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Atmospheric Measurement Techniques Discussions

Interactive comment on "Assimilation of GPS radio occultation data at DWD" *by* H. Anlauf et al.

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P1534: the abstract mentions that there is a positive impact on surface pressure with the assimilation of GPS RO observations. However, this is not shown in the text. I can only see a very marginal impact with the use of TerraSAR-X (Fig 7). The comment on surface pressure should be removed from the abstract or additional plots/discussion need to be provided.

We agree that the impact of the assimilation of GPSRO on surface pressure is small and we will remove the comment on surface pressure in the abstract.

We do actually see a small impact on surface pressure. However, with the introduction of GPSRO we had to simultaneously change the variational quality control for surface pressure observations as explained in section 2.2. It is difficult to disentangle the contributions from both changes, but the old VQC procedure for surface pressure was

known to give slightly better scores (before assimilation of GPSRO).

In order to quantify the combined impact of the changes, we show here (figures 1 and 2 at the end of this reply) the RMS differences of surface pressure forecast to analyses for the Northern and Southern Hemispheres. Error bars correspond to 68% confidence intervals, see also further down in this reply.

Note, however, that we do not intend to add these figures to the manuscript.

P1535: The introduction should contain a paragraph indicating that GPS RO data is being assimilated operationally at the major weather centers. References to the work being done within the operational community would also be appropriate.

We will mention the operational use of GPSRO at NWP centers and a reference to the proceedings of the GRAS SAF workshop and the OPAC2010 workshop where an overview of the work being done in the community can be found.

P1536: Is there a reference for Gorbonuv's forward operator?

Unfortunately there is no citable writeup of Michael Gorbunov's implementation of the 1D-Var forward operator. The calculation of the interpolated refractivity and its adjoint uses algorithms from the 3D ray-tracer documented in the cited MPI report 350. The method of numerical integration is outlined in the text below Eq.(3) and essentially corresponds to the "linear algorithm" described in GRAS SAF Report 07, available from the cited GRAS SAF website.

P1537: Equation 2 should contain a reference to the original author (Rueger) instead of the report/article where it was taken from. Many studies, in Europe and other places, make use of Rueger s equation.

We will add a citation of Rüeger's paper, clarify that the quoted GRAS SAF Report 05 recommends this formula, and stress the importance of the review paper by Healy. See also the answer to report #1.

P1537: Why do you use climatology information above the model top to compute the bending angles? Most centers usually extend the atmosphere by extrapolating the model top levels. One of the nicest features of the bending angle forward operator is that its assimilation can be done without requiring climatology information. Have you checked other approaches and if so, how do the results compare?

Judging from comparison to radiosondes, we do not consider the GME model state very reliable near the model top, see also Fig 2. Therefore we chose to extend the model state above the top by matching a profile from the MSIS climatology instead of extrapolating the model. We have not checked other approaches, like matching a forecast of another model on top of our atmosphere.

P1538: The errors you chose seem to be a combination of forward model errors and observational errors. The forward model component depends on the characteristics of the specific model being used. Have you tuned these errors to adjust them to the characteristics of your forecast model?

The error assigned to GPSRO observations, which is a combination of forward model error and observational error, is taken from a simple parameterization, i.e. the error model of Healy and Thepaut (2006). There is no separate treatment of forward model error and observational error yet, but currently there are also no error estimates by the processing centers for individual occultations (except for COSMIC by UCAR).

No tuning has been done. Statistical analysis of the differences of observation to forecast and observation to analysis (see e.g. Desroziers et al.) suggests that the optimal observation error does depend differently on height and on latitude, with larger errors in the tropics than in the extratropics, but the used error model works reasonably well for a first implementation. Furthermore, tuning also needs to regard the ratio of background and observation error. This is beyond the scope of the present article.

P1538: Was there a problem in the CDAAC processing of the profiles? Do you have a reference or explanation for this? I am not aware of any changes addressing the

coordinates of the assigned point on Earth for a profile.

The presentation of the issue with COSMIC data was too vague, so we will extend the description of the problem we encountered. Since this point was also brought up in referee report #1, please see the answer to that report.

P1544: Is there a particular reason for stopping the assimilation of bending angles at 30km? Is it close to your model top?

The GME model top is currently located at 5 hPa, which is at roughly 36km, and 30km is close to the second model level, thus model vertical resolution is already low. Furthermore, when GPSRO were being tested for operational use, there were known strong biases of the temperature near the model top, which is also visible from figure 2, and there were issues with the vertical background error covariances near the model top.

P1542: I am a bit confused with the paragraph describing the blacklisting of observations south of 65 degrees. Are these profiles being used in the operational configuration?

The blacklisting of GPSRO south of 65°S was only tested in a separate experiment. Since we did not find significant differences to the "control experiment" (including all GPSRO) in the comparison against radiosondes outside the Antarctic region, we decided against blacklisting in the operational implementation. We will improve the formulation in the text.

P1543: How often are the bias correction coefficients being updated in your static bias correction approach?

Since this point was also brought up in referee report #1, please see the answer to that report.

P1543: Fig. 2 shows a slight degradation around 150-200 mb in the tropics and southern hemisphere extra-tropics with the use of GPS RO data. Does this pattern repeat for other periods? Have you investigated possible explanations?

The origin of the apparent degradation in temperature bias around 150–200 hPa in the tropics and in the Southern Hemisphere is not completely understood. In the tropics, the GME is known to prefer a stable stratification of the troposphere (see e.g. the bias at 500 hPa and below), and the region around the tropical tropopause may not be well represented. The behaviour in the Southern Hemisphere is less clear. Biases do slightly vary with time, but the observed behaviour of biases was consistent for the months June (not shown) and July 2010, and the RMS difference to observations was always better for the GPSRO experiment. Also, the number of used temperature observations from radiosondes was consistently higher in the GPSRO experiment.

P1544: Since the relative humidity depends on the temperature, improvements on this variable might reflect an improvement on temperature rather than moisture. Have you looked at the verification of pure moisture variables, such as specific humidity?

In the 3D-Var, temperature and relative humidity are independent control variables, which is why these are shown in verification plots. This is also done by other centers, like ECMWF. Verification in specific humidity is currently not implemented.

P1544: What is the statistically significance of figures 4 and 5? Some information on the level of confidence of the results should be provided with these figures.

As written in the caption of figure 4, the given error bars are the estimated uncertainty of the mean as calculated from the time series in a very simple way. Since the error distribution is non-gaussian, one needs to use other methods to the estimate statistical significance. We checked this using the bootstrap method and found that the given error bars are roughly consistent with the 68% confidence interval from the bootstrap method.

We have also calculated the 90% confidence intervals for the anomaly correlation of the 500 hPa geopotential in the Southern Hemisphere using the bootstrap method. We will replace figure 5 (see figure 3 of this reply) and adjust the caption accordingly.

Fig. 6. The global mean (left) and standard deviation (right) of observation minus first-guess (continuous lines) and observation minus analysis (dashed lines) of the TerraSAR-X (blue) bending angle departures for impact heights from 3 km to 30 km, and compared to COSMIC FM-1 (red). The departures are normalized with respect to the observed bending angles. The statistics is based on 28 days of data (22 October to 18 November 2010). The central columns display the number of samples passing first-guess checks and being used after the variational quality control within a 1-km interval (left: TerraSAR-X, right: COSMIC). Impact heights between 21–22 km, 23–24 km, and 25–26 km were sparsely populated after vertical thinning.

P1545: Is it possible to add the statistics for COSMIC along with the statistics for TerraSAR-X. The text indicates that the quality of TerraSAR-X is similar to COSMIC; but this is difficult to verify it, if statistics for COSMIC is not provided.

We will replace Figure 6 by the version given below (figure 4 of this reply), with adjustments to the text (see the new caption). Note that agreement of the statistics between TerraSAR-X and COSMIC is very good for impact heights above 8km. Below 8km TerraSAR-X appears to have better bias and standard deviation in the comparison to the GME background. On the other hand, COSMIC occultations generally have a better penetration into the lower troposphere, which can be verified by comparing the number of used observations as function of the impact parameter. The smaller penetration of TerraSAR-X makes the interpretation of the statistics at smaller impact heights difficult, so that we can only claim similar quality.

P1454: Does the marginal impact found on surface pressure with the use of TerraSAR-X extend to other variables? I would like to know if the almost neutral impact is found for other fields as well.

The impact from the additional assimilation of TerraSAR-X data during this period was neutral or marginal but not significant for 500 hPa geopotential height, surface pressure, or temperature at 50 hPa. In the text we will replace "very little positive" by "marginal".

P1454: Please, add Taiwan along with UCAR to acknowledge the use of the data from the COSMIC/FORMOSAT-3 mission.

We will add TACC and Taiwan along with UCAR in the acknowledgments regarding the operational data provision from the FORMOSAT-3/COSMIC mission.

Interactive comment on Atmos. Meas. Tech. Discuss., 4, 1533, 2011.

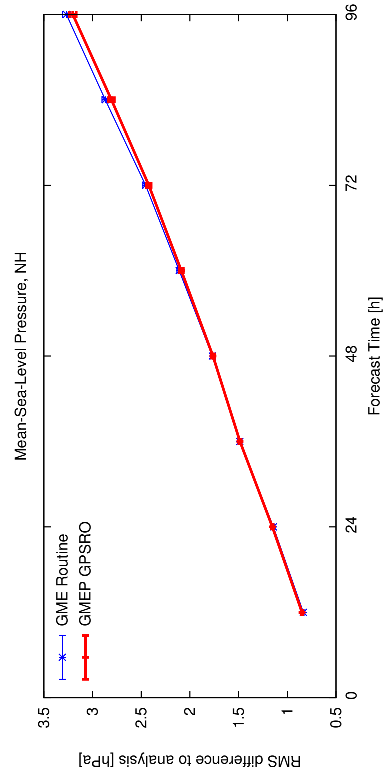


Fig. 1.

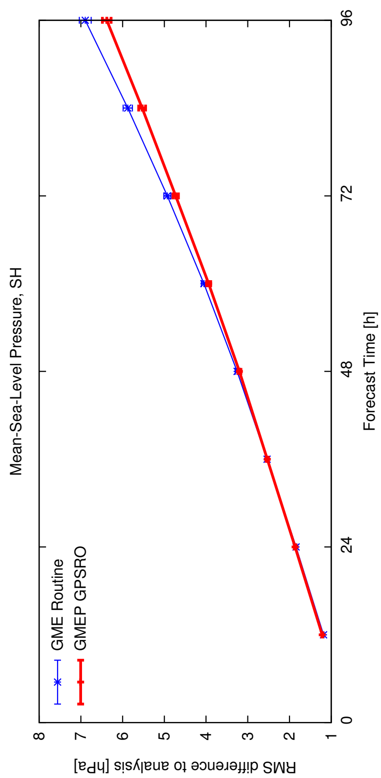

Mean-Sea-Level Pressure, SH
GME Routine
GMEP GPSRO
RMS difference to analysis [hPa]
Forecast Time [h]
0
24
48
72
96
1
2
3
4
5
6
7
8

Fig. 2.

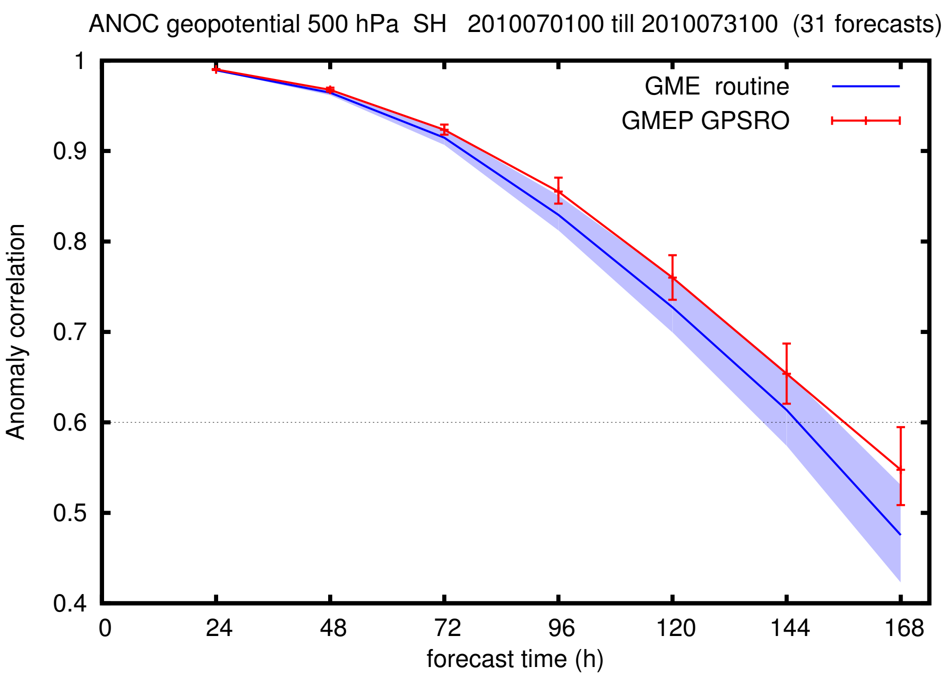
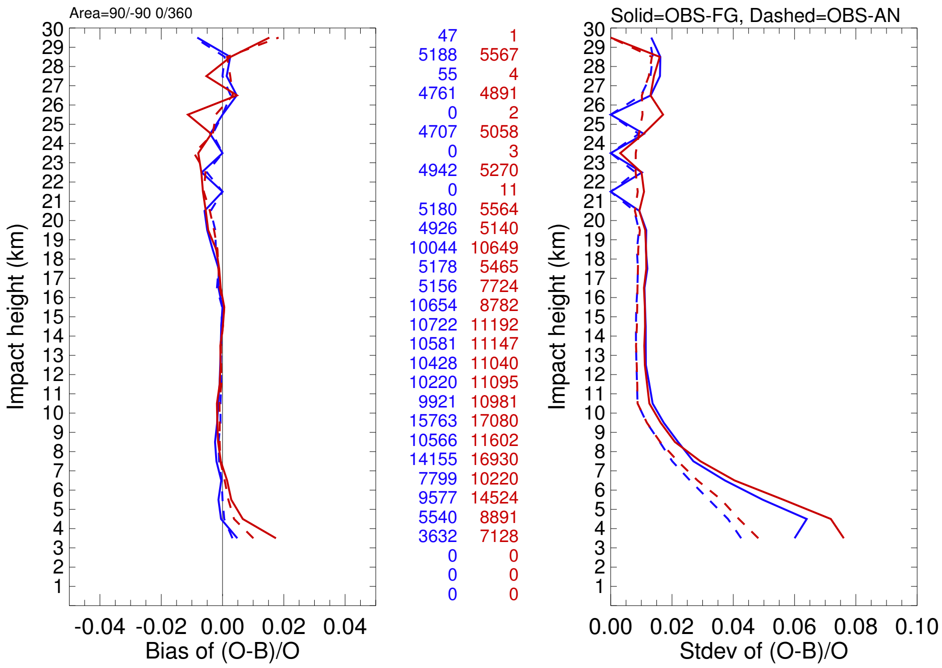

ANOC geopotential 500 hPa SH 2010070100 till 2010073100 (31 forecasts)
GME routine
GMEP GPSRO
Anomaly correlation
forecast time (h)
0.4
0.5
0.6
0.7
0.8
0.9
1
0
24
48
72
96
120
144
168

Fig. 3.


Area=90/-90 0/360
Impact height (km)
Bias of (O-B)/O
-0.04 -0.02 0.00 0.02 0.04
Solid=OBS-FG, Dashed=OBS-AN
Stdev of (O-B)/O
0.00 0.02 0.04 0.06 0.08 0.10
47 1
5188 5567
55 4
4761 4891
0 2
4707 5058
0 3
4942 5270
0 11
5180 5564
4926 5140
10044 10649
5178 5465
5156 7724
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9921 10981
15763 17080
10566 11602
14155 16930
7799 10220
9577 14524
5540 8891
3632 7128
0 0
0 0
0 0

Fig. 4.