Assimilation of GPS Radio Occultations at DWD

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The GME global model at DWD

The global model GME operated at the German weather service (DWD) is a state-of-the-art weather forecast model formulated on an icosahedral-triangular grid with a mean grid spacing of currently 30 km and a vertical discretization using 60 layers up to 5 hPa.

Initial data for the forecasts is provided by a 3D-Var data assimilation system with a 3-hourly update cycle.

The 3D-Var data assimilation system at DWD

In data assimilation, observational (y) and background (x_b) information is combined in a statistically optimal way, taking into account background and observation error covariance matrices B and R. A cost function

$$J(x) = J_b + J_o = (x-x_b)^T B^{-1} (x-x_b) + (y-H(x))^T R^{-1}(y-H(x))$$

is minimized in observation space to yield the analysis x. The global model GME provides the model background x_b.

Assimilation of GPS Radio Occultations

For GPS-RO observations, **bending angles** are chosen as quantity to be assimilated.

In preparation of operational assimilation of GPS radio occultation observations,

- evaluation of **bending angle forward operators H**
- **monitoring** of bending angle *(observation-first guess)*-statistics and
- numerical **forecast impact experiments**

were performed.

In a previous evaluation, a full three-dimensional ray-tracing GPS-RO forward operator based on geometrical optics was compared to several one-dimensional approximations that are based on the assumption of spherically symmetric atmospheric fields, thereby neglecting horizontal fluctuations of refractivity. These approximations apply an inverse Abel transform to the refractivity profile, yielding a bending angle profile.

It was found that using a properly optimized, numerically less expensive and therefore affordable one-dimensional forward operator works sufficiently well for initial operational use. The 1d forward operator chosen neglects the tangent point drift during the occultation. We use an effective georeferencing point that is obtained by averaging the tangential points of the lowest lying rays instead of the georeferencing point as given by the bending angle data provider.

The bending angle forward operator implemented in the 3D-Var is based on an implementation by Michael Gorbunov. The refractivity calculations are performed using the coefficients recommended by the GRAS-SAF project. An MSIS climatology is used for the extrapolation above the model top.

Observation errors

Observation error for GPS-RO is specified relative to the bending angle value. A functional model by S. Healy is applied:

- linear decrease from 10% to 1% for 0 to 10km impact height.
- Above 10km, the observation error is assumed to be 1% minimum, with lower absolute limit of $6x10^{-6}$ rad

The COSMIC/FORMOSAT-3 data contain an estimate of the associated bending angle observation error which is often significantly lower than the value of the Healy model. However, a closer look at observation minus first-guess statistics of our experiments suggested to use the larger value of either the provided error or the modeled error.

Bending angle selection, quality control

- A **consistency check of provided tangent point and georeferencing point** is applied for each ray (maximum separation: 330 km), which discovers occasional problems with COSMIC data
- A **4 sigma-(observation – first guess) check** is applied to remove outliers
- Observations with a **relative observation error > 10%** or an **absolute observation error > 0.01** rad are discarded: removes observations mostly in the tropical lower troposphere (influence of humidity fluctuations) and in the stratosphere (residual stratospheric fluctuations induce additional noise).
- The **value of the bending angle is confined** to the interval [0,0.02] to exclude errors due to ducting processes.
- **Adjustment of observation errors**: To achieve a better balance in the assimilation process, individual observation errors are adjusted such that e_o/e_{bg} > 0.5
- **Exponential smoothing** of bending angle profile (removes small scale fluctuations)
- **Clipping of the lowest section of the GPS-RO profile**: Resolution of nonlinearities by radio-optical processing can cause a non-monotonic bending angle profile. Beneath a given impact height parameter (presently 8000 m), the GPS-RO profile section below such points of non-monotonicity is discarded
- **Vertical thinning**: GPS-RO-observations passing quality control are vertically thinned to approximate model resolution:
  - 3 – 10 km impact height: thinning to a vertical spacing of 400 m
  - 10 – 20 km impact height: thinning to a vertical spacing of 500 m – 700 m
  - 20 – 30 km impact height: thinning to a vertical spacing 2 km
- Exclusion of **occultations starting above 20km**: these are mostly rising occultations which are expected to have larger first-guess departures

Results

Numerical experiments to assess the impact of the assimilation of GPS-RO on analyses and weather forecasts were performed for different periods and seasons. Here are selected results of recent comparisons with the operational system.

- Period: June 19 – July 20, 2010
- **Assimilated observation data**:
  - SYNOP
  - TEMP, PILOT
  - DRIBU, PAOB
  - AIREP
  - SATOB
  - SCATT
  - AMSU-A
  - GPSRO
    - COSMIC/FORMOSAT-3 FM1-FM6
    - GRAS/METOP-A
    - GRACE-A

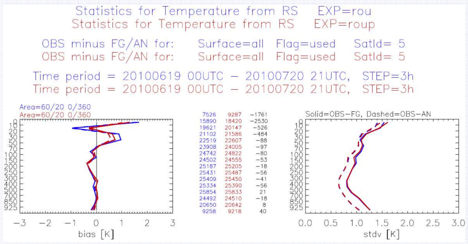

Figure 1: **Observation minus first-guess (3-hour forecast) statistics of radiosonde temperatures**, northern hemisphere (20°N-60°N). There is a large improvement of bias (left) and standard deviation (right) in the experiment (continuous red line) over the operational system (continuous blue line) especially in the upper troposphere and in the stratosphere. The number of used observations is higher in the experiment, indicating that the short-range forecast is closer to the observations.

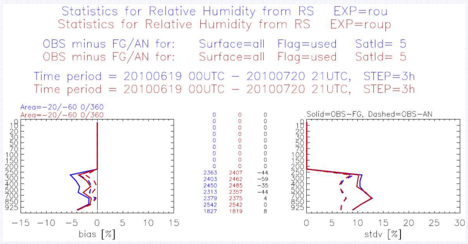

Figure 2: like fig.1, but for radiosonde **relative humidity**, southern hemisphere

Results (cont'd)

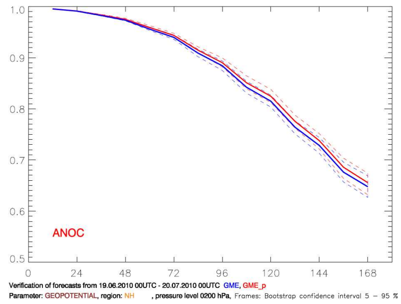

Figure 3: **anomaly correlation coefficient** as function of forecast time of **200 hPa geopotential** in the **northern hemisphere**

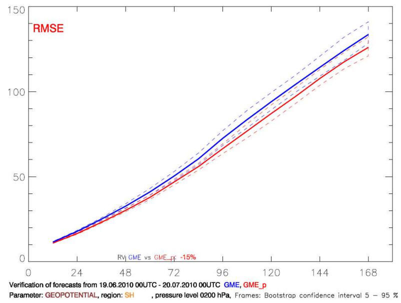

Figure 4: RMS error of **200 hPa geopotential, southern hemisphere**

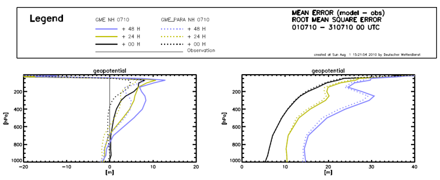

Figure 5: **Verification of forecasts against radiosondes, geopotential**, northern hemisphere, experiment (dotted lines) vs. operational system (continuous lines): Initialized analysis (black), 24 h forecast (yellow), 48 h forecast (blue). Left: bias, Right: RMS error.

Summary

- Assimilation of GPS-RO bending angle observations **significantly improves the weather forecast**, especially in the southern hemisphere, where there are less conventional observational data, but has a large positive impact on the northern hemisphere as well, particularly with respect to biases
- GPS-RO are used in the 3D-Var of the **operational** global forecast system at DWD **since 03-08-2010 00 UTC**

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