Quantitative evaluation of regional precipitation forecasts using multi-dimensional remote sensing observations (QUEST)

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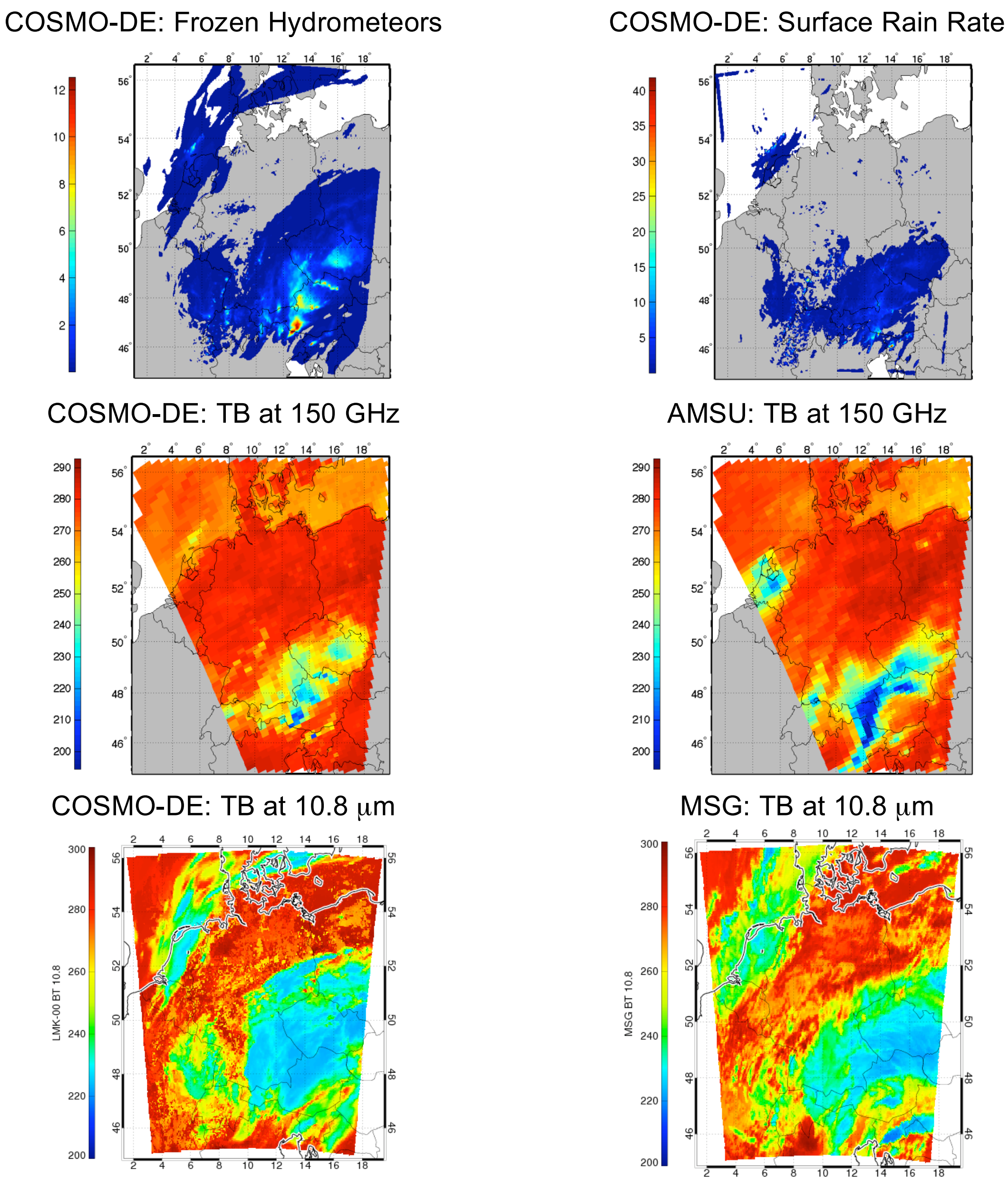

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Cover page:

An illustration of the model evaluation using a case study (3 August 2006, 14 UTC) when stratiform rainfall occurred in Southern Germany. Top: Forecasts of integrated frozen hydrometeor content (left) and surface rain rate (right) from the COSMO-DE run started at 0 UTC. Middle: Infrared brightness temperature (BT) at 10.8 μm from COSMO-DE (left) and Meteosat Second Generation (MSG) (right). Bottom: BT at 150 GHz from COSMO-DE (left) and the Advanced Microwave Sounding Unit (AMSU) (right). Both satellite observations are taken at window frequencies. The infrared image shows that COSMO-DE reproduces the location of high (cold) clouds in general relatively well, however, the spatial extension of cloud system over the Netherlands is too small. The observed BT depression at the microwave band stems from larger frozen particles (graupel/snow) concentrations located at the cores of precipitation systems. Clearly also the intensity of the system over the Netherlands is underestimated. Furthermore, the southern branch of the precipitation system in the Alps is missing in the model.

1. Introduction

In order to get insight in the ability of an atmospheric model to simulate the correct surface precipitation, it is of importance to understand the processes leading to formation of clouds and conversion of cloud water and ice into precipitation. Due to the complexity of atmospheric processes it is of utmost importance to observe the atmospheric state as complete as possible. This requires multi-dimensional remote sensing data since they are the only means to observe the spatial-temporal distribution of water in all its phases. Within the Priority Program (PP) of the Deutsche Forschungsgemeinschaft (DFG) the project "Quantitative evaluation of regional precipitation forecasts using multi-dimensional remote sensing observations" (**QUEST**) addresses this point. The work presented here demonstrates the status after about half of the 2nd PP phase (about 36 months in total) – the slight delay is due to changes in staffing. QUEST focuses on the use of active and passive remote sensing instruments both from ground and satellite for an identification of deficits in quantitative precipitation forecasts.

Apart from the classical method for model evaluation ("observation-to-model approach") we have also used the "model-to-observation approach". The latter method is applied since the remote sensing measurement is affected by complex interactions between radiation, the atmosphere (gases, aerosols and hydrometeors) and the surface. As a consequence the determination of model variables from the observations (retrieval) is not straightforward. From a known atmospheric state, the remotely sensed signal calculated with a forward operator ("model-to-observation approach") is much more accurate. Therefore the comparison of the remotely sensed signal calculated with a forward operator and corresponding remote sensing observations is preferred above a comparison of directly simulated and retrieved atmospheric properties. Since several model variables contribute to the remote sensing signal this constitutes an integral model evaluation. By looking at different spectral regions the sensitivity towards certain features, for example water vapor at the respective absorption channels, can be investigated but also the physical consistency across the full spectrum.

The first phase of PP was devoted to the set up of a data base, the development of evaluation tools, analysis of case studies and the first evaluation of model test suites [Van Lipzig et al., 2005]. The data base developed helped in the preparation of the General Observation Period (GOP) [Crewell et al., 2005] which started on 1 January 2007 and is currently ongoing. The case study analysis led to two refereed publications [Van Lipzig et al., 2006; Schröder et al., 2006]. The methods for characterizing cloud patchiness described in this paper have already been applied by others[2].

In the second PP period the focus is on the completion of tools (forward operators), their application within case studies and the long-term model evaluation using GOP data. Therefore this intermediate report consists of three parts:

- The report on the status of the projects work packages (sections 2-4)
- A manuscript on the application of the QUEST tools within two case studies [Pfeifer et al., 2008] which shall be submitted before the end of 2007.
- A manuscript giving an overview about the GOP [Crewell et al., 2008] where QUEST contributed to long-term model evaluations.

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[2] Söhne, N., J.-P. Chaboureau,and F. Guichard, 2008: Forecast verification of cloud cover with satellite observation over West Africa, *Mon. Weather Rev*., submitted.

To reach our goals, the work for the 2nd PP phase was stratified into four different tasks, which are the overall co-ordination (WP 1), the tool development (WP 2), the model evaluation (WP 3) and model improvement (WP 4). The model evaluation played a central role with several case studies, test suite analysis and the long-term evaluation (LTE) using GOP data. For the latter the LTE strategy [van Lipzig et al., 2004] developed already in phase 1 has been refined.

2. Workpackage "Tool development"

WP 2.1: A microwave radiation simulator (**SynSatMic**) originally developed for the French Meso-NH model [Mech et al., 2007] was adapted to the COSMO-DE model (formally known as Lokal-Modell-Kürzestfrist LMK) taking into account the assumptions in the COSMO-DE microphysics like drop size distributions, density etc. It was already applied within case studies (for example front cover and Pfeifer et al. [2008]) and the results were compared to AMSU observations. It was found that for the case of the Hoek van Holland on 19 September 2001 [Chaboureau et al., 2007] that Meso-NH and COSMO-DE gave different fractions of graupel and snow water content yielding different brightness temperature depression (not shown).

WP 2.2: The work on the polarimetric radar simulator (**SynPolRad**) concerned technical improvements as well as the integration of several different microphysical schemes [Pfeifer, 2007]. Fig. 1 clearly shows the strong effect of the different parametrizations on the thunderstorm representation. Work is also ongoing to compare COSMO model forecasts with those of the French Meso-NH model also including prognostic hail. SynSatMic has been applied to the same cases. Additionally, SynPolRad was adapted to cloud and micro rain radar (MRR) geometry which will become important tools within the third phase when the MRR network and COPS case studies will be investigated.

WP 2.3: After a problem with the angular geometry in the synthetic satellite simulator (**SynSat**) has been identified by QUEST the Meteosat radiances simulated by the updated code now agree well with explicit radiative transfer (RT) simulations by FUBs advanced RT code. Synthetic brightness temperatures are now used for COSMO model evaluation within case studies (see front cover) and for long-term evaluation as part of the GOP [Crewell et al., 2008]. In preparation for that special output routines and automatic statistical calculations were implemented into the automatic MSG processing at FUB. Synthetic brightness temperatures are now used for COSMO evaluation within case studies (see front cover) and for long-term evaluation as part of the GOP [Crewell et al., 2008].

WP 2.4: An algorithm to derive optical thickness from MSG observations has been developed, validated and implemented. The derived fields and time series at anchor stations are routinely produced as part of the GOP. Furthermore, the data have been used in case studies (compare Pfeifer et al. [2008]).

In summary up all items concerning the **tool development** have already been successfully completed.

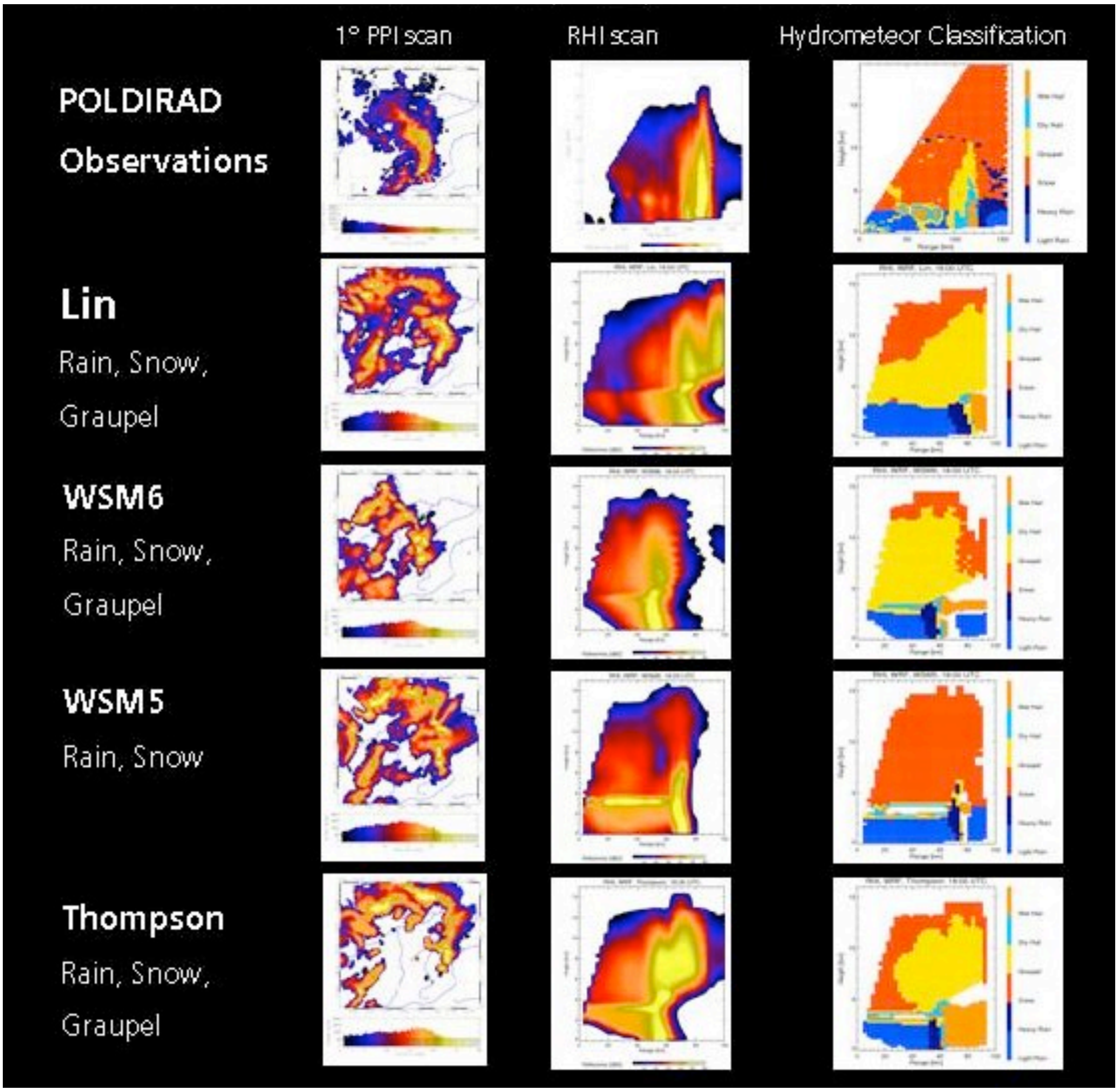

Figure 1. Comparison of synthetic radar azimuth (left) and elevation (middle) scans and hydrometeor classification (right) between observations (top) and different microphysical parametrizations.

3. Workpackage “Model evaluation”:

WP 3.1: Two **case studies** – one for a more convective an one for a more stratiform case – have been investigated in detail using the tools of WP2 [Pfeifer et al., 2008]. The cases were taken from the AquaRadar campaign 2006 which also provided information on the vertical variations in drop size distribution The synergy of radar, infrared and microwave satellite data reveals model deficits which result both from phase errors as also amplitude errors in microphysical parameters. The convective case of 28 June 2006 is currently used to evaluate the new convection scheme developed by the project by Bott (Bonn). In the remaining time of the 2nd phase we will already start looking at COPS Intensive Observation Periods which will be investigated together by several PP partners.

WP 3.2: The evaluation of the COSMO-DE **test suites** of summer 2005 has revealed strong deficits in the representation of the boundary layer [Crewell et al., 2006] which was found too humid with too low vertical extent. While cloud cover generally agreed well, the vertical extent of clouds was overestimated by the model. Significant difference were found between the runs started at 0 and 12 UTC with the 12 UTC run being drier and having less skill in cloud cover prediction. This might be caused by the dry bias in daytime radiosondes which could be identified when comparing modeled integrated water vapor observed in a comparison with the GPS derived values.

WP 3.3: The long-term evaluation of the **GOP** (http://gop.meteo.uni-koeln.de) is the central activity of QUEST. In addition to the radar and satellite data used in the model-to-observation approach further remote sensing observations which are routinely performed are taken into account. One interesting type of observations is the integrated water vapour (IWV) observed by GPS within large networks and already assimilated by some weather services. Within the Eumetnet GPS Water Vapour Programme (E-GVAP) project (http://egvap.dmi.dk/) HIRLAM analysis are compared online. Here we compare the shortterm COSMO-DE forecast with high temporal resolution (15 min) to the corresponding observations by the GFZ network. We can further exploit the fact that the COSMO-DE model is started every three hours for a forecast period of 21 h. Therefore 8 different forecasts are available for each given time.

When looking at the time series of the model bias and RMSE (Fig. 2) cases with good and poor model performance can easily be identified. It is also clear that forecasts with longer lead time have a systematically larger IWV bias (0.1 to 0.4 kgm^{-2}) than forecasts with a shorter lead time. In particular, some periods for example in the end March 2007 or on 18 July can be identified where the bias is strongly reduced the shorter the forecast lead time. This points at situations with poor predictability which are therefore well suited to be selected for case studies analysis. The RMSE is rather low with minimum of 1 kg m^{-2} indicating a general good forecast skill. As to be expected RMSE increases for longer lead times (2.0 to 2.4 kgm^{-2}). The higher values in summer result from the generally higher IWV (similar relative error). However, there are some days where the RMSE increases by more than a factor of 2 up to more than 4 kg m^{-2}.

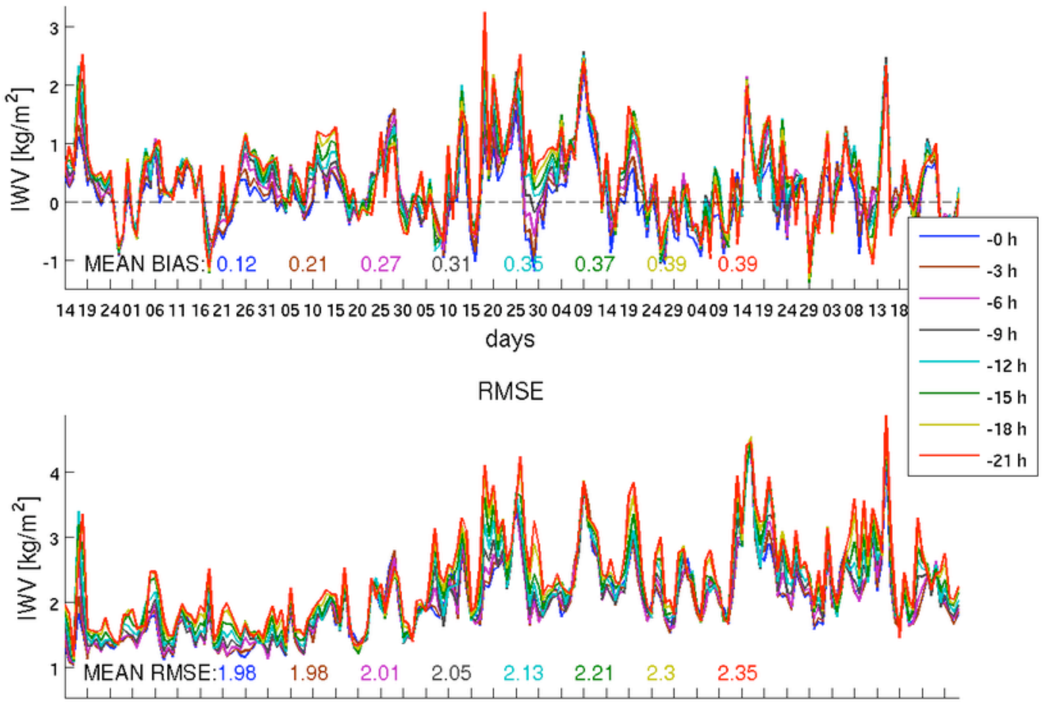

Figure 2. Model bias (model-observation; upper graph) and root mean square error (RMSE; lower graph) derived from a direct comparison of all GFZ GPS stations (about 150) with corresponding COSMO-DE forecasts averaged over all stations for a period from February 14, 2007 to August 31). The different colors show the different lead times.

Long-term model evaluation is performed not only in terms of model variables but also in observable space using the operators of work package 2. The comparison of brightness temperatures of MSG's window channel (10.8 μm) shows that the COSMO-DE model generally reproduces the observations well, however, a slight under estimation in TB points at deficits in the representation of high (cold) clouds. This is especially true in the beginning of July where also a strong underestimation of cloud top pressure, e.g. an overestimation of cloud top height, of nearly 200 hPa was observed (Fig. 3 bottom). It should be noted that the comparison of brightness temperatures relates to the full model domain while the cloud top comparison only considers whose pixels where both observations and model show a cloud.

Combined with the information on the existence of clouds (cloud mask) one can deduce hat COSMO-DE produces too many clouds and that these clouds show a too high cloud top. Still there might been some issues in the spatial agreement of modeled and observed clouds which require further investigation with a specific distincton of different cloud regimes over longer time scales

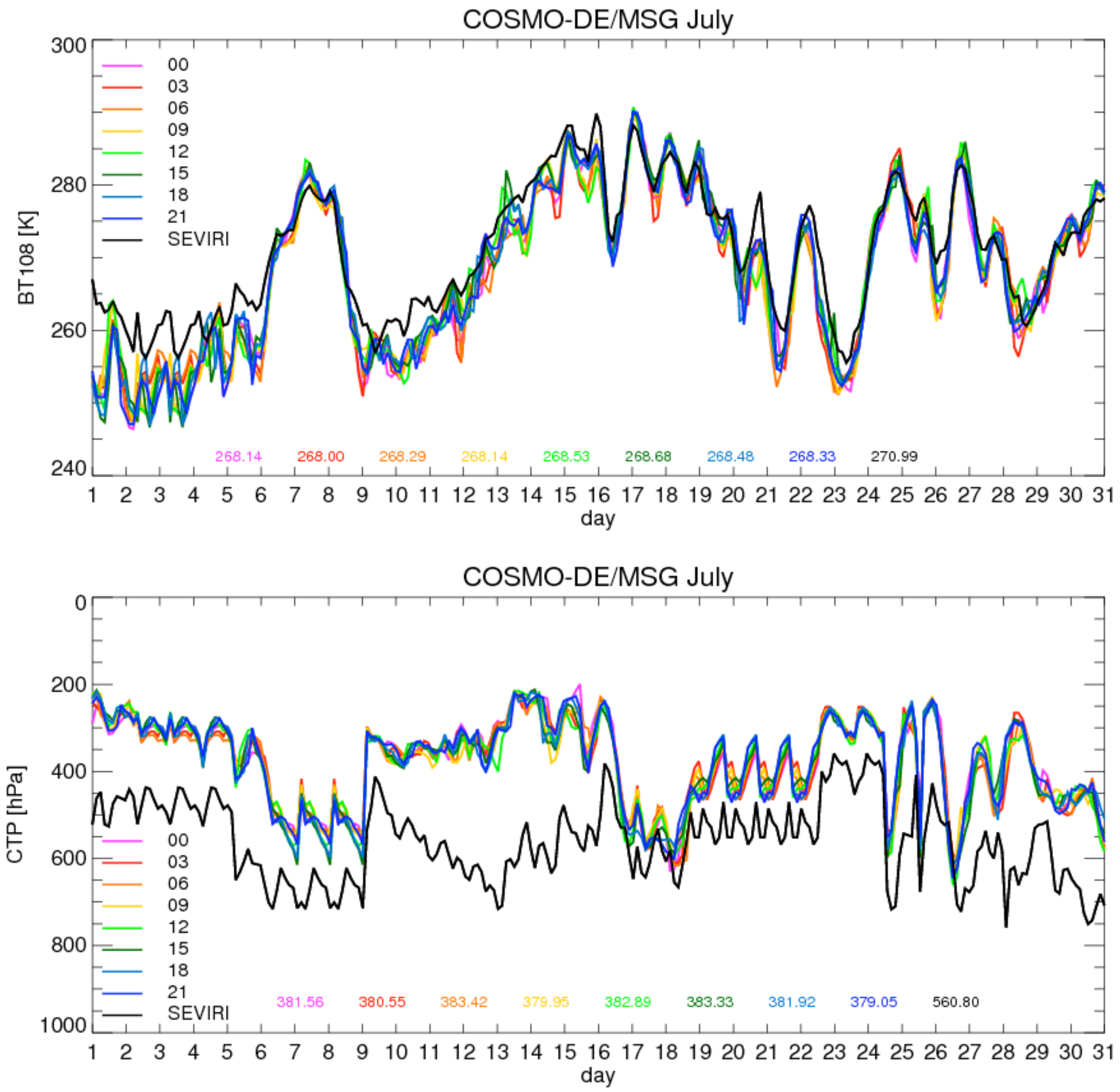

Figure 3. Time series of 10.8 μm brightness temperature (top) and cloud top pressure (bottom) for July 2007. Observations (black by MSG) and the COSMO-DE model for different lead times (colour coded).

When we investigated the diurnal cycle of IWV forecast quality [Crewell et al., 2008; Fig. 10] the runs started at 12, 15 and 18 UTC show a significant dry bias in the beginning. This can be pinned down to the fact that the radiosonde observations ingested into the assimilation run during daytime are affected by a dry bias [Crewell et al., 2008; Fig. 6]. To further investigate the dependency on forecast time the bias was also calculated as a function of the actual start time of the model the IWV (Fig. 3) for July 2007. Though this might be a rather short time and significant differences for the different months of 2007 (http://gop.meteo.uni-koeln.de/gop/doku.php?id=quicklooks:gop5_gps_gfzn:stats:dirvgl:crbc:mat:lmkandlme) occur it can be clearly stated that

- both COSMO models show drier runs when the forecasts are started between 12 and 21 UTC (upper half of he matrix). This effect is most pronounced for COSMO-EU.
- COSMO-DE is more humid than COSMO-EU EU (formally known als Lokal-Modell-Europa LME) by about 3 %.
- a slightly stronger diurnal bias structure is evident in COSMO-EU than in COSMO-DE indicating that in COSMO-EU model deficiencies are more clearly related to the time of the day than in COSMO-DE.

Since the QUEST focus is on a consistent representation of the water cycle we investigated together with the VERIPREG project the connection to other variables like cloud base height and precipitation (Fig. 3). In July the cloud base height of COSMO-DE is systematically too low with the best agreement around noon (lightblue diagonal).

By looking only at one month the statistical significance for intermittent variables like cloud base height and precipitation might not be guaranteed. Single events can mask the diurnal cycle. Therefore longer time periods will be investigated in the future. Furthermore, not only bias but other skill scores will be considered.

4. Workpackage: "Model improvement"

Within the 2nd PP phase QUEST the work related to model improvement is performed by closely co-operating with DWD and other PP projects like the one by Bott on convection parametrization or DAQUA on data assimilation. It wlil be the major work item in the 3rd PP phase.

WP 4.1: The strong impact of model changes in the COSMO-EU model on the boundary one of the nested COSMO-DE model in February 2007 (see also QUEST proposal) has drastically illustrated the importance of cloud **microphysical parametrizations**. Therefore we will further investigate the impact of different microphysical schemes (compare Figure 1) and specifically the assumptions on frozen hydrometeor characteristics (size distribution, density etc) by performing sensitivity studies on COPS IOP data.

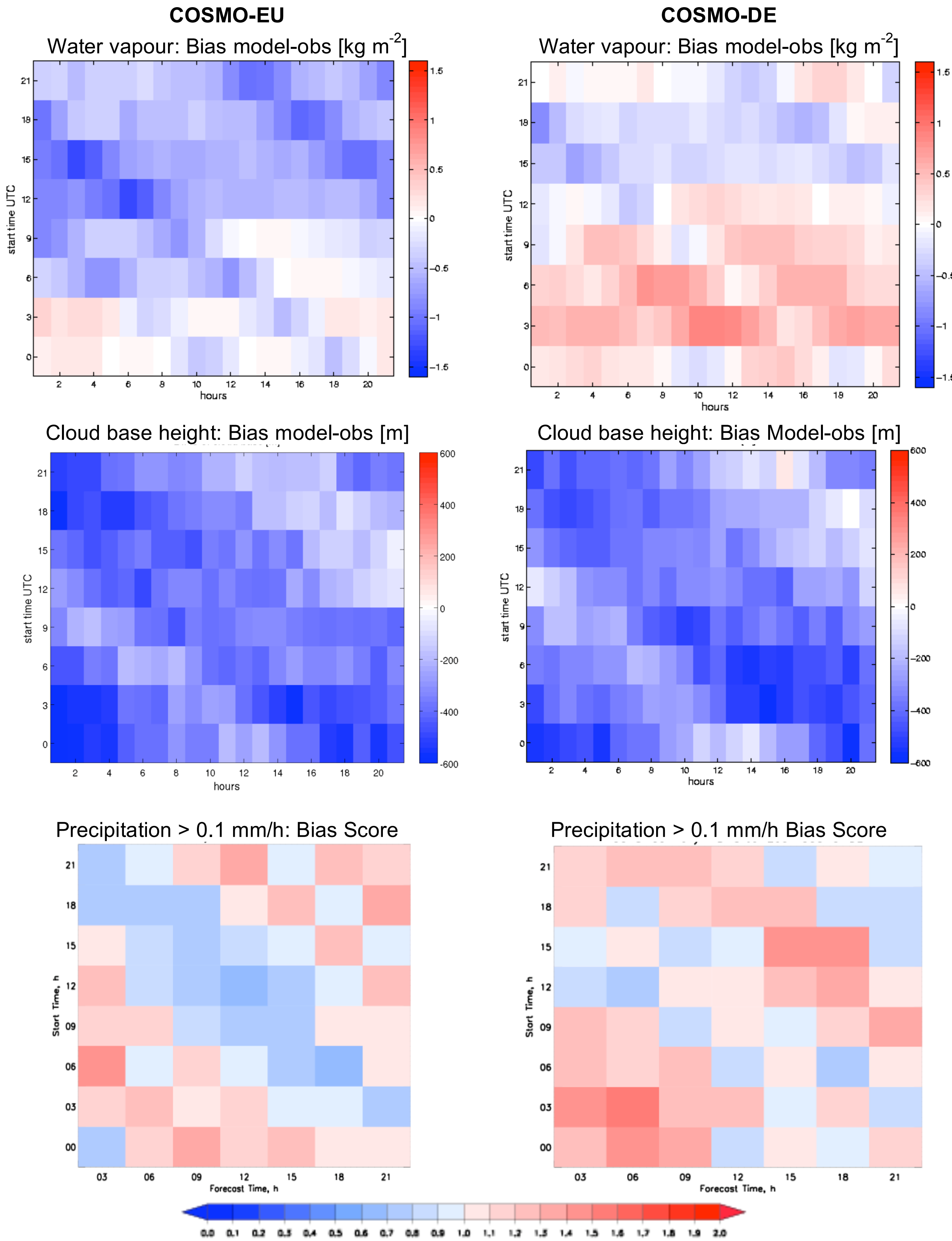

Figure 4: Bias information (model – observations) in integrated water vapour precipitation (top), cloud base height (middle) and precipitation occurrence (bottom) for both COSMO-EU and COSMO-DE models as a function of forecast time (x-axis) and start time of the model run (y-axis) for July 2007. Therefore diagonal lines correspond to the same time of day. Precipitation verification (bias score) courtesy of M. Zimmer and H. Wernli from the VERIPREG project.

WP 4.2: The planned work on land surface parametrizations was not directly performed within QUEST because Felix Ament left the project and continued at his new affiliation at MeteoSwiss to work on topics which are closely related to the planned QUEST activities: MeteoSwiss experienced serious soil dry-out problems in summer while introducing the new multi-layer soil module TERRA-ML of the COSMO model. Systematic evaluations of various enhancements [Ament, 2007] using a stand-alone version of TERRA-ML gave indications on promising modifications (e.g. revised bare soil evaporation, modified soil moisture transport). These potential improvements are currently tested with the full COSMO model system by analyzing the impact on near surface parameters and on precipitation forecasts. Furthermore, MeteoSwiss intends to resolve parts of the subgrid-scale variability of the land surface by using the mosaic/tile approach of Ament and Simmer [2006]. The implementation of this scheme is ongoing and first test suites will be available for evaluation in summer 2008.

WP 4.3 The model evaluation performed up to now (see also Crewell at al. [2006] and [2008]) has identified deficits in the representation of the **boundary layer** which is found too low and too shallow. DWD has performed several test suites including changes in the turbulent length scale whose evaluation will a major work item within the next months.

5. Summary

The work proposed for the 2nd phase of the PP program is well underway. The tool development has already been finished. Within the third phase we plan to make the tools available to the general public. The ongoing evaluation of the GOP has already revealed some model problems:

COSMO forecasts started at 12, 15 and 18 UTC show a dry bias [Crewell et al, 2008; Fig. 6] which seems to be caused by a dry bias in daytime radiosonde humidity measurements caused by radiative effects[3] and propagated into the model through the assimilation. Though these model runs gain moisture with time the average humidity is lower than in runs started other times of the day. Since a correction has been suggested by Kady-Peirera et al. [2008, to be published] the benefit of these correction could be investigated in the future.

The IWV bias offeres the chance to investigate the connection of water cycle parameters in the model. For the month of July (Fig. 4), however, a clear connection to cloud base height and precipitation could not be found. Some diurnal tendency is obvious which can not easily be explained. This is currently further investigated using different MSG products. Furthermore, the results from the VERIPREG project indicate that the consideration of longer time scales provides much clearer signals. Therefore the analysis of the full GOP period (and beyond) including the strong cross correlation of the different water cycle parameters will be the main focus of future QUEST activities.

It should be noted that QUEST has set up close co-operations with other projects in the PP which deal with the verification of model forecasts, namely VERIPREG (Mainz), STAMPF (Berlin), the COPS field experiment (Hohenheim/Karlsruhe), the assimilation project DAQUA (Simmer, Bonn) and the development of a new convection scheme (Bott, Bonn).

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