AUTOMATIC MONITORING OF NWP FIELDS
USING SYNTHETIC SATELLITE IMAGES: FIRST RESULTS

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ABSTRACT

A process-based modelling approach is used to generate synthetic satellite images from the Limited-Area Model LM of the Deutscher Wetterdienst (DWD). The approach is based on the radiative transfer model code RTTOV-7 developed at the European Centre for Medium Range Weather Forecasts (ECMWF). From LM, profiles of pressure, temperature, specific humidity, cloud liquid water, cloud ice, cloud cover, ozone, and some surface variables are used to calculate microwave and infrared radiation as well as brightness temperatures as they would be seen by the Meteosat-7 MVIRI and the Meteosat-8 SEVIRI radiometers.

First results of our strategy to compare synthetic with actual satellite images are presented. This effort is part of a comprehensive Automatic Monitoring and Alerting system (AutoMON) that is currently being developed at the DWD. This system is able to permanently monitor significant weather situations in observations and model forecasts and alert the meteorologist in case of critical weather events. Furthermore, it monitors the quality of Numerical Weather Prediction (NWP) fields in comparison to observations using various techniques. For the comparison between synthetic and actual satellite images, statistical and image comparison techniques are used. Difference images, correlation between images, and displacement vectors are used to quantify the deviations. The meteorologist is automatically alerted in case a predefined level of disagreement between synthetic model output and the latest observed satellite image is reached.

It is anticipated that this system will help the meteorologist to evaluate the quality of simulated model fields with respect to their value for the current weather forecast. Weather situations that may develop in a way that has not been predicted by models can be recognised at an early stage.

1. INTRODUCTION

The operational numerical weather prediction system at the Deutscher Wetterdienst (DWD) currently consists of two models, the Global Model GME and the Limited-Area Model LM. The Global Model GME is an icosahedral-hexagonal grid point model with a horizontal mesh size of approximately 60 km and a vertical resolution of 31 layers. At hourly intervals, it provides boundary values for the nonhydrostatic Limited-Area Model LM with a horizontal resolution of approximately 7 km and 35 vertical layers. The LM model allows short range weather forecasting for Central and Western Europe.

With the cooperation of the German Space Research Centre (DLR, Institute for Physics of the Atmosphere), the Deutscher Wetterdienst (DWD) has implemented the radiative transfer model RTTOV-7 for the
computation of synthetic satellite images from NWP models, currently generating images from the Model LM (Figure 1). RTTOV-7 simulates IR and WV channels of Meteosat-7 MVIRI and Meteosat-8 SEVIRI radiometers using gridpoint fields (GRIIB) of the LM as input.

The effort is part of a comprehensive Automatic Monitoring and Alerting System (AutoMON) currently being developed at the DWD. This system is able to permanently monitor significant weather situations and the performance of NWP models with respect to observations. Within this context, synthetic satellite images allow large-scale spatial comparisons between NWP model forecasts and reality.

2. GENERATION OF SYNTHETIC SATELLITE IMAGES

Synthetic satellite images are an indicator for the state of the atmosphere as predicted by NWP models.

2.1 The RTTOV-7 Model

Using the radiative transfer model RTTOV-7, microwave and infrared radiation as well as brightness temperatures can be simulated as it would be seen by the MVIRI or the SEVIRI radiometer on board of the METOSAT-7 and METEOSAT-8 satellite, respectively. As input variables, the RTTOV-7 needs the following parameters provided by LM: temperature, specific humidity, cloud liquid water, cloud ice water, cloud cover, pressure, surface pressure, skin temperature, 2-meter temperature, 2-meter specific humidity, land-sea mask. The following approximation of the top of atmosphere upwelling radiance is used [Saunders, 2002]:

\[ L(\nu, \Theta) = (1 - N)L_{\text{CLR}}(\nu, \Theta) + NL_{\text{Cld}}(\nu, \Theta) \]

The radiance for clear sky conditions is simulated as:

\[ L_{\text{CLR}}(\nu, \Theta) = \tau_s(\nu, \Theta)\varepsilon_s(\nu, \Theta)B(\nu, T) + \int_{\tau_s}^{1} B(\nu, T)d\tau + (1 - \varepsilon_s(\nu, \Theta))\tau_s(\nu, \Theta)\int_{\tau_s}^{1} \frac{B(\nu, \Theta)}{\tau^2} d\tau \]

The radiance for cloudy sky conditions is expressed as:

\[ L_{\text{Cld}}(\nu, \Theta) = \tau_{\text{cld}}(\nu, \Theta)B(\nu, T_{\text{cld}}) + \int_{\tau_{\text{cld}}}^{1} B(\nu, T)d\tau \]

with
- \( \tau_s \) : surface to space transmittance
- \( \varepsilon_s \) : surface emissivity over water surfaces
- \( B(\nu, T) \) : Planck function for frequency \( \nu \) at temperature \( T \)
- \( \tau_{\text{cld}}(\nu, \Theta) \): cloud top to space transmittance
- \( T_{\text{cld}} \) : cloud top temperature
- \( \nu, \Theta \) : frequency \( \nu \), viewing angle \( \Theta \) from zenith at the surface
- \( N \) : fractional cloud cover
Figure 2 shows an example for a synthetic satellite image using LM-output and the corresponding observed image.

2.2 Main Limitations of RTTOV-7

- RTTOV-7 only simulates top of the atmosphere radiances from a nadir or off-nadir view which intersects the Earth's surface (i.e. no limb paths)
- RTTOV-7 does not include any reflected solar component
- RTTOV-7 does not include scattering effects
- RTTOV-7 only allows for water vapour and ozone to be variable gases with all others included in the mixed gas transmittance calculation [Matricardi et al., 2001]
- The accuracy of simulations for very broad channels (e.g. SEVIRI channel 4 at 3.9 microns) is poor, significant biases (1-2K) have been noted. This is the case for all versions of RTTOV [Saunders, 2002; Keil & Tafferner, 2003]

3. EVALUATING NWP MODEL PERFORMANCE USING SYNTHETIC SATELLITE IMAGES

In order to evaluate large-scale NWP model performance, synthetic and observed satellite images are compared. The following parameters are planned to be permanently monitored by the DWD “AutoMON” system:

3.1 Difference Image

Pixel values of the observed image are subtracted from the corresponding pixel values of the synthetic image (Figure 3). The results are displayed as an overlay on top of the observed satellite image. Pixels of the difference image with values lying within a defined interval of allowance (considering also systematic errors in the synthetic satellite images) are regarded as 0 pixels and are not coloured (i.e. no difference between synthetic and observed image). Values above zero (white) indicate that temperatures in the synthetic satellite image are too high indicating too few or too low clouds in the NWP model. Values below zero (black) indicate
that temperatures in the synthetic satellite image are too low indicating too many / too high clouds in the NWP model.

The average sum over the absolute values of the differences serves as a warning parameter for the AutoMON monitoring system.

3.2 Correlation

The correlation coefficient $r$ of the Brightness temperatures of the image pair is calculated, according to the equation:

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}$$

where

$x$: pixel values of the synthetic image

$y$: pixel values of the observed image

$n$: number of pixels in image

For each image pair one correlation coefficient is computed.

3.3 Displacement Vectors

Using a pattern-matching technique, the displacement of cloud-clusters between the synthetic and the observed image is calculated (Figure 4). The image is divided into squares of defined size. For these squares a best match is searched in the local neighbourhood of the same position in the second image, using a pattern matching technique. The local neighbourhood is an area of defined size, configurable by the user. The size of this area also determines the maximum possible displacement vector [CineSat Software User Manual V2.6, 2001].

As a comparison-parameter the normalised cumulative vector-length for the entire image is calculated. In the ideal case, i.e. the forecast exactly meets the actual state of the atmosphere, there would be no displacement between the observed and the synthetic satellite image with a parameter value of zero.
4. **MONITORING THE QUALITY OF THE LOCAL MODEL (LM) USING SYNTHETIC SATELLITE IMAGES WITHIN AUTO MON (“QUALISAT”)**

AutoMON is part of the meteorological workstation system „NinJo“ [Koppert, 2002] currently developed at the DWD in co-operation with its partners, the Geophysikalischer Beratungsdienst der Bundeswehr, MeteoSwiss, the Danmarks Meteorologiske Institut, and the Meteorological Service of Canada. It automatically detects warning events and alerts the forecaster. Figure 5 gives an insight into the Graphical User Interface of AutoMON as applied to QualiSAT.

AutoMON Quality Monitoring permanently monitors the forecast model performance, in this case deviations between synthetic and observed satellite images. The meteorologist is alerted as soon as one of the parameters described above (quantifying deviations between model forecast and reality) exceeds a defined threshold value. Using the Graphical User Interface, the observed deviations can be further examined. This can help in order to early recognise weather situations that may develop in a way that has not been predicted by models.

![Figure 5: NinJo - Graphical User Interface AutoMON applied to QualiSAT](image)

5. **SUMMARY AND CONCLUSIONS**

Synthetic satellite images are generated from the Local Model LM of the DWD using the radiative transfer model RTTOV-7. They are compared to observed satellite images in order to evaluate NWP Model...
performance. Difference images, correlation between images, and displacement vectors are used to quantify deviations.

It is anticipated that the AutoMON system applied to synthetic satellite images will help the forecaster to evaluate the quality of the simulated model fields with respect to their value for the current weather forecast. Weather situations that may develop in a way that has not been predicted by models are expected to be recognised at an early stage. The described statistical techniques are currently being tested and evaluated for further enhancements of the comparison.

6. REFERENCES