Abstract

Simulated satellite images are an ideal tool to test and validate both satellite retrievals and Numerical Weather Prediction (NWP) models. Here atmospheric profiles and cloud information from the COSMO-DE NWP model are used to simulate solar and thermal MSG/SEVIRI radiance observations. The simulated cloud scenes will be used for testing the MSG/SEVIRI cloud products retrieval algorithms by comparing the retrieved cloud properties from the simulated radiances to the one of the NWP clouds.

INTRODUCTION

Clouds and their interaction with radiation is an important question for climate and weather. On global scale passive satellite remote sensing is the most important tool to observe clouds. But for a given satellite image only the radiance is known, and the cloud properties must be derived by finding an inverse solution for radiative transfer. At the same time the validation of retrieved cloud properties is complicated as few independent methods are available. Systematic errors are expected when comparing ground or in-situ observations to satellite images due to the different observation geometries, the different sensitivities, and also three dimensional (3D) effects. Indeed as has been shown e.g. by Zinner and Mayer [2006] cloud inhomogeneity and 3D effects introduce bias and considerable noise into the retrieved optical thickness and effective radius.

A new approach is presented here to assess derived cloud properties accuracy. Cloud scenes as observed from MSG are simulated using the libRadtran/SIMSAT and libRadtran/Mystic models based on known cloud properties from Numerical Weather Predictions Model (NWP) outputs. The spatial details of real cloud scenes needed to conduct meaningful radiative transfer is generated by downscaling the NWP resolution of several kilometers to a few hundreds of meters. The simulated radiative constitute a dataset to assess the derived cloud information from MSG images. Standard algorithms for the derivation of cloud top height, cloud phase, effective particle radius, or optical thickness will be applied to these simulated images on the real MSG spatial resolutions.

INPUT CLOUD DATA

The input cloud data with fully known properties is constructed based on the outputs of the German Waether Service (DWD) model COSMO-DE. It is a high resolution non-hydrostatic model with a horizontal resolution of 2.8 km on a 421 x 461 horizontal grid.

For our radiative transfer simulations we use vertical profiles of pressure, temperature, specific humidity, cloud liquid water and cloud ice together with surface skin temperature, orography, and the land-sea mask.

For the simulations presented in this study, the domain of interest is located over the North of Germany and the selected time is July 3, 2008, 12:00 UTC, where an extended cirrus cloud on top of water clouds or cloud-free regions is present (see Figure 1), in order to address some of the most delicate retrieval situations (thin cirrus, multi-layer clouds).
As the COSMO model, like all weather models, does not provide information on scales below a few kilometres, statistical downscaling is applied as a possibility to merge the potential of weather models to provide realistic large scale cloud structures in three dimensions and the potential of statistical models to generate realistic small scale variability at the (10-100 m) scale. Starting from the original horizontal resolution of 2.8 km, the resolution of the main output quantities of the COSMO is increased by a factor of 5 to 0.56 km under the constraint that water content (liquid and ice) must not change on the original horizontal resolution (2.8 km). The core idea is that the Fourier spectrum of the water fields shall behave according to a -5/3 power law, as shown by various in-situ observations, e.g. [Davis et al. 1999]. Thus, layer by layer the 5/3 Fourier power spectrum is forced on the sub COSMO resolution cloud fields while the total water content at the original COSMO resolution is conserved. The Fourier spectrum of the original COSMO fields is thus conserved on larger scales while it is forced towards a -5/3 power law at smaller scales after resolution enhancement (see Figure 2).

Once resolution has been enhanced, cloud microphysics needs to be associated to the cloud liquid and ice water fields because NWP models as well as most other cloud models do not provide
information about water droplet or ice particle size or numbers. For water clouds we use a parameterization of the effective radius $r_{\text{eff}}$ [$\mu$m] as function of the liquid water content LWC [kg/m$^3$] provided by the model:

$$r_{\text{eff}} = \left( 0.75 \times \left( \frac{LWC}{\pi \times k \times N \times \rho} \right) \right)^{1/3} \times 10^{-6}$$

The droplet number density $N$ [1/m$^3$] is determined by the number of cloud condensation nuclei; here we assumed a constant number density of 150 cm$^{-3}$. $k$ is the ratio between the volumetric radius of droplets and their effective radius which is determined by the size distribution of the droplets [Schüller et al. 2003]:

$$k = \frac{r_v}{r_{\text{eff}}}$$

Here we used a typical value of $k = 0.75$. $\rho$ is the density of liquid water at 4°C in kg/m$^3$.

For ice clouds the parameterisation of randomly oriented hexagonal columns by Wyser and Ström [1998] and McFarquhar et al. [2003] is used which relates ice particle effective radius to ice water content and temperature. More complex relationships are easily introduced into the scheme.

Figure 3 shows an example of a horizontal cross section of the three-dimensional ice water content (IWC) field from COSMO output and then after downscaling. The white zones are cloud-free pixels. The cloud contours are more smooth and show finer structure after the downscaling process.

**Figure 3:** Cross section of the 3D ice water content from COSMO-DE (left) with a resolution of 2.8km (left) and after downscaling with a resolution of 0.56 km (right).

**RADIATIVE TRANSFER MODELS**

The satellite images are computed with libRadtran/SIMSAT in the case of one dimensional simulations, and with libRadtran/MYSTIC for three dimensional simulations [Mayer and Kylling, 2005; Mayer 2009]. libRadtran is freely available at http://www.libradtran.org and has been used for many different purposes as documented by more than 150 peer-reviewed publications listed at the web page. libRadtran has been validated in several model intercomparison campaigns, e.g. [Cahalan et al. 2005], and by direct comparison with observations, e.g. [Mayer et al. 1997; Bais et al. 2003]. Different methods to solve the radiative transfer equation are implemented. In the current 1D simulations the standard discrete coordinate code DISORT by Stamnes et al. [1988] is used whereas for the 3D simulations a Monte-Carlo solver MYSTIC (Monte Carlo code for the physically correct tracing of photons in cloudy atmospheres) is used in the backward mode.
The 1D simulations are processed with the independent pixel approximation (i.e. The net horizontal radiation transport between neighbouring pixels is neglected). Each pixel of the 3D cloud scene is hence computed independently.

Optical properties of water droplets are computed using Mie theory. Several parameterisations are available for ice clouds, here the one described by Yang et al. [2000] is applied.

For both 1D and 3D simulations, the atmospheric gas absorption was parameterized by LOWTRAN 7 [Pierluissi et al. 1985] which uses an exponential sum fit with a resolution of 20 cm\(^{-1}\). We adopted 15 spectral grid points to simulate each channel.

The underlying surface was described in terms of a Lambertian spectral albedo reconstructed from the MODIS BRDF product MCD43C3 [Schaaf et al. 2002] for the year 2008 and the Julian day 177 for the area corresponding to the COSMO-DE region and the corresponding three solar MODIS bands (1, 2 and 6). For the 10.8 µm thermal channel emissivity has been taken from collocated pixels of the UW-Madison Baseline Fit Emissivity Database [Seemann et al. 2008] for July.

RESULTS: SIMULATED MSG/SEVIRI IMAGES

The 1D results computed with libRadtran/SIMSAT with a horizontal resolution of 560 m are then projected to the MSG geometry, averaged to the MSG resolution, smoothed with the correct Point Spread Function (PSF).

The simulated images represent the cloud scene on July 3, 2008 at 12:00 UTC as the MSG/SEVIRI instrument would see it. Here we show examples for the visible channel centered at 600 nm (Figure 4) and the thermal channel centered at 10.8 µm (Figure 5).

*Figure 4: MSG/SEVIRI channel 600 nm: observation from SEVIRI (left), simulated image (right)*

The MSG/SEVIRI measurements show a convective cell on the east corner that was not represented in the COSMO-DE outputs that is why it does not appear in the simulation results. However this indicate that these simulation beside validating the MSG cloud property retrieval algorithms, could also be used to validate NWP models.

The goal of this study is not to validate COSMO-DE but to produce a dataset for the validation of the MSG/SEVIRI retrieval algorithms, and the measurements are presented here together with the simulation results to show that the simulated images are realistic. Indeed if the caption does not indicate which one is the simulated cloud scene, it is difficult to find it out.
An example of a 3D simulation is shown in Figure 6, compared to the corresponding 1D simulation. The false colour composite presented in Figure 6 is built using the 600 nm, 800 nm and the inverted 10.8 µm channels simulated in 1D (left), and in 3D (right) on July 3, 2008 at 12:00 UTC. The image represents an area 150 km large and 500 km long. For this comparison, the results are not post processed as explained before. The resolution of both images is 560 m. In the 3D simulations, the satellite viewing geometry was set to polar orbiting geometry pathing from South to the North, but having all other properties similar to MSG/SEVIRI. The accurate viewing geometry of MSG/SEVIRI require an extra adaptation of the Monte-Carlo backward model that is currently being developed.

In the false colour composite thin cirrus clouds appear violet-blueish, while low water clouds are white. Notice the structure of the surface albedo as well as the shadows (only in 3D simulations) northwards
of the clouds on the underlying cloud or ground surface. Furthermore, the cirrocumulus structures produced by the resolution enhancement procedure are also clearly visible. The 3D simulation results have the advantage to take into account horizontal photon transport and inhomogeneities. However, the current computing time is still high and needs to be reduced to simulate a cloud scene as large as Europe.

CONCLUSION AND OUTLOOK

The downscaling method from NWP data provides realistic high resolution cloud fields with known properties. Accurate RT models enabled us to produce realistic simulated satellite images. This cloud dataset can also be used to simulate other satellite geometries (e.g. MetOp), and test cloud retrieval algorithms or even to validate NWP models. The 3D radiative transfer computations with libRadtran/MYSTIC allow to correctly account for the horizontal photon transport and inhomogeneities especially at large zenith angles. The results from the 1D simulations will allow us to quantify these effects.

REFERENCES


