Satellite Data in the Verification of Model Cloud Forecasts: a convective case in summer 2003 seen from NOAA satellites

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1 Introduction

Satellite measurements form a vast source of observational atmospheric data. This Data is suitable for verification of cloud forecasts produced by numerical weather prediction (NWP) models, especially where conventional observations are sparse. For an inter-comparison of model and satellite, radiative transfer models (RTM) can be utilized to simulate the outgoing radiation at the top of the atmosphere for a given atmospheric profile (Morcrette 1991). Such RTM is used in this study to calculate radiances from HIRLAM forecasts. A convectively active period during July 2003 is studied, comparing simulated radiation from the model to NOAA AVHRR satellite observations.

2 Methodology and material

2.1 Methodology

To use satellite data in the verification of the cloud forecasts, the model output and the satellite's radiance measurement have to be turned into comparable quantities.

Satellite instruments measure, within a certain band of wavelength, radiance arriving at the top of the atmosphere. For the detection of clouds, the parts of the infrared spectrum of the Earth is employed where the atmosphere is transparent for radiation (atmospheric window region). An important window region can be found at $11\mu m$. All the radiation arriving at a satellite instrument, sensible in this band of wavelength, is assumed to originate either from solid or liquid particles in the atmosphere or from the Earth's surface.

NWP models forecast the atmosphere's behavior. The structure of the atmosphere, together with the surface parameters, is responsible for the transfer of radiation (RT) to space. RTM can be employed to simulate what a satellite instrument measures when looking at particular atmospheric profiles. The comparison between such a simulation and the satellite observation enables a judgement on the coupled parameterized processes in the model (Morcrette 1991).

2.1.1 The radiative transfer model

RTTOV 8.5 (Saunders & Brunel 2004) is applied to simulate outgoing radiances of atmospheric profiles, forecasted by the HIRLAM, for two NOAA AVHRR infrared channels. RTTOV uses profiles of T, q, clw, cli, cf, O_3, handles clear and cloudy multilevel radiances, multi-phase cloud fields (water/ice/mixed) and it has a consistent random overlap scheme (Räisänen 1998). In addition, RTTOV allows to choose between 4 effective diameter schemes for ice particles and 2 crystal aggregates.

2.2 Forecast model

48 hour forecasts have been produced at ECMWF for the days from July 15th to 21st with HIRLAM version 6.2.5. The domain covers the region of Scandinavia at a horizontal resolution of 0.2 x 0.2 deg ($\sim$ 22 km), the vertical discretization is 40 levels and boundary conditions are taken from the ECMWF model. Analysis, initialization and forecast were run in a 3-hourly cycle. In this first case study, only the forecast starting on July 15th at 06 UTC has been considered, as the first two days of the period were most active in terms of convection. For verification a sub-region, covering Finland, has been chosen.

2.3 Satellite data

The observational data used for the case study originates from the AVHRR instrument on four NOAA polar orbiting satellites. The two infrared channels in the atmospheric window region have a central wavelength of $10.8\mu m$ $(10.3-11.3\mu m)$ and $12\mu m$ $(11.5-12.5\mu m)$ and a resolution of 1 km at sub satellite point. The time gap between the satellites passes over the target area is highly irregular and varies from 1/2 to 6 hours.

To match the very high resolution satellite data with the HIRLAM grid, a simple up-scaling has been performed based on following two assumptions:

- the model grid values represent the mean of the grid-box,
- neighboring satellite pixels tend to have similar properties.

Each calibrated pixel of the AVHRR image is assigned to a particular model grid-box, according to the navigation information (Fig. 1). The number of satellite pixels in a grid-box varies between 50 and $\sim$ 400, depending on the satellite viewing angle. A simple arithmetic mean is calculated from all pixels assigned to a grid-box. The very high resolution structure of the satellite image is lost, while the general features, important for the verification process, are preserved.

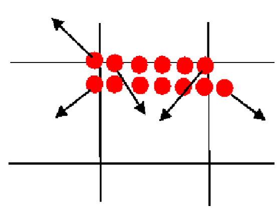

Figure 1: Re-sampling scheme used for up-scaling satellite pixels to the model grid.

3 Results

Standard verification scores at the time of satellite over-passes are calculated for the area of Finland, RMS-error and correlation coefficient are plotted in figure 2. A clear daily cycle is found: RMSE is much lower during night than during day, correlation is significantly higher during night. This is mainly due to the clear sky nighttime conditions observed practically over the entire area of Finland. The satellite receives radiation originating from surface and not much modified by the atmosphere while there are no clouds in the model either and the radiative transfer is calculated on clear conditions. Convection, however, is a phenomenon known to be hard to forecast in pattern and intensity. This fact is also mirrored in worse scores during the day and especially during the afternoon, when convection is strongest.

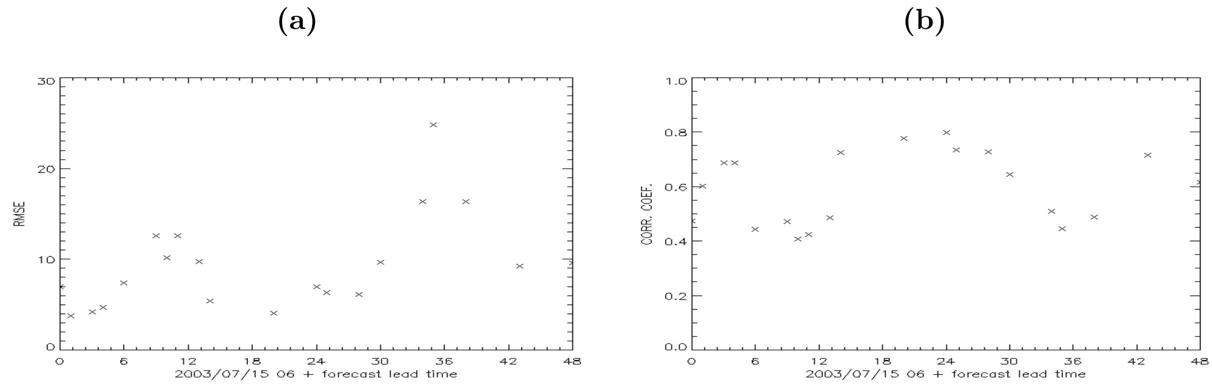

Figure 2: 2003/07/15 06 UTC - 2003/07/17 06 UTC, (a) RMS-error, (b) correlation coefficient for all available fc/obs-pairs.

Figure 3 indicates a strong underestimation of convection by the model. In the late afternoon, the satellite (Fig. 3 b) observed a much lower temperature than was simulated from predicted model profiles (Fig. 3 a). The difference is, in the center of the convective cell, bigger than 45 K, whereas in cloud-free areas of the domain the model is capable of simulating the surface temperature within $\pm$ 5K (Fig. 3 c). As the scatter-plot in figure 3 d shows, the hot pixels (cloud free during day) in the satellite image are well predicted by the model and the difference to observations is small. Observations of cold brightness temperatures are not well simulated by the model.

However, the model indicates weak convective activity in the right place (low pattern error).

4 Conclusions and further work

The reasons for the clear underestimation of the BT in the model are multi-fold. About 1/2 of the BT-error can be explained by the RTM's high sensitivity to cloud-fraction. Only a small error in the representation of cloud fraction in the input profiles can cause huge errors in the calculation of the BT. It will be subject of a further study, how realistic the cloud-fraction in the HIRLAM model under convective conditions is. The other 1/2 of the BT-error can be caused by the convective scheme. It looks like convection cannot grow higher than a certain level, which might have different reasons. One is the entrainment of air into the convective cell, another could be the tropopause being to low in the model.

Figure 3(a) and (b) indicate, that there is some agreement in the pattern of convection and the main reason for bad scores during afternoon is a big intensity error. To divide these two sources of error, an entity based verification method should be applied to this, and several other cases.

The low temporal resolution of NOAA polar orbiting satellites and their irregularity is a clear disadvantage in verifying convective activity predicted by a NWP. Continuous observations are provided by METEOSAT satellites and should be implemented in further studies.

5 Acknowledgement

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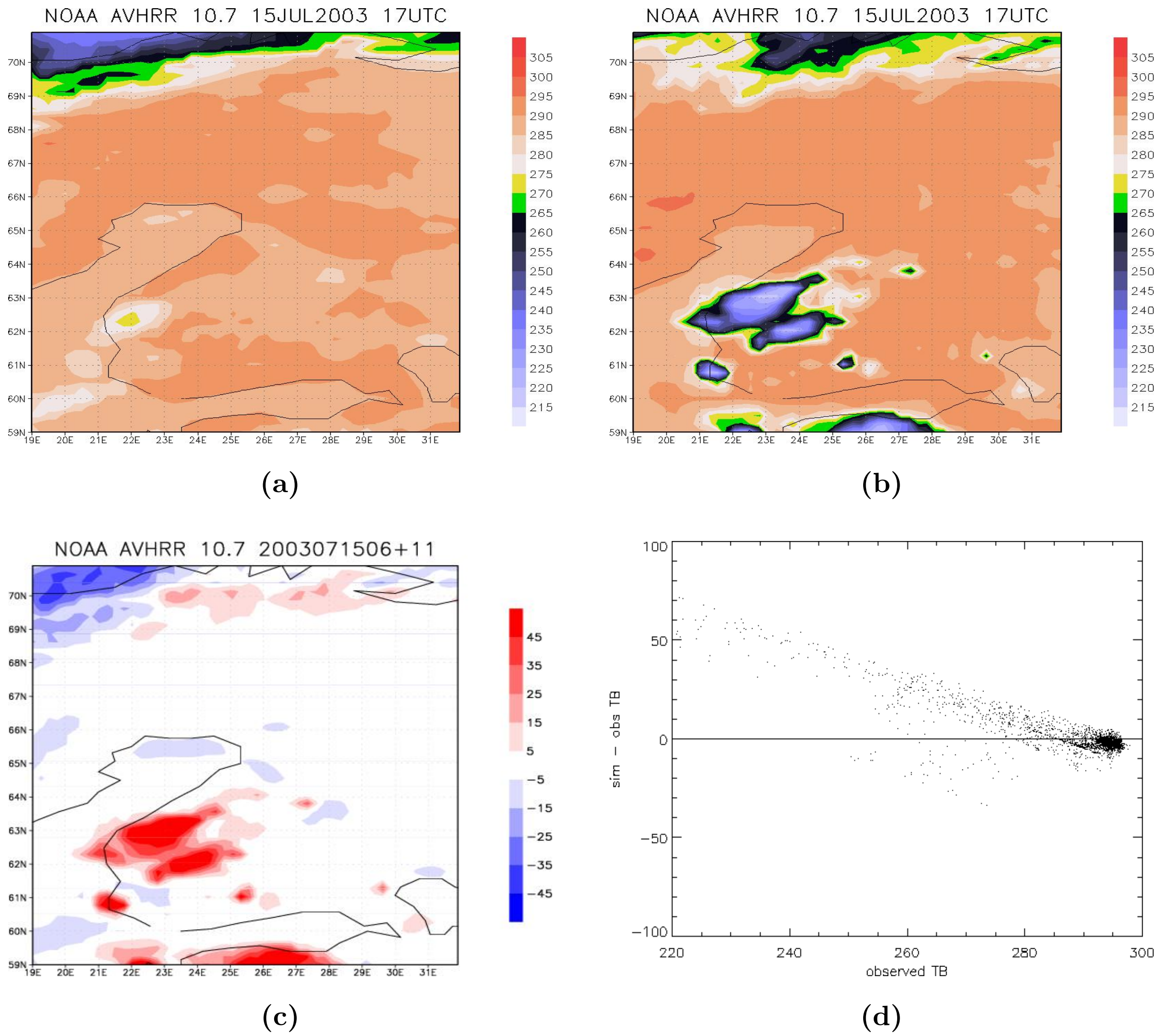

Figure 3: (a) Simulated model brightness temperature (BT), (b) observed satellite BT, (c) difference plot (fc - obs), (d) scatter-plot obs / (fc - obs).

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