A 4D-Ensemble-Variational System for Ensemble Initialization

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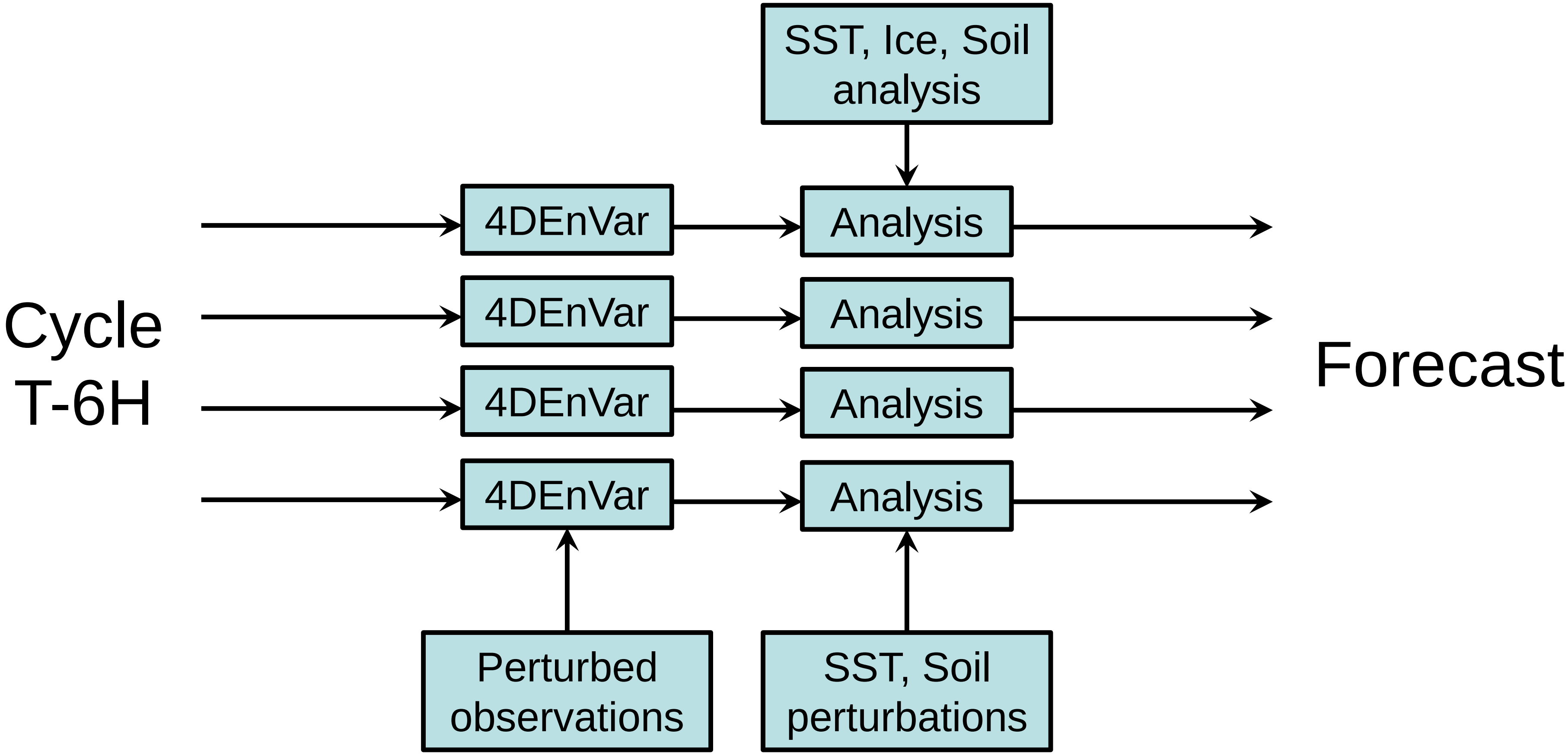
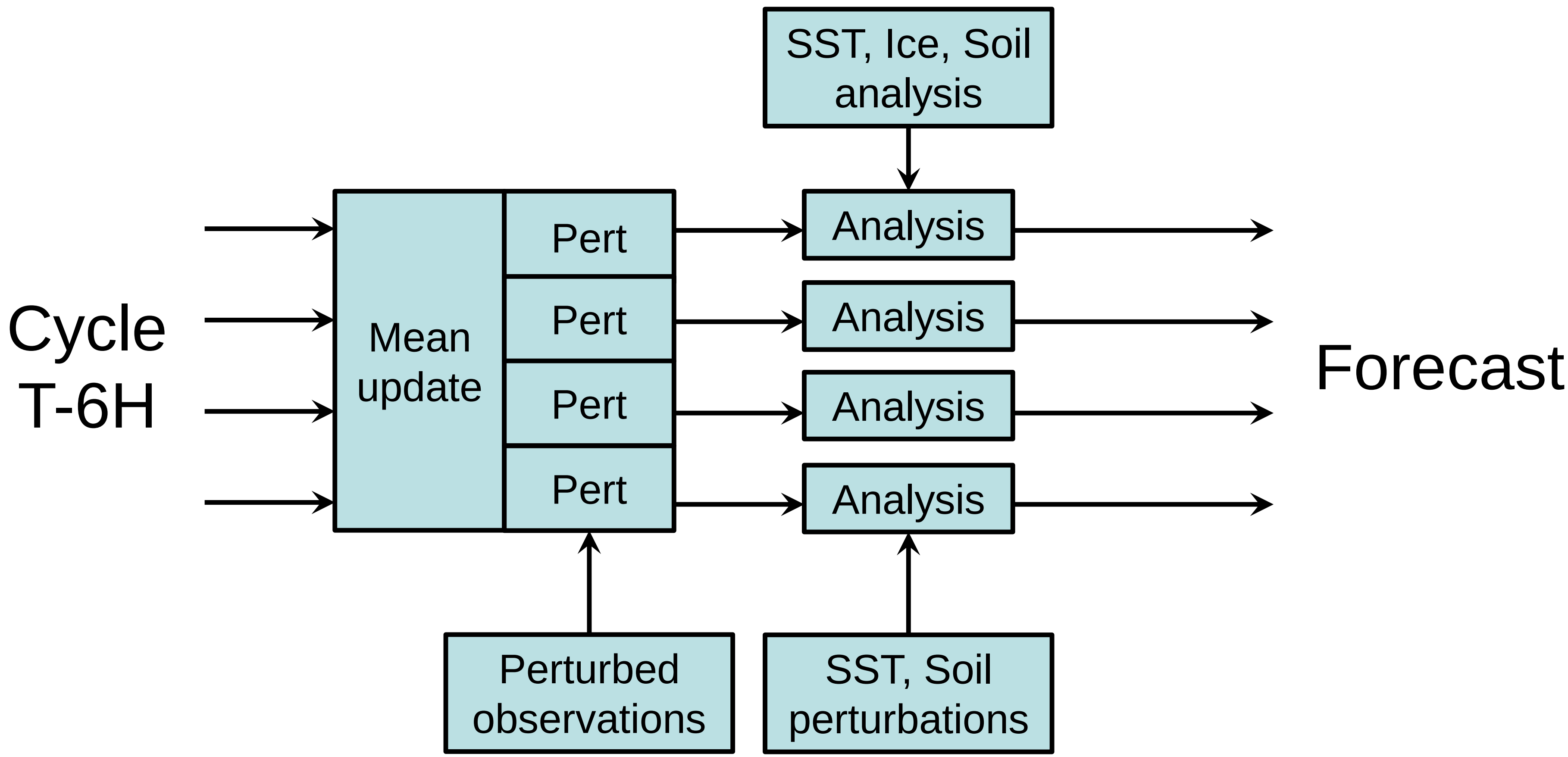
En-4DEnVar features

- Ensemble of data assimilations
- Hybrid 4DEnVar for each member
  - No TL/AD model, 4D DA
  - Ensemble mean calculated by ensemble
  - Mean-perturbation update to speed computation
  - Choice of hybrid weighting
- Perturbed observations according to own errors
- Self-exclusion to avoid inbreeding
- Model error simulation includes additive inflation

Ensemble update flow diagram



Ensemble update flow diagram



Poster by Jardak et al.

Self exclusion

- Normal update (e.g. non-hybrid 4DEnVar)

$$J(\mathbf{w}_i) = \frac{1}{2}\mathbf{w}_i^T\mathbf{w}_i + \frac{1}{2}\left(\mathbf{y} + \mathbf{r}_i - H\left(\underline{\mathbf{x}}_i^b + \underline{\delta\mathbf{x}}_i\right)\right)^T \mathbf{R}^{-1}\left(\mathbf{y} + \mathbf{r}_i - H\left(\underline{\mathbf{x}}_i^b + \underline{\delta\mathbf{x}}_i\right)\right)$$

$$\underline{\delta\mathbf{x}}_i = \underline{\mathbf{U}}_p \sum_{j=1}^{N} \underline{\mathbf{L}}\mathbf{w}_{i,j} \circ \underline{\mathbf{T}}_p \underline{\mathbf{x}}_j' \qquad \text{for} \quad i = 1, \cdots, N$$

- $\mathbf{w}_{i,i}$ is used much more than the other weights (inbreeding)

- Instead use

$$\underline{\delta\mathbf{x}}_i = \underline{\mathbf{U}}_p \sum_{j \neq i} \underline{\mathbf{L}}\mathbf{w}_j \circ \underline{\mathbf{T}}_p \underline{\mathbf{x}}_j'$$

- Ensemble spread larger after analysis

Model uncertainty

- Physically based model uncertainty perturbations
  - Random parameters
  - Stochastic kinetic energy backscatter
- Statistical model uncertainty perturbations
  - Additive inflation:
    - 3 month archive of analysis increments (from high-resolution 6h cycling hybrid-4DVar)
    - Randomly selected for each ensemble member and 6h period – added every time-step
    - Use 3-month average increment to correct bias

Inflation

- RTPP – relaxation to prior perturbations

$$\mathbf{x}_i^{a}{}' \rightarrow \alpha \mathbf{x}_i^{f}{}' + (1-\alpha)\mathbf{x}_i^{a}{}'$$

- ~~Compared with fixed multiplicative inflation~~

$$\cancel{\mathbf{x}_i^{a}{}' \rightarrow (1+\alpha)\mathbf{x}_i^{a}{}'}$$

- RTPS – relaxation to prior spread

$$\mathbf{x}_i^{a}{}' \rightarrow r\mathbf{x}_i^{a}{}'$$

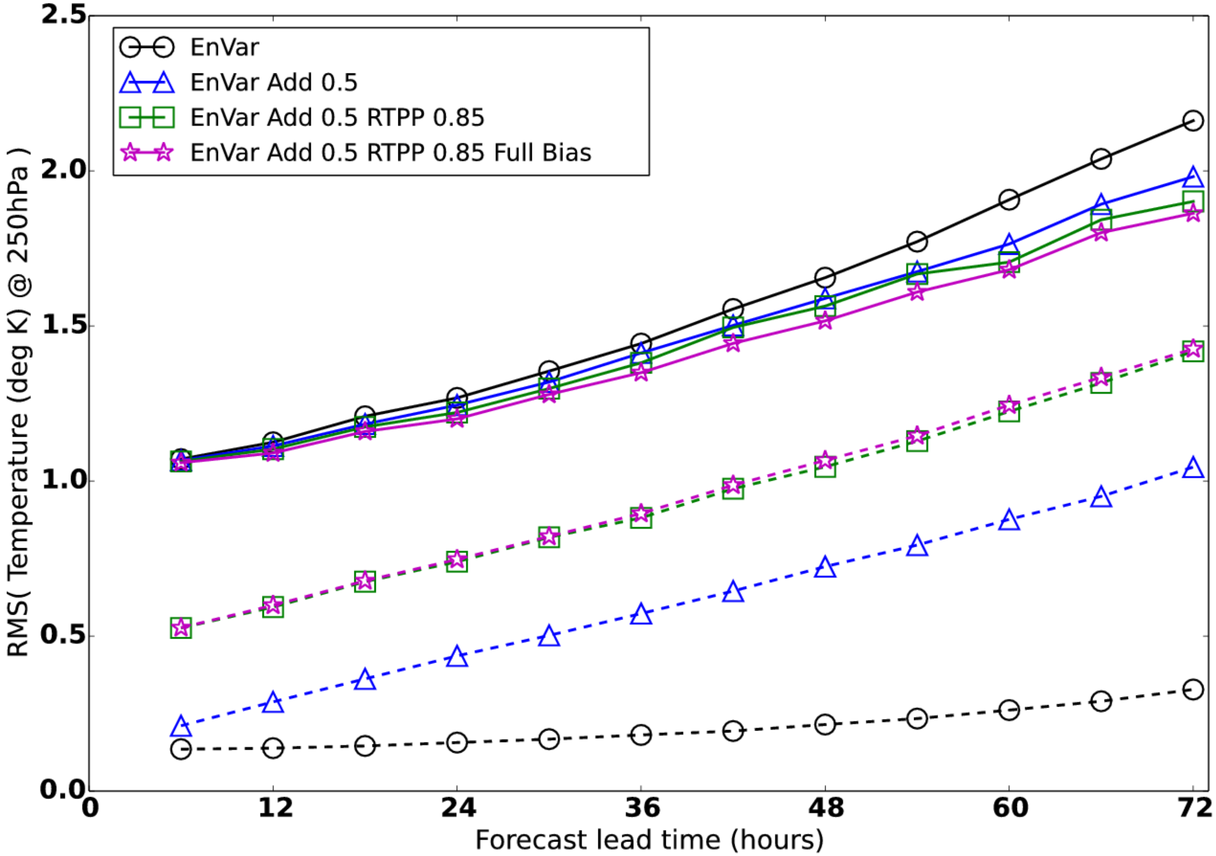
$$r = \frac{\alpha\sigma\left(\mathbf{x}_i^{f}{}'\right) + (1-\alpha)\sigma\left(\mathbf{x}_i^{a}{}'\right)}{\sigma\left(\mathbf{x}_i^{a}{}'\right)}$$

Results

Additive inflation

Temperature 250 hPa – northern extra-tropics

- Archive of analysis increments – Jan-Mar 2015
- Applied during 6h windows
- Scaled by 0.5
- Remove sample mean, add seasonal mean
- Verification against sondes, subtracting observation error

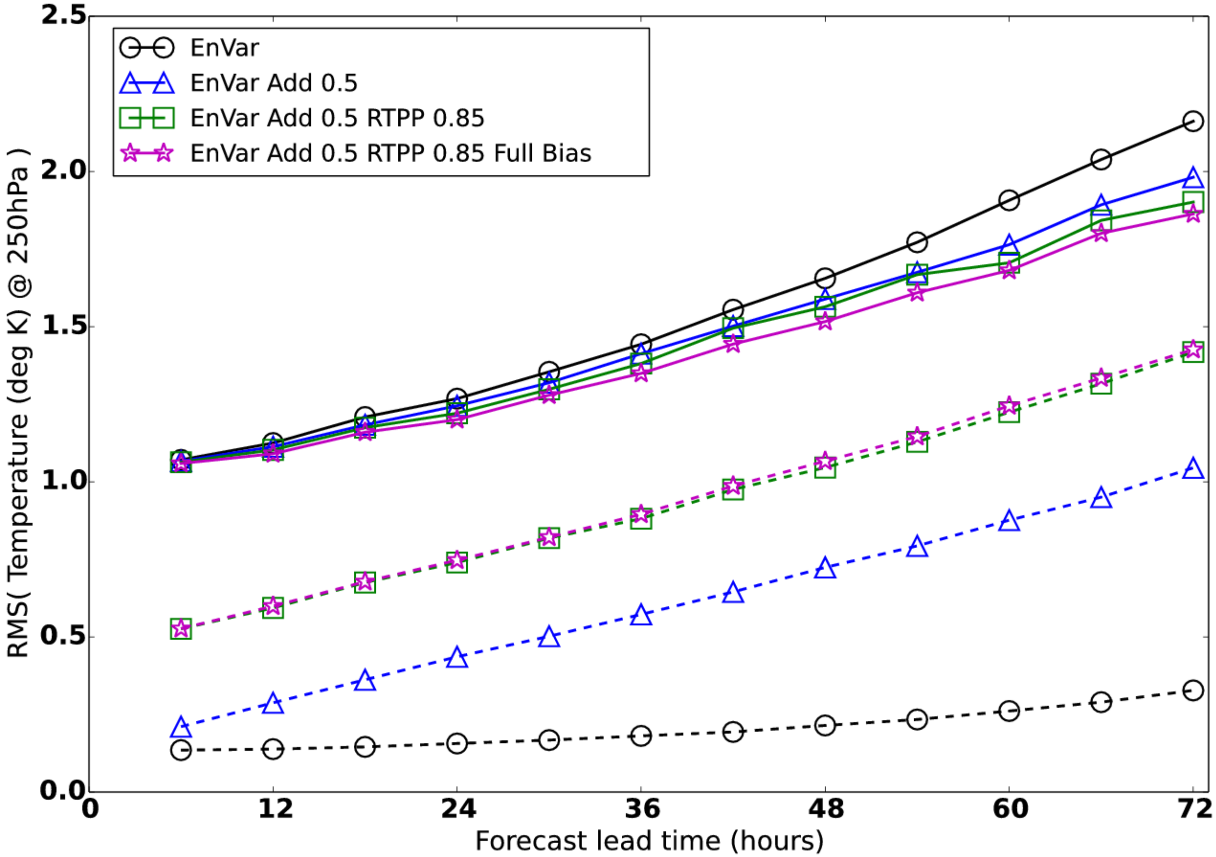


Hybrid weights $\beta_c^2 = 0.8 \quad \beta_e^2 = 0.5$

Additive inflation

Temperature 250 hPa – northern extra-tropics

- Without model uncertainty schemes spread is very small
- Spread grows much faster with additive inflation
- Combining with RTPP (0.85) gives respectable spread
- Seasonal mean correction reduces RMSE



Inflation experiments

- Final configuration included
  - Additive inflation (scale 0.5)
  - RTPP (factor 0.5)
  - RTPS (factor 0.9)
  - Perturbed observations
  - Self-exclusion

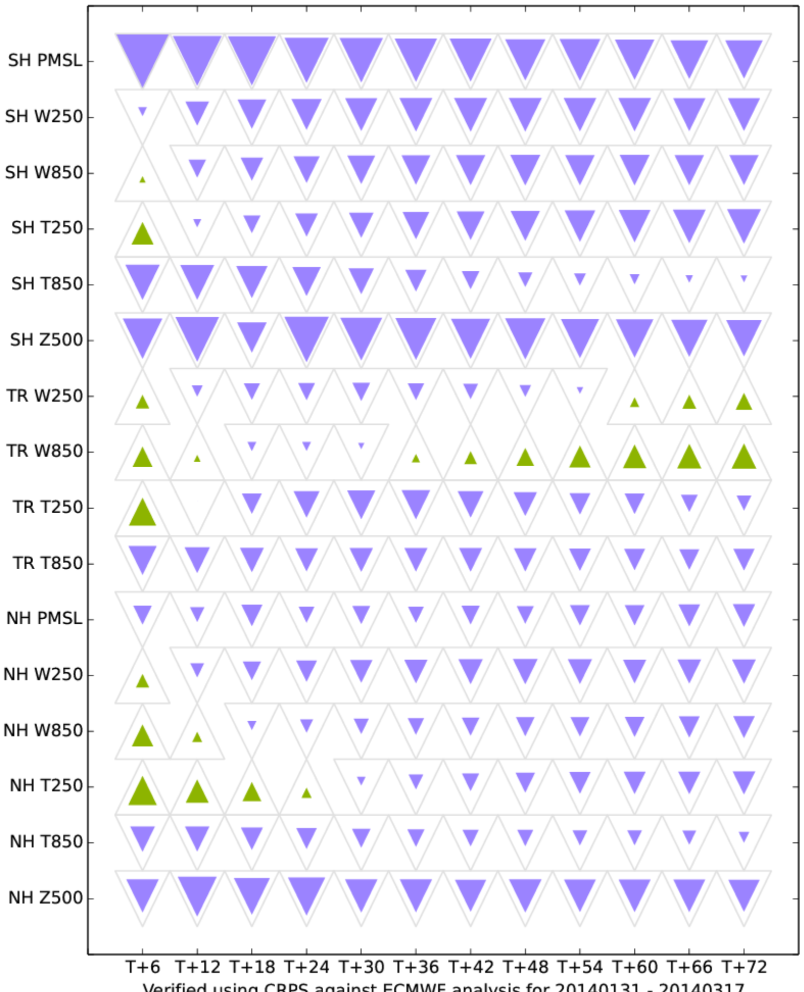
Model uncertainty scheme

Not satisfactory when used alone

Ensemble update: ETKF → (Hybrid-)En-4DEnVar

ETKF → En-4DEnVar (Pert Obs, RTPP 0.5, RTPS 0.9, Add 0.5, self-excl)

(44-member trials, 50% $\mathbf{B}_c$ / 50% $\mathbf{B}_e$)



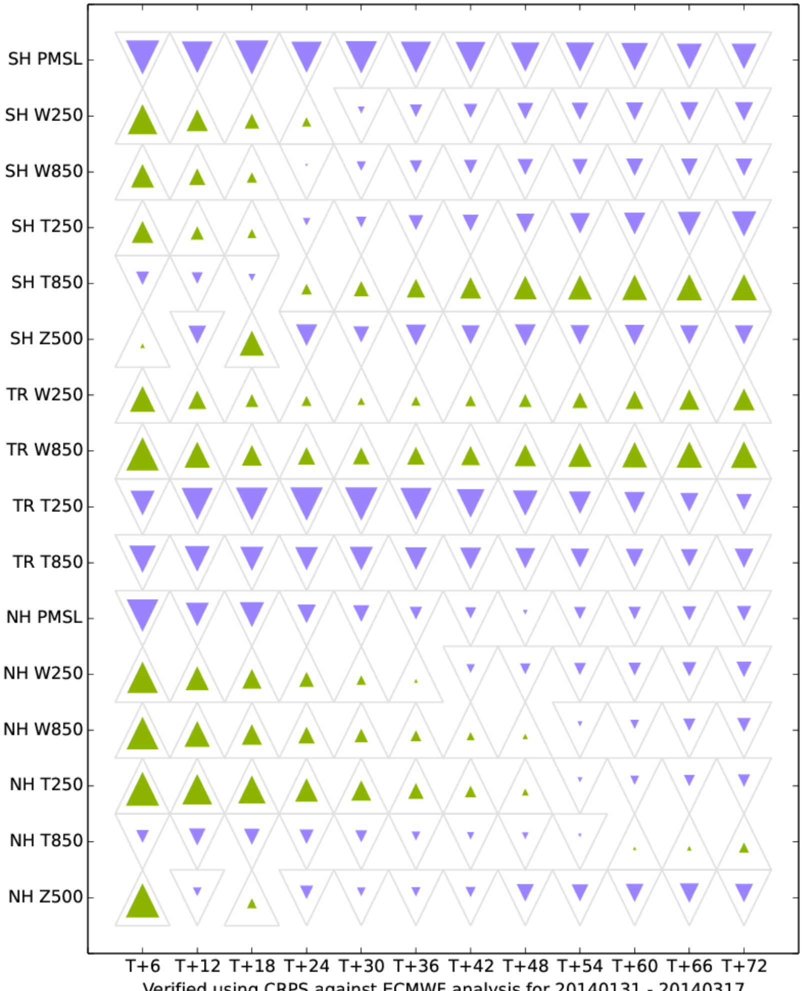
Green △ = better **Blue ▽ = worse**

- "Ensemble scorecard", based on CRPS: Continuous Ranked Probability Score.
- Area of plotted triangle proportional to percentage change in score
- Grey outline indicates 20% change in score
- EnVar generally scores worse than ETKF
  - ETKF forecasts are recentred around a high-resolution operational analysis every cycle
  - EnVar spread generally less

Ensemble update: ETKF → (Hybrid-)En-4DEnVar

ETKF → Recentred En-4DEnVar

(44-member trials, 50% $\mathbf{B}_c$ / 50% $\mathbf{B}_e$)



Green △ = better Blue ▽ = worse

- Recentring the En-4DEnVar forecasts reduces the gap.
- But scores still significantly worse for some fields, mainly because of relatively low spread.
- Should be able to fix this by adjusting the inflation schemes.

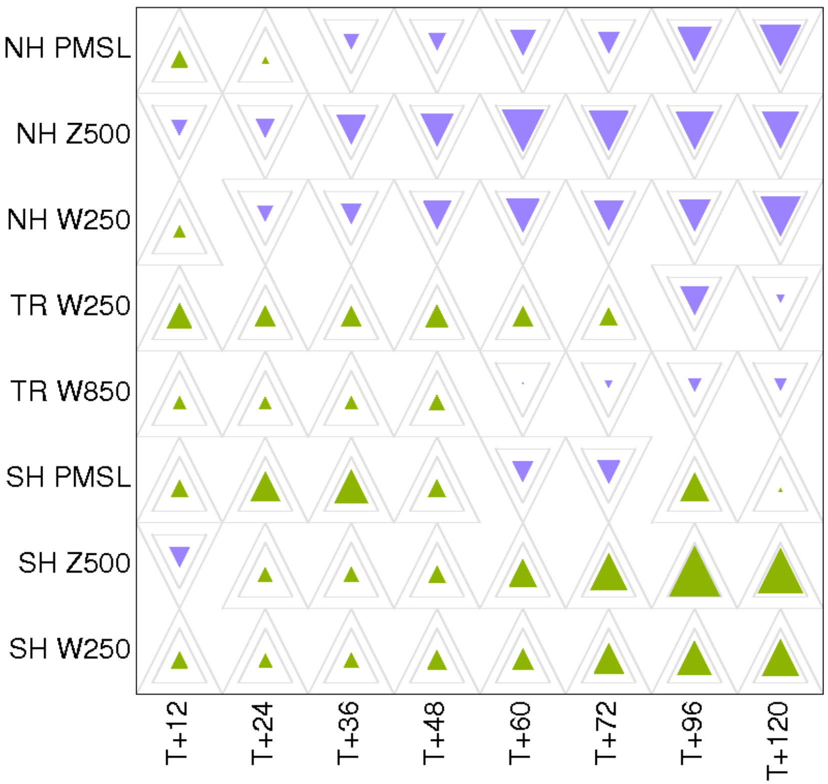
Hybrid DA trials using the En-4DEnVar ensemble

En-4DEnVar ensemble → Recentred En-4DEnVar ensemble

(44-member trials, 30% $\mathbf{B}_c$ / 70% $\mathbf{B}_e$)

Verification vs. ECMWF analysis

Area gives percentage change in RMSE
max = 5 (grey = 2)

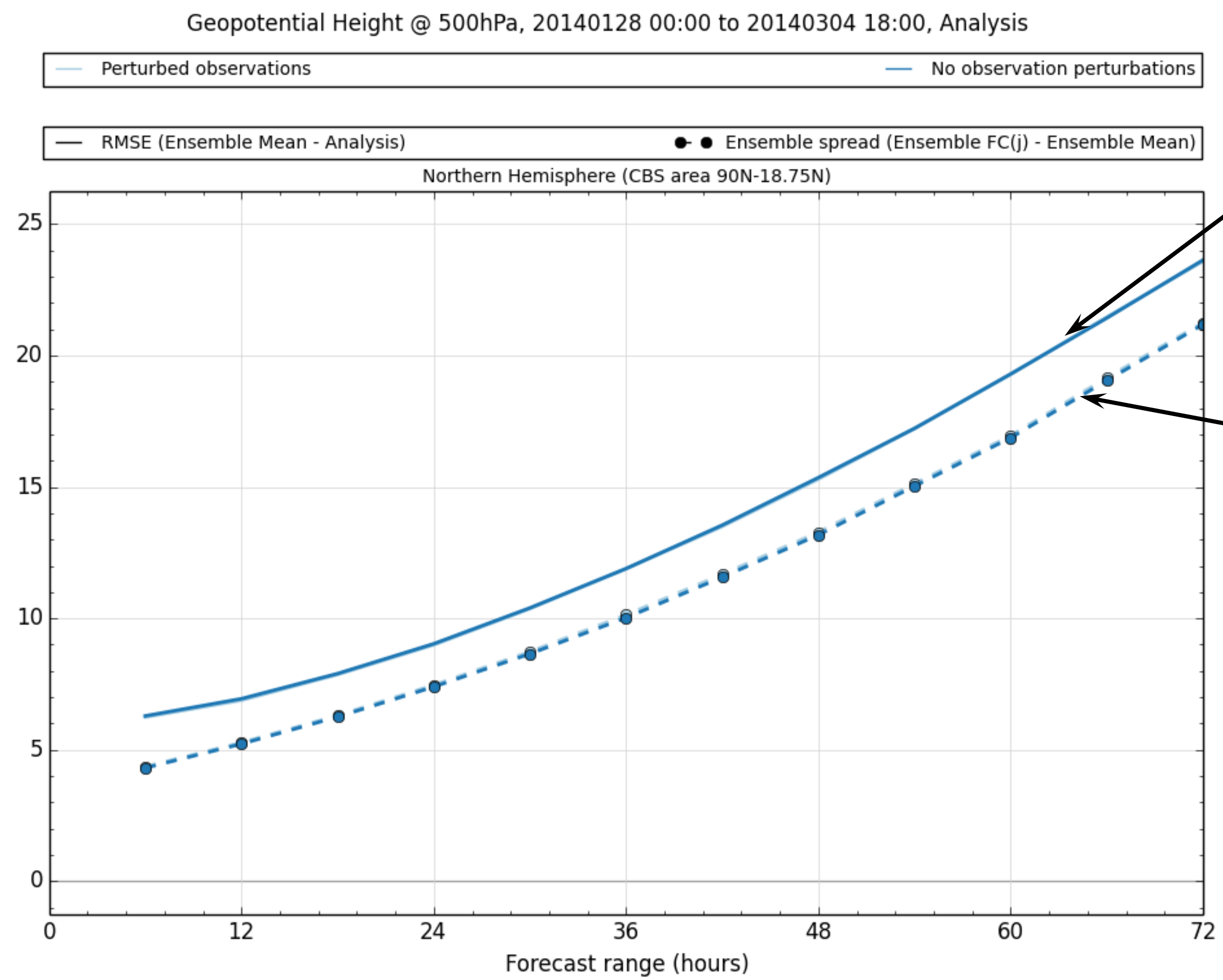


Green △ = better Blue ▽ = worse

- Effect of ensemble recentring on deterministic forecasts using ensemble covariances
- Mixed results
  - Better in SH
  - Worse in NH
- Orographic effects in the northern hemisphere?

Perturbed observations

En-4DEnVar, RTPP 0.5, RTPS 0.9, Add 0.5, Self-excl

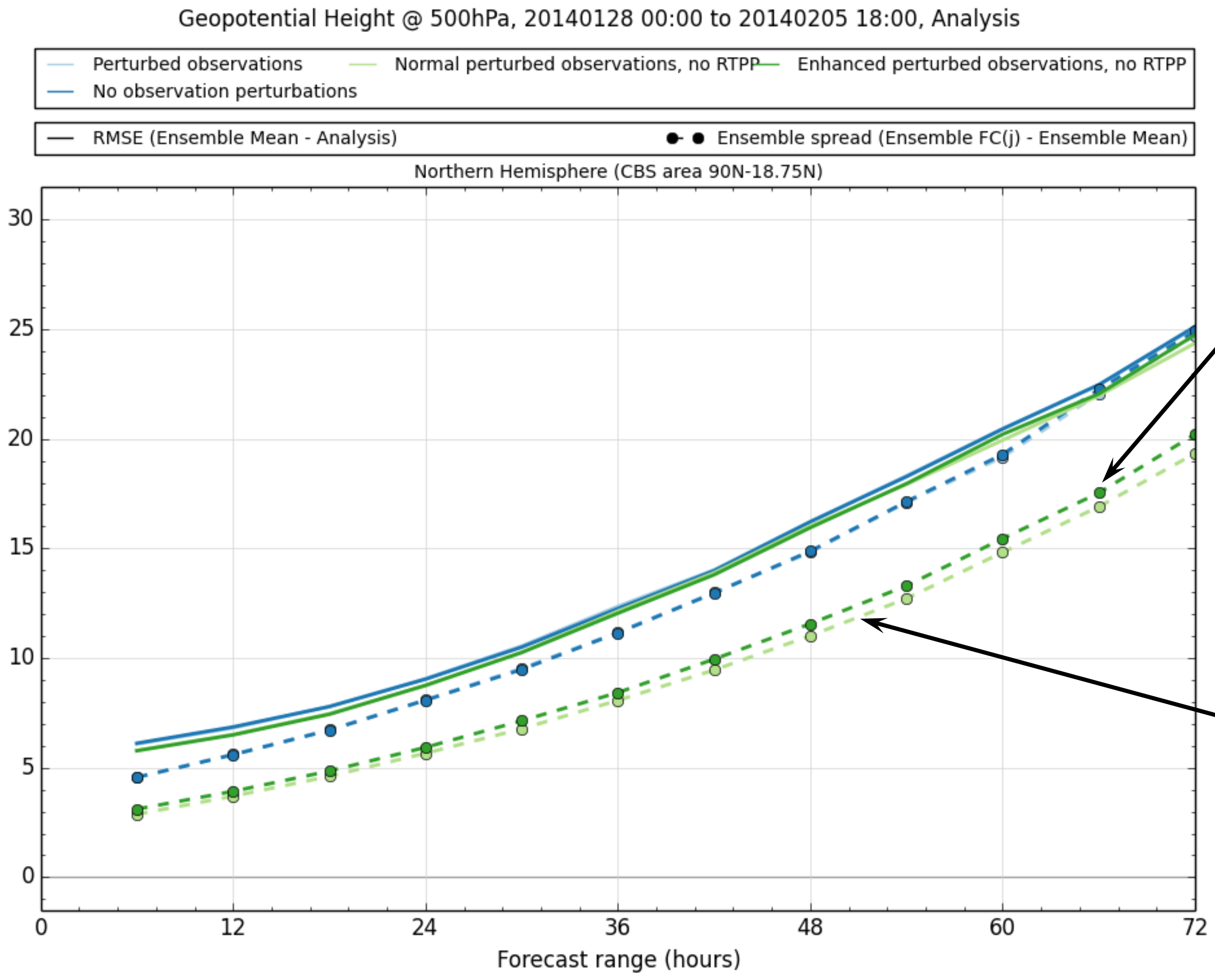


RMSE

Ensemble spread, with and without perturbed observations

Perturbed observations

En-4DEnVar, RTPP 0.0, RTPS 0.9, Add 0.5, Self-excl



Ensemble spread, without RTPP, with enhanced (√3) perturbed observations

Ensemble spread, without RTPP, with perturbed observations

Summary and future work

- The initial version of the new En-4DEnVar ensemble
  - is a little worse than the current ETKF-based ensemble according to standard ensemble metrics,
  - but produces better error covariances for data assimilation.
- Further scientific and computational enhancements will be made to replace the ETKF with an En-4DEnVar ensemble in 2017-2018.
- Recentring the ensemble around the high-resolution analysis improves the ensemble, but has mixed impacts on the hybrid deterministic analysis
- Perturbing the observations seems to do very little

Latest results