Virtual Workshop:
Warm Conveyor Belts
10-12 September 2020

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

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Introduction

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- NWP models have been designed primarily on dynamical and numerical considerations
- It is argued that there is one component missing
- What do we want from a forecast model? Zero forecast error

$$\epsilon = 0$$

Introduction

- Due to the nonlinearities in the governing equations, perfect forecasts are impossible to obtain
- What is the next best option? Unbiased forecast

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

- A new way of combining **dynamics** and **statistics** to evaluate NWP models

Introduction

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- 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
- They can be used to study processes behind phenomena
  - Air-mass modification around cyclones (e.g. Martinez-Alvarado et al. 2016)
  - Model error (Saffin et al. 2017)
  - WCB embedded convection (Oertel et al. 2019)

Aim

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Assess the behaviour of forecast model against that of a theoretical unbiased model (no systematic error)

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

Approach

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

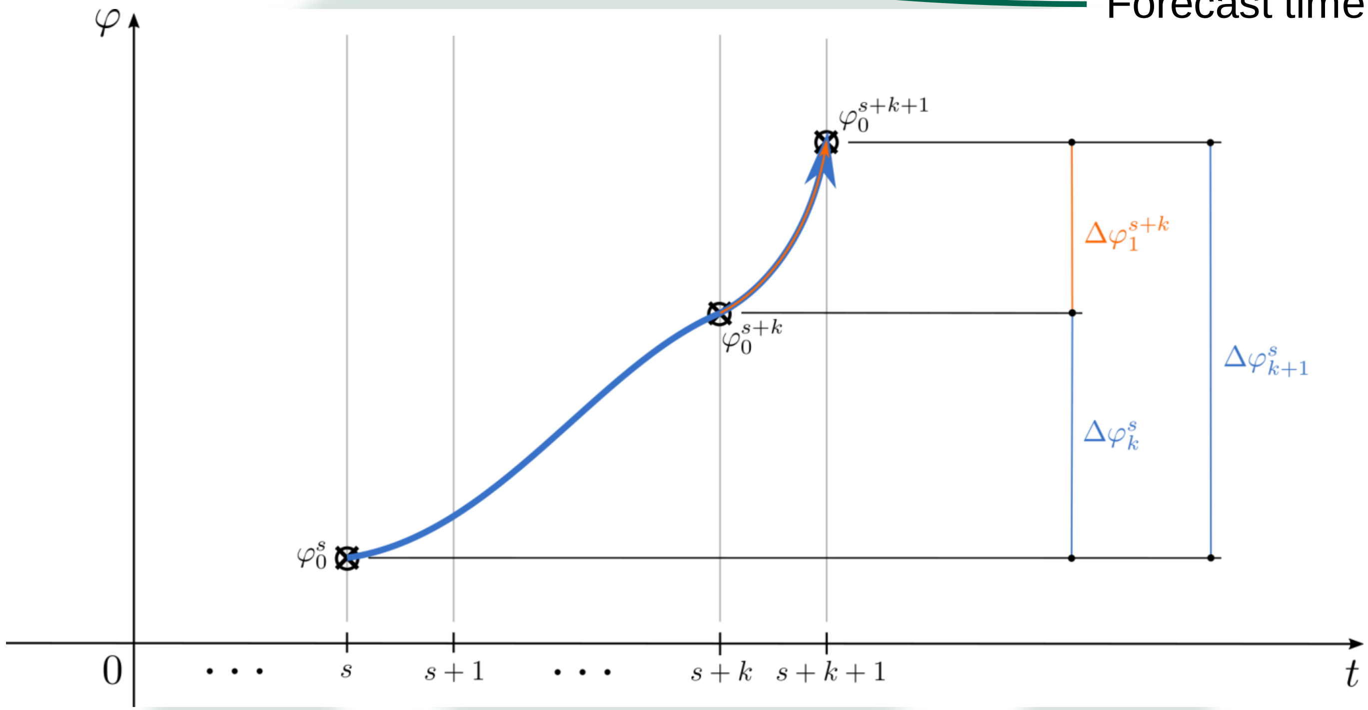
$$\theta(x,t) = \theta_0(x,t) + \delta\theta(x,t)$$

Eulerian description

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

Forecast base time

Forecast time step



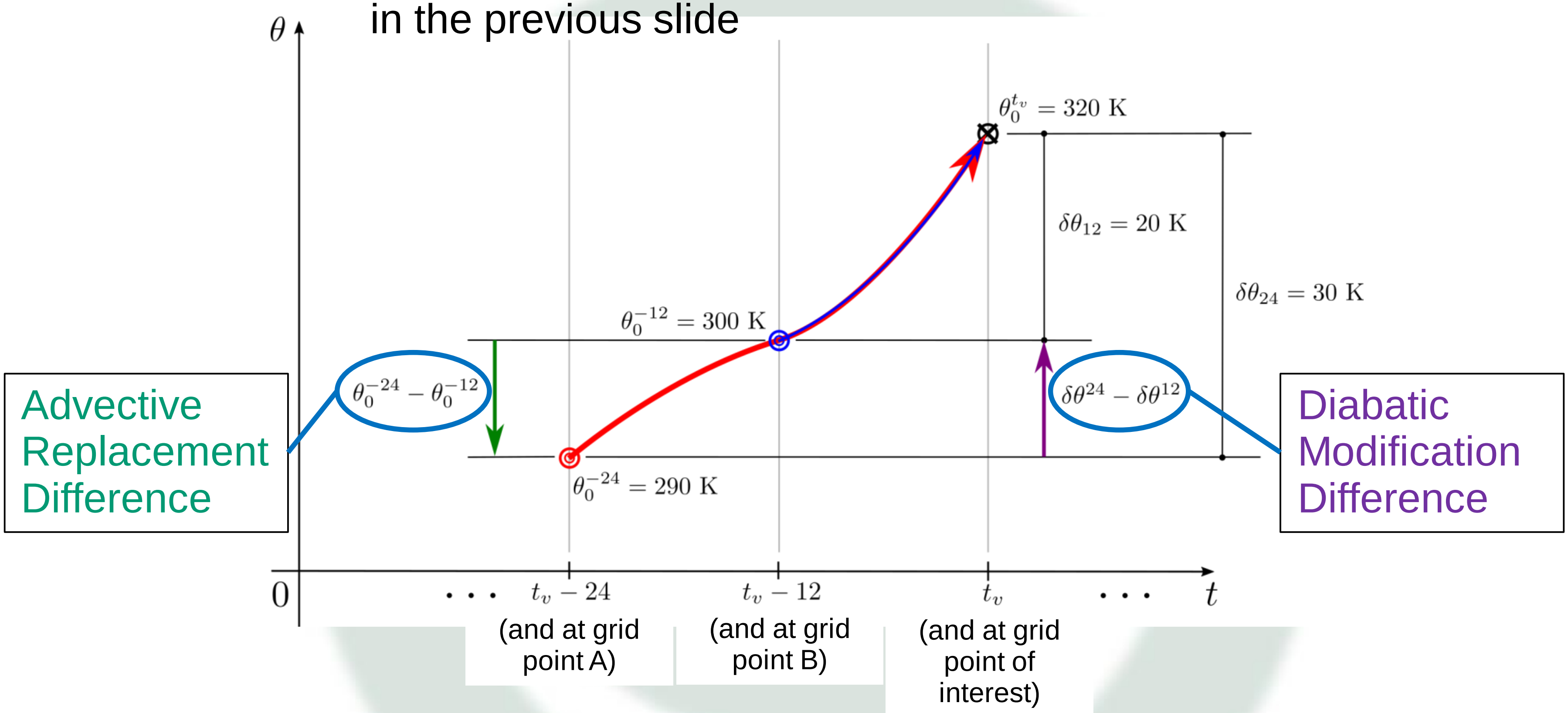
For an unbiased model:

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

The change in φ between two points in time should be equal (on average) regardless of the length of the simulation

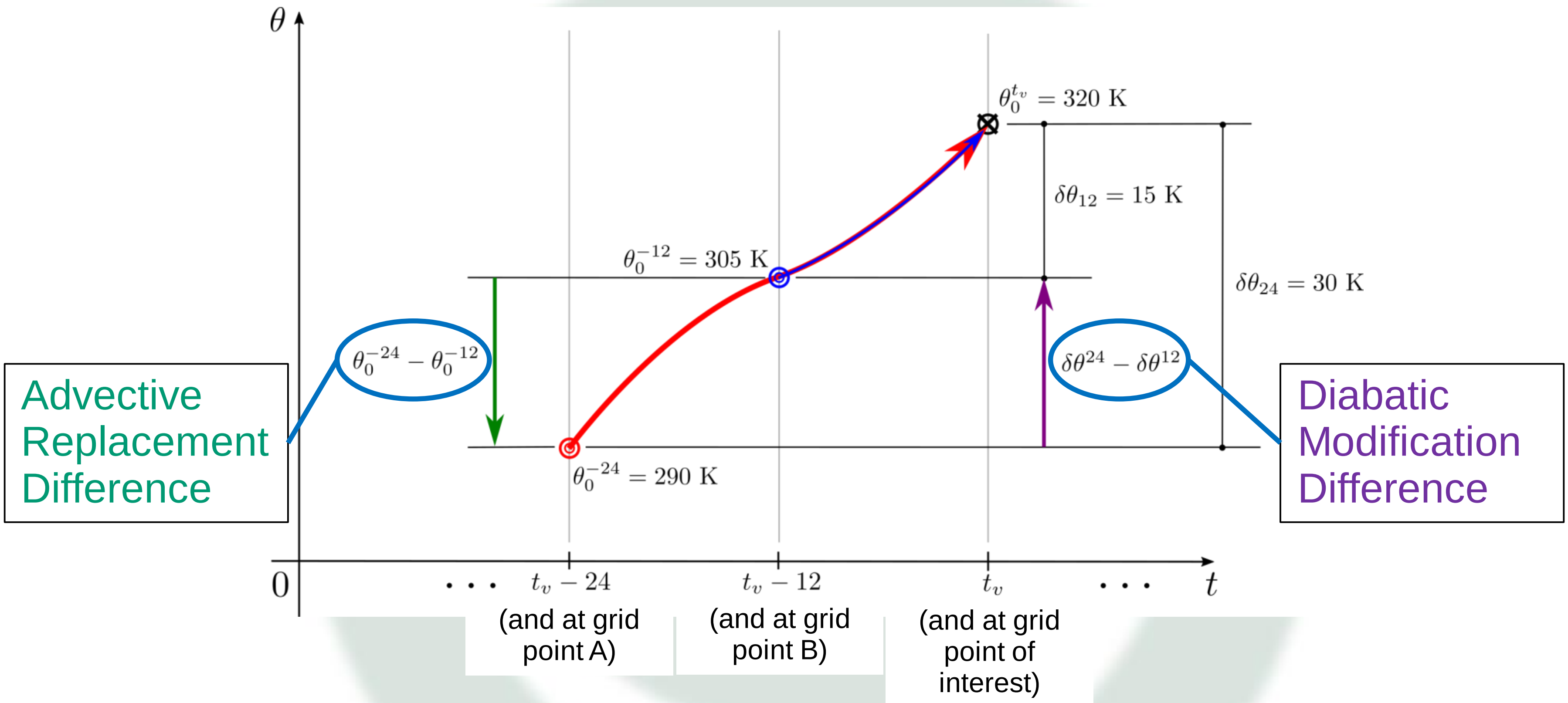
Lagrangian description

WARNING: This diagram is different to that in the previous slide



- The Lagrangian description examines the consistency between parcel's trajectories
- Only possible thanks to the availability of advance techniques: diabatic tracers and online trajectories

Lagrangian description



- The Lagrangian description examines the consistency between parcel's trajectories

$$ARD(\varphi) = -DMD(\varphi)$$

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

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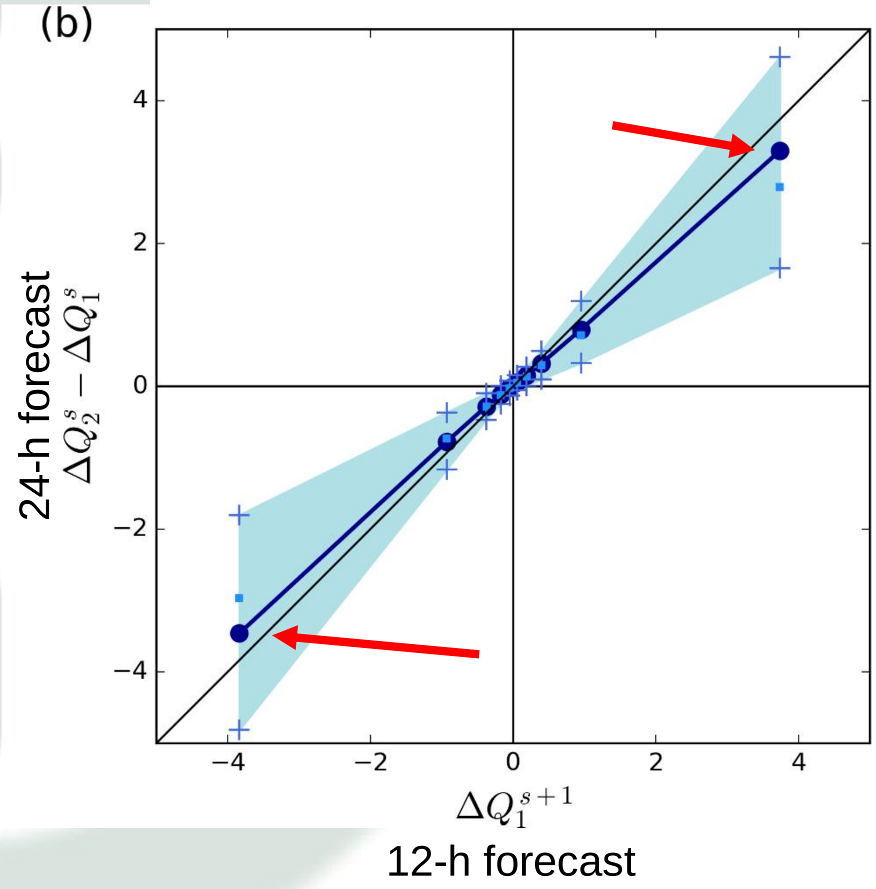
Grid points in upper troposphere
(6.8 km – 11.2 km)

$$\langle \Delta Q^s_{k+1} - \Delta Q^s_k \rangle = \langle \Delta Q^{s+k}_1 \rangle$$

Changes in 24-h forecast

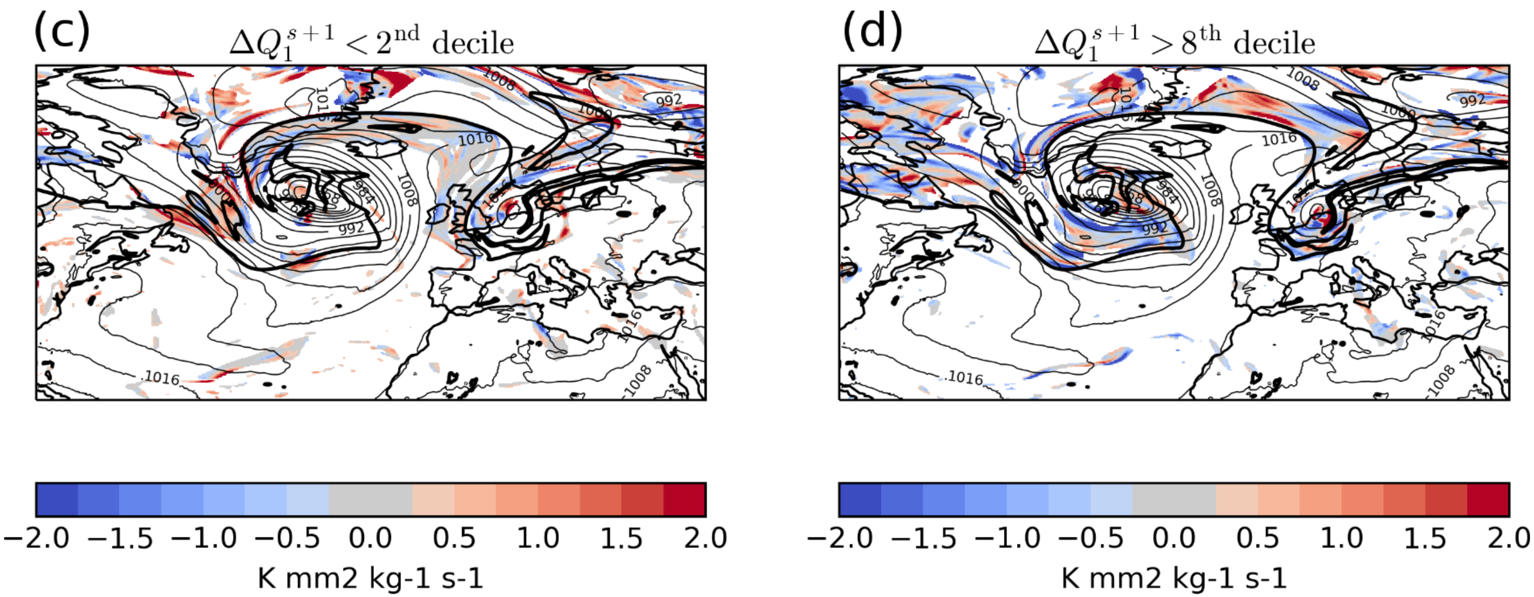
Changes in 12-h forecast

Potential vorticity



Eulerian description

Location of grid points with largest Eulerian deviation



Lagrangian-tracer description

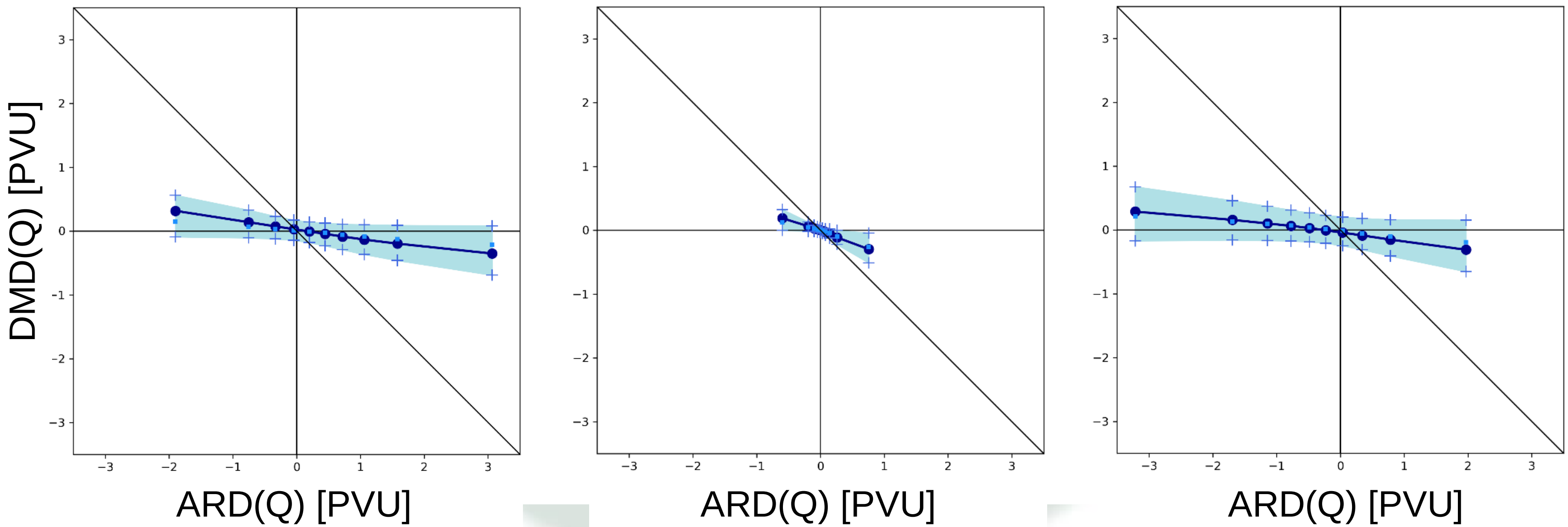
$$\langle \delta Q_{k+1}^{s} - \delta Q_{1}^{s+k} \rangle = -\langle Q_{0,k\to k+1}^{s} - Q_{0,0\to 1}^{s+k} \rangle$$

DMD(Q) **ARD(Q)**

Upper levels (6.8 km – 11.2 km)

Potential vorticity

$\Delta Q_1^{s+1} < 1^{st}$ decile | 4^{th} decile $< \Delta Q_1^{s+1} < 6^{th}$ decile | $\Delta Q_1^{s+1} > 9^{th}$ decile

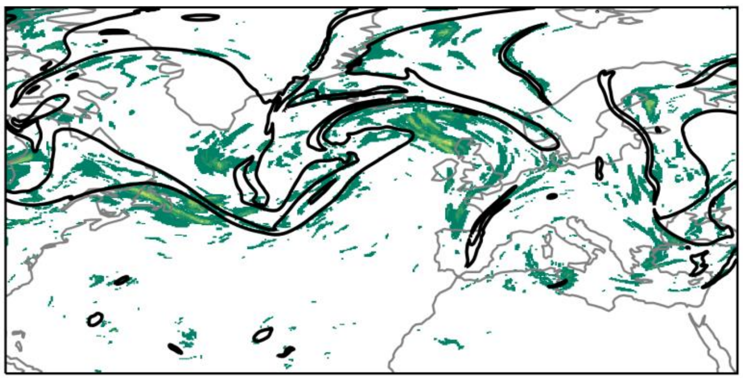


Lagrangian description

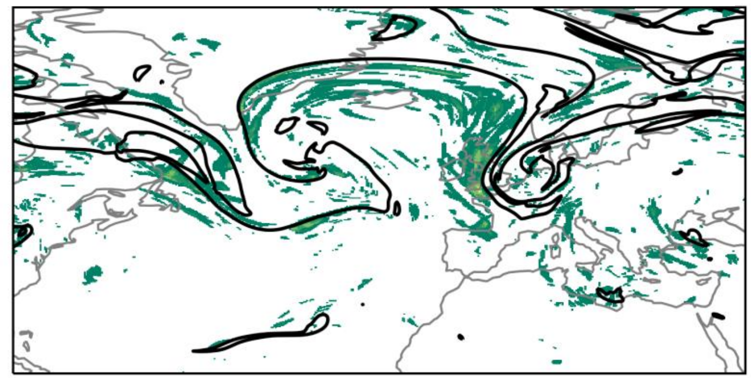
Location of grid points with largest Lagrangian deviation both in potential temperature and PV

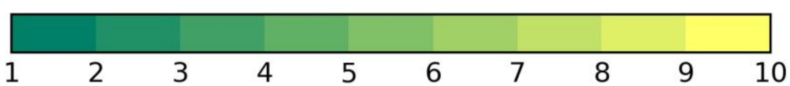
Two examples from the NAWDEX field campaign in 2016

Cyclone Vladiana
1200 UTC 23 September 2016



Stalactite Cyclone
1200 UTC 2 October 2016





Number of grid points in a column (upper troposphere) exhibiting large deviations from the behaviour of the unbiased model

Conclusions

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- Proposing a novel method to combine dynamics and statistics to evaluate (and perhaps design) NWP models
  - 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**)
  - These points correspond to WCBs outflows in the upper troposphere
- 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

Martínez-Alvarado, O. and Sánchez, C. (2020) Examining model error in potential temperature and potential vorticity via weather forecasts at different lead times. *Q. J. R. Meteorol. Soc.* doi: https://doi.org/10.1002/qj.3736