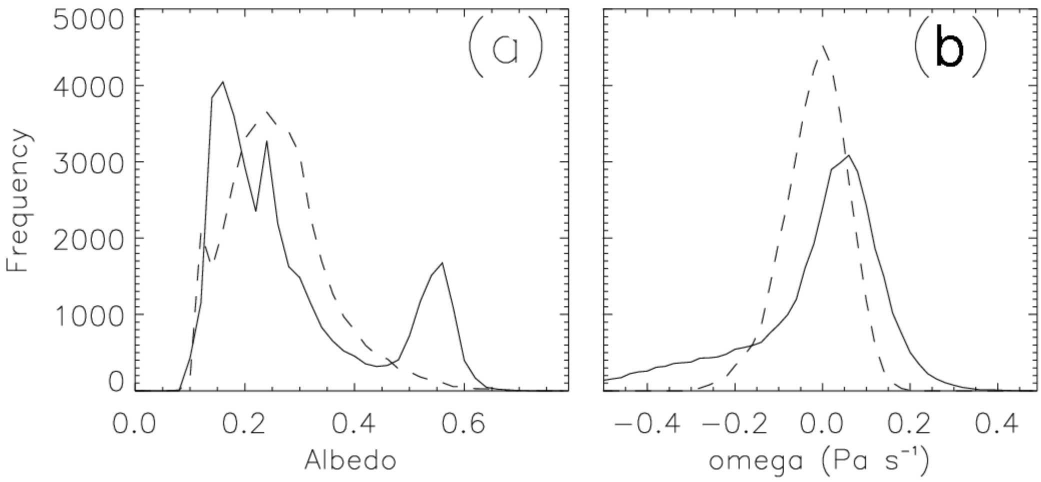

Figure 6: Frequency distribution for (a) albedo and (b) 500 hPa vertical motion (omega) for July 2003 at 1200 UTC for the model (solid) and GERB/NCEP (dashed)

8. CONCLUSIONS

Comparisons of the top of the atmosphere radiation budget measured by the GERB instrument and simulated by the Met Office NWP model have been conducted since May 2003. The GERB data are preliminary and subject to ongoing validation. Nevertheless, a number of conclusions may be drawn:

1) There has been a reduction in the model-GERB differences in OLR and albedo over the period May 2003 to March 2004 relating mainly to the improved geolocation and radiance to flux processing of the GERB data. Errors in GERB albedo and OLR due to radiance to flux conversion are likely to be large prior to December 2003, in particular for data further than 30^o from the Greenwich meridian and for albedo at 0600 and 1800 UTC.

2) There is excellent agreement between the model simulations and GERB measurements for clear-sky OLR over the open ocean. Because there is high confidence in the realism of model simulated fluxes for these situations, the agreement suggests the GERB data are also of a high quality.

3) Agreement between model and GERB total-sky OLR and albedo is generally good, particularly for middle latitude regions where the simulated moisture fields and the resulting diagnosed cloud distributions are well constrained by the assimilation of data by the model.

4) Albedo and OLR differences over north Africa during DJF are likely to relate to an unrealistically low surface albedo in the model. However, the high optical depth of mineral dust aerosol may explain model minus observed OLR differences of up to 50 Wm^{-2} that occurred over the Sahara during July 2003 (Haywood et al. 2004).

5) Deep convection in the model, as denoted by low OLR and high albedo over low latitude regions, appears significantly more organised spatially in the GERB data compared to the model simulations.

6) The model appears to overestimate albedo over much of the ocean, especially the marine stratocumulus regions. While simulated cloud fraction appears not to be in error, the cloud reflectivity and complexity of spatial structure appear overestimated by the model.

7) Unrealistically low OLR over the ocean is occasionally produced by the model. This appears to be related to an unrealistic simulation of the cirrus outflow from oceanic convection.

In future work, we plan to continue the preliminary evaluation of the model over selected regions by analysing model diagnostics in more detail and by including case studies involving further integrations of the forecast model. We intend to extend the comparisons between the model and GERB by simulating and comparing with SEVIRI radiances. This will aid the validation of GERB data as well as the model evaluation. Combination of the top of atmosphere radiative diagnostics with radiometric measurements from surface stations are also planned and we are exploring the value of model clear-sky radiative fluxes in combination with GERB derived fluxes to calculate hybrid cloud radiative effect diagnostics.

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