Continuous Evaluation of Atmospheric Models Using a Combination of Different Observations – the General Observation Period (GOP)

S. Crewell[1], T. Reinhardt[1], C. Selbach[1], N. van Lipzig[2], T. Akkerman[2], J. Fischer[3], F. Ament[4] , A. Seifert[5]

[1] *University of Cologne, Zülpicher Str. 49a, 50674 Köln, Germany, crewell@meteo.uni-koeln.de*
[2] *K.U.Leuven, Celestijnenlaan 200E, P.O.Box 02409, B-3001 Heverlee, Belgium, Nicole.VanLipzig@ees.kuleuven.bel*
[3] *Free University of Berlin, Carl-Heinrich-Becker-Weg 6-10, 12165 Berlin, Germany, fischer@zedat.fu-berlin.de*
[4] University of Hamburg, Bundesstr. 55, 20146 Hamburg, Germany, felix.ament@zmaw.de
[5] Deutscher Wetterdienst, Frankfurter Straße 135, 63067 Offenbach, Germany, Axel.Seifert@dwd.de

ABSTRACT

Two years of observations (2007-2008) from the General Observation Period (GOP) are used to evaluate corresponding forecasts of DWDs operational COSMO model. Here we focus on water cycle variables. i. e. integrated water vapor, cloud base height and precipitation. Model deficiencies are found to be related to data assimilation, the parametrization of stable boundary layer, and wintertime precipitation. Therefore, these research domains need further attention in order to improve the model performance. A classification into different weather types is promising in further assessing model deficits.

1. INTRODUCTION

Precipitation forecasts are hindered by the fact that precipitation itself is the end product of a complex process chain. Therefore when trying to identify and eventually overcome the deficits of precipitation forecasts all variables involved in the water cycle need to be considered. This approach is the underlying theme of the General Observation Period (GOP) [1] which takes place as part of the German priority program on Quantitative Precipitation Forecast (QPF) [2] since the beginning of 2007. For an area focusing on central Europe observations by in-situ and remote-sensing instruments with special focus on water cycle variables are used for a long-term evaluation of the numerical weather prediction models COSMO-EU and COSMO-DE of the German Meteorological Service. Model output is tailored to match the observations and perform model evaluation in a near real-time environment (http://gop.meteo.uni-koeln.de/). Since these models are run as a lagged-ensemble where new forecasts are started every 3 h it is possible to investigate systematic model behaviour.

Within this paper we focus on the consistency in the forecasts of water cycle parameters which can be derived from relatively low cost instrumentation, i.e. from GPS (integrated water vapour, IWV), ceilometers (cloud base height, CBH) and rain-gauges and radar observations (surface precipitation).

2. GOP OVERVIEW

The GOP involves measurements of surface precipitation, weather radar, vertically resolved drop size distributions by micro rain radar (MRR), GPS, ceilometer and lightning networks, satellite measurements as well as radiosoundings in central Europe (Fig. 1). Due to their good spatial distribution and temporal coverage we focus on three data sets:

1) The Global Positioning System (GPS) is utilized to estimate **IWV** from the total delay of the GPS signal in the atmosphere. After ionospheric correction the wet delay is taken as the difference between the observed total delay and the hydrostatic delay. The later can be calculated from surface pressure and then converted using empirical relationships to IWV. For the GOP, GFZ Potsdam provides near-real time IVW data with a temporal resolution of 15 minutes and accuracy of 1-2 kgm^{-2} for a GPS network consisting of approx. 200 stations.

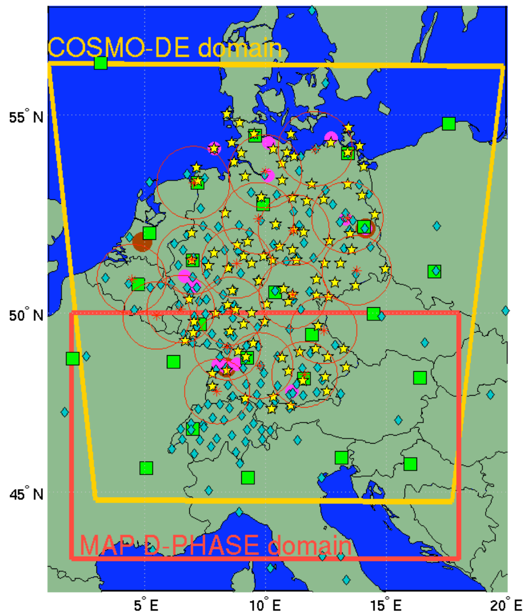

Figure 1. Map of GOP area indicating micro rain radar stations (pink circles), radio sounding stations (green squares), DWD ceilometer network (yellow stars), GPS network (blue diamonds) and 100 km radius (red circles) of Germany and Belgium weather radars (red stars). Furthermore, the domains of DWD's operational COSMO-DE model and the D-Phase models are given (taken from [1]).

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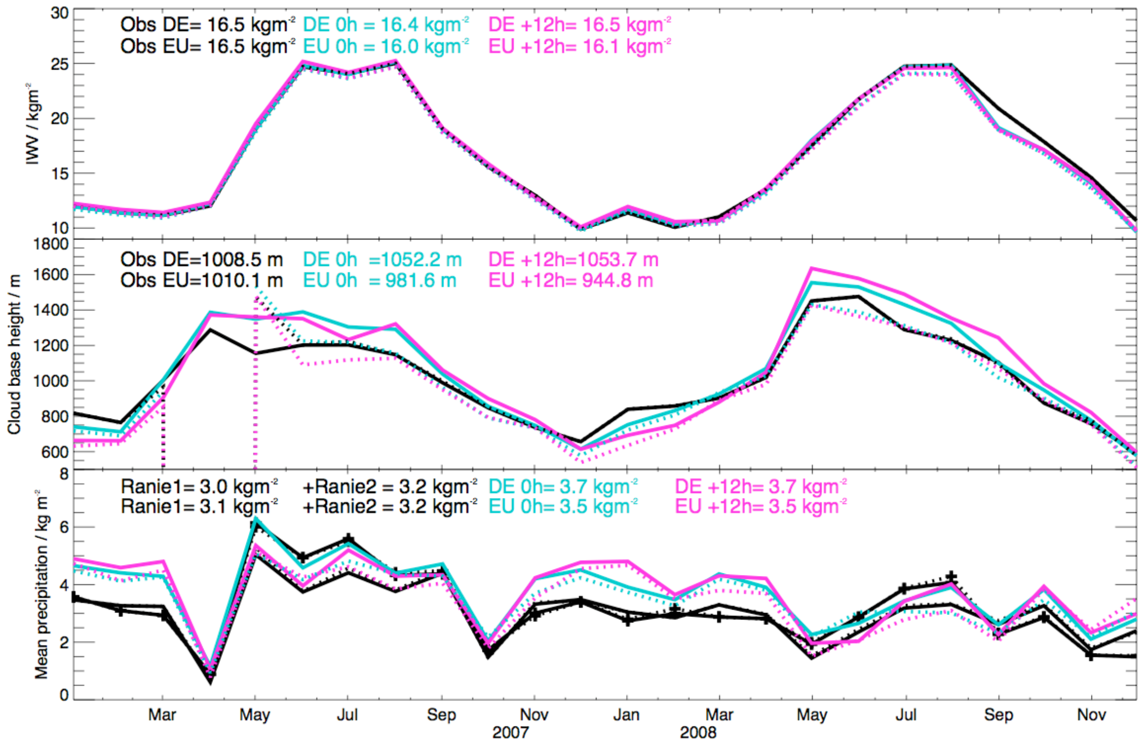

Figure 2. *Temporal development of IWV (top), cloud base height (middle) and precipitation (bottom) during 2007 & 2008 from observations (black) and short-term model forecasts by COSMO-DE (solid) and COSMO-EU (dotted; blue for +0h and magenta for +12 forecasts).*

2) Measurements from lidar ceilometers at more than 100 stations within Germany are measured by DWD with 10 min resolution providing **cloud base height** with accuracy better than 30 m for up to three layers. Note that the full backscatter profile is not available from this network and we limit the analysis to clouds below 3000 m. Because these data are in principle available on real-time base their use in model evaluation explores a new path for standard verification. It should be noted that cloudiness derived from the observations might be biased towards lower values due to the altitude limitation (mostly 7 km) which depends on the actual ceilometer type.

3) The operational **surface precipitation** product RANIE is provided by DWD giving accumulated surface precipitation for 6 h periods on a 1x1 km^2 grid. Two data sets, one from pure in-situ observations (RANIE1) and one composed of in-situ and radar information (RANIE2), are available.

3. COSMO MODEL

In order to improve regional operational NWP, convection-resolving NWP models have been introduced recently or are to be introduced in the near future. Since spring 2007 German Meteorological Service (DWD) runs operationally a convection-resolving version of the COSMO model (COSMO-DE, formerly called LMK) [2] with 2.8 km horizontal resolution nested in the 7 km resolution COSMO-EU, the latter employing a parameterization for deep convection. The domain of COSMO-DE is shown in Fig. 1, together with the domain of the numerical weather prediction models (NWP) participating in the ongoing Mesoscale Alpine Programs (MAP) Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region (D-PHASE) project (not analyzed here)

4. EVALUATION OF MONTHLY MEAN VALUES

For the evaluation of model forecasts model, output from the operational runs has been extracted corresponding to the observations as close as possible, e.g. diagnosis of cloud base heights matches the ceilometer measurement process. Here we concentrate on the forecasts with +0h and +12h lead time. The first one is the analysed model field while the latter is typical range of interest for a short-term forecast.

A comparison between monthly mean model output and measurements for the whole two-year period (Fig. 2) shows that in general the model represents the atmospheric water vapour rather well with the exception of September 2008. One should note, that over the two-year period considered here some model changes have been introduced, affecting the model performance especially during September 2008. Another major model upgrade was the introduction of the latent heat nudging in the COSMO-DE in April 2007. While COSMO-DE is nearly bias free with a mean value of 16.5 kgm^{-2} compared to 16.4 kgm^{-2} the larger scale model has a slight dry bias (IWV is 16.1 kgm^{-2}).

Similar to IWV the cloud base height shows a clear annual cycle with maximum heights in summer. Since most clouds captured by the ceilometer are low level clouds this represents the deeper boundary layer in summertime. Model forecasts are not as good as for

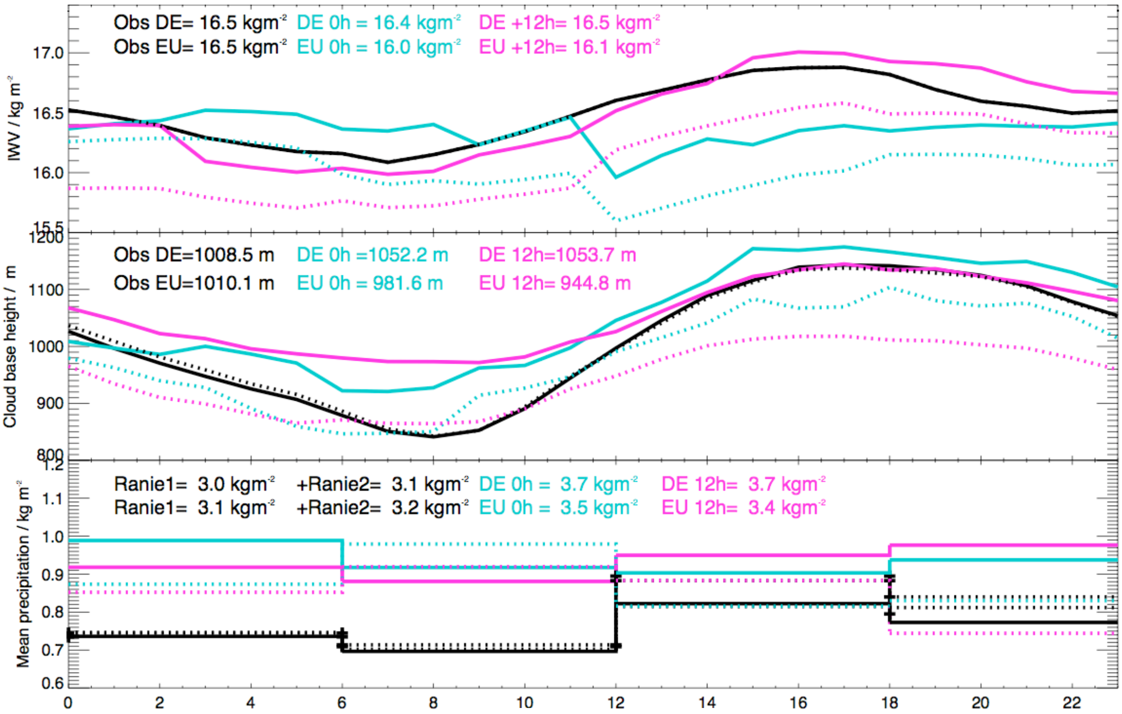

Figure 3. Diurnal cycle of *IWV (top), cloud base height (middle) and precipitation (bottom) during 2007 & 2008 from observations (black) and short-term model forecasts by COSMO-DE (solid) and COSMO-EU (dotted; blue for +0h and magenta for +12 forecasts).*

IWV because cloud formation involves sub-grid scale processes, which are highly parameterized in the model. Note also that only a rather small part of the water vapour is converted into cloud water and an even smaller one into rain. Generally CBH is underestimated in winter and overestimated in summertime, e.g. the seasonal cycle is too strong. The difference between analysed and short-term forecasted CBH is generally small, but the CBH in COSMO-EU is slightly lower than in COSMO-DE, especially in summer. Note that April 2008 was nearly cloud free and is therefore not representative.

Precipitation forecasts (Fig. 2) show the weakest performance of all model parameters, as it is the end product of several complex processes, but also the most difficult parameter to measure. In general the models forecast 20% more precipitation during winter compared to what has been measured, but – as these overestimates are mainly in orographic regions during northerly flow conditions (not shown) – this might be related to problems in the measurement of solid precipitation. In the summer months the RANIE2 observations are systematically higher than RANIE1 because the smaller scale convective precipitation is better captured by the addition of radar measurements to the coarse rain gauge network.

5. EVALUATION OF THE DIURNAL CYCLE

When looking at the mean diurnal cycle (Fig. 3) a clear signal in IWV and CBH can be detected in observations and model forecasts while the coarse 6 h resolution of the precipitation product barely indicates a maximum in the afternoon. Strong differences in the +0h and +12h forecasts reveal problems in the model analyses of IWV. At 12 UTC a jump of about 0.5 kgm^{-2} lower values is clearly visible. This can be explained by the assimilation of radiosondes launched at 12 UTC which suffer from a dry bias due to radiative effects [1]. Interestingly after 12h of forecast IWV has recovered from this dry bias. The best correspondence between model and measurements occurs for the COSMO-DE 12-hour forecasts with only a slight overestimation of the diurnal cycle.

The ceilometer observations show a stronger diurnal cycle than the models. With increasing lead time (+0 to +12h) the diurnal cycle weakens. Similar to IWV the COSMO-EU model shows in a weaker diurnal cycle indicating the importance of high resolution for boundary layer processes. The generally lower values of CBH in COSMO-EU compared to COSMO-DE can be explained by the fact that the same thresholds are used in both models for detecting cloud base height from the vertical distribution of cloud fraction. While COSMO-DE captures the maximum CBH in the afternoon (when the boundary layer has its maximum vertical extent) the early morning CBH is overestimated. This is likely due to the underestimation of fog which is often observed by the ceilometers during that time of the day. The difficulty of correctly predicting morning fog in summer is also emphasized by the large RMS errors (not shown).

All COSMO models show higher values compared to the RANIE products throughout the day, reflecting that the wintertime overestimation of precipitation compared to the measurements does not have a clear diurnal cycle, The afternoon maximum of the observations typical for convective precipitation does not show up in any of the COSMO models. However, a better time resolutions is needed for a detailed analysis of the diurnal cycle.

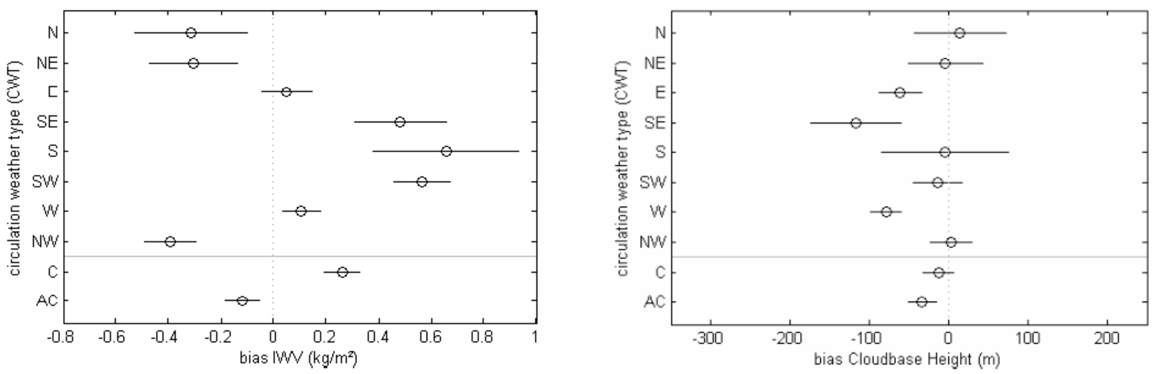

Figure 4. *Dependence of bias in IWV (left) and cloud base height (right) on circulation weather type for the full domain.* The grey horizontal line separates the 8 directional CWT classes from the vorticity classes (cyclonic and anticyclonic). The grey vertical dotted line indicates the zero-bias (where the mean bias between model and observations equals zero).

6. REGIME-DEPENDENT MODEL EVALUATION

The previous analysis concentrated on the model bias over the full period of two years. Compensating model biases might not show up in such an analysis. A regime dependent model evaluation can identify compensating biases, but can also help in finding the underlying causes for the model biases.

The classification scheme used here [2] is a variant of the Jenkinson-Collison technique, which is in turn an automated version of the Lamb classification. Every 3 hours the main weather type is calculated from the COSMO-EU analysis of the geopotential height field at 850 hPa for the whole domain and separately for a southern, central and northern Germany. In total 10 different regimes (circulation weather type CWT) are discriminated with 8 directional (, North – N, North East – NE, East – E, South East – SE, South – S, South west – SW, West – W, North West – NW) and two vorticity classes (cyclonic – C and anticyclonic – A).

From a multiple comparison of means (MCM) test, it appears that model biases are dependent on the circulation weather type, especially for IWV but also – to a lesser extent – for CBH (Fig. 4). The COSMO-DE model underestimates IWV by -0.3 to -0.4 kg m^{-2} during the northerly flow conditions, whereas it overestimated IWV +0.5 to +0.6 kg m^{-2} during southerly flow conditions. This means that for northern CWTs the air is modeled too humid and for the southern CWTs too dry. A somewhat similar pattern is recognizable if the classification is based on the 500 hPa level, but here the underestimation is less clear and for the northern and northeastern regimes even not significantly different from zero.

When looking at the CWT dependency of the cloud base height (Fig. 4 right) an inverse picture to IWV emerges. During southerly flow the model overestimates humidity and therefore ascending air parcels reach saturation earlier leading to a lower cloud base. Although the CWT dependency of the CBH is weak compared to the IWV for the entire domain the signal becomes much clearer if only Northern Germany is considered (not shown). Because Northern Germany is much flatter than the rest of the country orographically induced clouds might mask the signal in the Central and Southern Germany.

7. CONCLUSIONS

An approach for long-term model evaluation using GPS and ceilometer network together with surface precipitation observations is presented. The analysis of the COSMO-DE and COSMO-EU forecasts over a period of two full years yields the following results:

1) Data assimilation has a strong influence on the diurnal cycle through the dry bias of radiosondes launched during noon. During 12h of forecast COSMO-DE has compensated initial water vapour deficits and developed even a slightly stronger diurnal IWV cycle (1.0 kgm^{-2}) than observed (0.8 kgm^{-2}).

2) Diurnal cycle in cloud base height is predicted too weakly while the seasonal cycle is predicted too strongly. The poorest forecasts occur during night in summer indicating that the parameterization of stable boundary layer needs further attention. The connection between cloud base height and atmospheric moisture is most pronounced in summer during undisturbed conditions when the boundary layer is often too moist and not deep enough.

3) The 20% larger models forecast of precipitation during winter compared to the measured values indicates that precipitation is the most difficult parameter to model and to measure.

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