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Modification of potential temperature and PV in forecasts of different lead times

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Motivation

- Lagrangian tracers and on-line trajectories enable an unprecedented level of detail in model output
  - These techniques allow us to follow air parcels (in model world) while still solving an Eulerian model
- We can use them to study processes behind phenomena
  - Air-mass modification around cyclones (e.g. Oertel et al. 2018)
  - Predictability barriers (Claudio's talk)
- We can also use them to study model error (Saffin et al. 2017)
- Can we use them to identify systematic model error structure in model tendencies?

Approach

- Describe modification at a given grid-point
    - In purely Eulerian terms

$$\theta(x,t) = \theta(x,t=0) + \Delta\theta(x,t)$$

    - In terms of Lagrangian tracers

$$\theta(x,t) = \theta_0(x,t) + \delta\theta(x,t)$$

- Assume a theoretical unbiased model (no systematic error)

$$\langle\epsilon\rangle = 0$$

- Compare 12-h v 24-h forecasts from operational model against the expected behaviour of the theoretical unbiased model

Data

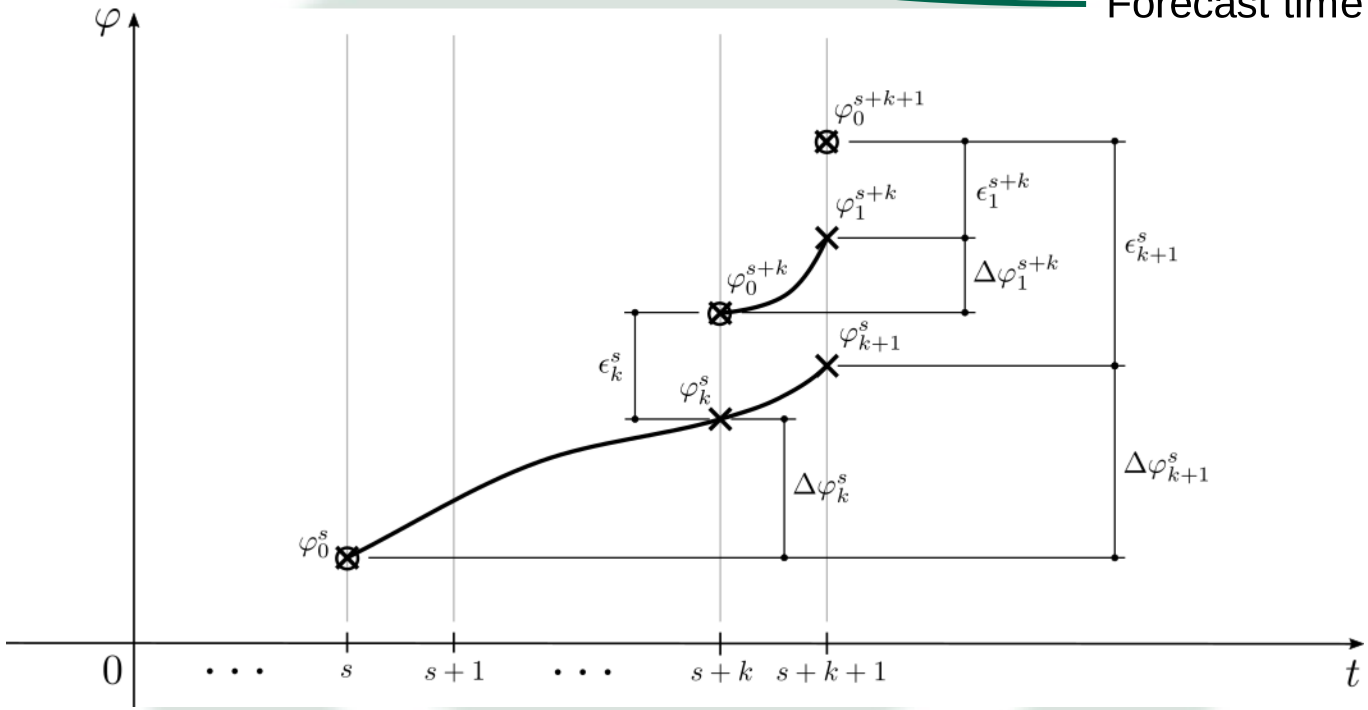
- Variables of interest: Potential temperature and PV
- NAWDEX field campaign: 17 September – 22 October 2016 (Schäfler et al. 2017)
- Met Office MetUM vn10.4 hindcasts, including diabatic tracers
  - Here including only forecasts between 0000 UTC 20 September – 1200 UTC 14 October 2016 every **12 hours**
- Global N768 (17 km at 50° latitude)
- Output on 20ºN – 80ºN, 80ºW – 40ºE
  - 197890 grid points per level
  - **Statistically robust analysis** over 10 model levels, i.e. ~2 x 10^6 grid points per day and ~10^8 grid points in the dataset

Eulerian description

Forecast base time

On a given grid point: $\varphi_n^m = \varphi_n^m(\boldsymbol{x})$

Forecast time step



$$(\Delta\varphi_{k+1}^s - \Delta\varphi_k^s) - \Delta\varphi_1^{s+k} = \epsilon_1^{s+k} - \epsilon_{k+1}^s + \epsilon_k^s$$

For an unbiased model:

$$\boxed{\langle \Delta\varphi_{k+1}^s - \Delta\varphi_k^s \rangle - \langle \Delta\varphi_1^{s+k} \rangle = 0}$$

Lagrangian-tracer description

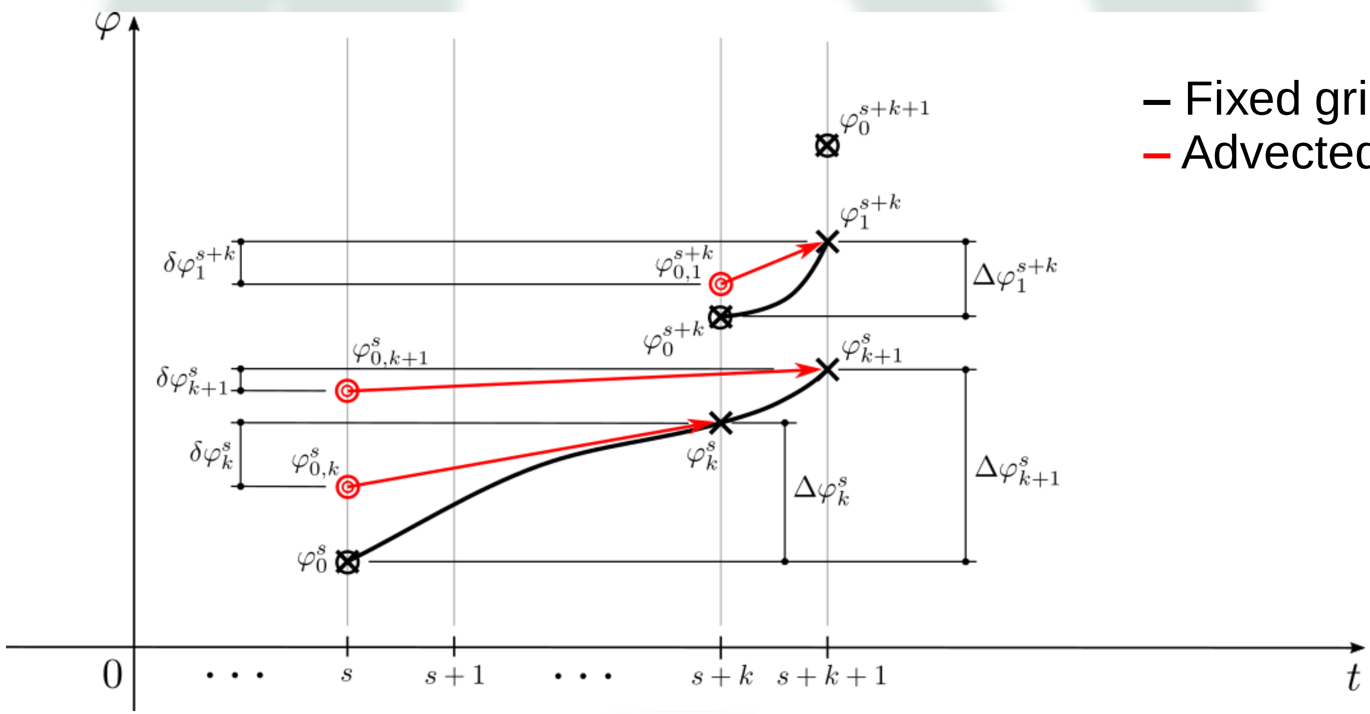
Still on a given grid point:

$$\varphi_n^m = \varphi_{0,n}^m + \delta\varphi_n^m$$

Parcel's initial φ-value (at forecast base time m) advected to the grid point at forecast time step n

φ-increment due to parametrised diabatic processes

$$\Delta\varphi_n^m = \delta\phi_n^m + \left(\varphi_{0,n}^m - \varphi_0^m\right)$$



– Fixed grid point
– Advected air mass

Lagrangian-tracer description

University of Reading

For an unbiased model:

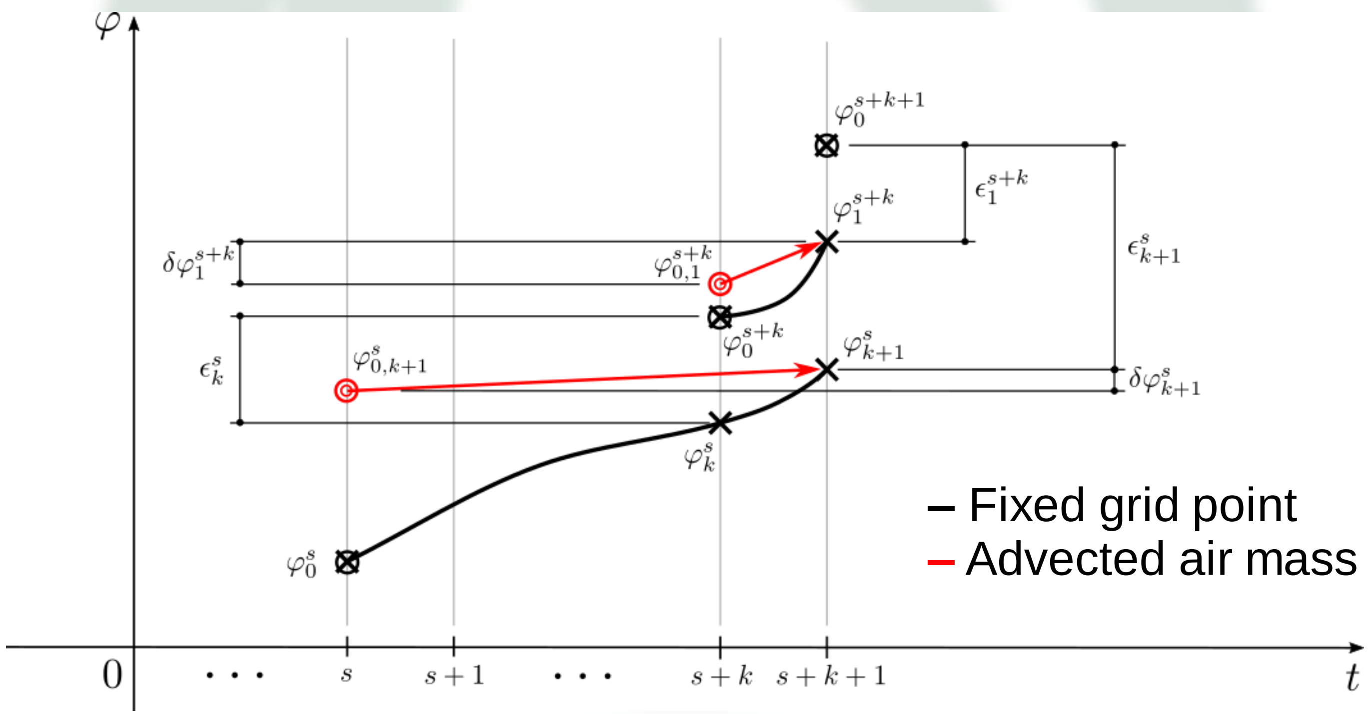
$$\boxed{\left\langle \varphi^{s}_{0,k\to k+1} - \varphi^{s+k}_{0,0\to 1} \right\rangle + \left\langle \delta\varphi^{s}_{k+1} - \delta\varphi^{s+k}_{1} \right\rangle = 0}$$

Advection

Along-trajectory modification

where

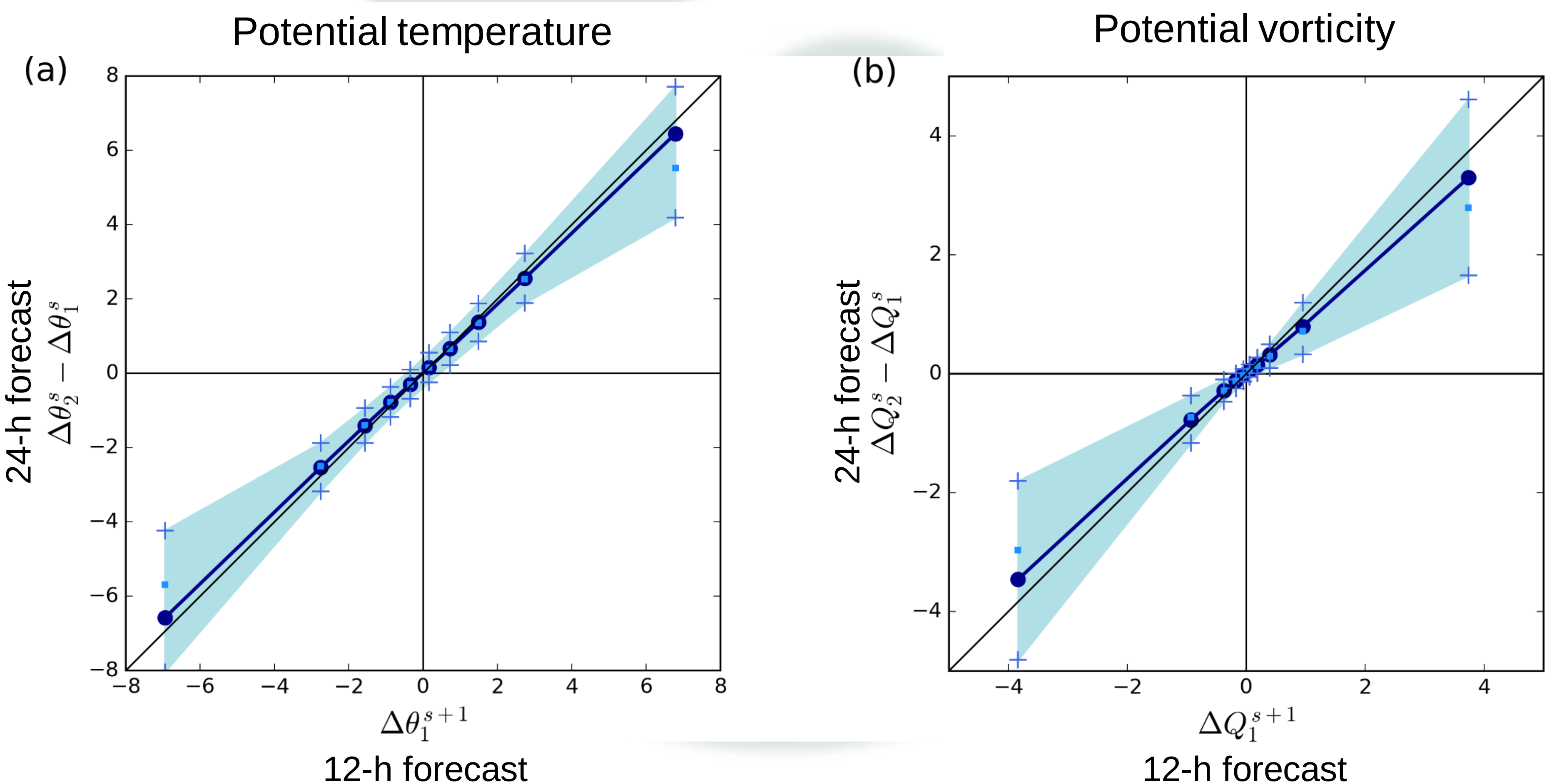
$$\varphi^{s}_{0,n\to m} = \varphi^{s}_{0,m} - \varphi^{s}_{n}$$



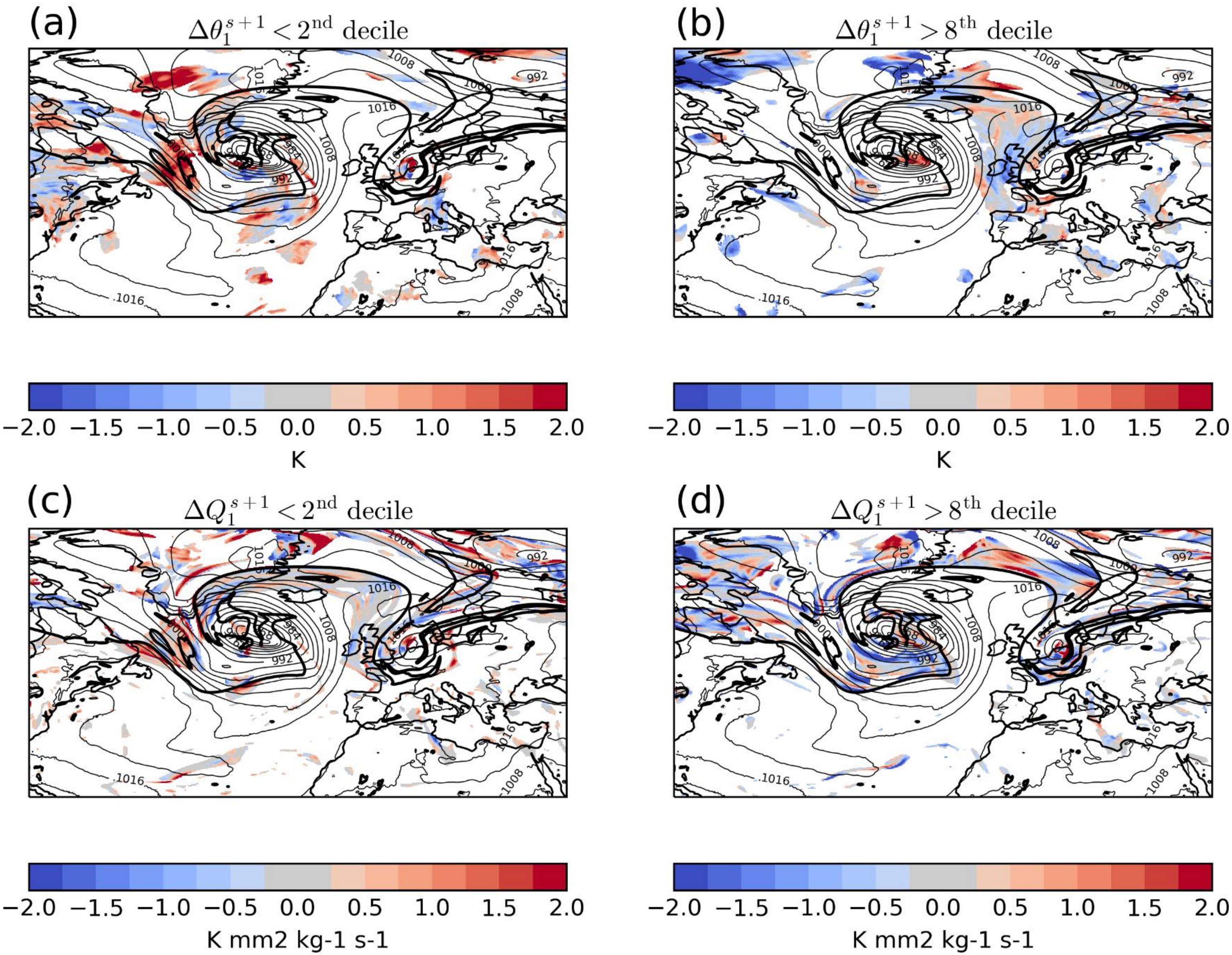
Eulerian description

$$\langle \Delta\varphi_{k+1}^{s} - \Delta\varphi_{k}^{s} \rangle = \langle \Delta\varphi_{1}^{s+k} \rangle$$

Upper levels (6.8 km – 11.2 km)



Eulerian description



Lagrangian-tracer description

$$\boxed{\left\langle \delta\varphi_{k+1}^{s} - \delta\varphi_{1}^{s+k} \right\rangle = -\left\langle \varphi_{0,k\to k+1}^{s} - \varphi_{0,0\to 1}^{s+k} \right\rangle}$$

Along-trajectory modification

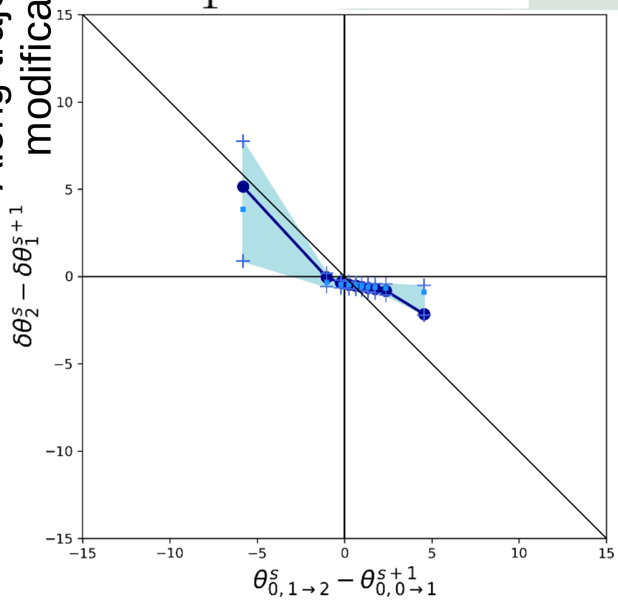
Advection

Upper levels (6.8 km – 11.2 km)

Potential temperature

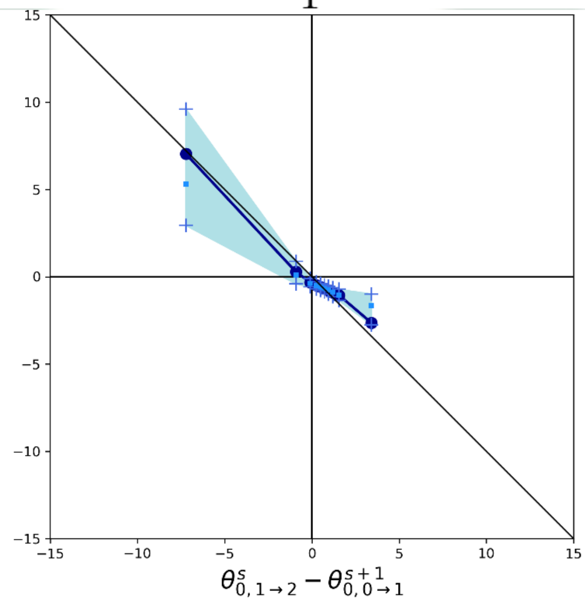
Along-trajectory modification

$\Delta\theta_1^{s+1} <$ 1st decile



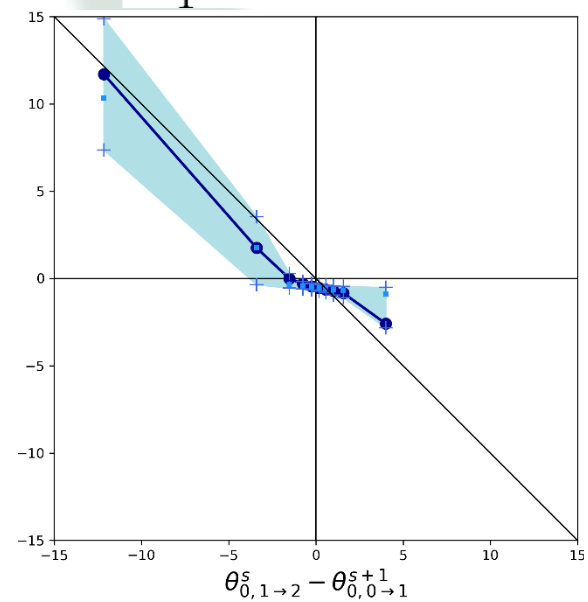
Advection

4th decile $< \Delta\theta_1^{s+1} <$ 6th decile



Advection

$\Delta\theta_1^{s+1} >$ 9th decile



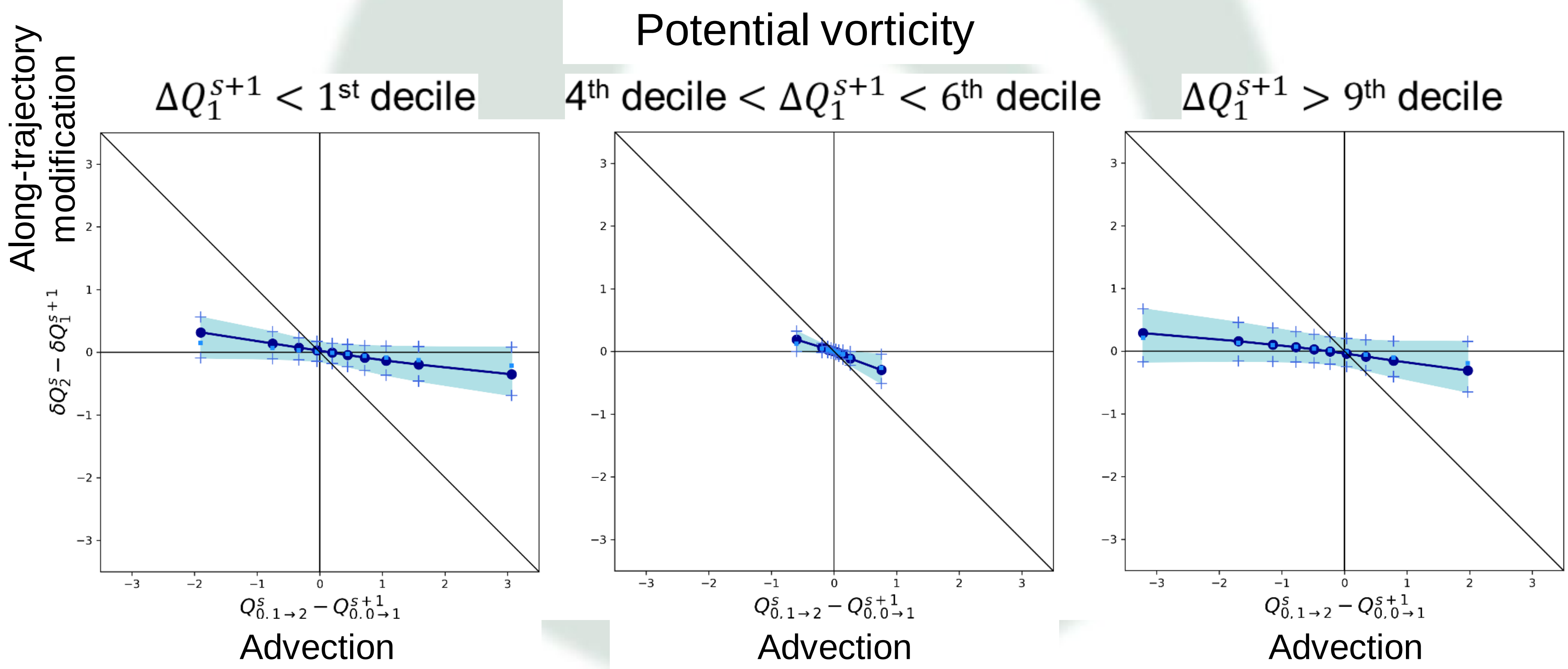
Advection

Lagrangian-tracer description

$$\left\langle \delta\varphi^{s}_{k+1} - \delta\varphi^{s+k}_{1} \right\rangle = -\left\langle \varphi^{s}_{0,k\to k+1} - \varphi^{s+k}_{0,0\to 1} \right\rangle$$

Along-trajectory modification | **Advection**

Upper levels (6.8 km – 11.2 km)



Conclusions

- Analysis of systematic errors in **changes** of potential temperature and PV using
  - An **Eulerian** description
  - A **Lagrangian-tracer** description
  - And a theoretical unbiased model's behaviour as a reference
- The largest **Eulerian** deviations in the long forecast correspond to the largest changes in the short forecast (i.e. **more dynamically active grid points**)
- Lagrangian tracers revealed that for PV, there was **a clear deviation** from the behaviour of the unbiased model regardless of the level of Eulerian change

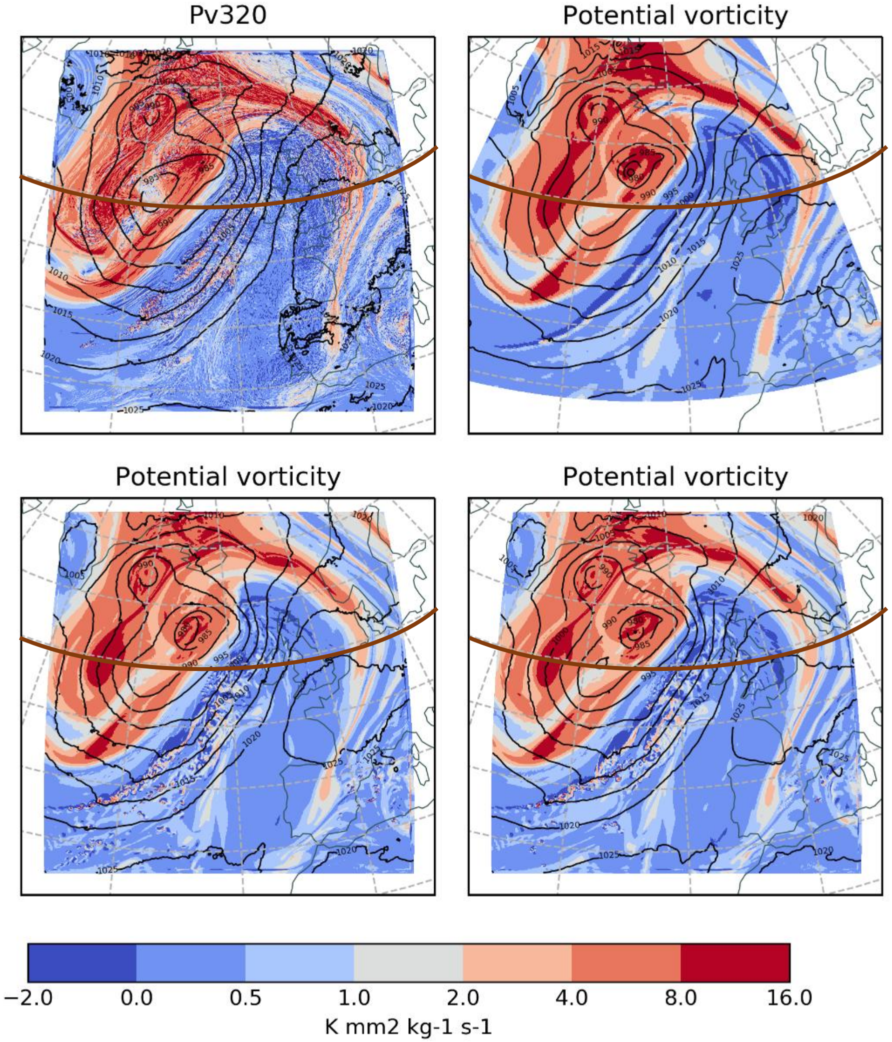
T + 36

2-km COSMO

N768 UM 17-km

4.4-km UM Smith

4.4-km UM PC2



Collaborative work with Annika Oertel, Hanna Joos, Claudio Sanchez and Ben Harvey

T + 36

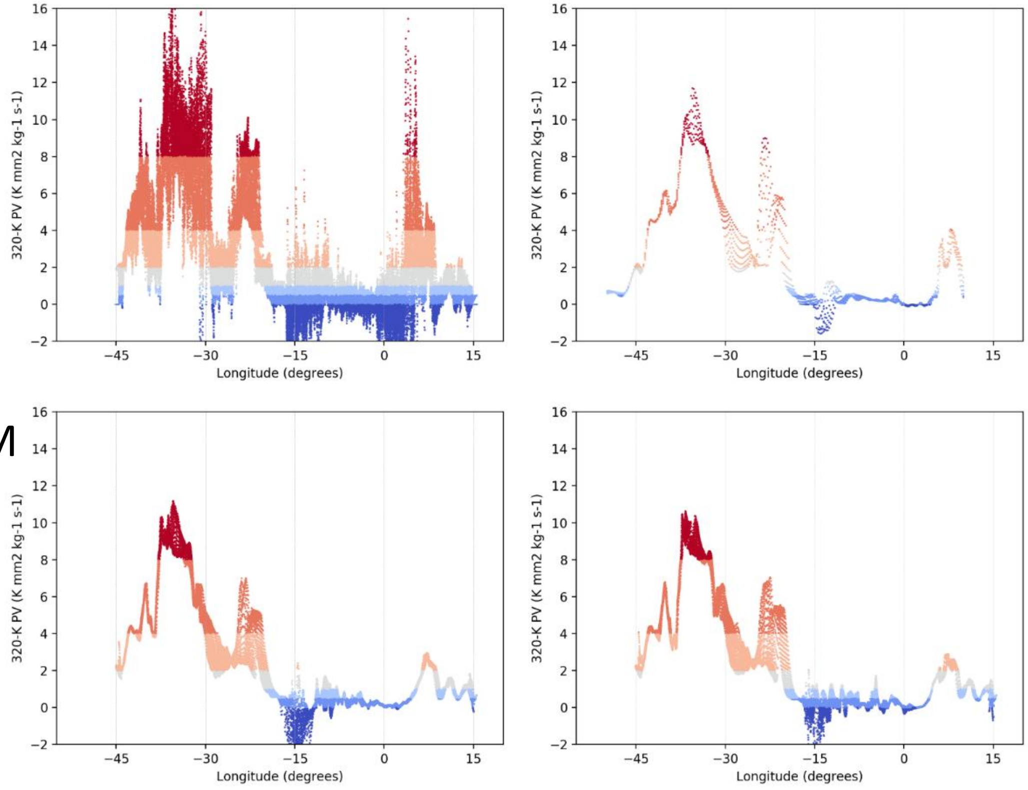
1°-band centred on 54°N

2-km COSMO

N768 UM 17-km

4.4-km UM Smith

4.4-km UM PC2



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