Estimating the Optimal Number of GNSS Radio Occultation Measurements for Numerical Weather Prediction

ESA funded GALILEO science study

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Background

- GPS RO data assimilated operationally at ECMWF since Dec 2006:

  bending angle profiles as function of impact parameter

  with 1D observation operator
- ~ 2000 GPS RO profile measurements used per day

  as part of ~ 20 million operationally used observations:

  90 % radiances, 5 % other satellite data, 5 % conventional

→ positive impact of GPS RO in ECMWF system

- Observing System Experiments (OSEs) (Radnoti et al 2011):

  → no signal of 'forecast impact saturation'

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Background

- **one of ECMWF aims:**

  ‘Contribute towards the optimisation of the Global Observing System’

- **no guidance regarding the optimal number of RO observations in the future Global Observing System (GOS)**

- **Outcome of NWP sub-group at the 1st IROWG Workshop:**

  ‘IROWG recommends to encourage observing system simulation experiments (OSSE) to determine the optimal number of observations for different applications.’

Aims of the study

(1) How does the impact of GPS RO measurements scale with the observation number?

(2) Is an apparent saturation limit in the observation impact?

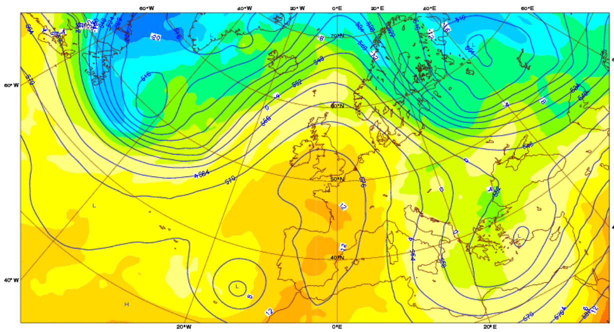
- **Generation of simulated GPS RO bending angle profiles:**

  up to 64000 per day

- **OSSEs that use an ensemble of data assimilations (EDA) approach to investigate the impact of simulated GPS RO bending angle profiles in the ECMWF model**

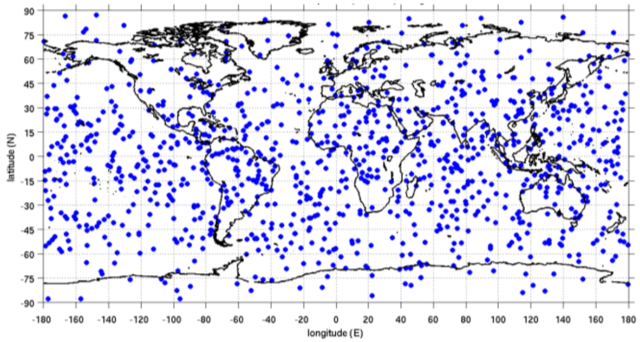
Simulation of GPS RO data

ECMWF NWP analysis at T799 (~25 km) and L91 → proxy for the 'truth'



interpolate

randomly distributed observation time and location (lat, lon, limb-azimuthal angle)



2D bending angle operator *(Healy et al. 2007)*

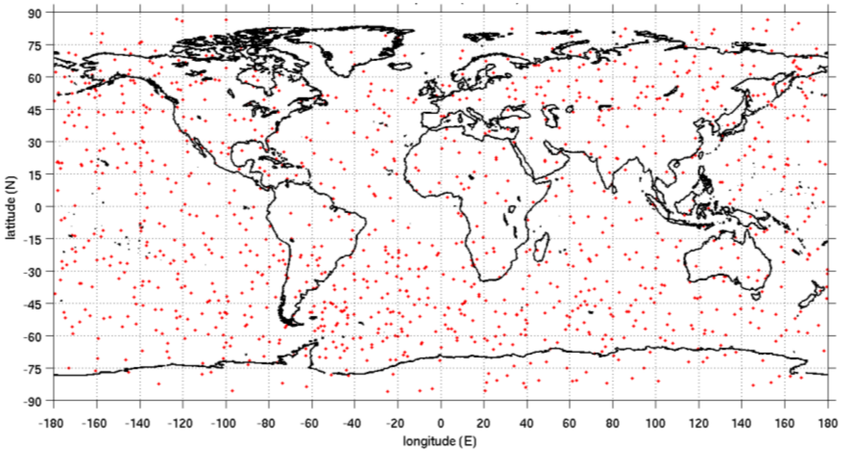
add realistic observation errors

simulated bending angle profiles *α(a)*

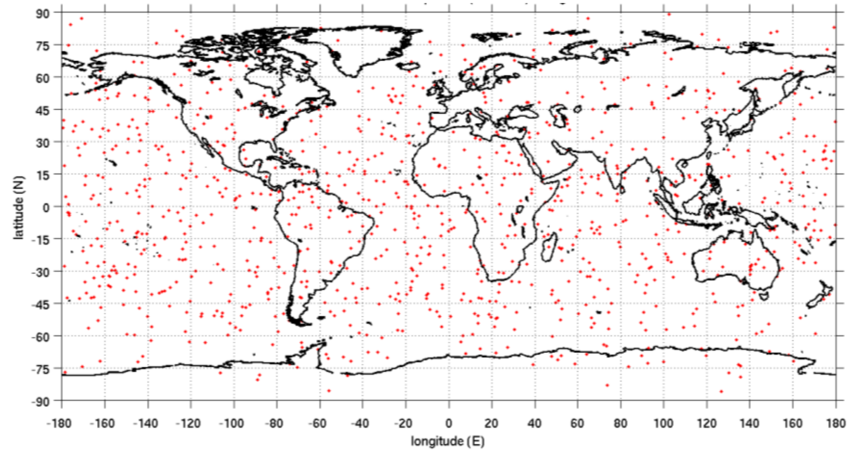
bending angles on 247 fixed impact heights h (a - R_c) similar to operationally used GRAS data

12-hourly coverage of GPS RO data

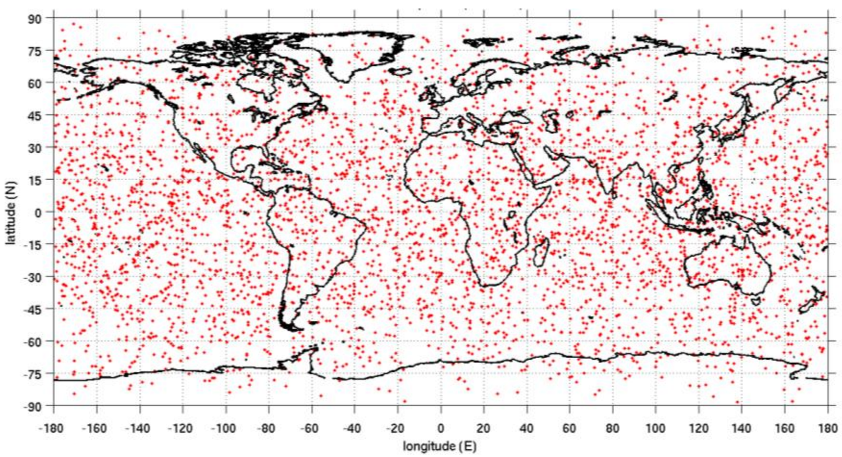
real GPS RO data (N = 1157)



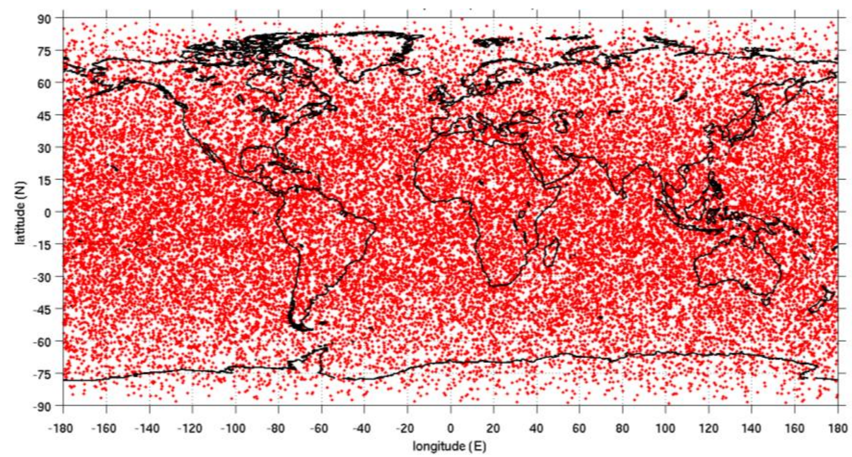
simulated GPS RO data, N = 1000



N = 4000

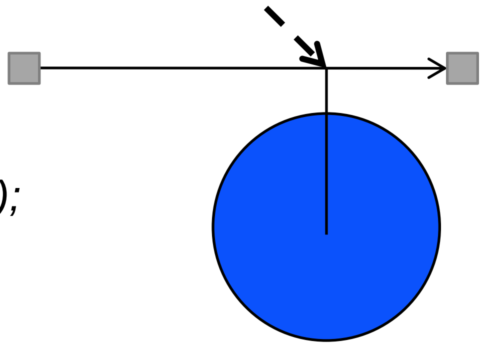


N = 32000



Assimilation of simulated data

- **Assimilation of bending angles with 1D observation operator used operationally at ECMWF. Ignore the 2D nature of the measurement and integrate**



$$\alpha(a) = -2a\int_a^\infty \frac{d\ln n / dx}{\sqrt{x^2-a^2}}\,dx$$

Healy and Thepaut (2006);

$$N = \frac{77.643P_d}{Z_d T} + \frac{6.3938e}{Z_w T} + \frac{3.75463\times 10^5 e}{Z_w T^2}$$

Rüeger (2002);
Healy (2011)

- **no tangent point drift**
- **assumed observation error:**

20 % *of the observed value at* ***h = 0****,* *falling linearly to* ***1 %*** *at* ***h = 10km*** ***1 %*** *for* ***h > 10 km*** *until this reaches a lower limit of* ***3 µrad (~ 32 km)***

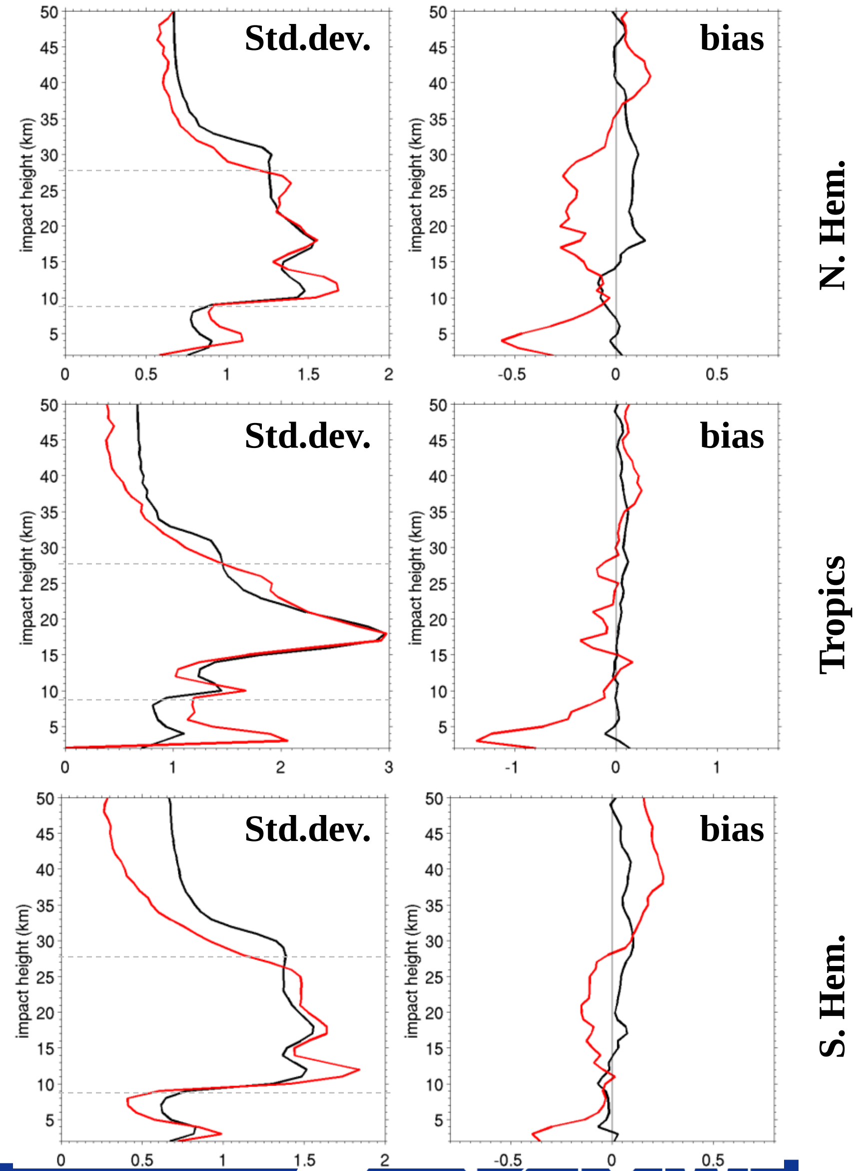
4D-Var test experiment for July 2008

Observation error statistics

simulated 64000 GPS RO
normalized background fit

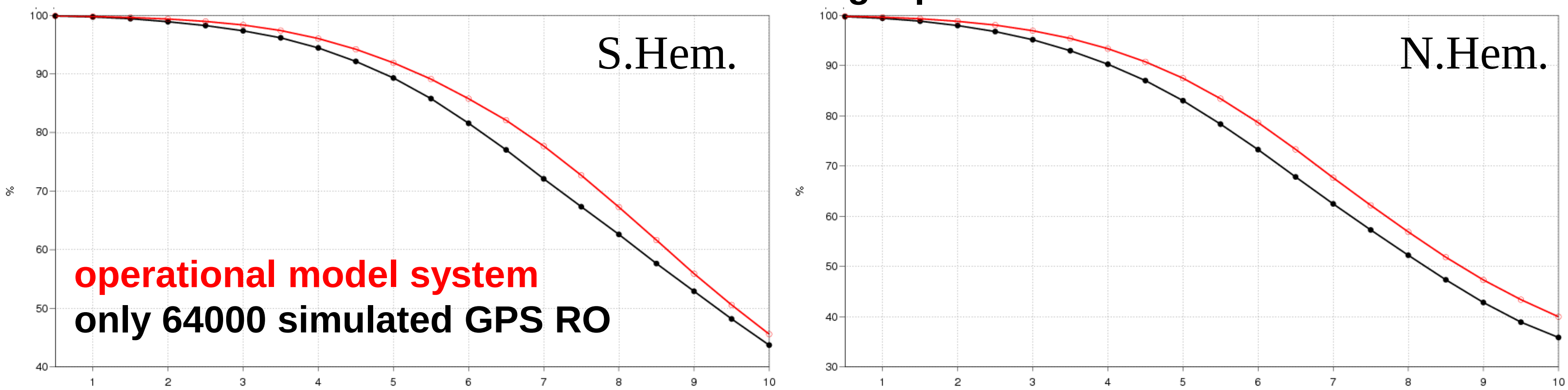
operational used GRAS data
normalized background fit

- ‘naked’ 4D-Var exp: no other observations assimilated
- normalized fit $\frac{\mathbf{y}-H(\mathbf{x})}{\sigma_o}$
- larger observation errors assigned to GPS RO obs above 26 km in 2008

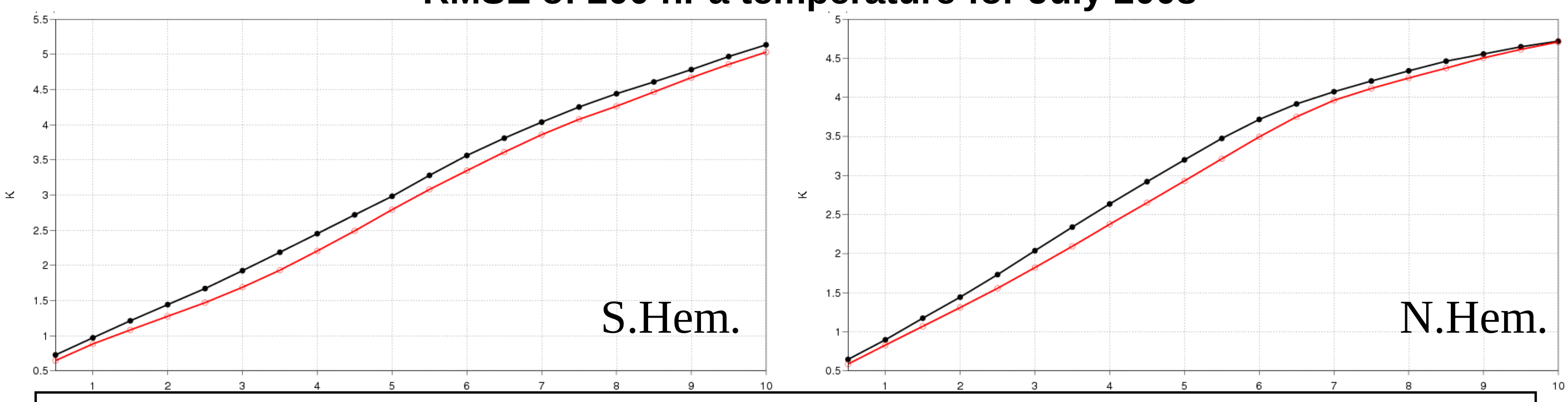


Forecast impact of simulated GPS RO

ACC of 200 hPa geopotential



RMSE of 200 hPa temperature for July 2008



→ **even 64000 GPS RO profiles per day are not able to capture the full information content of the operational ECMWF analysis**

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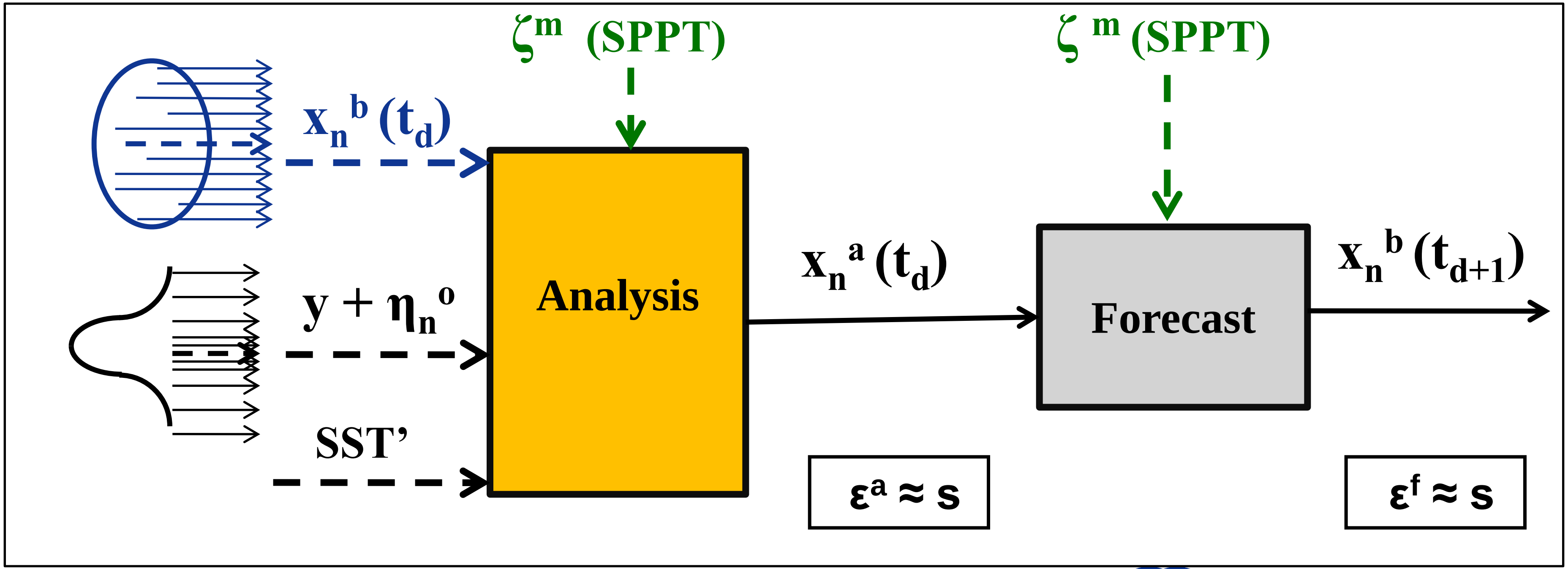
The EDA concept

- ensemble of n-independent 4D-Var data assimilation members
- correct representation of the main analysis error sources
  - → spread of the ensemble of analyses x_n^a and forecasts x_n^f yields information on analysis error ε^a and forecast error ε^f
  - → flow-dependent background errors

(Žagar et al. 2005; Isaksen et al. 2010)



Setup of EDA experiments

- **period July – September 2008**
- **6 EDA experiments with operationally assimilated observations +**

2000 4000 8000 16000 32000 64000

simulated GPS RO profiles

10 member ensemble

↓

12-hourly 4D-Var analyses (EDA)
at T399 L91 with two minimisations at T95 / T159
at **00 UTC** and **12 UTC**

↓

120 hour forecasts at 00 UTC at T399 L91

The OSSE – EDA approach

- proof of concept for simulated ADM-AEOLUS data (*Tan et al. 2007*)
- only observations of interest (GPS RO) need to be simulated
- realism, interpretation and calibration of OSSEs may be difficult
- evaluation of ensemble spread

$$s_i = \sqrt{\frac{1}{D}\sum_{d=1}^{D}\left(\frac{1}{N-1}\sum_{n=1}^{N}(x_n - \overline{x})_i^2\right)}$$

- no consideration of the absolute observation impact

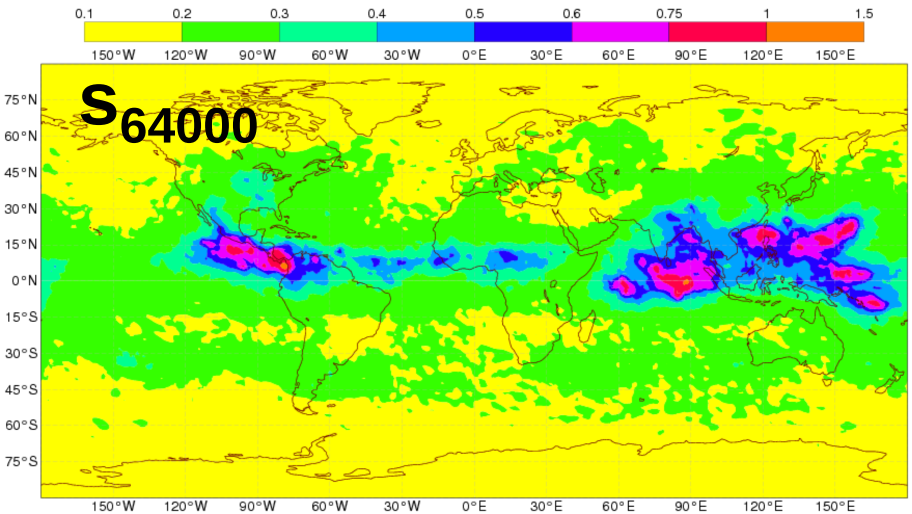
  → no re-scaling of the spread
- positive impact of additional simulated GPS RO → reduced spread

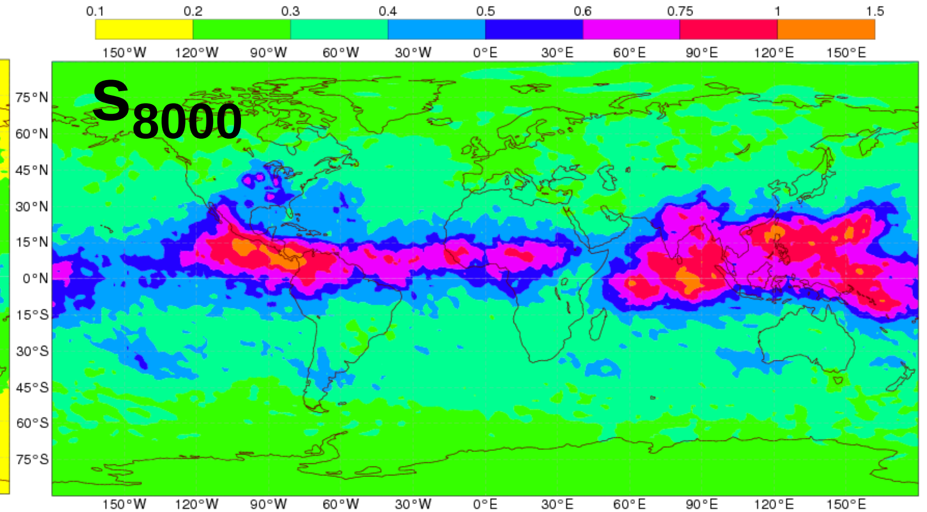
$$I_{64000 \rightarrow 8000} = s_{64000} - s_{8000}$$

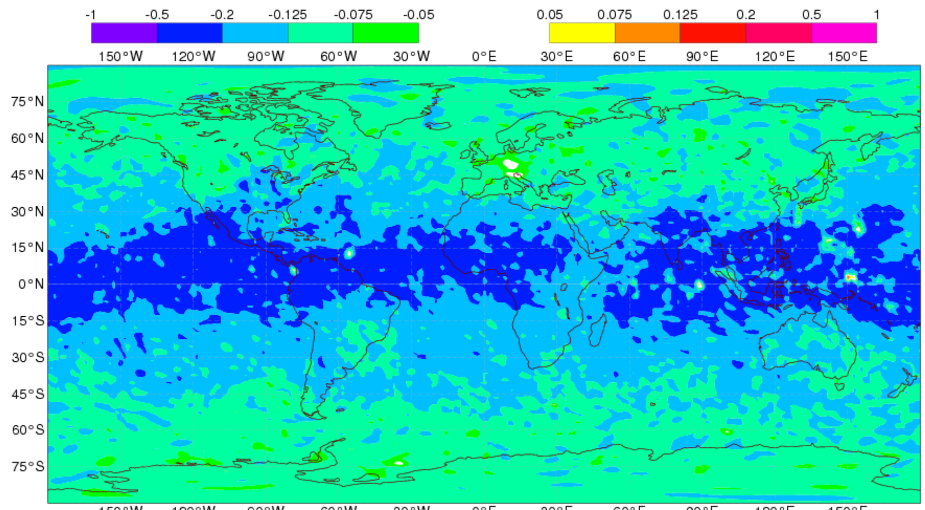
- extent of spread reduction → onset of saturation

First results (July 08 – 17, 2008)

T (K) at 100 hPa: 10-member ensemble spread for + 0 h for June 8 - 17, 0 / 12 UTC



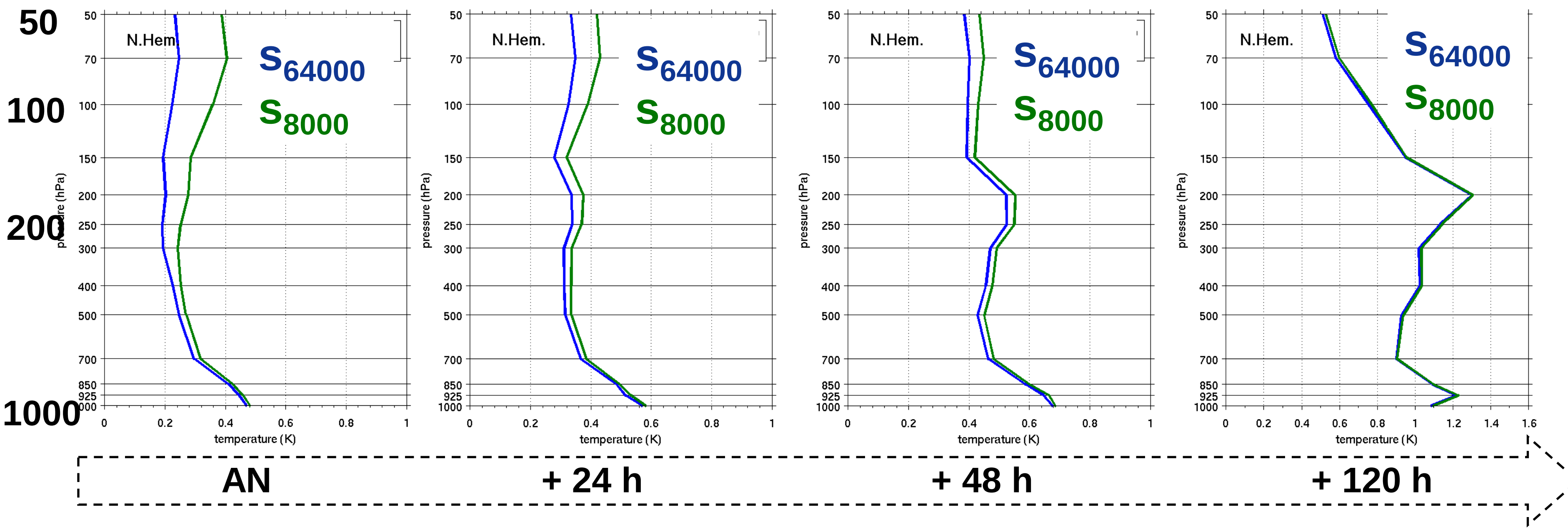




$s_{64000} - s_{8000}$

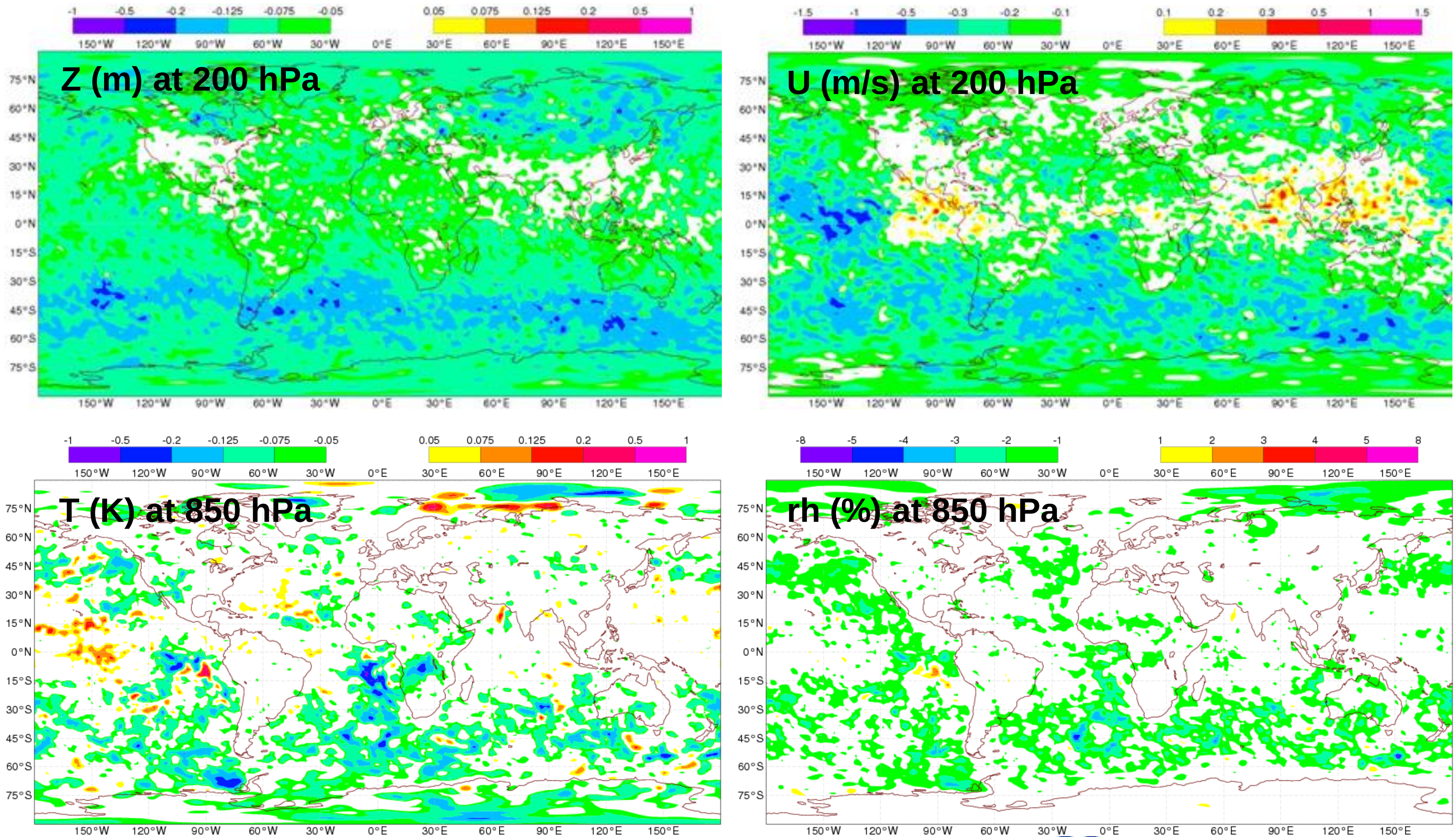
First results (July 08 – 17, 2008)

- reduction of spread for T with more GPS RO profiles
  - larger at higher levels
  - largest for analysis
  - consistent through different FC lead times



First results (July 08 – 17, 2008)

$s_{64000} - s_{8000}$

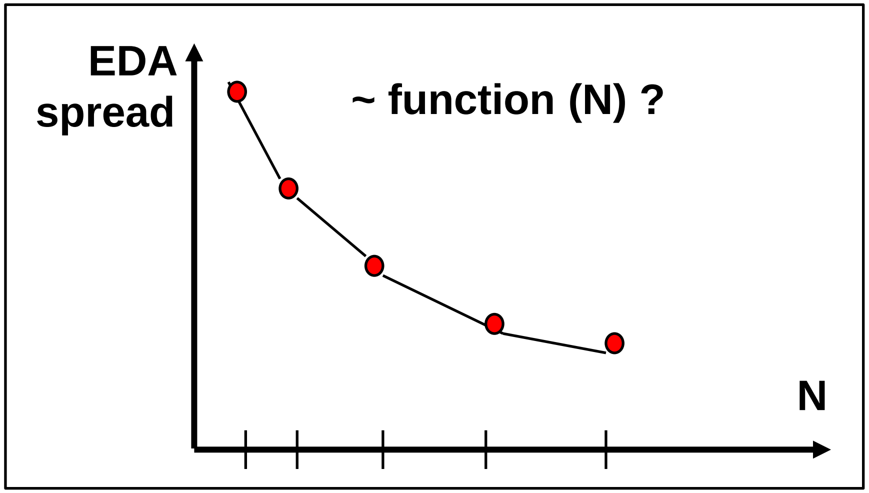


Summary & Outlook

- OSSEs using the EDA approach → applied to simulated GPS RO
- positive impact of 64000 vs. 8000 simulated GPS RO profiles per day in the ECMWF EDA system
- largest impact on upper-tropospheric / stratospheric T
- positive impact also on other parameters (rh, Z, U, ...)

perform full set of experiments with simulated GPS RO for information on impact saturation

→ How many GPS RO profiles?



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