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Combined State-Parameter Estimation with the LETKF for Convective-Scale Weather Forecasting

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Motivation

Convection permitting models are highly prone to model error due to the complexity of important subgrid-scale processes. If model error is not well represented in the ensemble, observations are not used optimally to produce initial conditions, leading to poor forecasts. Our focus is on representation of clouds in models, which depends on highly uncertain surface fluxes.

Goal

- Reduce forecast errors caused by inaccuracies of surface fluxes
- Better capture the uncertainty of forecasts

Approach

Identify parameters that directly influence surface fluxes (roughness length) and estimate them along with the state in COSMO-KENDA (*Schraff et al, 2016*) for a weakly forced high impact weather period (04. 06.2016-10,06,2016). Verification is done against VIS/NIR (*Scheck et al, 2016*) and radar reflectivity data.

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Parameter estimation

Goal: estimate unknown state vector $x \in \mathbb{R}^n$

Given: $x_{t+1} = f(x_t, \theta_t) + w_t, \quad w_t \sim \mathcal{N}(0, Q)$

$y_t = h(x_t) + v_t, \quad v_t \sim \mathcal{N}(0, R)$

Parameters are updated based on their correlation with observed state variables

1) Update:

$$\begin{pmatrix} x_i^a \\ \theta_i^a \end{pmatrix} = \begin{pmatrix} x_i^b \\ \theta_i^b \end{pmatrix} + \begin{pmatrix} P \\ \mathrm{Cov}(x^b, \theta^b) \end{pmatrix} H^T (HPH^T + R)^{-1} (y_i - Hx_i^b)$$

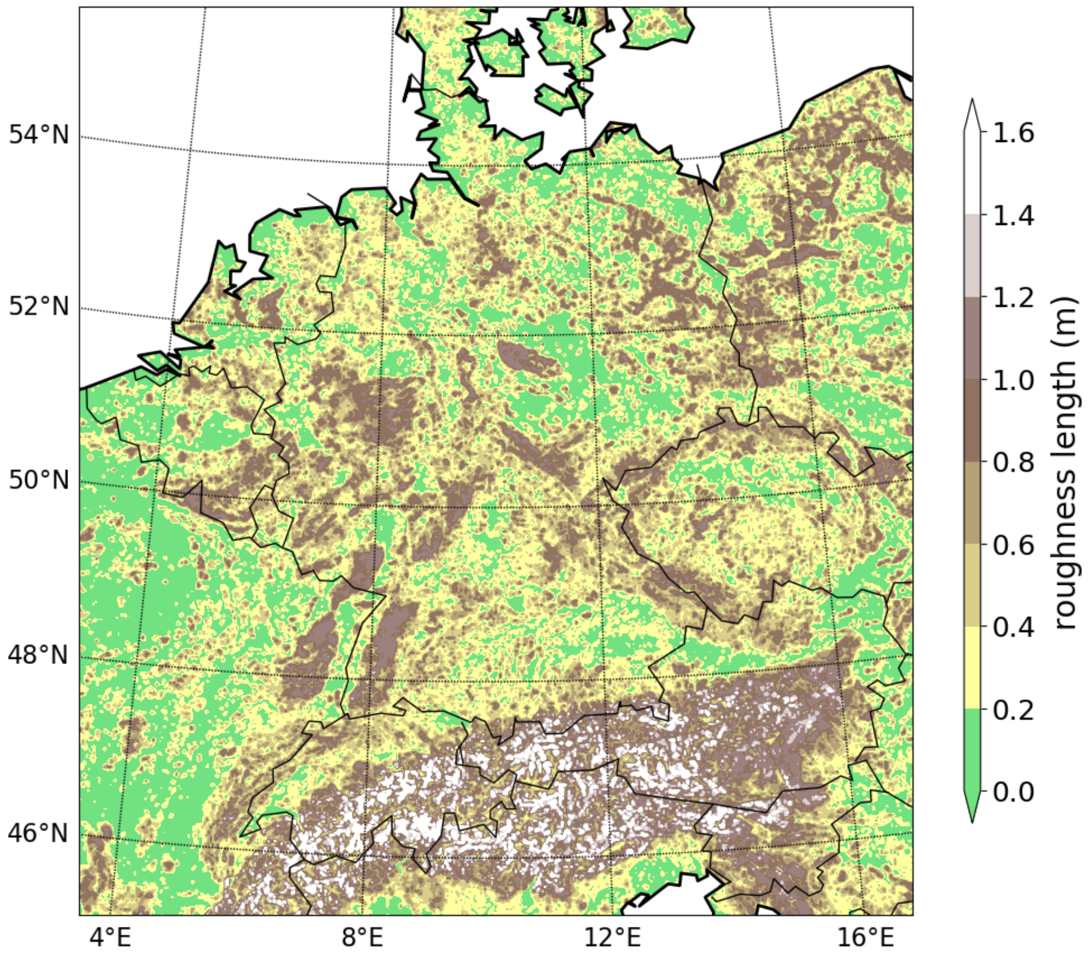
2) Predict:

$$x_i^b = f(x_i^a, \theta_i^a) + w_i$$

Get $\mathrm{cov}(x, \theta)$ from ensemble $\{x_1^b, x_2^b, \ldots, x_N^b, \theta_1^b, \theta_2^b, \ldots, \theta_N^b\}$

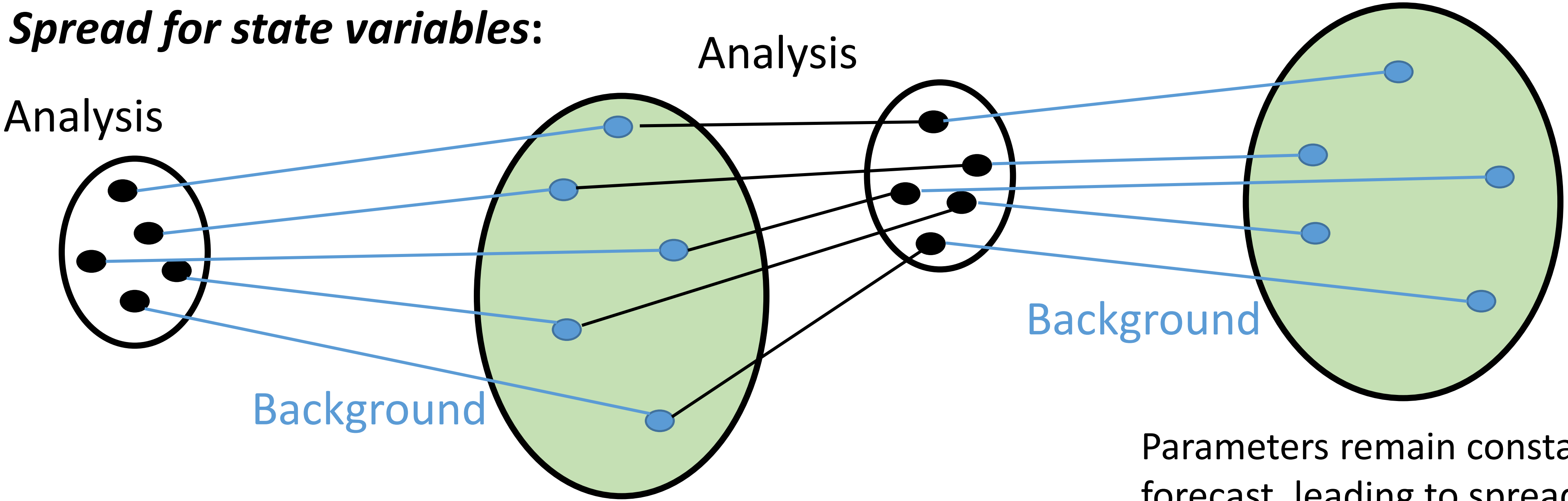
Application to roughness length in COSMO-KENDA

- Roughness length accounts for subgrid-scale orography and land use
- Operational configuration
- Assimilate conventional observations and radar reflectivity
- Strongly convective week 04.06 - 09.06 2016



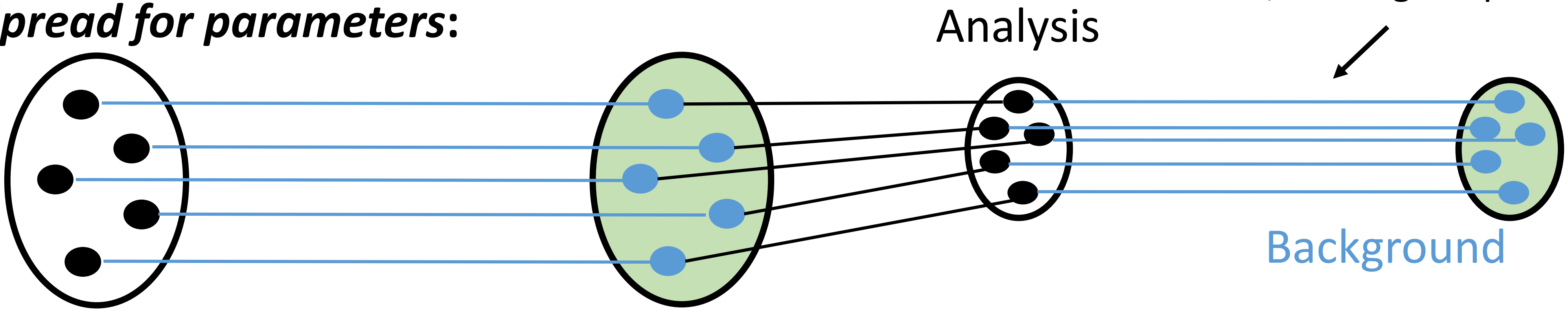
Parameter spread

***Spread for state variables*:**



Parameters remain constant throughout forecast, leading to spread collapse.

***Spread for parameters*:**



Stochastic model for roughness length

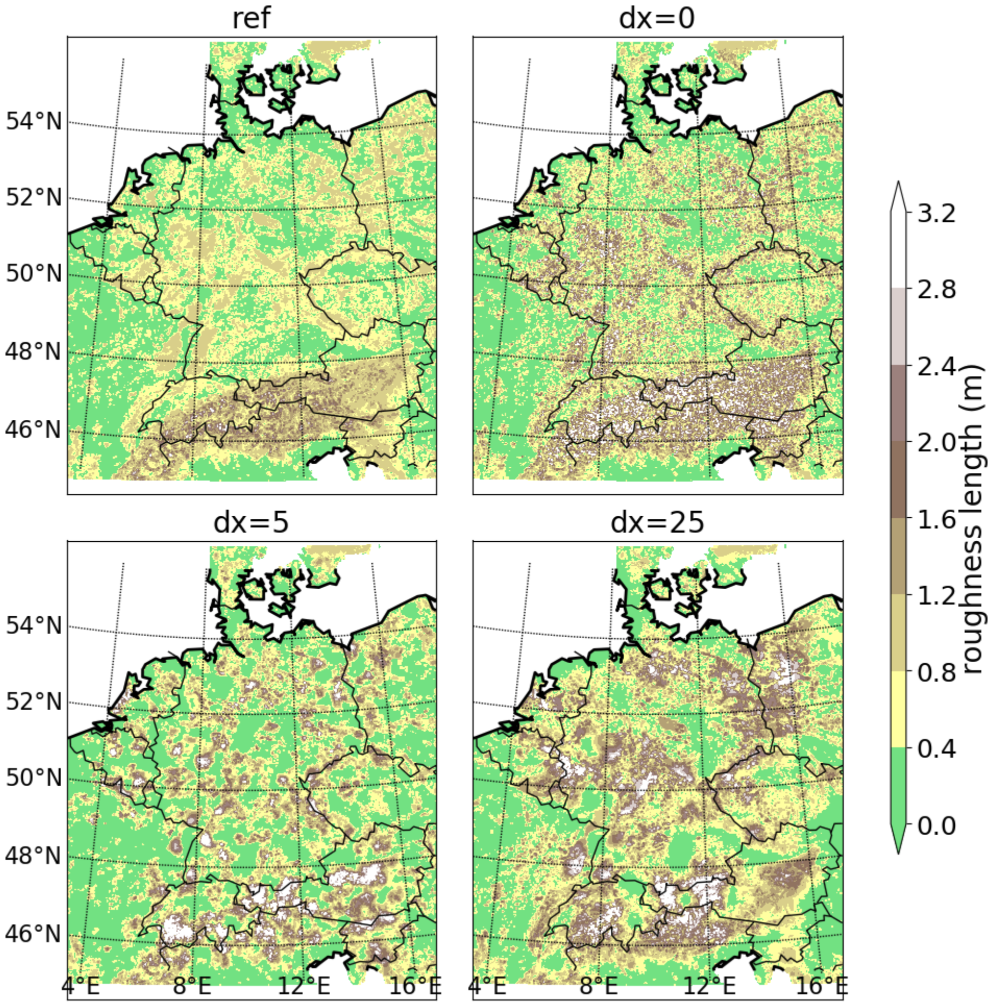
To avoid spread collapse we introduce a stochastic model for the parameter.

$$\theta^f_{t,i} = \theta^a_{t-1,i} + \mathbf{D}_{t-1,i}\mathbf{Q}^{\frac{1}{2}}\eta$$

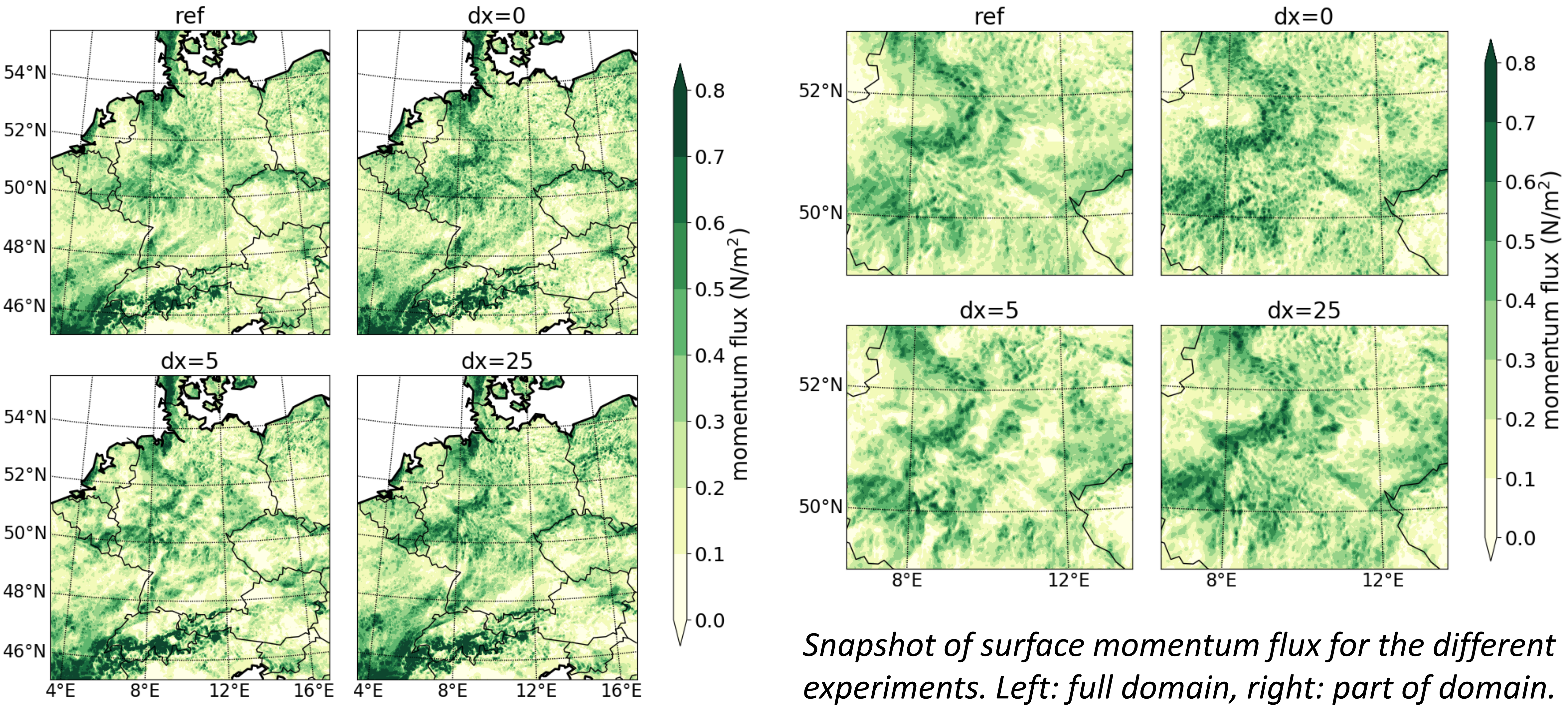
$$\eta \sim \mathcal{N}(0,1)$$

Diagonal $\mathbf{D}_{t-1,i}$ is chosen such that $\mathrm{std}\left[\theta^b_t\right] = 0.25\,\bar{\theta}^b_0$

$\mathbf{Q}$ is Gaussian, with correlations length scale ***dx=0***, ***dx=5*** and ***dx=25*** grid points



Effect on surface fluxes (snapshot)



Snapshot of surface momentum flux for the different experiments. Left: full domain, right: part of domain.

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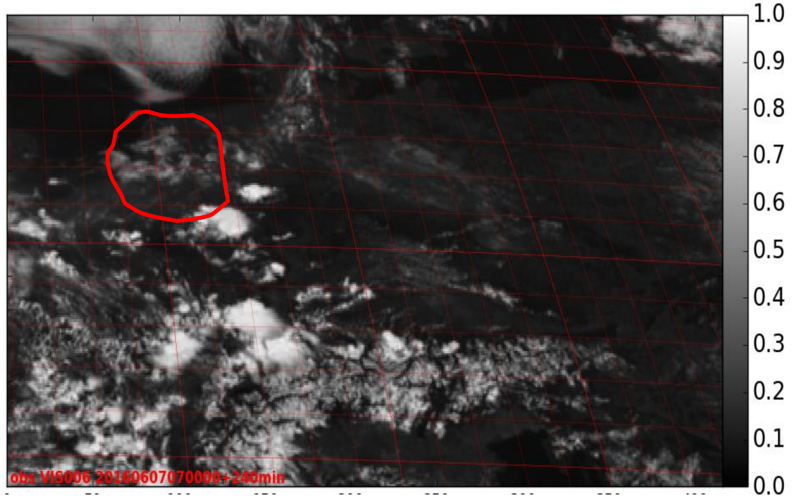
Snapshot of visible satellite images (reflectance)

Observations

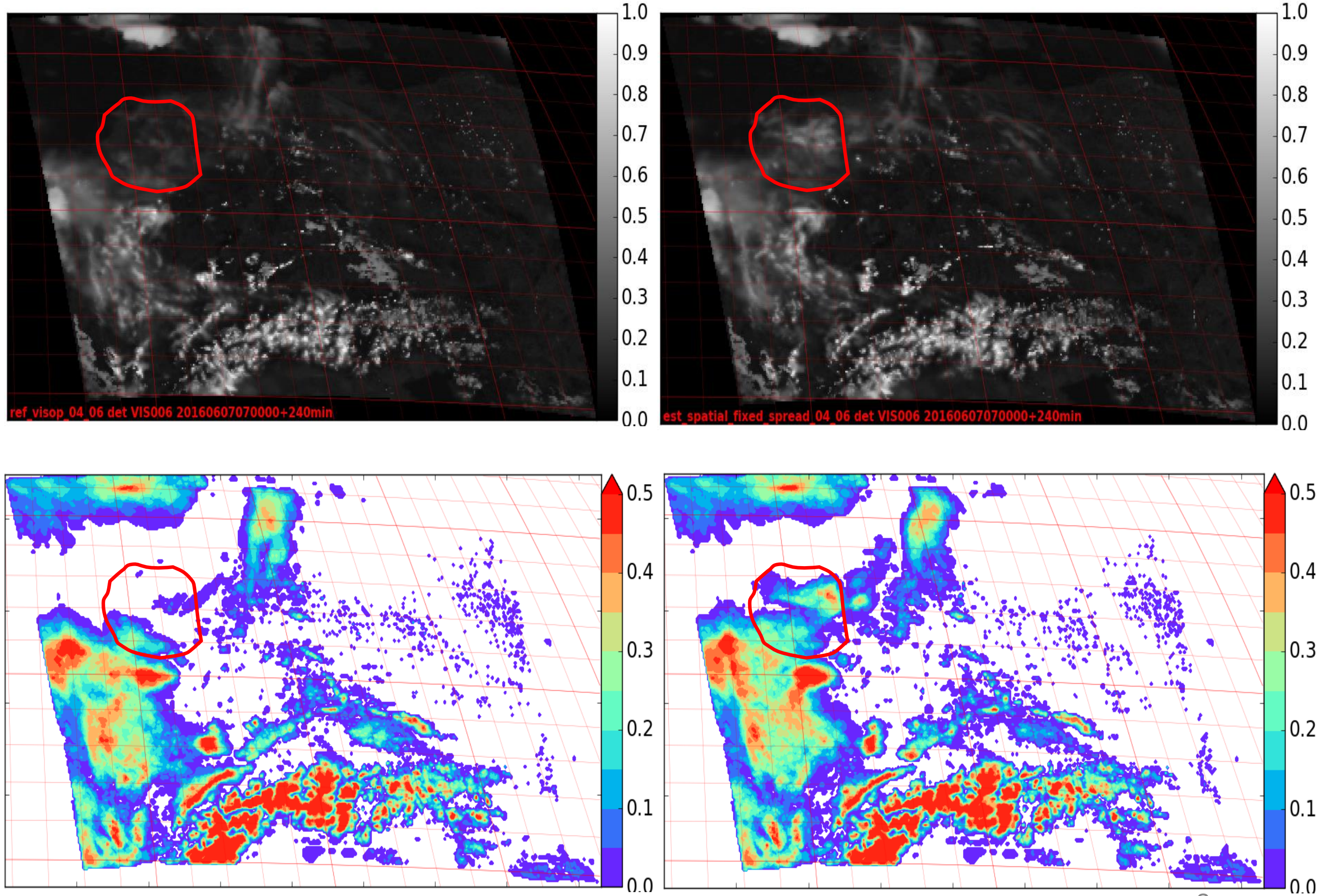


Observation operator by Scheck et al (2016)

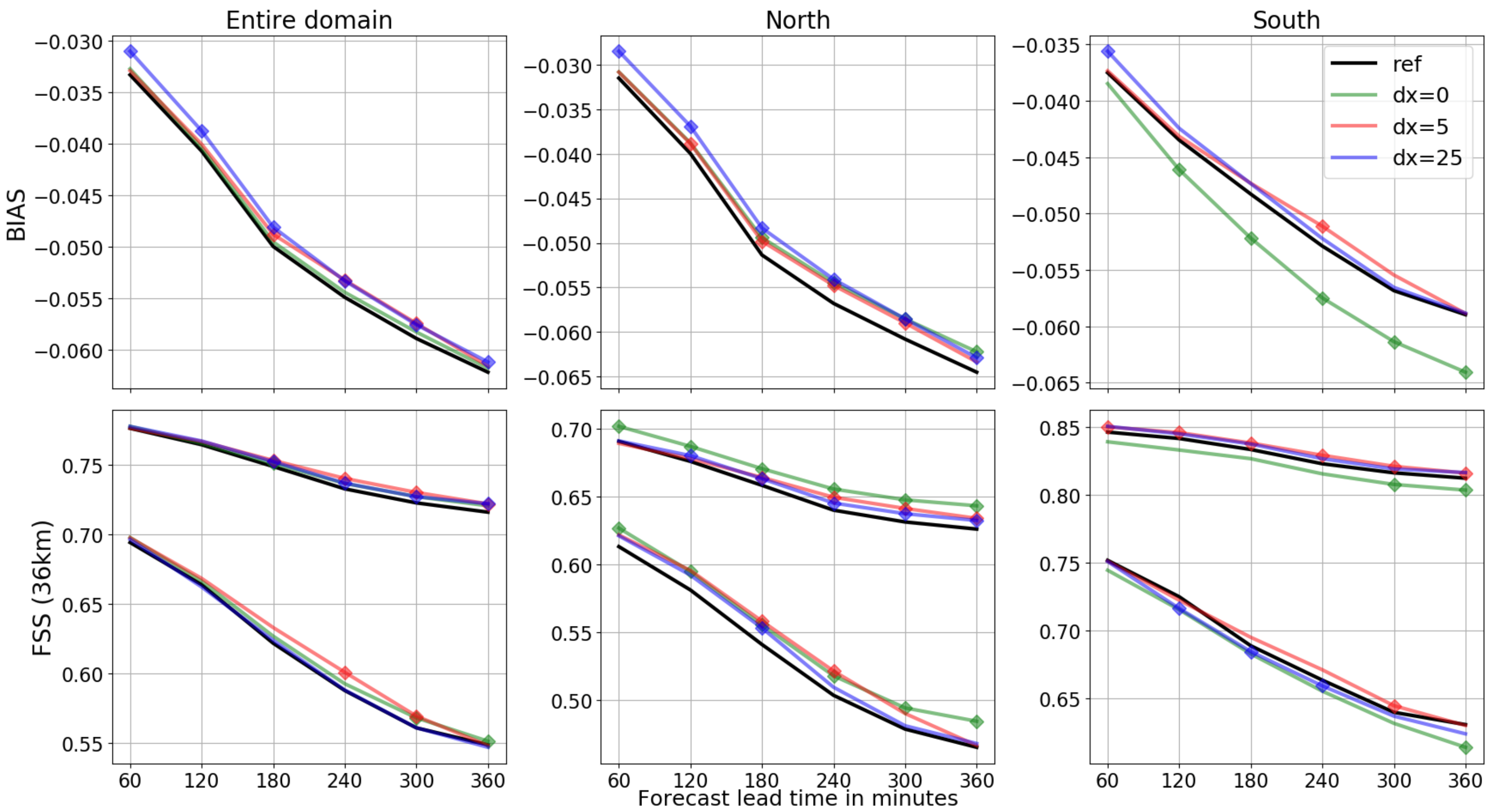
Reference **dx=5**

Deterministic

Ensemble

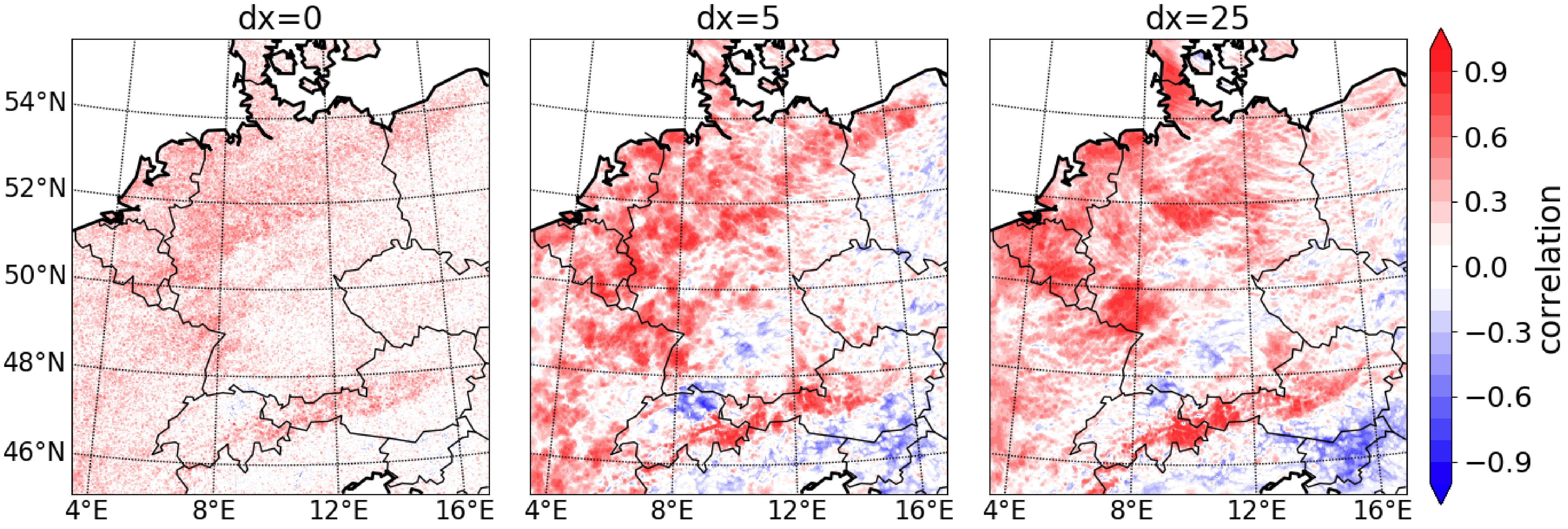


Reflectance scores



- 6 days
- 10 forecasts a day (6-15 UTC)

Correlation to surface wind (snapshot)



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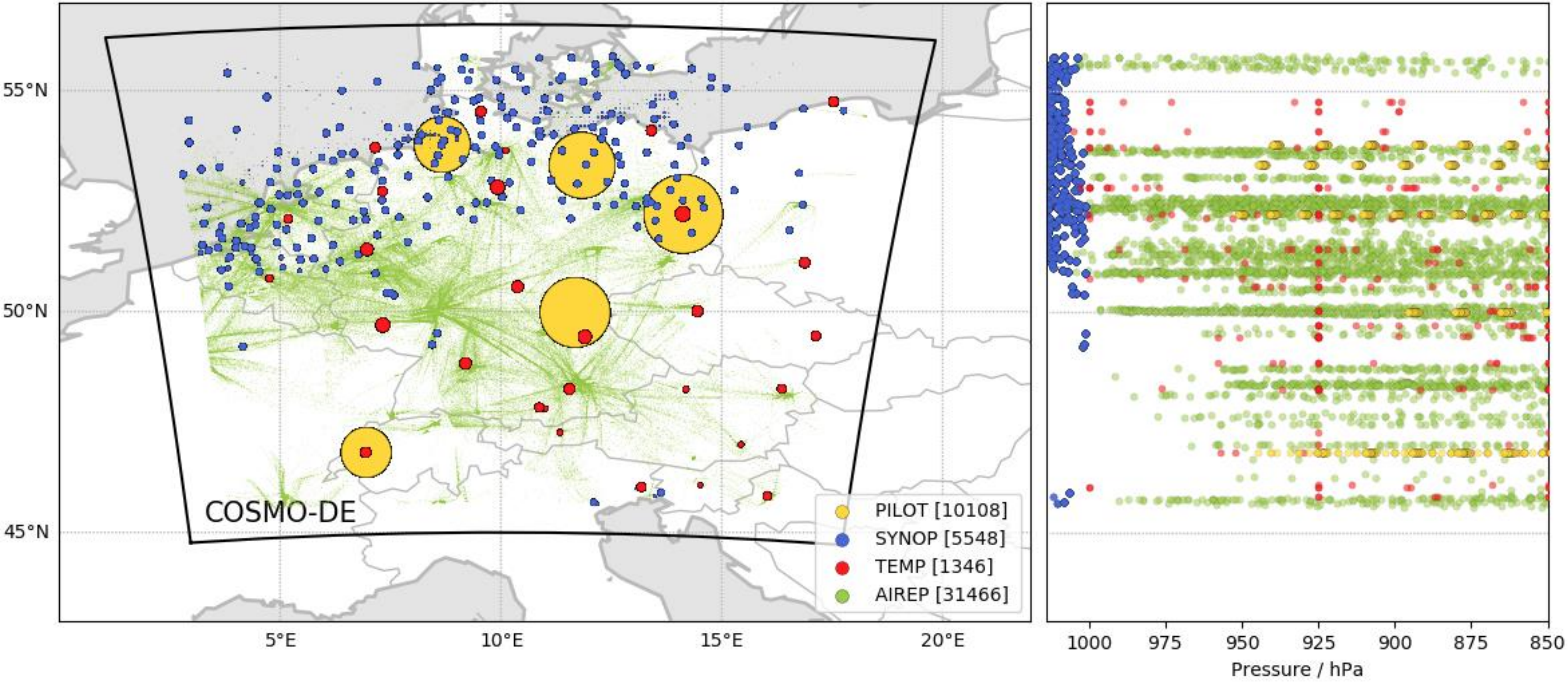
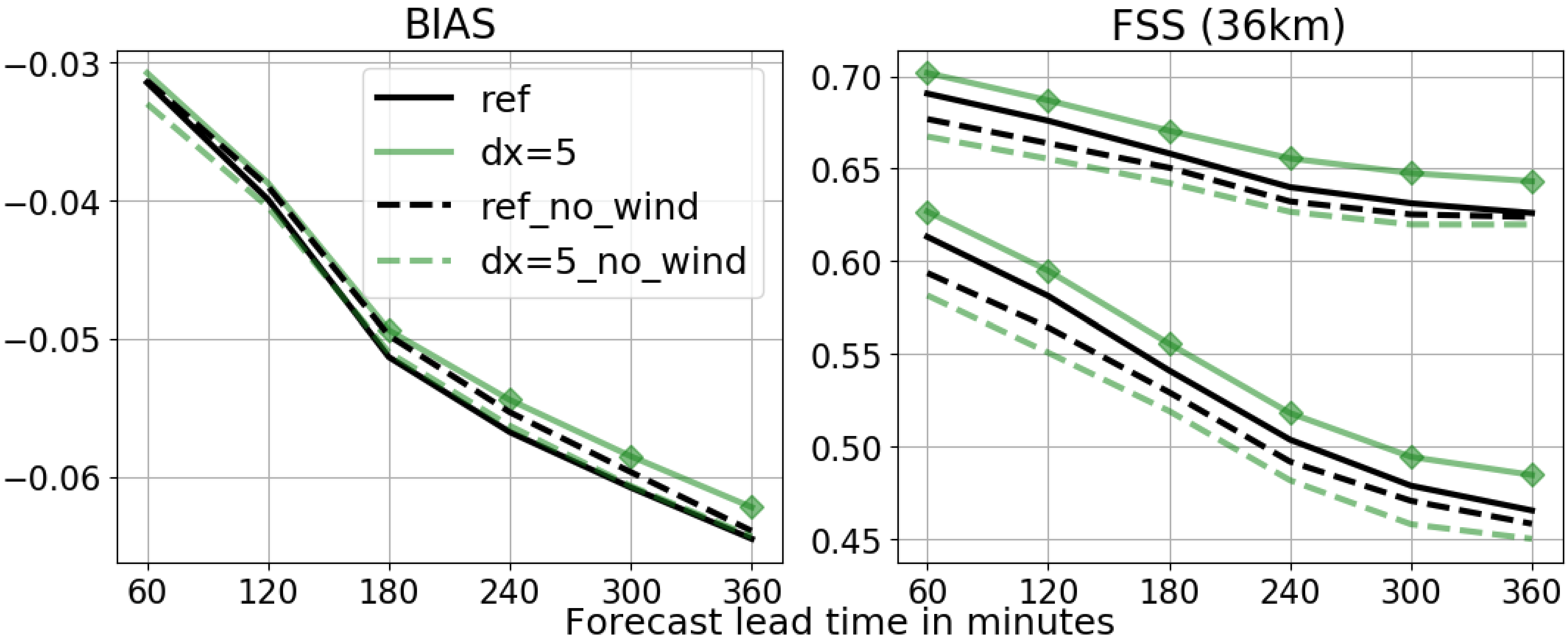
Assimilated wind observations (daily average)



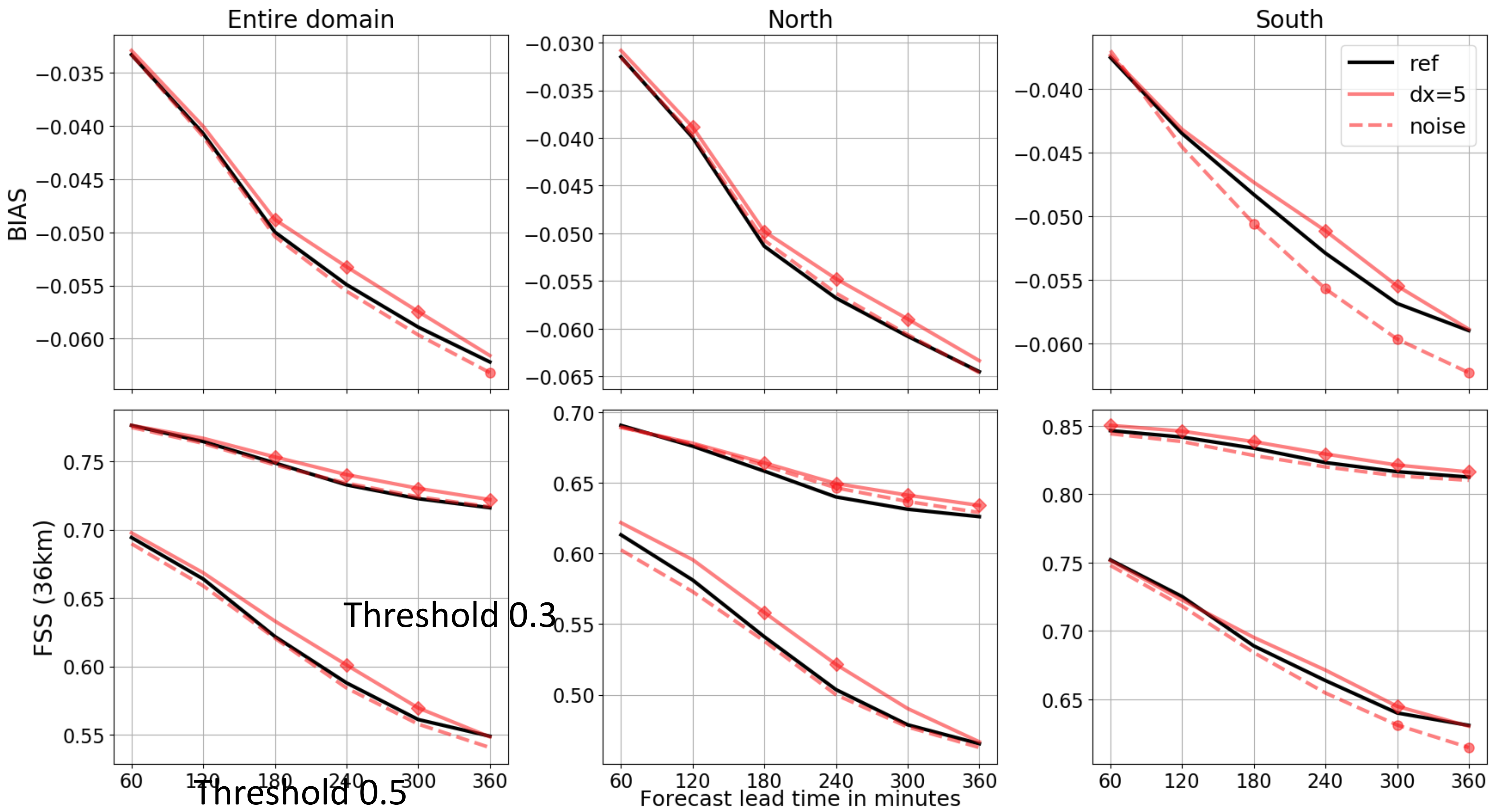
Due orography, surface wind measurements only consistently pass quality control in the Northern part of the domain. As a result there is lack of assimilated surface wind measurements in the South.

Without assimilating surface wind…



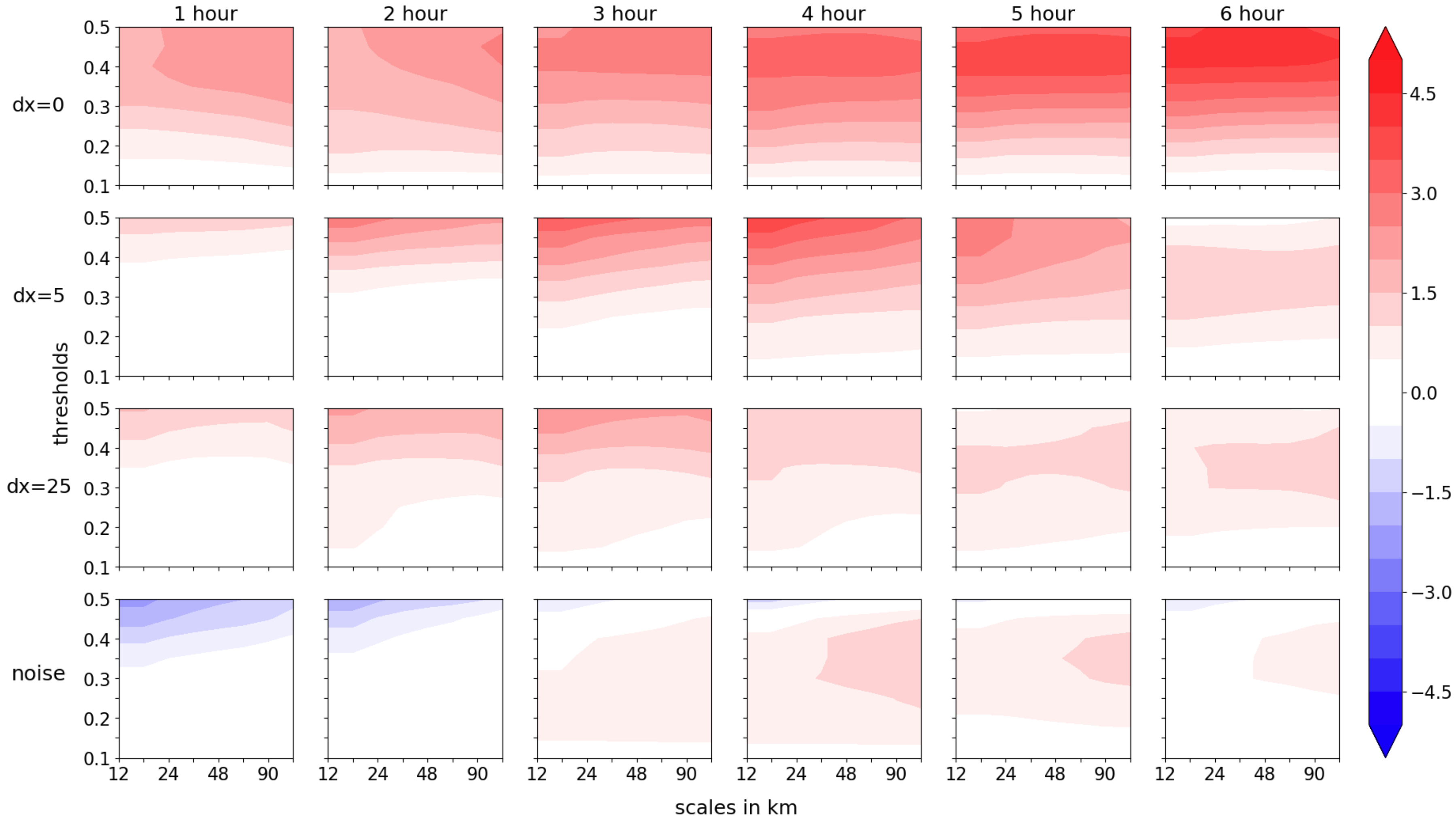
Reflectance scores. Dashed lines are experiments where surface wind was not assimilated. Plot shows the Northern part of the domain. Conclusion: surface wind measurements are important for this application!

Reflectance scores

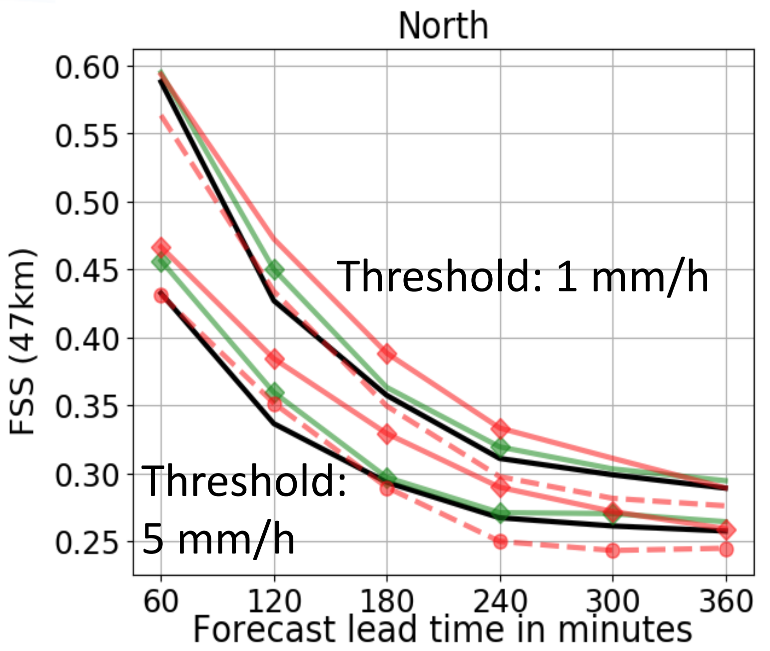


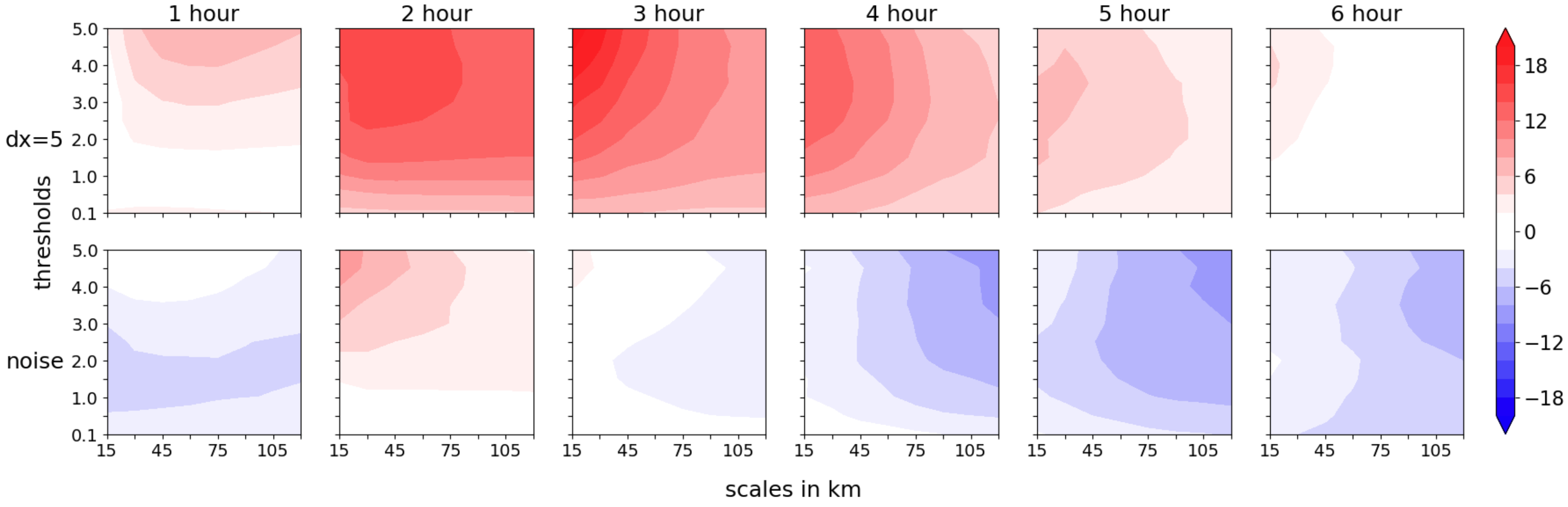
For the experiment labeled "noise" we only perturb the parameter with dx=5. The parameter ensemble mean is not updated during the assimilation.

Reflectance FSS scores

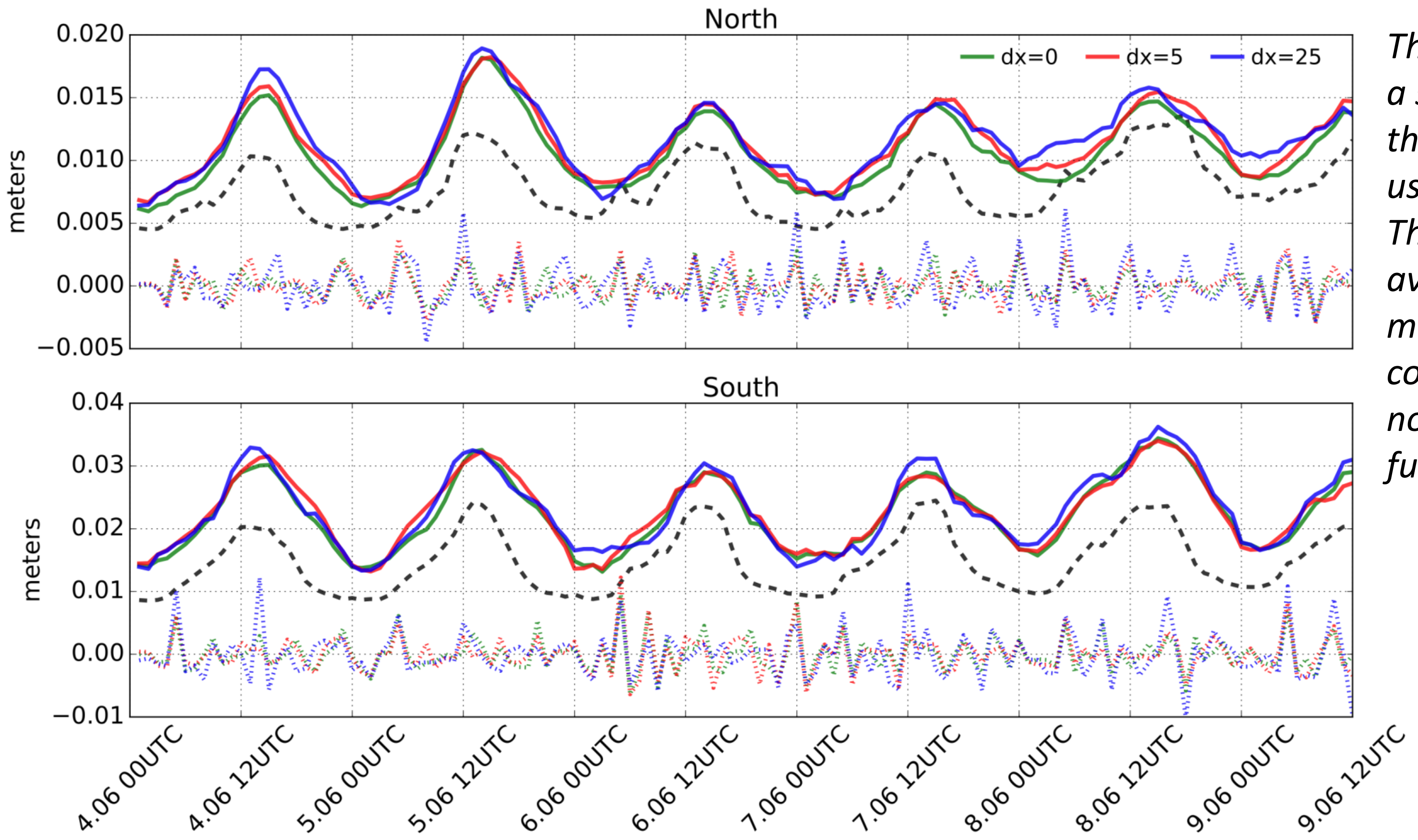


Verification against radar reflectivity





Domain averaged analysis increments of the rougness length



The increments are separated into a smoothed part (solid lines) and the remaining noise (dotted lines) using the Savitzky-Golay filter. The dashed black line is the average hourly absolute surface momentum flux differences corresponding to the reference run, normalized with some linear function for visualization purposes.

A clear diurnal cycle is visible!

Conclusion

- Forecast errors are significantly reduced, but roughness length is now accounting for more than subgrid scale orography and land use and is therefore flow dependent
- Surface wind measurements are important to update the roughness length
- Introducing a correlation length scale in the roughness length fields can partially compensate for lack of surface wind measurements
- In strongly synoptically forced regimes, benefits of roughness length estimation are less significant but still present (not shown)

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References

- Ruckstuhl, Y. and T. Janjić, 2020: Combined State-Parameter Estimation with the LETKF for Convective-Scale Weather Forecasting. *Mon. Wea. Rev.*, **148**, 1607–1628, https://doi.org/10.1175/MWR-D-19-0233.1
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- Schraff, C., and R. Hess, 2012: A description of the nonhydrostatic regional COSMO-model. Part III: Data assimilation. COSMO Tech. Rep. V4_22, 99 pp., http://www.cosmo-model.org/content/model/documentation/core/cosmoAssim.pdf.