COMPARISON OF TWO DISTINCT EARTHCARE MULTI SPECTRAL IMAGER SIMULATORS

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Abstract

The Earth Cloud-Aerosol-Radiation Explorer (EarthCARE) is a multi-instrument satellite mission of the ESA Earth Explorer Core missions, which will be launched in 2013. EarthCARE will observe the atmosphere in order to better understand the interactions between clouds and aerosols with respect to solar radiation and to their feedbacks on the climate system.

One of the four instruments onboard the EarthCARE satellite, the Multi Spectral Imager (MSI), will passively observe the atmosphere using 7 channels at visible and thermal infrared wavelengths. This imager observes with a swath-width of 150 km and a pixel resolution of 0.5 km. The MSI observations will produce the data needed for describing the horizontal spatial distribution of cloud optical and microphysical properties.

In order to prepare for the EarthCARE mission configuration and for the required retrieval algorithms, ESA developed the EarthCare SIMulator (ECSIM). ECSIM is a tool capable to simulate the four instruments onboard EarthCARE for the same cloud scene simultaneously. For the evaluation of the ECSIM-MSI, we present a comparison of the ECSIM 3-Dimensional MSI simulations against simulations of the well tested ”Monte Carlo code for the Physically correct tracing of photons in the cloudy atmosphere” (MYSTIC), which is part of the libRadtran radiative transfer package.

Both simulations are based on an identical input provided by the Numerical Weather Prediction (NWP) model COSMO-DE developed at the German Weather Service. Differences in the radiative transfer models and in the simulated radiances will be discussed. The two simulators show good ability in simulating the reflectances coming from the modelled cloud scene. Furthermore, with this work we show that both simulators, ECSIM and LibRadtran/MYSTIC, are also suitable to simulate large cloud scenes with high spatial resolution.

INTRODUCTION

The solar radiation, influencing the atmospheric circulation, drives the climate and the weather. Solar radiation, hence, is a very important aspect of the troposphere to study and there is the need to better understand how it interacts with atmospheric components such as clouds and aerosols. Climate and weather models try to describe the tropospheric conditions in order to deliver accurate forecasts. Unfortunately, the accuracy of these models is not always very high and errors in the forecasts are produced. In order to understand the interactions between cloud and aerosols with Sun radiation, the European Space Agency is launching the EarthCARE satellite hosting onboard four instruments dedicated to study in detail clouds, aerosols and radiation. EarthCARE is due for launch at the end of 2013 and will carry onboard a 94 GHz Cloud Profiling Radar (CPR), a High Spectral Resolution Lidar (HSRL) at 353 nm, a Multi Spectral Images (MSI) and a BroadBand Radiometer (BBR). These four instruments will simultaneously observe the same part of the atmosphere to obtain information on the vertical and horizontal spatial distribution of the clouds and aerosols in the atmosphere. The European Space Agency in preparation for the EarthCARE mission supported the development of an EarthCARE SIMulator - ECSIM. ECSIM is a computational tool which can simulate the complete EarthCARE mission using forward models and synthetic observations specific for the four instruments. Few other satellite simulators have been developed in the science community and they are mainly used for testing the satellite cloud retrievals with Numerical Weather Prediction (NWP) outputs. One of these simulator is the simulator used at the German Space Agency (DLR) that uses NWP model outputs and LibRadtran radiative transfer model to simulate the Meteosat Second Generation (MSG) and the EarthCARE MSI observations as well as any Sun-satellite or sensor geometry.

In this work, we compare the ECSIM-MSI simulator with the MSI simulator used at DLR using the same input scene obtained from the output of the NWP COSMO-DE from the German Weather Service. In the following chapters, the common input data used for the simulations are described, first. Then, the results for the two simulations are shown in a comparative manner together with the plot of the differences for each of the four channels. The last chapter gives a summary and an overview of the possible future works.

THE INPUT DATA

The comparison work described in this paper is based on the fact that the inputs for both simulators should be as more consistent as possible to each other. Several issues appear when comparing the two simulators and they are due to their different characteristics in describing the cloud scene and in the computational methods.

The same input into both simulators is used for the comparison of the two MSI simulators. The input data have been derived from the output of a Numerical Weather Prediction model, the COSMO-DE by the German Weather Service (DWD). This model is a non-hydrostatic model with an horizontal resolution of 2.8 Km on a 421 x 461 horizontal grid. The domain used in the simulations is located over Germany (figure 1) and it refers to July, 3^{rd}, 2008 at 12:00 UTC, when several atmospheric conditions can be observed such as cirrus clouds above water clouds and cloud-free areas. The selected domain for the comparison is 150 x 213 Km and is within the red box in figure 1. The original COSMO-DE horizontal resolution of 2.8 Km has been downscaled to 0.56 Km, resulting in 268 x 380 pixels (Faure et al., 2009). Because NWP do not provide information about the size or numbers of the water droplets or the ice crystals, there is the need to associate cloud microphysics information to the cloud liquid and ice water fields. The water clouds have been assumed to be composed of spherical droplets, while for the cirrus clouds the ice crystals were parametrized as hexagonal columns.

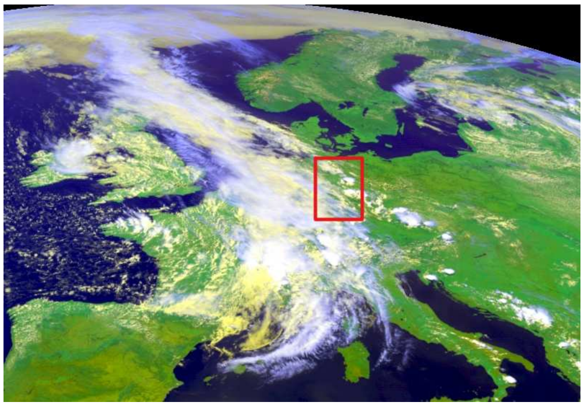


Figure 1: **Location of the selected cloud domain (red box)**

Differences in the input data

Even if a lot of attention has been put in having exactly the same input for the two MSI simulators, there are few features that could not be met. Both simulators computes the 3D cloud fields using the

Monte Carlo approach, however, they have few differences in the Monte Carlo solver approach and in the parametrization of the input data when creating the cloud field used for the simulations. The main difference, however, is related to the surface albedo parametrization, in fact, the DLR MSI simulator uses a real topography and wavelength dependent albedo for the solar channels and emissivity for the infrared channel. Conversely, ECSIM assumes a flat terrain and the surface albedo is set for low-moderate vegetation. The other difference is related to the different parametrization of the ice clouds, even if both simulators assume column hexagonal ice crystals, for ECSIM they are vertically oriented while for the DLR-MSI they are randomly oriented.

THE MULTI SPECTRAL IMAGER SIMULATORS

The EarthCARE Simulator - ECSIM

The European Space Agency supported the developement of an end-to-end satellite simulator for the EarthCARE mission (Voors et al, 2007). This simulator makes use of forward and retrieval models, utility programs and plotting tools to simulate and visualize what the EarthCARE measurements and retrievals would be. ECSIM can simulate all the 4 instruments aboard EarthCARE satellite in a straitghforward way: given a cloud scene as input and chosen the instruments to be simulated, ECSIM runs the selected models and simulations and gives netcdf file outputs for every chosen instrument for further data analysis. The cloud scenes, as input for the simulations, can be created using the embedded ECSIM cloud generator or they can be converted from Cloud Resolving Models, from Large Eddy Simulations, from Numerical Weather Prediction models or from “real” ground-based observations to ECSIM standard input cloud scene.

ECSIM - MSI

The Multi Spectral Imager onboard the EarthCARE satellite has 7 channels from the visible to the thermal infrared. The swath width is 150 Km with a pixel resolution of 500 meters.

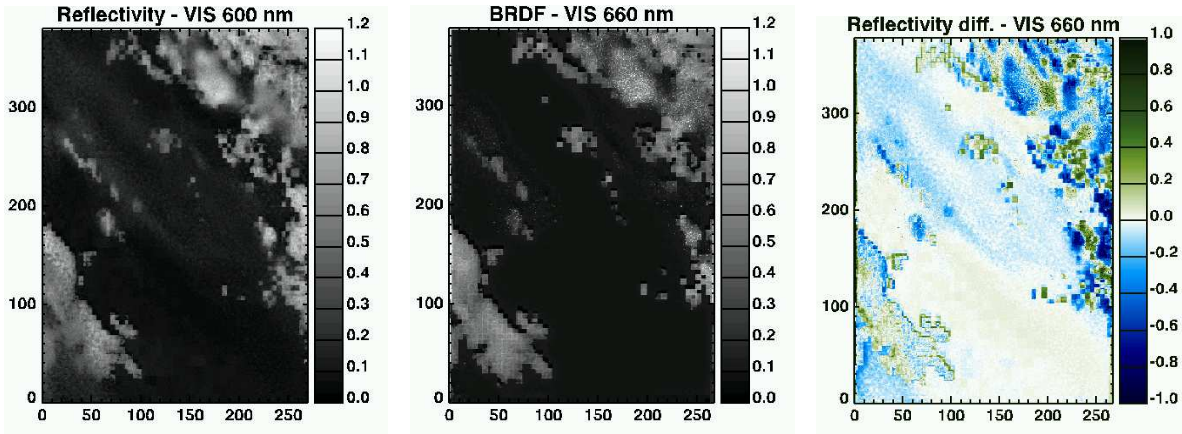
ECSIM can simulate the seven narrowband channels of the Multi Spectral Imager (0.660, 0.865, 1.61, 2.20, 8.8, 10.8, 12.0 microns) giving as output the Bidirectional Reflectances Distribution Functions (BRDF’s) at the Top-of-Atmosphere (TOA). The calculations for the shortwave channels are computed using the shortwave model, while for the thermal infrared channel the longwave model is used. The radiative transfer calculations can be run with two different models: the 1-D or the 3-D radiative transfer mode. The two radiative transfer models implemented in ECSIM are the mono-dimensional Independent Column Approximation with the DISORT solver and the tri-dimensional Monte Carlo solver with a local estimate approach.

The LibRadtran Satellite Simulator

The libRadtran simulator can simulate the instruments on board the EarthCARE satellite, except for the Cloud Profiling Radar. LibRadtran computes irradiances, radiances and heating rates over the complete solar and thermal spectral ranges. Here the Monte Carlo code MYSTIC (Monte Carlo code for the physically correct tracing of photons in cloudy atmosphere) is used. libRadtran/MYSTIC does not make any simplifying assumptions and serves as a benchmark for radiation in complex environments (Mayer 2009, Mayer et al. 2009).

The configurations for the simulations

Both simulations have been run using the same settings as much as possible. The geometry is set to resemble the real situation of the NWP day, July 3rd, 2008 at 12:00 UTC, in the selected domain in order to compare the simulation outputs with the MSG observations. The Sun zenith angle is set to 29.5° while the Sun azimuth angle is set at 0°, positioning the Sun to the South. The satellite zenith angle is set to 180° at sub-satellite point and it flies from the South to the North direction. The atmospheric data used for the simulations refer to the mid-latitude summer standard atmosphere. The simulations



(a) Mystic - 0.66 μm

(b) ECSIM - 0.66 μm

(c) Differences for the 0.66 μm channel

Figure 2: **Simulation outputs for the visible channel at 0.66 microns**

are run with the 3-D Monte Carlo radiative transfer model and an output sensor resolution of 0.56 Km, equivalent to the resolution of the input scene.

THE SIMULATION OUTPUTS

This chapter shows the outputs obtained after running the simulations for the 3-D Monte Carlo radiative transfer models for both simulators. The comparisons are given for 4 different channels, 660 nm, 865 nm, 1.61 μm and 10.8 μm. For the visible (0.66 and 0.865 μm) and near-infrared (1.61 μm) channels the ECSIM BRDF's and the MYSTIC reflectivities are compared, while for the thermal infrared channel the comparison is between the brightness temperatures (BT).
In the next paragraphs, the results for each channel are shown and the images of the differences ECSIM minus MYSTIC are given.

Channel 1: 0.66 microns

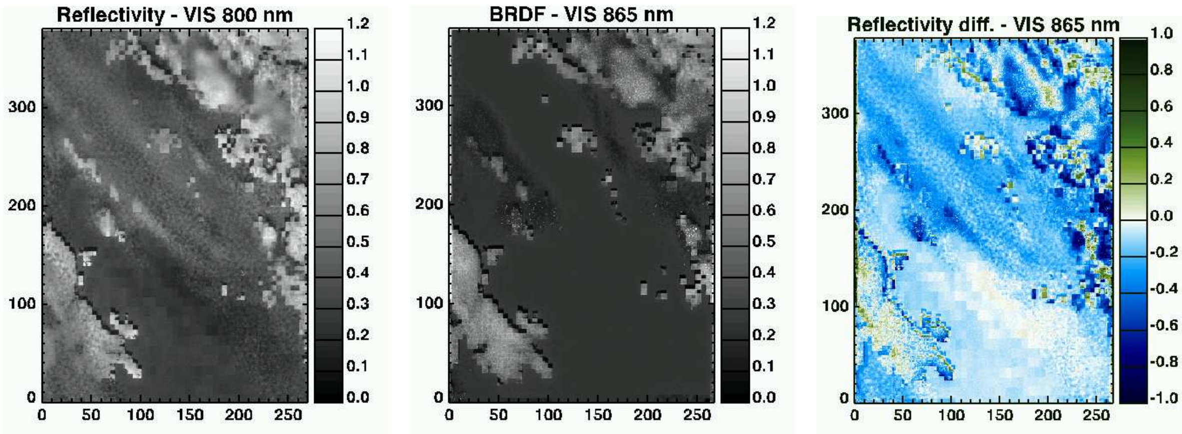
Figure 2 shows the images referring to the simulations outputs of the first EarthCARE visible channel at 0.66 μm. The first image shows the reflectivity simulated by the MYSTIC simulator, while the second image shows the TOA-BRDF's simulated by ECSIM. The third image shows the differences between the ECSIM and the MYSTIC's reflectances. ECSIM can represent well the reflectances for the 0.66 μm channel, even if there are few parts on the right-hand side of the images where the differences are high with ECSIM underestimating the reflectances.

Channel 2: 0.865 microns

The comparisons for the second visible channel at 0.865 μm are shown in figure 3. Both simulators can describe accurately the atmospheric conditions in this narrowband channel, even if it is very clear that ECSIM produces lower reflectances than MYSTIC, as it can be seen from the image of the differences. In this channel, the main differences are caused by the different parametrization of the surface.

Channel 3: 1.61 microns

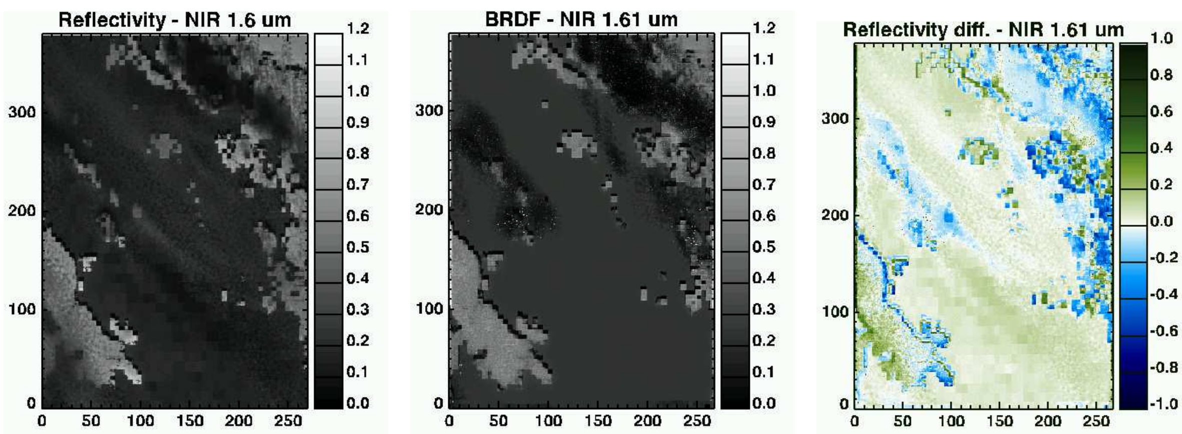
Figure 4 shows the outputs for the simulations for the near-infrared channel at 1.61 μm. The comparison for this channel show a good agreement between the two simulators, in fact, most of the pixels show a small overestimation of the reflectances from ECSIM. Again, the main differences are in the right-hand side of the picture, showing the presence of some strange events possibly due to the presence of broken clouds and to the different models used in computing the reflectivities. The 3D effects



(a) MYSTIC - 0.865 μm (b) ECSIM - 0.865 μm (c) Differences for the 0.865 μm channel

Figure 3: **Simulation outputs for the visible channel 0.865 microns**

are relevant in this area and might be difficult to capture.



(a) MYSTIC - channel 1.61 μm (b) ECSIM - channel 1.61 μm (c) Differences for the 1.61 μm channel

Figure 4: **Comparison of the near-Infrared channel 1.61 microns**

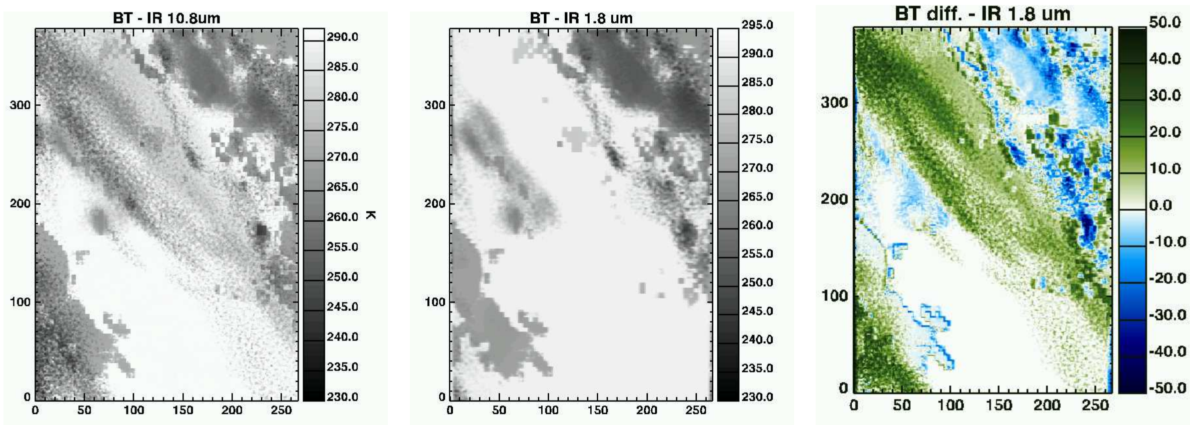
Channel 6: 10.8 microns

The last channel used in the comparison for the two simulators is the thermal infrared channel at 10.8 μm. The brightness temperatures are compared and it can be seen from figure 5 that the temperatures are similarly simulated in the two cases. The ECSIM brightness temperatures are slightly higher for cloud free areas, whereas the cirrus brigthness temperatures are colder.

Differences in the simulation outputs

The main differences appearing from the comparison of the two MSI simulators are related to the different way of describing the surfaces. The different parametrizations for the surface used in the two simulators influence the radiative transfer outputs for the thin clouds and the clear sky pixels. Furthermore, the differences in the outputs of the simulators can be also due to the different parametrization of the ice clouds and to the use of different Monte Carlo solvers.

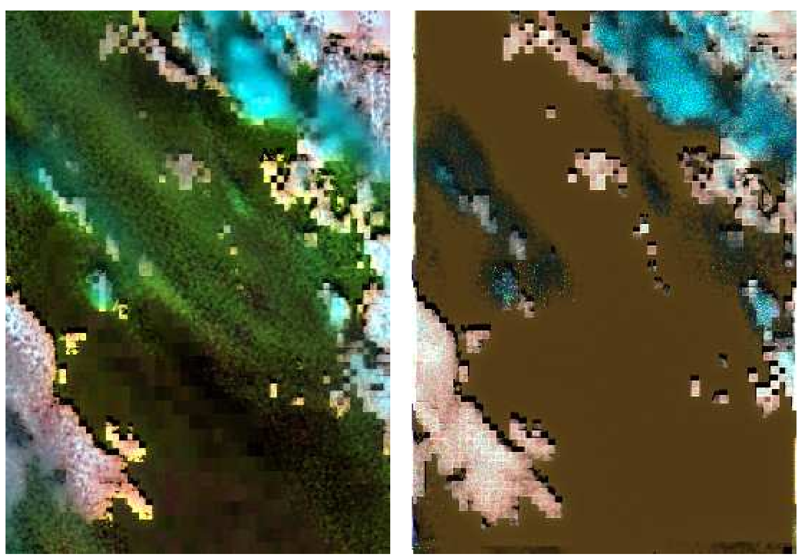
Nevertheless, it can be concluded, as shown in the RGB composite image in figure 6, that the two simulators can describe correctly the cloud fields even if there are differences in the outputs. The main



(a) MYSTIC - 10.8 μm (b) ECSIM - channel 10.8 μm (c) Differences for the 10.8 μm channel

Figure 5: **Comparison of the thermal infrared channel at 10.8 microns**

difference appearing in the RGB composite is due to the parametrization of the homogeneous surface in ECSIM without including any topography. However, ECSIM can be run with real surface topography, in fact, the cloud scene can be georeferentiated to Earth's Latitude and Longitude making use of the ESA Digital Elevation Model data files. However, for this work we did not use the ECSIM georeferentiation feature.



(a) MYSTIC RGB (b) ECSIM RGB

Figure 6: **RGB composite with channels: 1.61, 0.865 and 0.66 microns**

SUMMARY AND CONCLUSIONS

The use of satellite simulators will gain more interests and importance in the future researches, especially for the better understanding of the 3-D radiative effects on the satellite retrievals and for the development and improvements of the cloud property satellite retrievals. The 3D simulations have the advantage to handle the horizontal transports of the photons and it is possible to see the cloud shadows in the visible channels. The possibility to use simulated satellite reflectances for several cloud situations and with known cloud properties will be of major help for the improvement of regional and climate models.

In this work, we compared two different satellite simulators, the ESA EarthCARE Simulator and the LibRadtran/MYSTIC MSI simulator. Both simulators were given, as input, cloud scene obtained by downscaling of the COSMO DE outputs to simulate the EarthCARE MSI observations. The simulation have been run at the resolution of 0.56km, so that the input cloud scene is realistic and close to the resolution of the MSI pixels. The use of the “realistic” 3-D simulations show the presence of the shadows of the clouds on the surface and these features will not be seen with the 1-D radiative transfer model.

These two simulators can be used for further studies on the 3D effects on the cloud property retrieval algorithms as well as for testing different the cloud property retrievals.

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