GPS-ZTD and radar data assimilation using a convection permitting WRF 3DVAR-RUC configuration

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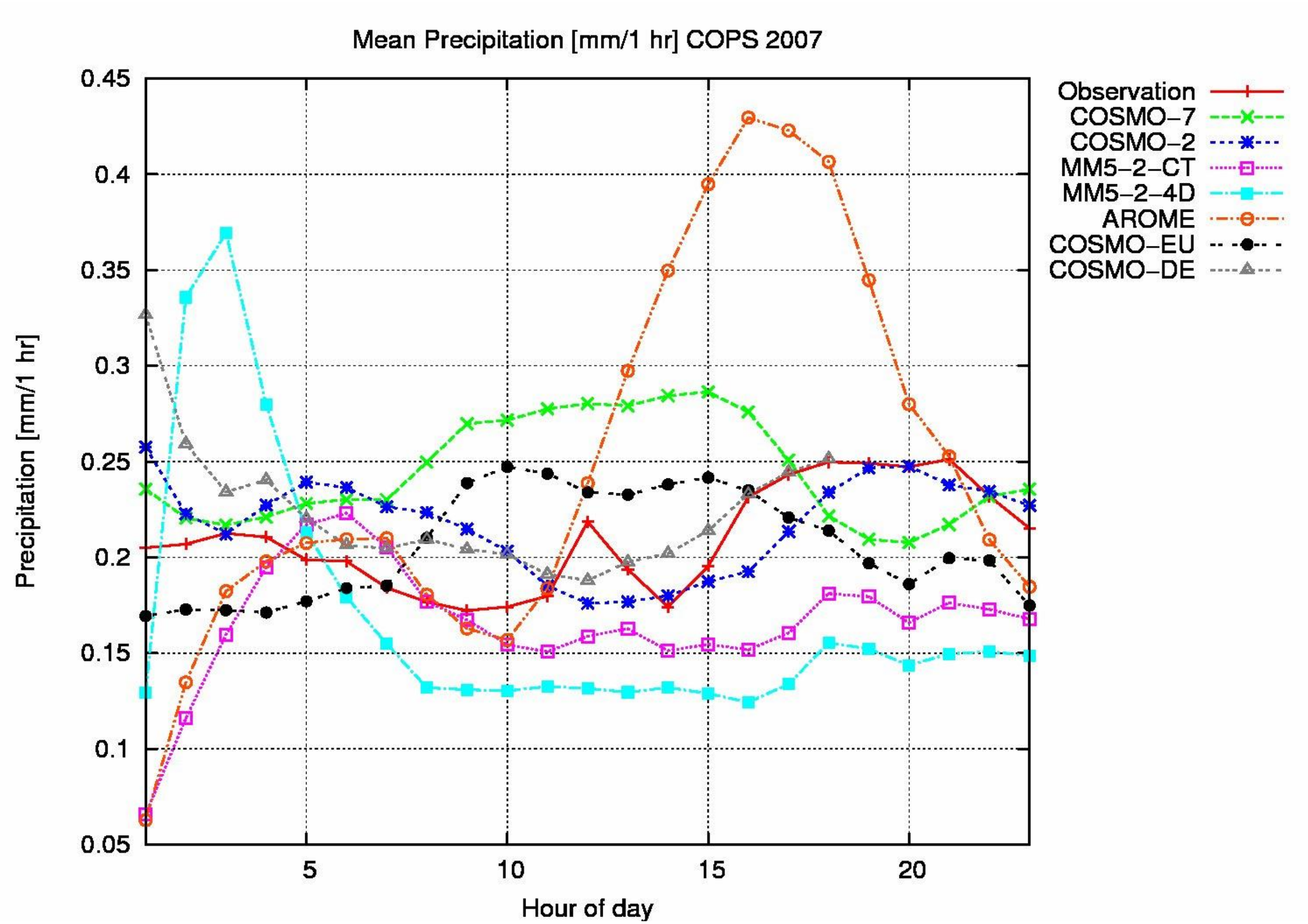
Outline

- Variational data assimilation techniques in Numerical Weather Prediction (NWP)
- Remote sensing data for nowcasting applications: GPS & Radar
    - Assimilation of GPS & Radar in WRF
- Summary
- Outlook

Why data assimilation?



Some aspects of data assimilation

- Think about crossing the street - this is data assimilation!
  - ➢ Estimating the current state using observations and your background
- A classical method is the Four-dimensional data assimilation (e.g. applied for the operational COSMO models)
  - Model fields are adjusted by adding a weighting term to the prognostic equations
  - Allows only assimilation of model's "prognostic observations"
- More recent methods are deterministic variational schemes like 3DVAR and 4DVAR
  - Use observation error matrices (**R**)
  - Include model background errors representing meteorological and model variability (**B**)
  - Allow non-prognostic observations (Radar, GPS, radiances…)
  - Uses the (full) forecast model in case of 4DVAR

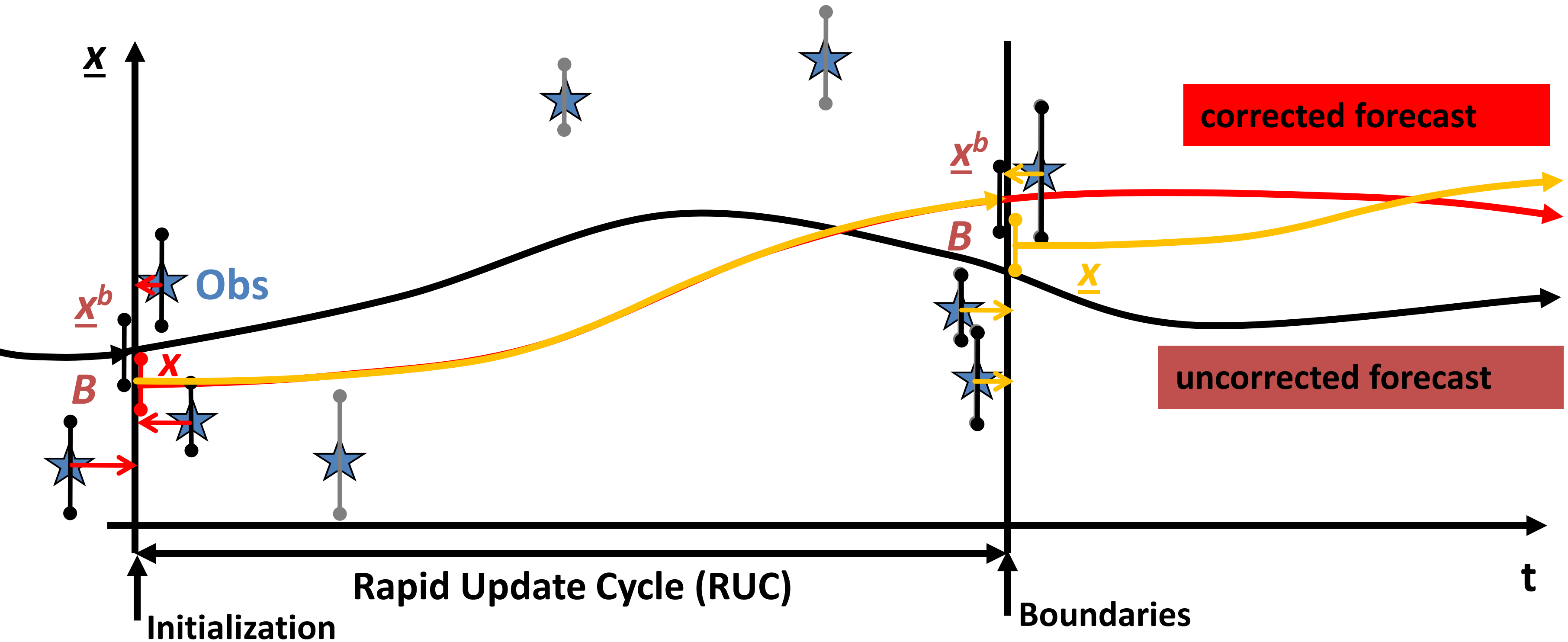
Some aspects of data assimilation (2)

- Requires a forward operator (H) and its adjoint
- New initial state ($\underline{x}$) is determined by minimizing a "cost function" (J), describing differences between observations ($\underline{y}$) and background ($\underline{x}_b$)

$$J(\underline{x}) = \left(\underline{x} - \underline{x}^b\right)^T \underline{\underline{B}}^{-1} \left(\underline{x} - \underline{x}^b\right) + \left(\underline{y} - H(\underline{x})\right)^T \underline{\underline{R}}^{-1} \left(\underline{y} - H(\underline{x})\right)$$

- **B** would be a 10^7x10^7 matrix, therefore control variables are introduced to reduce the size of B to 10^7 elements
- **R** is usually a diagonal matrix describing the observation errors. Cross correlations are neglected (except for high-resolution satellite data).
- 3DVAR rapid update cycle (RUC) used by several meteorological centers
- High-resolution 4DVAR is often in development state
- Requires lots of computing resources

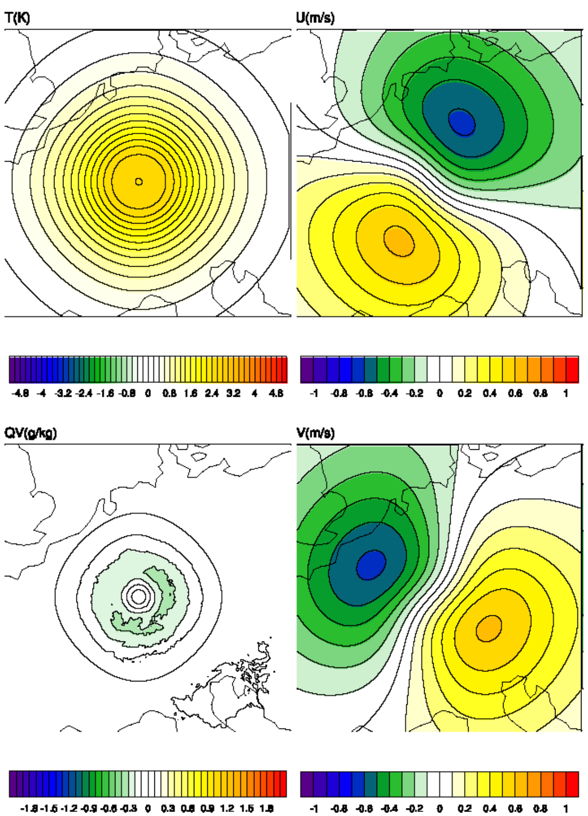
3DVAR Methodology

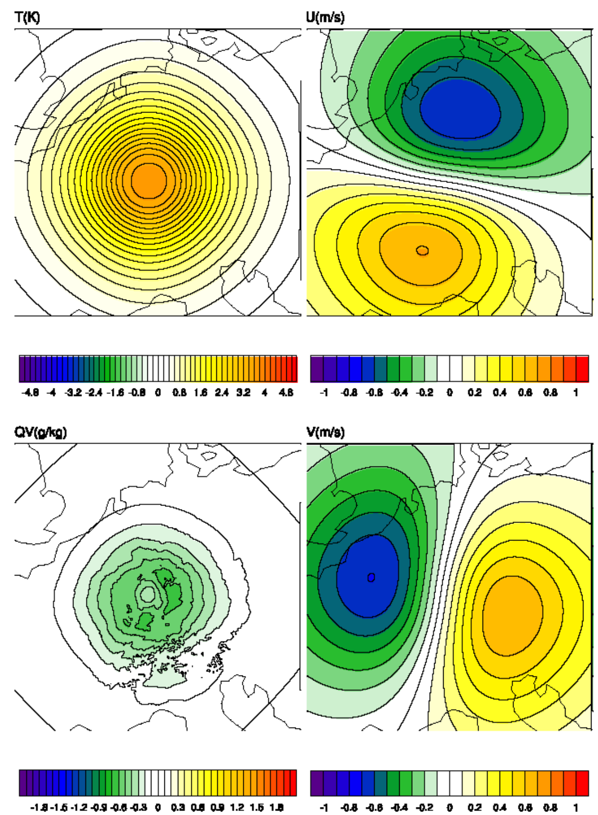


In a 3DVAR RUC, the full complex model can be applied between the assimilation steps, but *B* matrix remains constant and the adjoint of *H* required.

Some informationsabout **B**

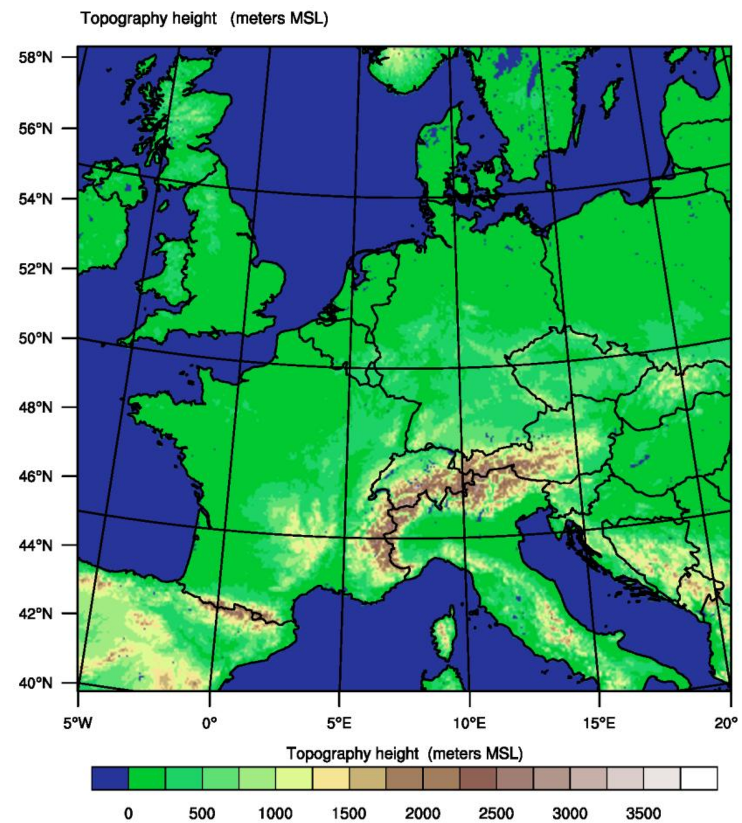
- ***B*** must spread information both vertically & horizontally with proper weights to observations and first guess.
- Contains correlations and cross correlations between control variables



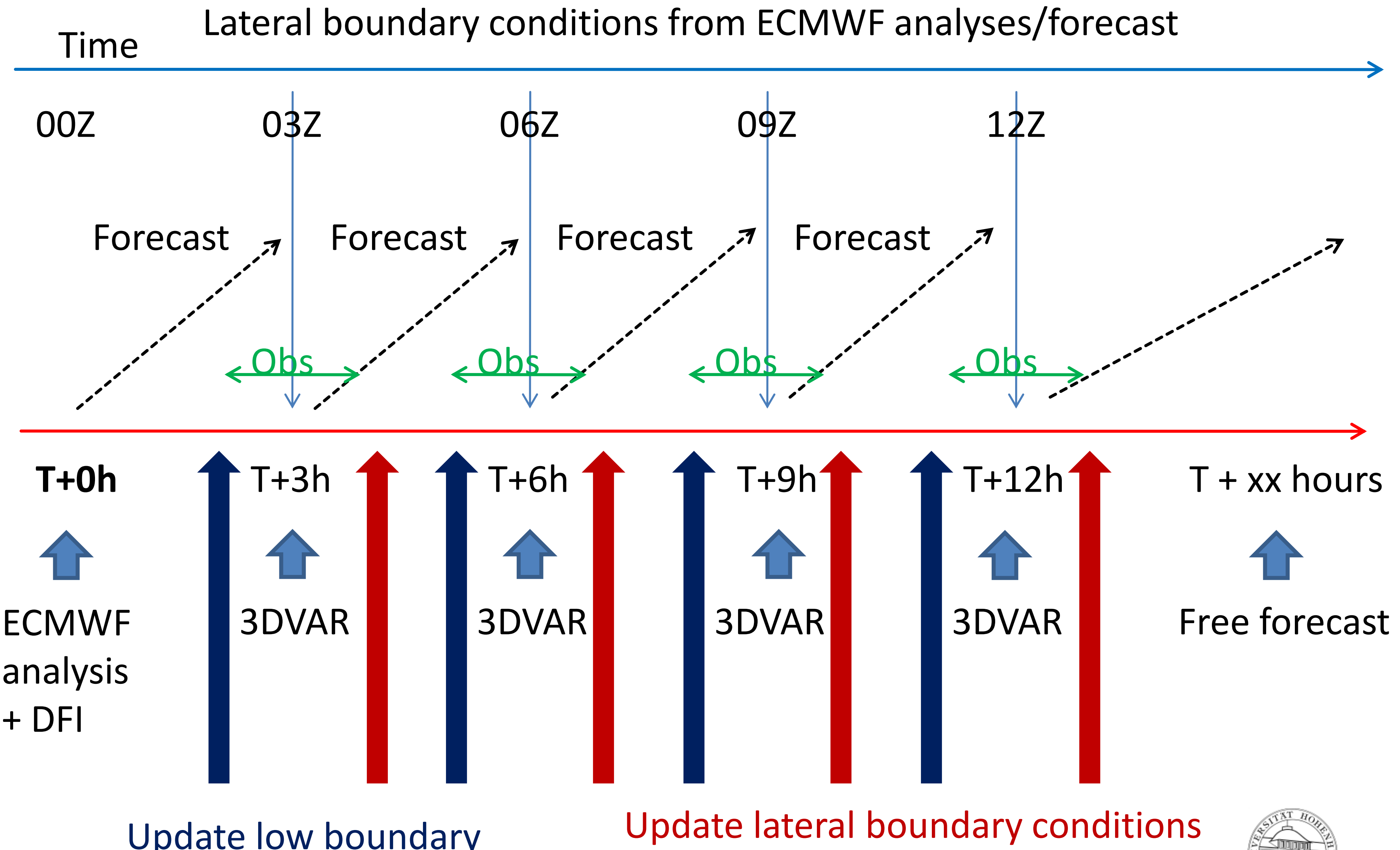


WRF model setup

- Convection permitting resolution of 3km
- 691*682*57 grid boxes (COSMO-IT 502*604*50@2.8km)
- Two-Moment microphysics
- Digital Filter initialization
- New vegetation fraction from MODIS
- Boundaries from ECMWF
- Shallow convection
- 3DVAR RUC
- Simulations are performed on a Cray XE6/XC30 system using 960 cores



Rapid Update Cycle approach with WRF used at IPM



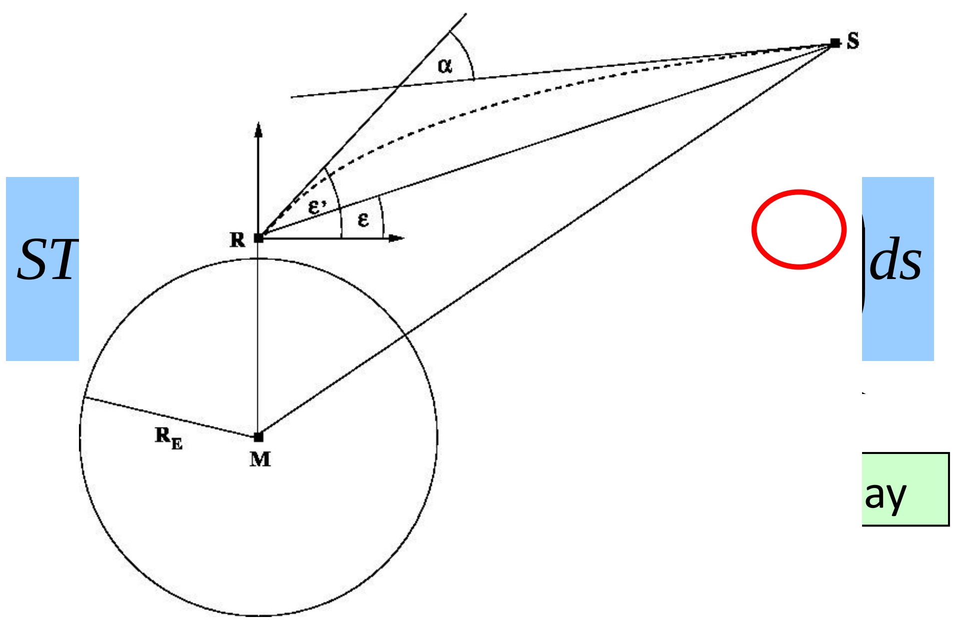
Available observations

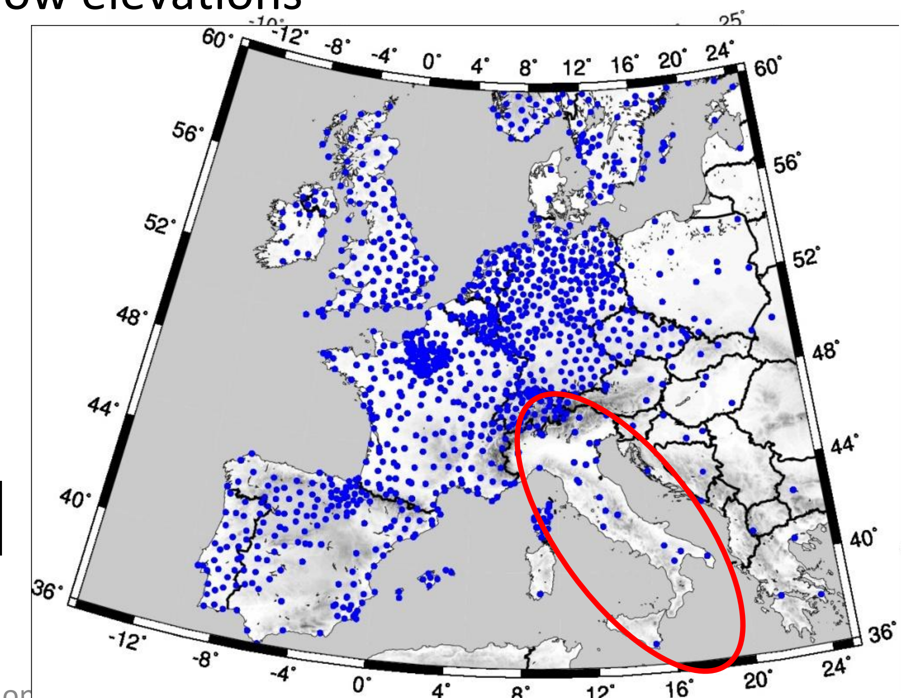
- **Conventional observations (SYNOP, AMDAR, TEMP…)**
- **MSG Atmospheric Motion Vectors from IR, WV and HRV channels**
- **QuickScat sea winds (12.5km resolution)**
- **GPS-ZTD data (~950 stations in our domain, over land only!)**
- **Radar radial velocities and reflectivities (only French and German data used -> OPERA?)**
- **Satellite radiances from polar orbiting satellites (HIRS, AMSUA/B, AIRS, IASI, MHS)**
- Raman Lidar data (experimental)

- Conventional observations are obtained via the ECMWF MARS
- AMV and QSCAT data are retrieved from EUMETSAT UMARF archive
- GPS-ZTD are downloaded from EGVAP
- Radar data have been received directly from Météo France and DWD during COPS
- Satellite data are received from the NCEP archive (dss 735.0)

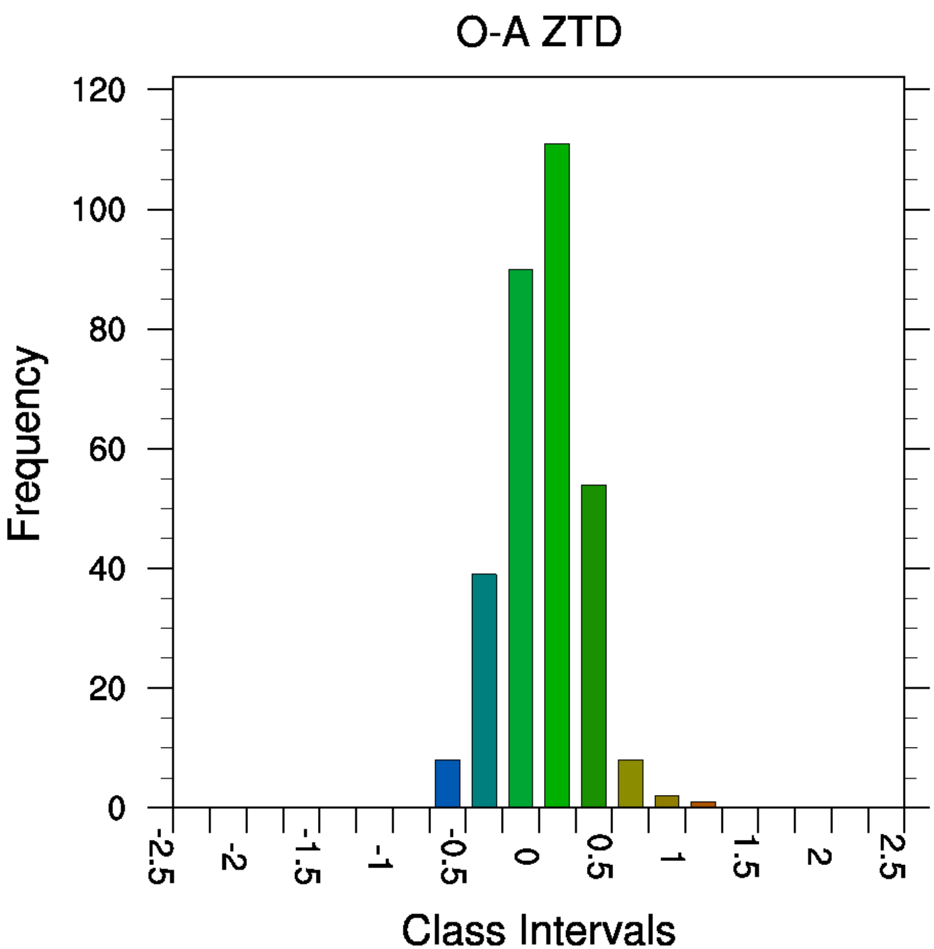
GPS data assimilation

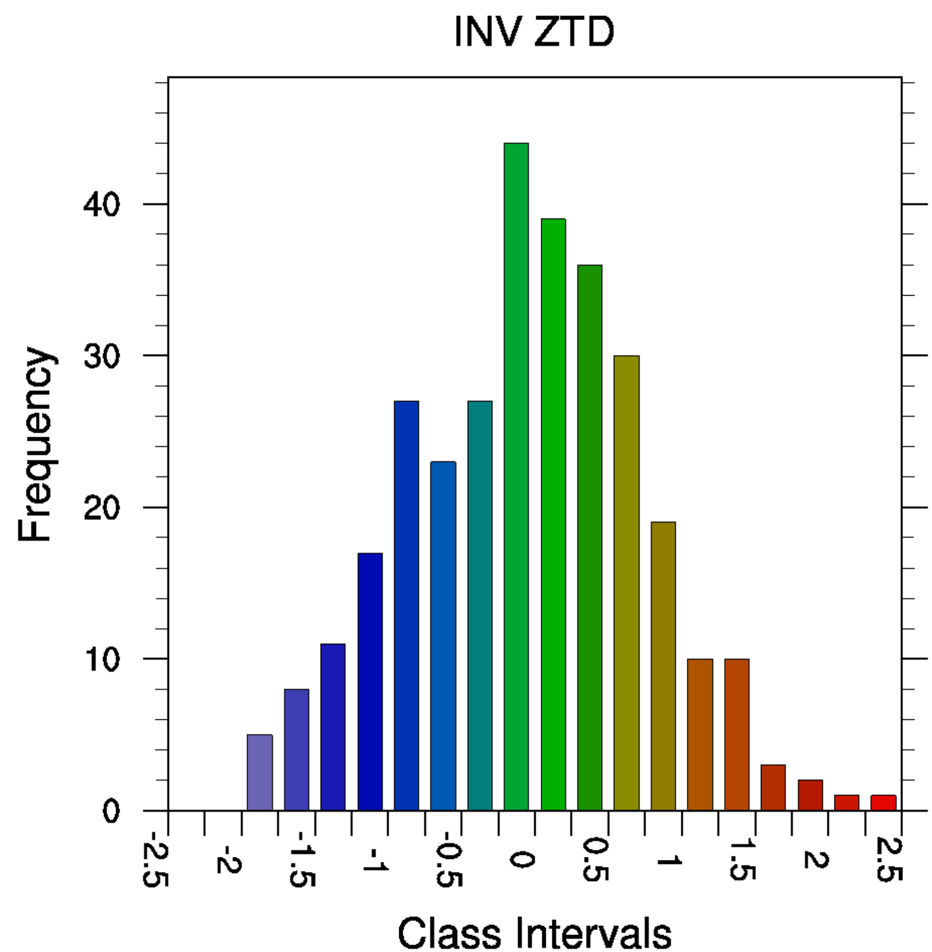
- Water vapor information can be derived from GPS by measuring the signal delay between satellite and receiver
- GPS provides data with large spatial coverage and high time resolution (15 minutes) under all weather conditions.
- A large impact of GPS data assimilation on the improvement of the initial water vapor field is expected.
- Complex STD operator required for low elevations





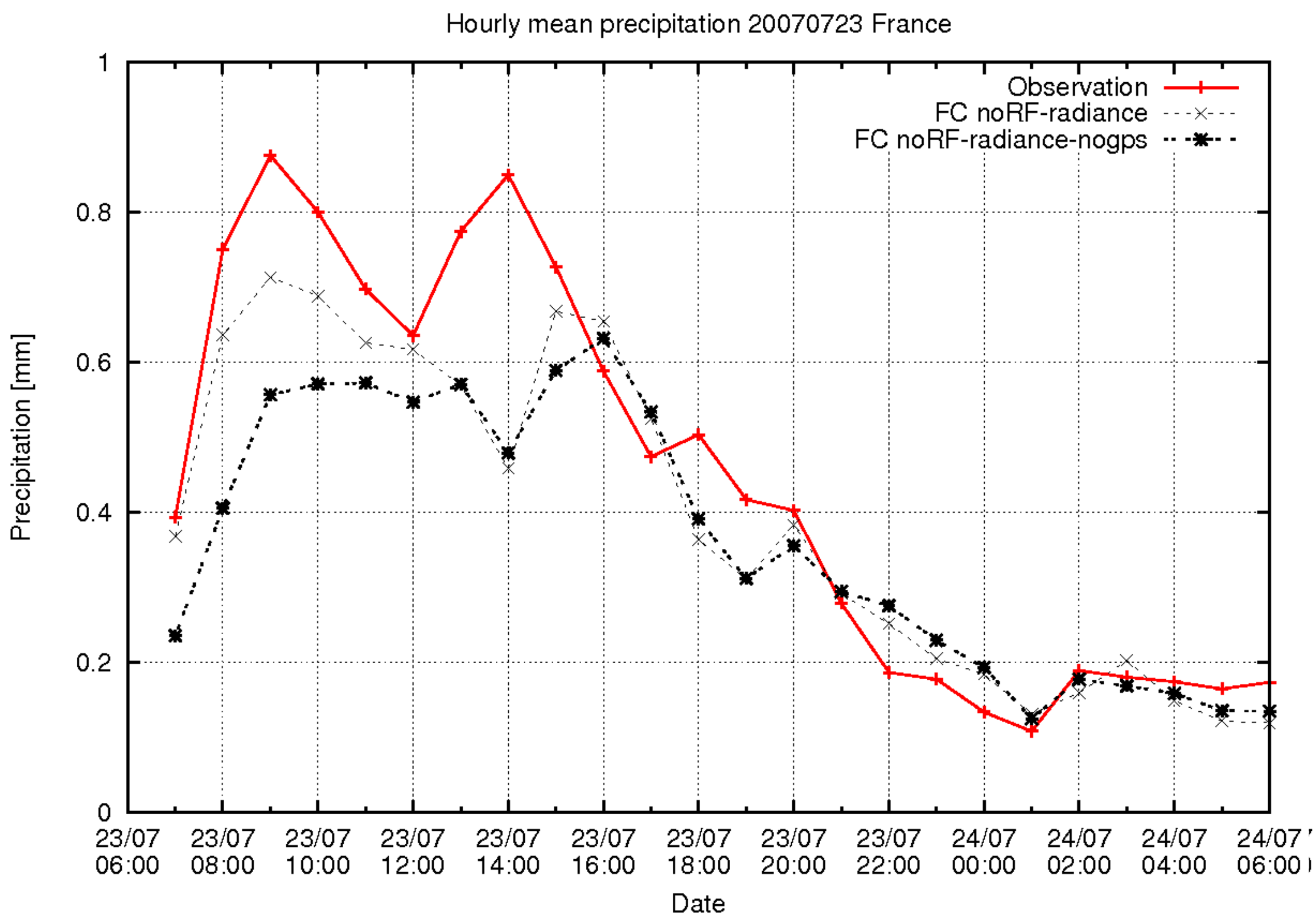
GPS-ZTD data assimilation experiment



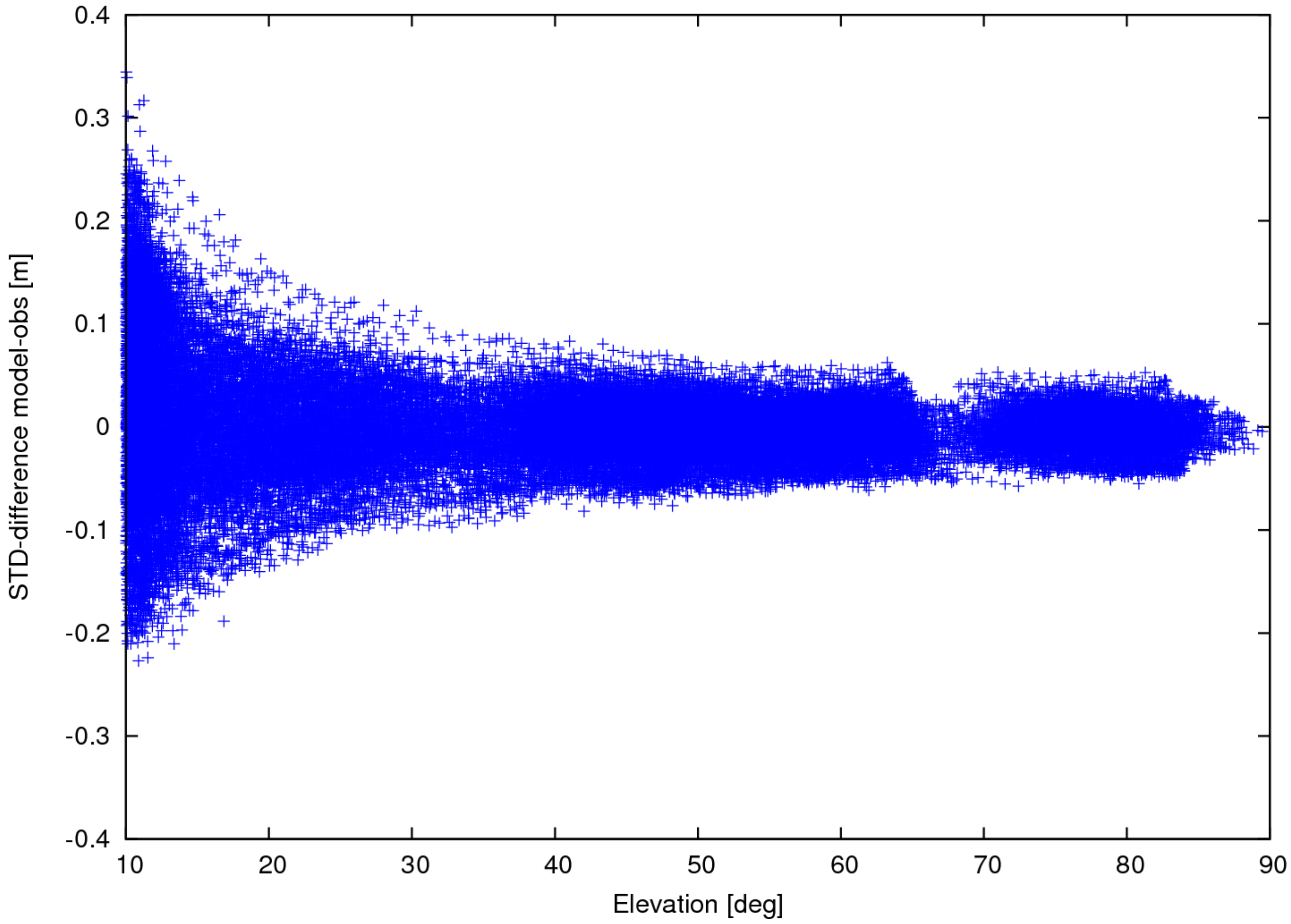


Observations rejected where h_{model}-h_{obs} > 100m

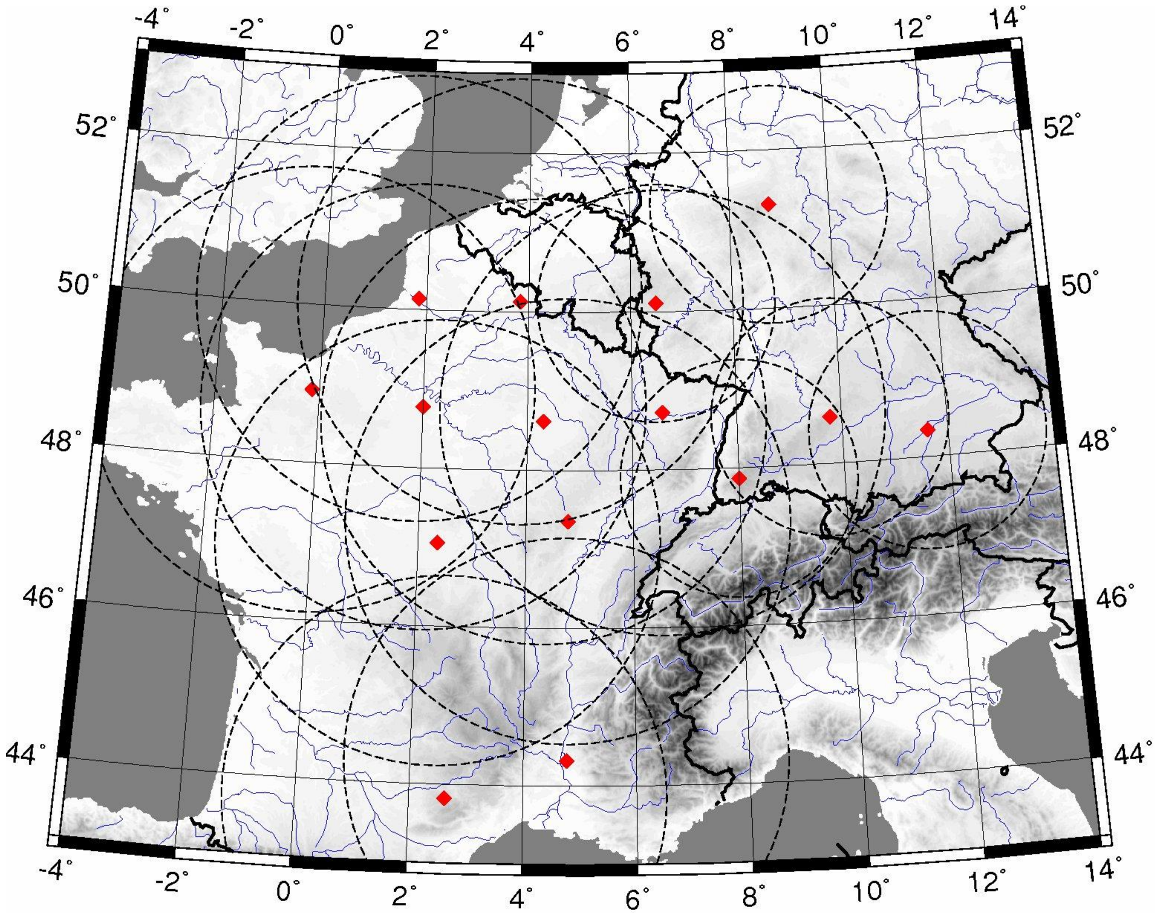
GPS-ZTD data assimilation experiment (2)



STD difference model-observation



Radar data coverage during COPS



- 15 Doppler radar in total
  - 10 from France
  - 5 from Germany
- S- and C-Band radars
- Scanning radius up to 250km
- Range resolution 1km
- R^{u}_{max}= 60m/s and 32m/s
- 3D volume data

Mostly NO clear air data!

Assimilation of radar data in WRF

Radial velocity assimilation:

$$v_r = \frac{x - x_i}{r_i} \cdot u + \frac{y - y_i}{r_i} \cdot v + \frac{z - z_i}{r_i} \cdot (w - v_T)$$

Terminal velocity v_T represents the fall speed of rain. It depends on the rain water mixing ratio q_r under the assumption of a laminar flow ($R_e \approx 300$).

Reflectivities (dBZ) are assimilated applying the following operator:

$$Z = 43.1 + 17.5 \log\left(\frac{\rho_{air} q_r}{1kg / m^3}\right)$$

Derived from a Marshall-Palmer distribution with $N_0 = 8*10^6 m^{-4}$

Only based on rain water mixing ratio!

Quality control and data thinning

Raw observations amount is too large and data are noisy

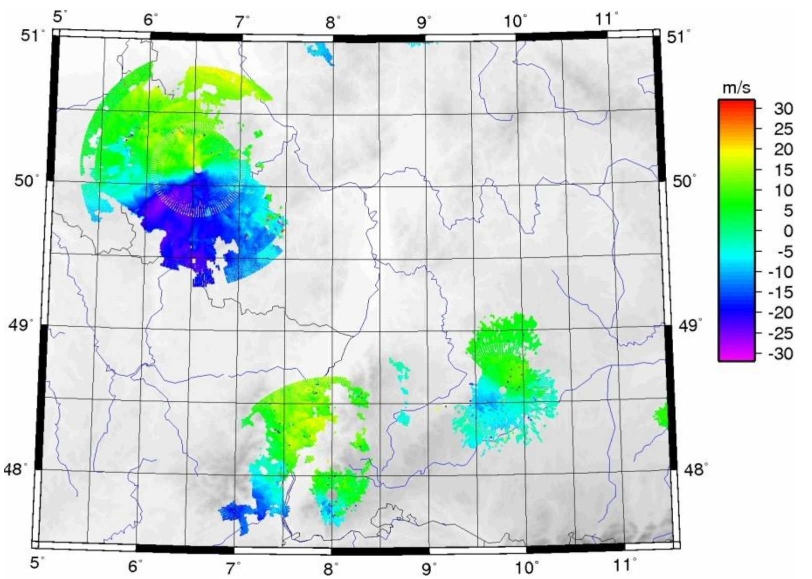
→ Data thinning and filtering prior to its use in a data assimilation scheme

Applied filtering procedure for e.g. German radar data:

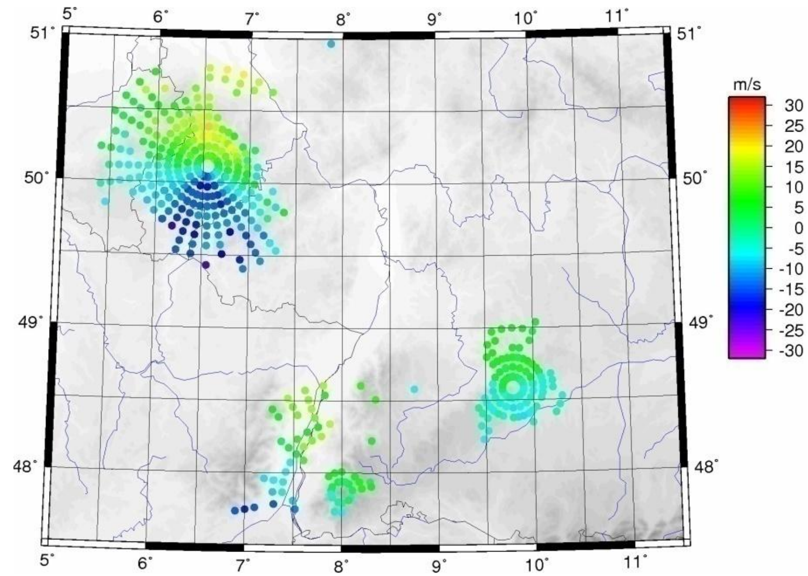
1) According to quality flags, the raw observation is set to missing value
2) Calculation of a 3x3 average value
3) Calculation of variance for every raw observation
4) Variance rejection threshold 50dBZ² for reflectivity and 60m²/s² for radial velocity (Xiao, WRF Workshop 2008)
5) Additional smoothing along the ray and azimuth

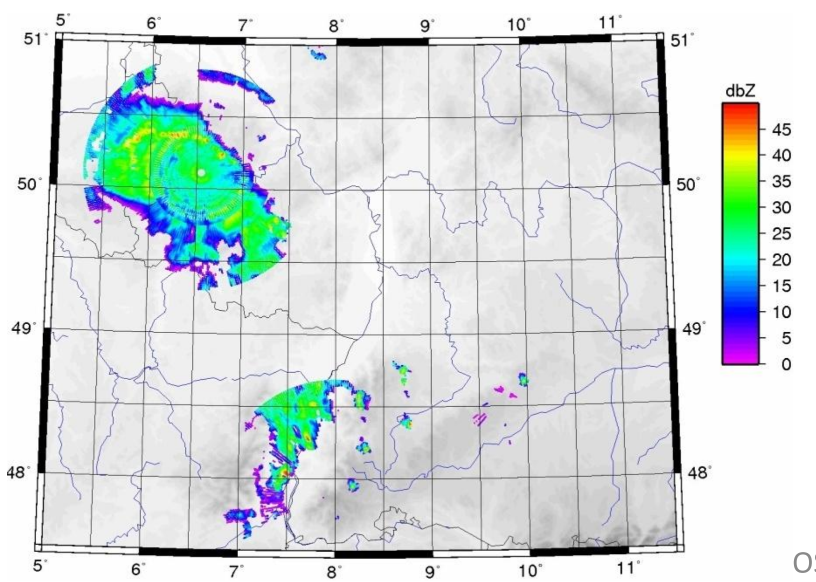
Radial wind observation error = f(range)
Reflectivity error set to 5dBZ
Reflectivities are discarded above 4000m AGL

Quality control and data thinning

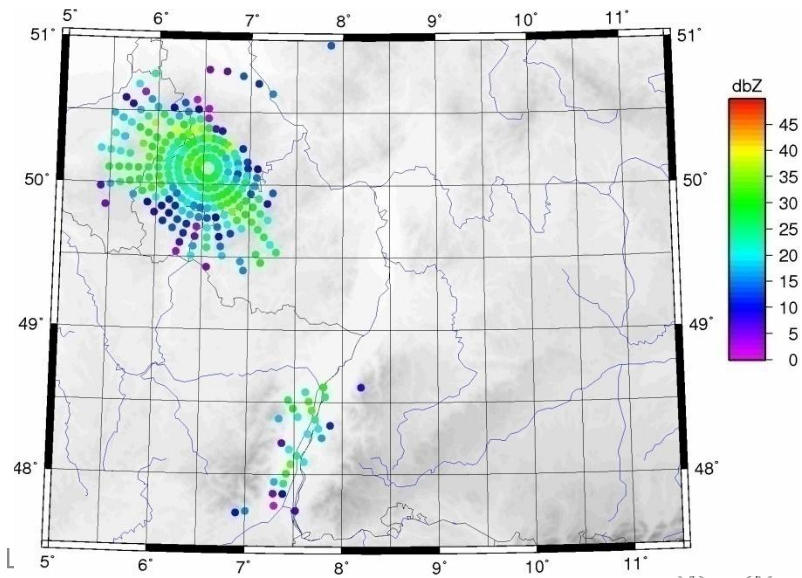


V_r



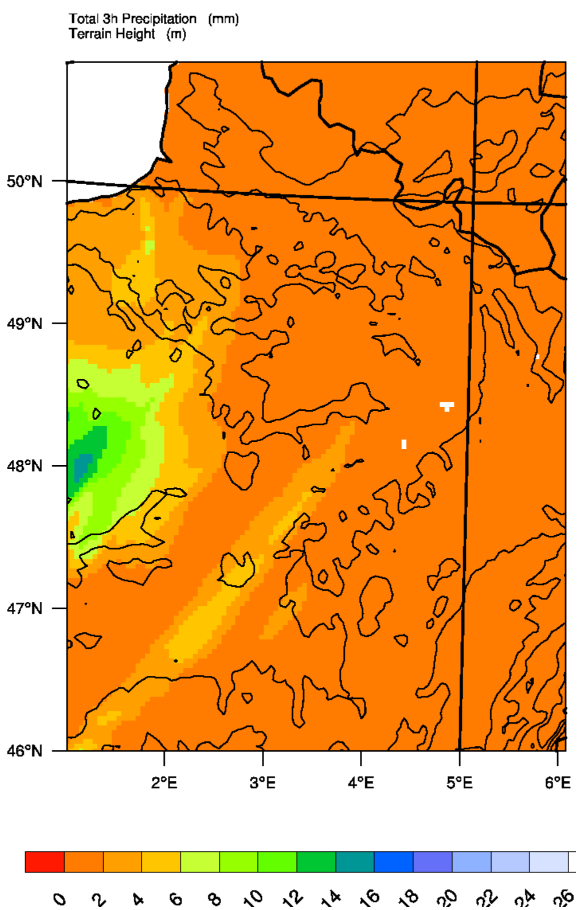


RF

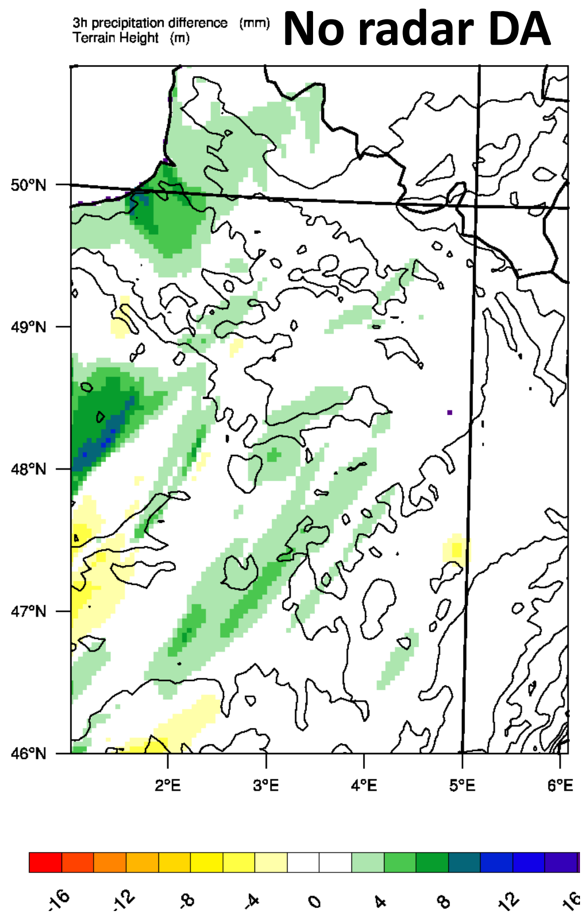


WRF RUC and Radar DA during COPS IOP10

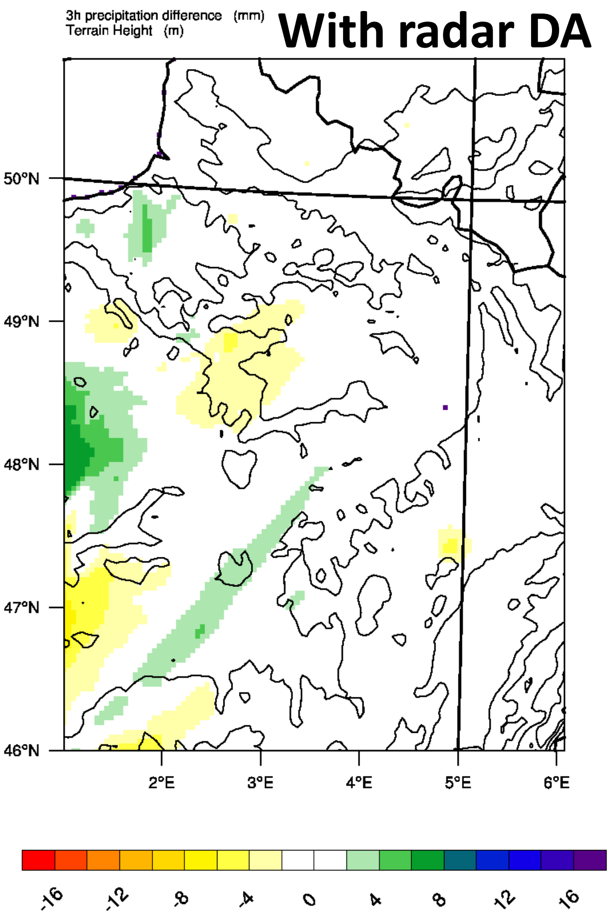
Improvement of precipitation nowcasting after RUC from 6-9 UTC:



Simulation with radar DA



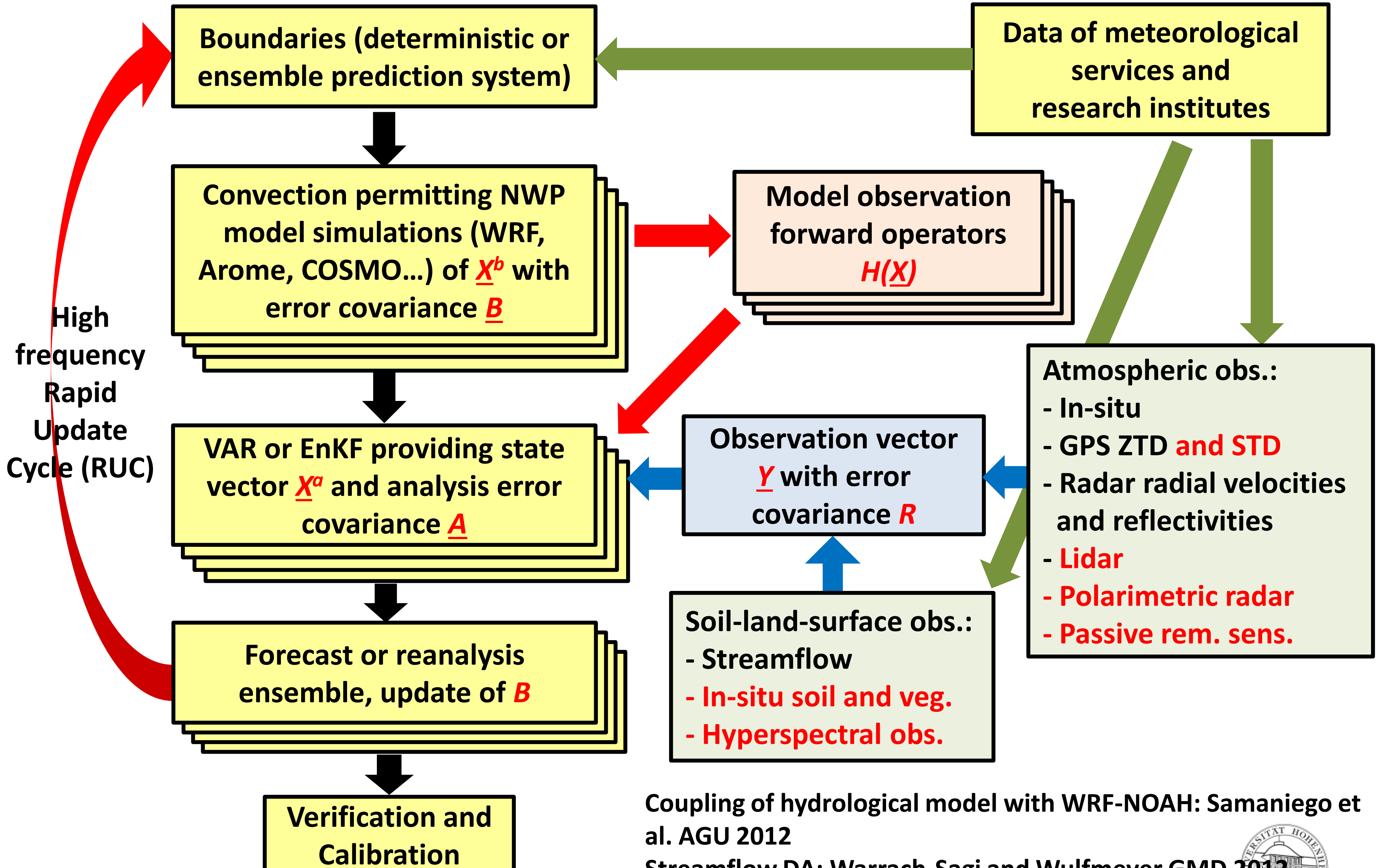
„No-radar“ – Obs.



„Radar-DA“ – Obs.

Promising reduction of precipitation bias by 50 %. Improvement of spatial distribution (Schwitalla et al. submitted to Meteorol. Z. 2013).

Integrated (Ensemble) Simulation Model



Coupling of hydrological model with WRF-NOAH: Samaniego et al. AGU 2012

Streamflow DA: Warrach-Sagi and Wulfmeyer GMD 2012

Summary

- Setup of a unique WRF Rapid Update Cycle over central Europe applying a convection permitting resolution
- Beneficial impact of GPS-ZTD data
- First steps to assimilate 3D volume radar data from two different networks with WRF over Europe
- Results are promising, but still deficiencies due to model imbalances, deficits in clear air dynamics
- Quality issues of reflectivities – bias correction or new Z-q_r relation required to adopt for European radar systems?

Outlook

- Harmonize radar data quality and interpolation procedures
  → OPERA European radar data base (work in progress)
- Utilize polarization radar data (www.caos-project.de)
- Comparison of 3DVAR-RUC and 4DVAR (challenging....)
- Testing (hybrid) ensemble data assimilation methods (EnKF, 3DVAR-ETKF, Ensemble-3DVAR)
- Use of MODE-S aircraft data (Clear air data!)
- Incorporate GPS slant total delays to further improve the water vapor fields
- GPS data over the Ocean?