# Assimilation of GPS observations into the MM5 4D-Var system during a six month period covering D-PHASE and COPS

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## Introduction

Precipitation has a strong influence on our economy and general livelihood. Especially, the forecast of small-scale severe precipitation events is among the most difficult tasks in meteorology. More sophisticated observing systems, e.g., lidar or GPS, will be available operationally in the future.

Lack of precise and continuous water vapor observations is besides model physics one of the major error sources in QPF. Integrated water vapor measurements from satellite have a very high coverage, but are affected by clouds.

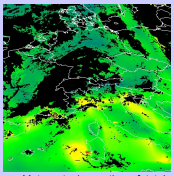

*Figure:* Meteosat observation of total precipitable water for 00UTC on 2007-08-14. Regions covered by clouds are black.

## Observations and Forward Operator

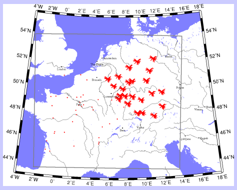

*Figure:* Used observations from a representative 3h period during D-PHASE. Shown are the rays from the receivers to the model top.

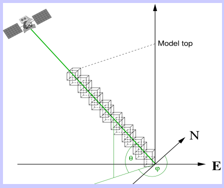


*Figure:* GPS ray passing the model atmosphere.

### GPS observations

GPS (Global Positioning System) STD (Slant Total Delay) observations contain indirect information about water vapor content, temperature and pressure of passed air masses.

Benefits are:

- High spatial coverage and temporal resolution
- Observations are also available in the presence of clouds.
- A bunch of slant observations provide small-scale structure of the boundary layer.

Slant data were provided by the Geoforschungszentrum Potsdam and additional zenith path data for France were supplied by UK MetOffice.

### Forward operator

$$\mathrm{STD} = \int_{\mathrm{receiver}}^{\mathrm{model\ top}} \left( C_1 \frac{p}{T} + C_2 \frac{pq}{(C_3+q)\,T^2} \right) ds + \mathrm{STD}_0$$

- Data with a too large difference to the ECMWF analysis and a too large difference between real and modeled terrain height were filtered out.
- For the calculation of the line integral along the ray path, the bending of the ray was neglected.
- Interpolation of Temperature (T), water vapor mixing ratio (q), and pressure (p) to intersection points of the ray and MM5 sigma levels
- Numerical integration along the ray path
- Contribution to the STD, which stems from above the model top ($\mathrm{STD}_0$), was calculated with the Saastamonian model.

## Problems and Possible Solutions

**Problem:**

- Horizontal diffusion along sigma levels leads to upward transport of moisture along mountain slopes.
- Anthes-Kuo convection scheme leads to over prediction of precipitation.
- Overestimation of moisture on top of hills enhances the effect of the Anthes-Kuo convection scheme.

**Solution:**

- Implementation of a horizontal diffusion and its adjoint similar to the one proposed by Zängl 2002.
- Implementation of the Grell convection scheme instead of the Anthes-Kuo convection scheme.

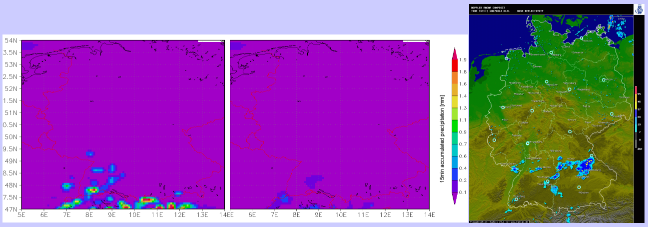

*Figure:* Rerun of the 18km forecast for August, 14 with model physics as in the assimilation, but exchanged horizontal diffusion scheme. Shown is the impact of on the precipitation for 2UTC. **Left panel**: 4D-Var configuration as in the operational D-PHASE set-up, **middle panel**: with exchanged horizontal diffusion, and **right panel**: radar composite from DWD.

## Model and Assimilation Set-up

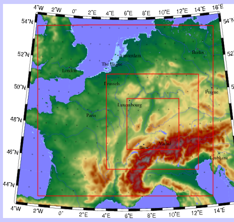

*Figure:* Boundaries of the 3 two way nested MM5 domains with 18, 6, and 2km horizontal resolution.

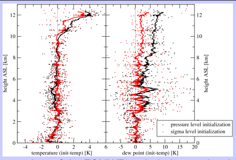

*Figure:* Comparison of the ECMWF analysis (mapped to the MM5 grid) with radiosondes. The red and black data show two different methods to map the ECMWF analysis to the MM5 grid.

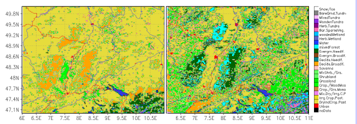

*Figure:* Comparison of the CORINE landuse dataset (right) used in our forecasts with the default USGS dataset (left).

**Assimilation**

- 18km horizontal resolution
- 36 vertical layers
- Simplified model physics (e.g. Anthes-Kuo convection scheme, sigma diffusion)
- 3h assimilation window (00 - 03UTC)
- ECMWF analysis is used as first guess and background

**Two free forecasts**

- 3 two way nests with 18, 6, and 2km horizontal resolution
- 36 vertical layers
- Sophisticated model physics (e.g. Kain-Fritsch convection scheme, horizontal diffusion of temperature perturbation)
- Explicit convection in the 2km domain
- Two forecasts:
  - initialized by the ECMWF analysis
  - initialized by our assimilation

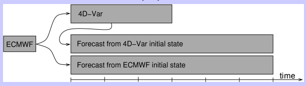


*Figure:* Experimental set-up during COPS/D-PHASE.

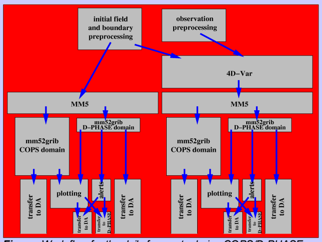


*Figure:* Work flow for the daily forecasts during COPS/D-PHASE.

## First Results

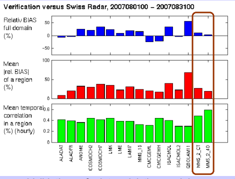


*Figure:* Validation of deterministic models, operational during D-PHASE, with Swiss radar. The same river catchments was used for all models. (by courtesy of Felix Ament (MeteoSwiss))

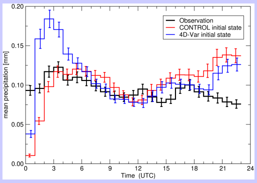


*Figure:* Mean diurnal cycle of precipitation in the COPS region for the three month period August-October 2007.

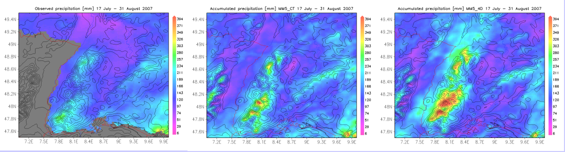

*Figure:* Horizontal distribution of the accumulated precipitation July, 17th to August, 31st. The panels are **left**: observation (REGNIE product of DWD), **middle**: MM5_2_CT, **right**: MM5_2_4D.

- The diurnal cycle of the precipitation was corrected by the assimilation later in the forecasts.
- Too much precipitation was forecasted in the assimilation window.
- Overestimation of precipitation especially in mountainous regions during the first hours of the forecasts.

## Outlook

**Further improvement of the model physics:**

- Spin-up run
- Coupling of atmosphere and soil model

**Observation systems from COPS:**

- Radar radial velocities
- Scanning lidar systems
- Temperature from Raman lidars
- Airborne lidar measurements

**Perform impact and process studies (COPS-GRID poster)**

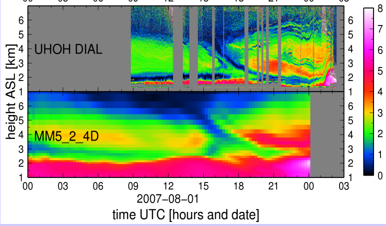


*Figure:* Comparison of observations from the water vapor DIAL system located at Hornisgrinde and the MM5 2km resolution water vapor forecast for IOP13 (2007 August, 1st)