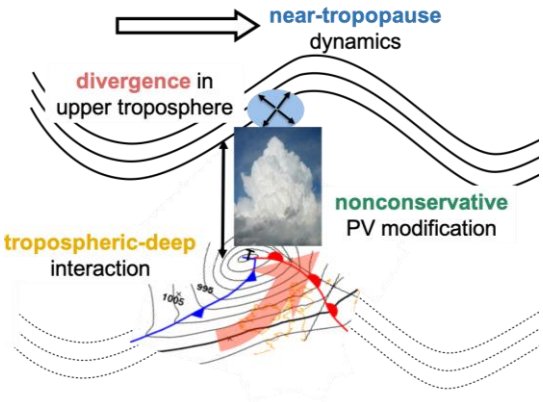
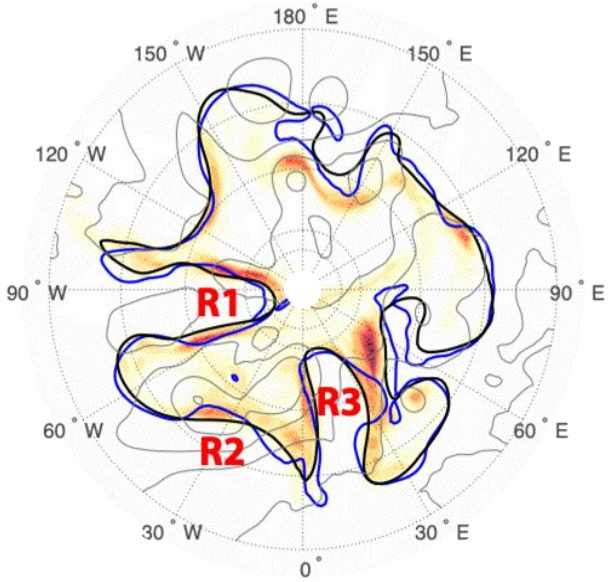
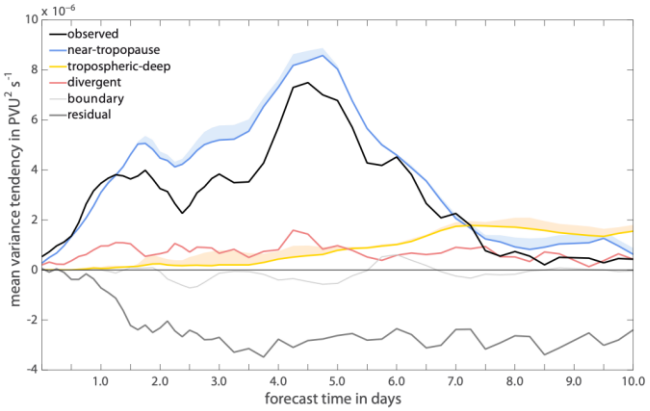
Amplification of forecast uncertainty in the ECMWF ensemble: Ex-Karl and the evil cut-off

Marlene Baumgart and Michael Riemer
Johannes Gutenberg-Universität Mainz

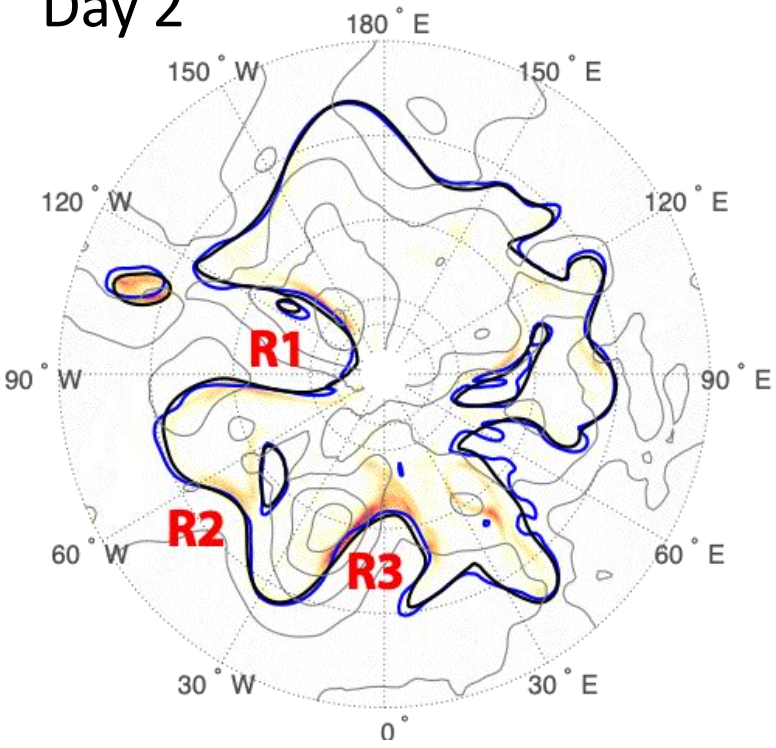




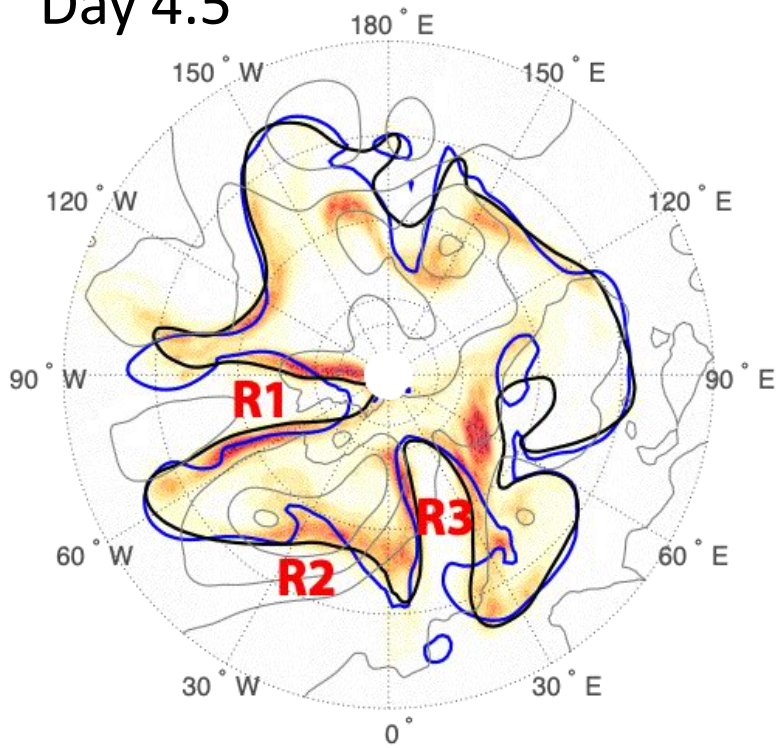


Processes governing the amplification of ensemble spread in a medium-range forecast with large forecast uncertainty, Quart. J. Roy. Met. Soc., (to be) submitted

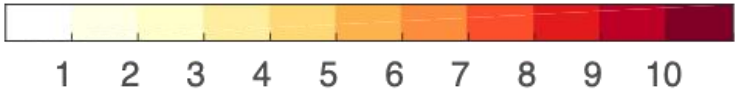
Day 2



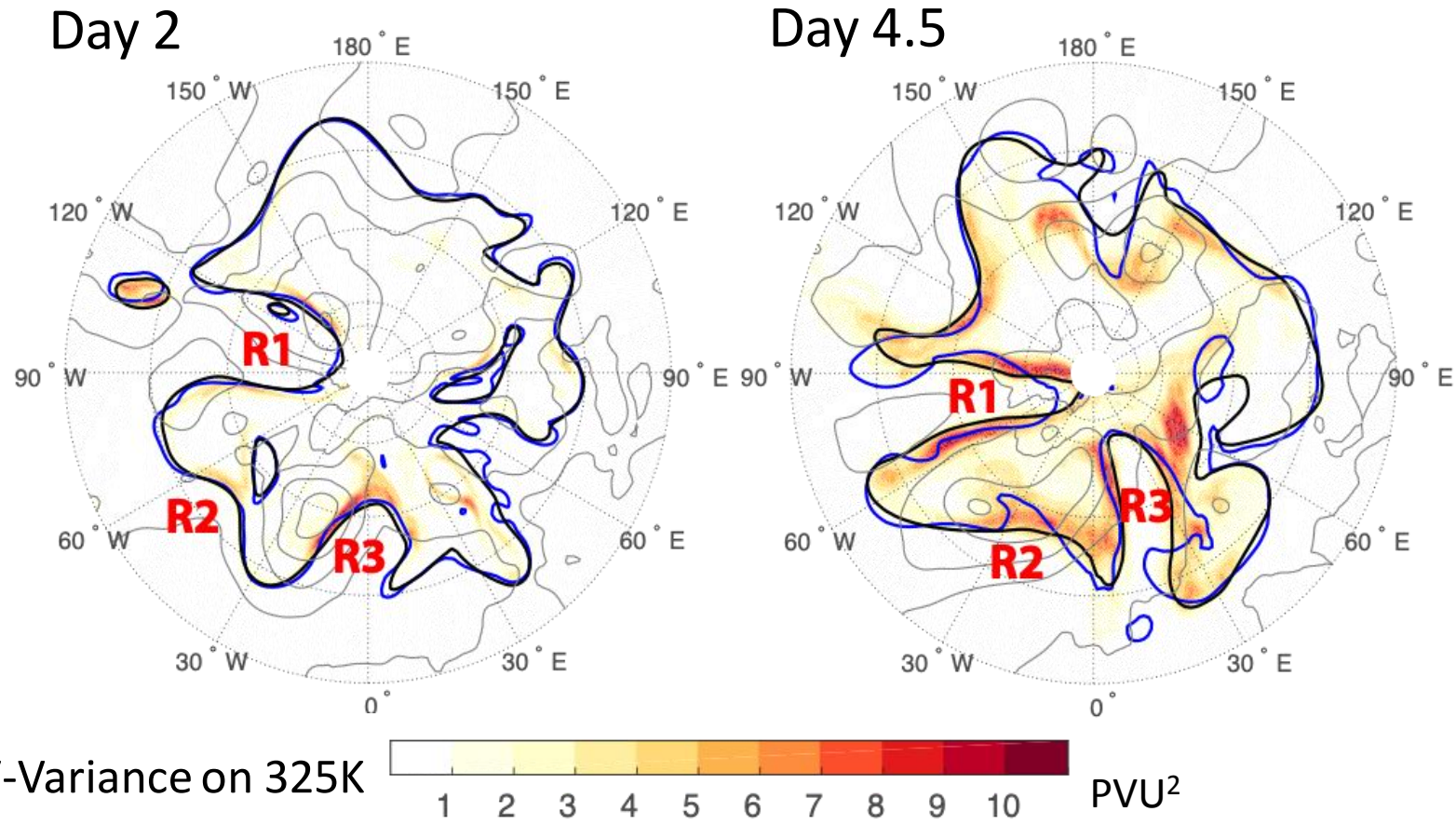
Day 4.5



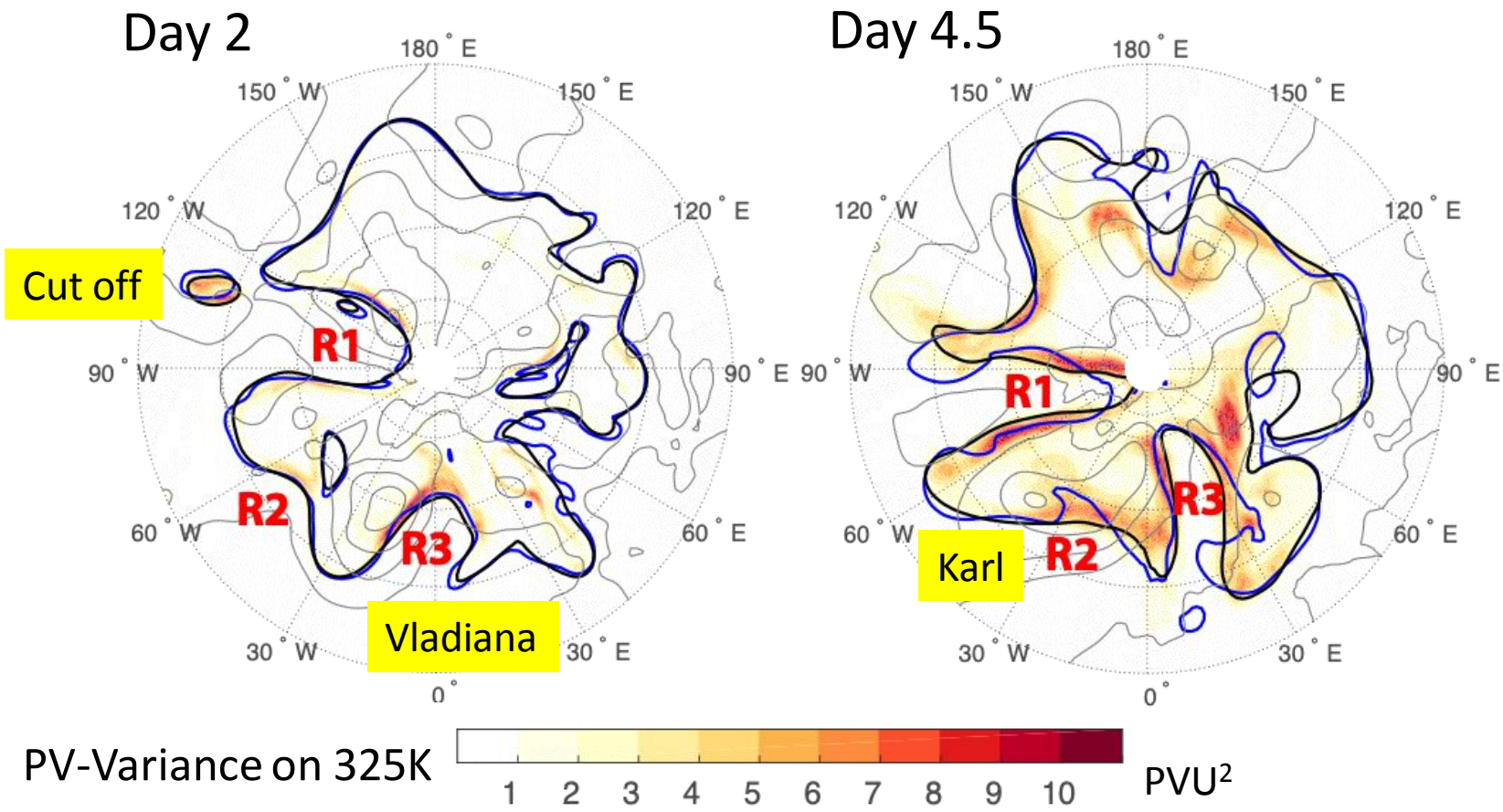
PV-Variance on 325K



PVU^2



Which mechanisms govern the evolution of (medium-range) forecast uncertainty?

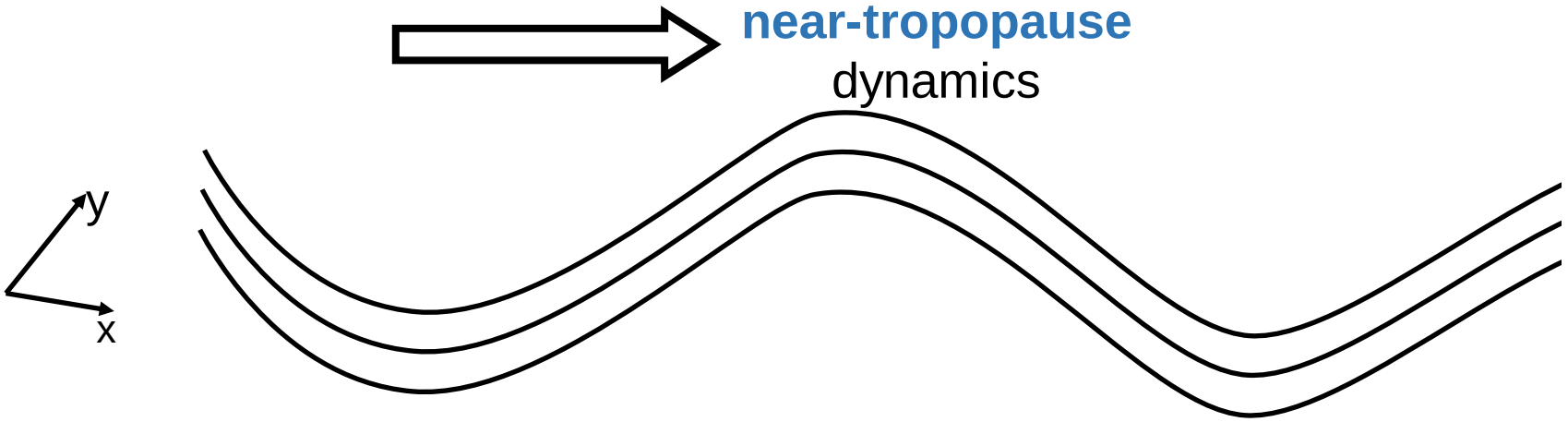


Which mechanisms govern the evolution of (medium-range) forecast uncertainty and how do they differ from case to case?

Quantification of Mechanisms: Potential-Vorticity Framework

Partitioning of mechanisms

Mid-latitude dynamics based on PV thinking



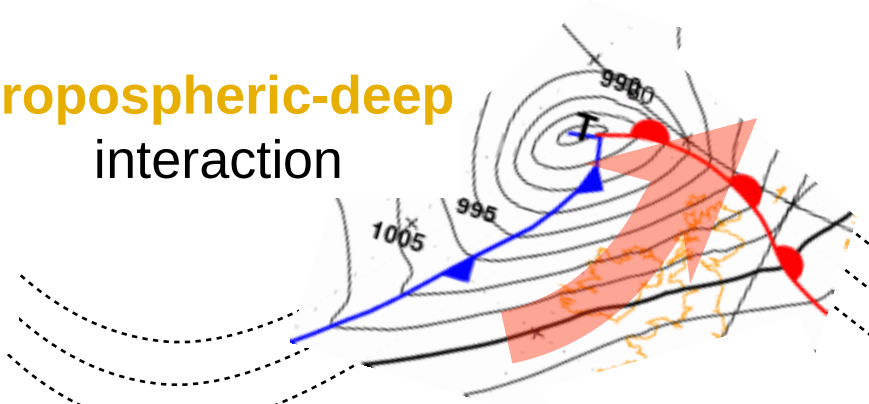
Hoskins et al., 1985

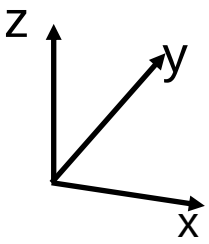
Partitioning of mechanisms

Mid-latitude dynamics based on PV thinking

near-tropopause
dynamics

tropospheric-deep
interaction





Hoskins et al., 1985
Eady, 1949
Heifetz et al., 2004

Partitioning of mechanisms

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near-tropopause
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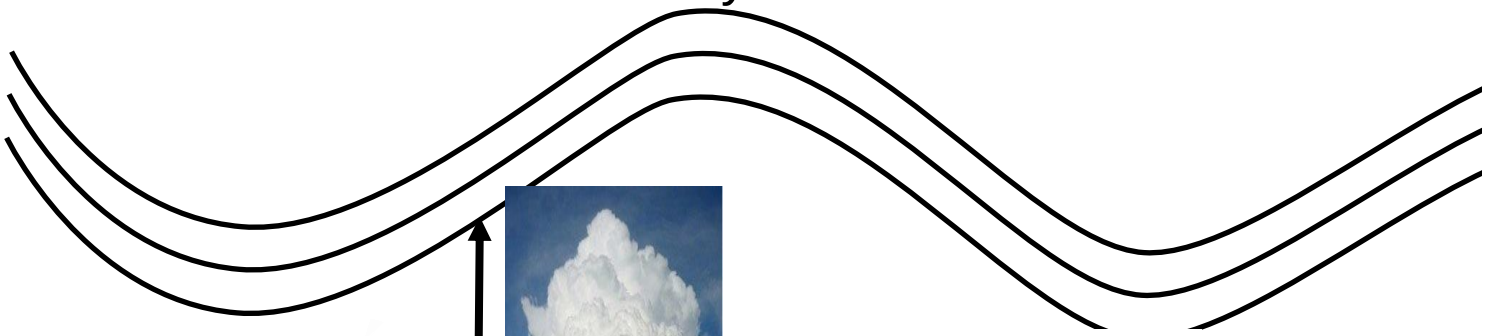
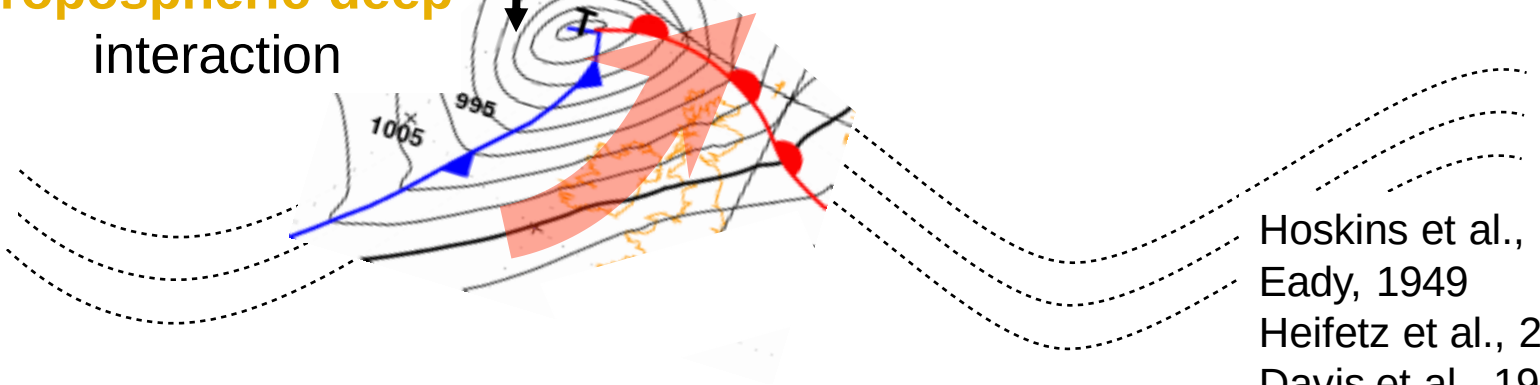


nonconservative
PV modification

tropospheric-deep
interaction



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Davis et al., 1993

Partitioning of mechanisms

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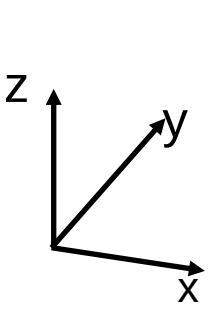
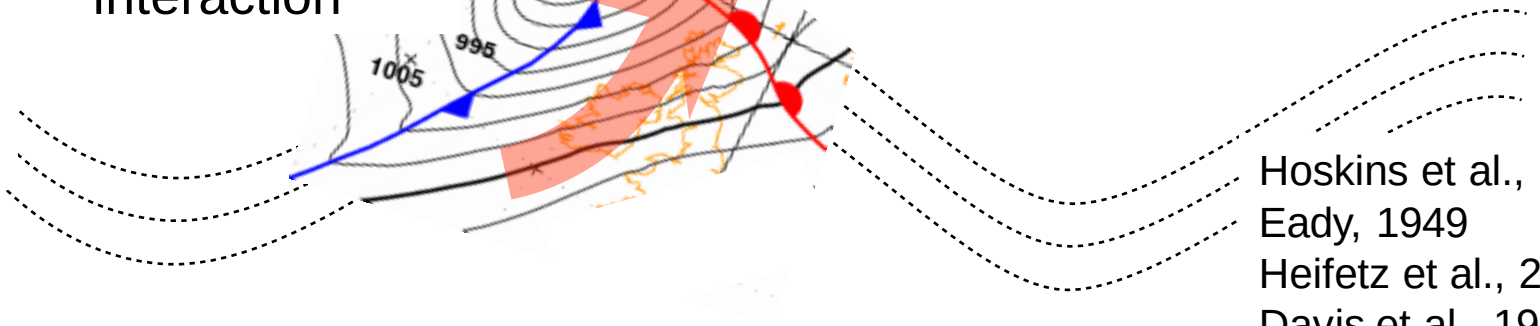
near-tropopause dynamics

divergence in upper troposphere

nonconservative PV modification

tropospheric-deep interaction





Hoskins et al., 1985
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Davis et al., 1993

Dynamics in terms of PV tendencies

- Ertel PV $PV = \frac{1}{\rho}\vec{\eta} \cdot \vec{\nabla}\theta$
- Local tendency of PV (PV advection + noncons. PV modification)

$$\frac{\partial PV}{\partial t} = -\vec{v} \cdot \nabla PV + \mathrm{NonCons}$$

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$$\vec{v} = \overrightarrow{v_{\mathrm{nTP}}} + \overrightarrow{v_{\mathrm{TPd}}} + \overrightarrow{v_{\mathrm{div}}}$$

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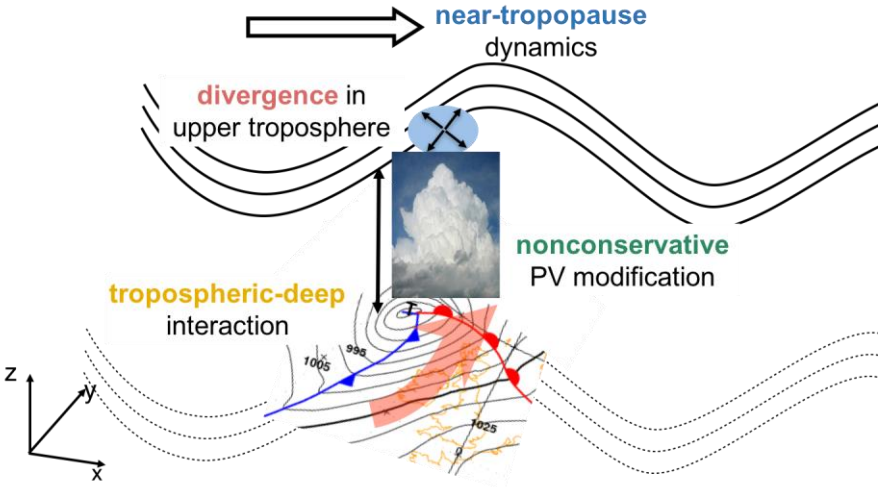

Dynamics of PV errors

PV error: $PV^* = PV_{\text{forecast}} - PV_{\text{analysis}}$

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Tendency for PV error (following Davies and Didone, 2013):

$$\frac{\partial}{\partial t} PV^* = \frac{\partial}{\partial t} PV_{\text{forecast}} - \frac{\partial}{\partial t} PV_{\text{analysis}}$$

$$= -\overrightarrow{v^*} \cdot \vec{\nabla} PV - \overrightarrow{v^*} \cdot \vec{\nabla} PV^* - \vec{v} \cdot \vec{\nabla} PV^* + NonCons^*$$

with *: error fields
without *: analysis field

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with *: error fields
without *: analysis field

Tendency for PV error amplification (Baumgart et al. 2018):

$$\frac{\partial}{\partial t} \frac{PV^{*2}}{2} = -PV^* \overrightarrow{v^*} \cdot \vec{\nabla} PV + \frac{PV^{*2}}{2} \vec{\nabla} \cdot \left(\vec{v} + \overrightarrow{v^*}\right) + NonCons^*$$

Dynamics of PV “spread”

- PV difference: $PV_i^* = PV_{\text{mean}} - PV_{\text{member\_i}}$

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$$\frac{\partial V_P}{\partial t} = \frac{2}{n-1}\left[\underbrace{-\sum_{i=1}^{n}\delta P_i \boldsymbol{\delta \mathbf{v}_i}\cdot\nabla\overline{P}}_{\text{nonlinear production term}} \underbrace{-\sum_{i=1}^{n}\nabla\cdot\left(\frac{(\delta P_i)^2}{2}\mathbf{v_i}\right)}_{\text{flux term}} \underbrace{+\sum_{i=1}^{n}\frac{(\delta P_i)^2}{2}\nabla\cdot\mathbf{v_i}}_{\text{area change term}}\right] + \text{Nres.}$$

PV-variance

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$$\frac{\partial V_P}{\partial t} = \frac{2}{n-1}\left[\underbrace{-\sum_{i=1}^{n}\delta P_i \boldsymbol{\delta}\mathbf{v_i}\cdot\nabla\overline{P}}_{\text{nonlinear production term}} \underbrace{-\sum_{i=1}^{n}\nabla\cdot\left(\frac{(\delta P_i)^2}{2}\mathbf{v_i}\right)}_{\text{flux term}} \underbrace{+\sum_{i=1}^{n}\frac{(\delta P_i)^2}{2}\nabla\cdot\mathbf{v_i}}_{\text{area change term}}\right] + \text{Nres.}$$

PV-variance

$$\frac{\partial V_P}{\partial t} = \frac{2}{n-1}\left[\underbrace{-\sum_{i=1}^{n}\delta P_i(\boldsymbol{\delta}\mathbf{v}_{\text{i, nTP}} + \boldsymbol{\delta}\mathbf{v}_{\text{i, TPd}} + \boldsymbol{\delta}\mathbf{v}_{\text{i, div}} + \boldsymbol{\delta}\mathbf{v}_{\text{i, uct}})\cdot\nabla\overline{P}}_{\text{nonlinear production term}} \underbrace{-\sum_{i=1}^{n}\nabla\cdot\left(\mathbf{v}_{\text{i}}\frac{(\delta P_i)^2}{2}\right)}_{\text{flux term}} \underbrace{+\sum_{i=1}^{n}\frac{(\delta P_i)^2}{2}\nabla\cdot\mathbf{v}_{\text{i, div}}}_{\text{area change term}}\right] + \text{Nres.}$$

Dynamics in terms of PV tendencies

- Ertel PV $PV = \frac{1}{\rho}\vec{\eta} \cdot \vec{\nabla}\theta$ (absolute vorticty · static stability)
- Local tendency of PV (PV advection + noncons. PV modification)

$$\frac{\partial PV}{\partial t} = -\vec{v} \cdot \nabla PV + \mathrm{NonCons}$$

- Tendency of error-enstrophy

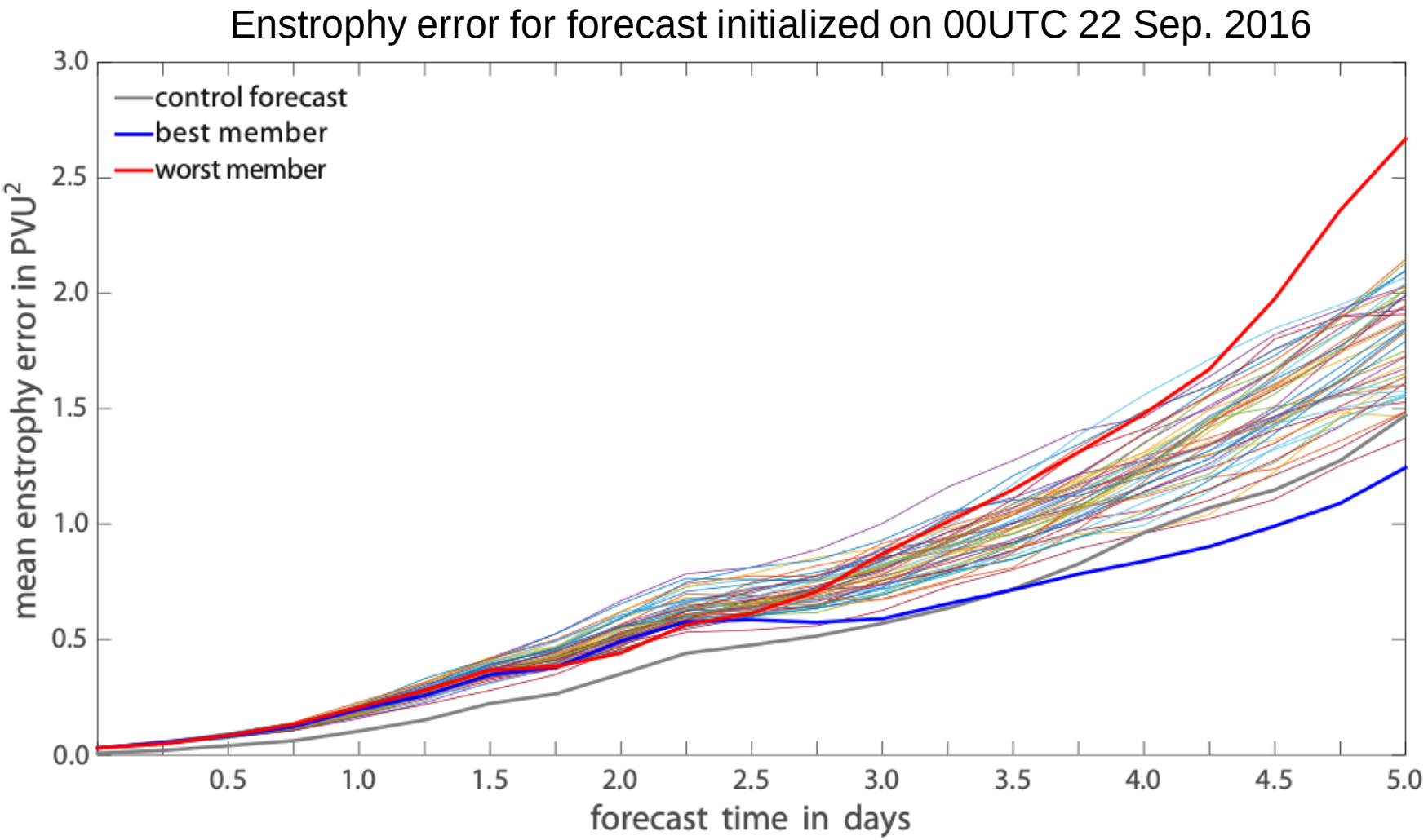
$$\frac{\partial}{\partial t}\frac{PV^{*2}}{2} = -PV^{*}\overrightarrow{v^{*}} \cdot \vec{\nabla}PV + \frac{PV^{*2}}{2}\vec{\nabla} \cdot \left(\vec{v} + \overrightarrow{v^{*}}\right) + NonCons^{*}$$

- Tendency of PV variance

$$\frac{\partial V_P}{\partial t} = \frac{2}{n-1}\Bigg[\underbrace{-\sum_{i=1}^{n}\delta P_i \boldsymbol{\delta}\mathbf{v_i} \cdot \nabla\overline{P}}_{\text{nonlinear production term}} \underbrace{-\sum_{i=1}^{n}\nabla \cdot \left(\frac{(\delta P_i)^2}{2}\mathbf{v_i}\right)}_{\text{flux term}} \underbrace{+\sum_{i=1}^{n}\frac{(\delta P_i)^2}{2}\nabla \cdot \mathbf{v_i}}_{\text{area change term}}\Bigg] + \mathrm{Nres.}$$

Spread and Errors: Operational ECMWF Ensemble Forecast

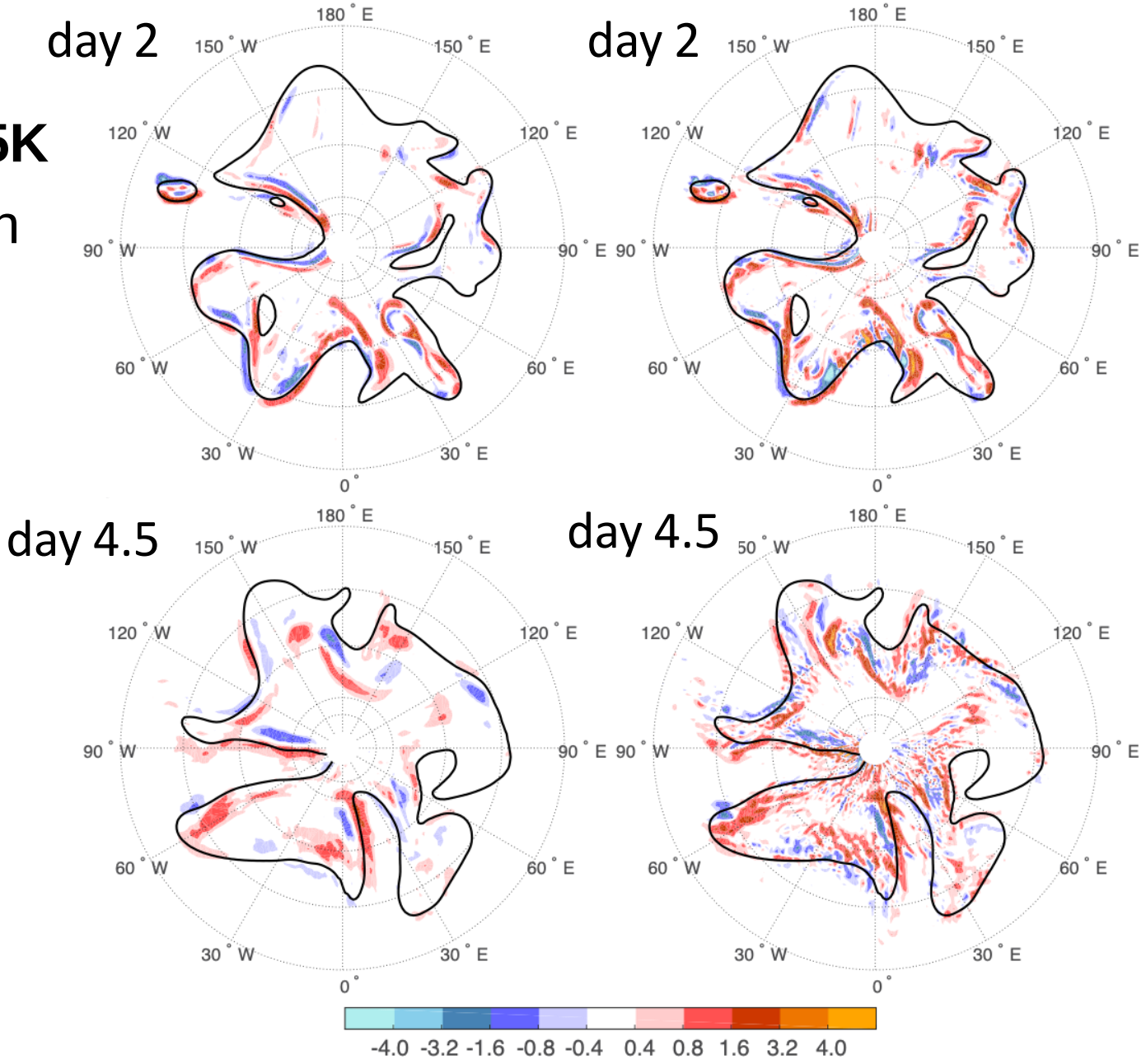
Error evolution in individual ensemble members



PV-variance tendency on 325K

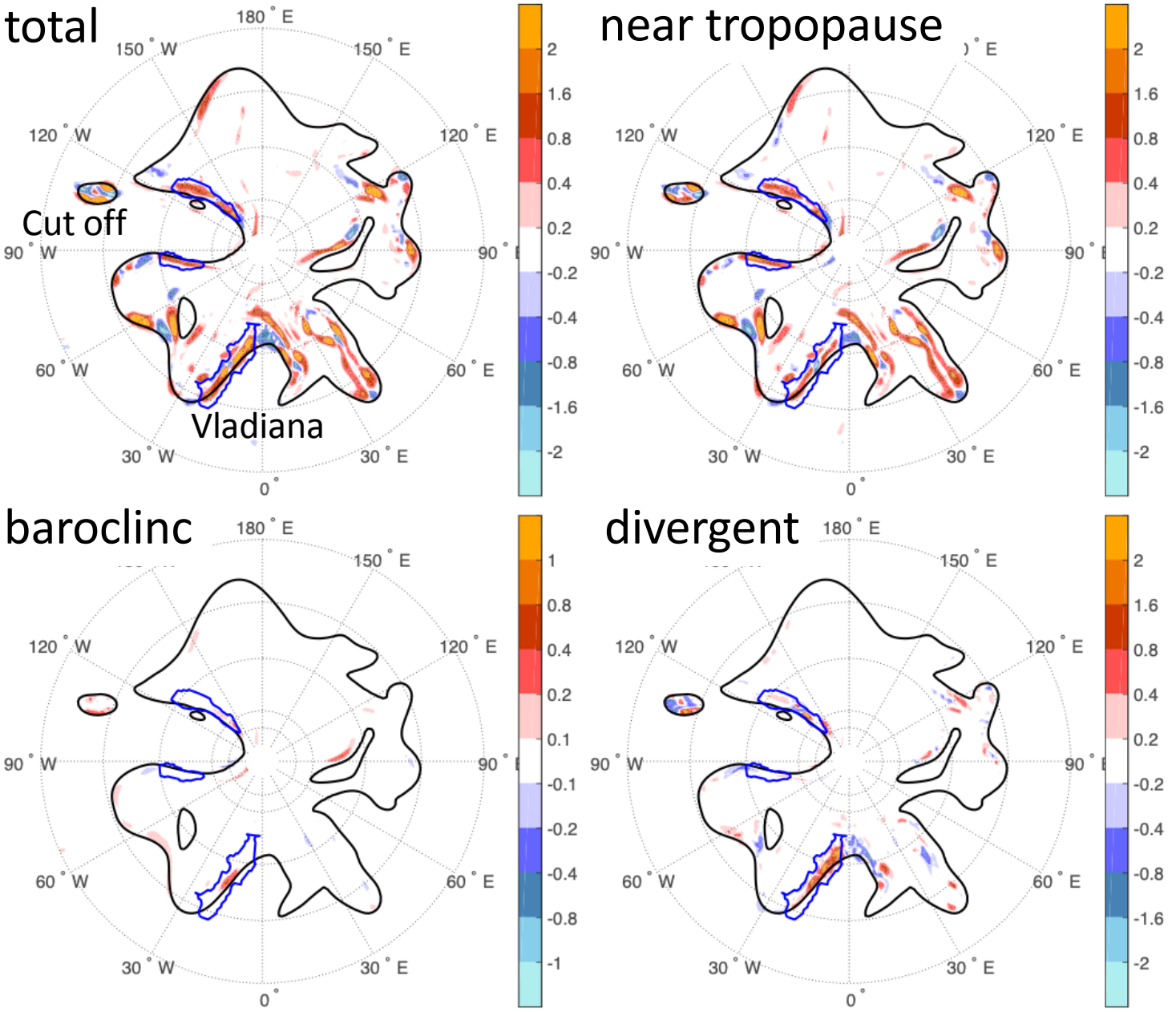
(left: observed, 6h finite difference

right: analyzed, instantaneous)



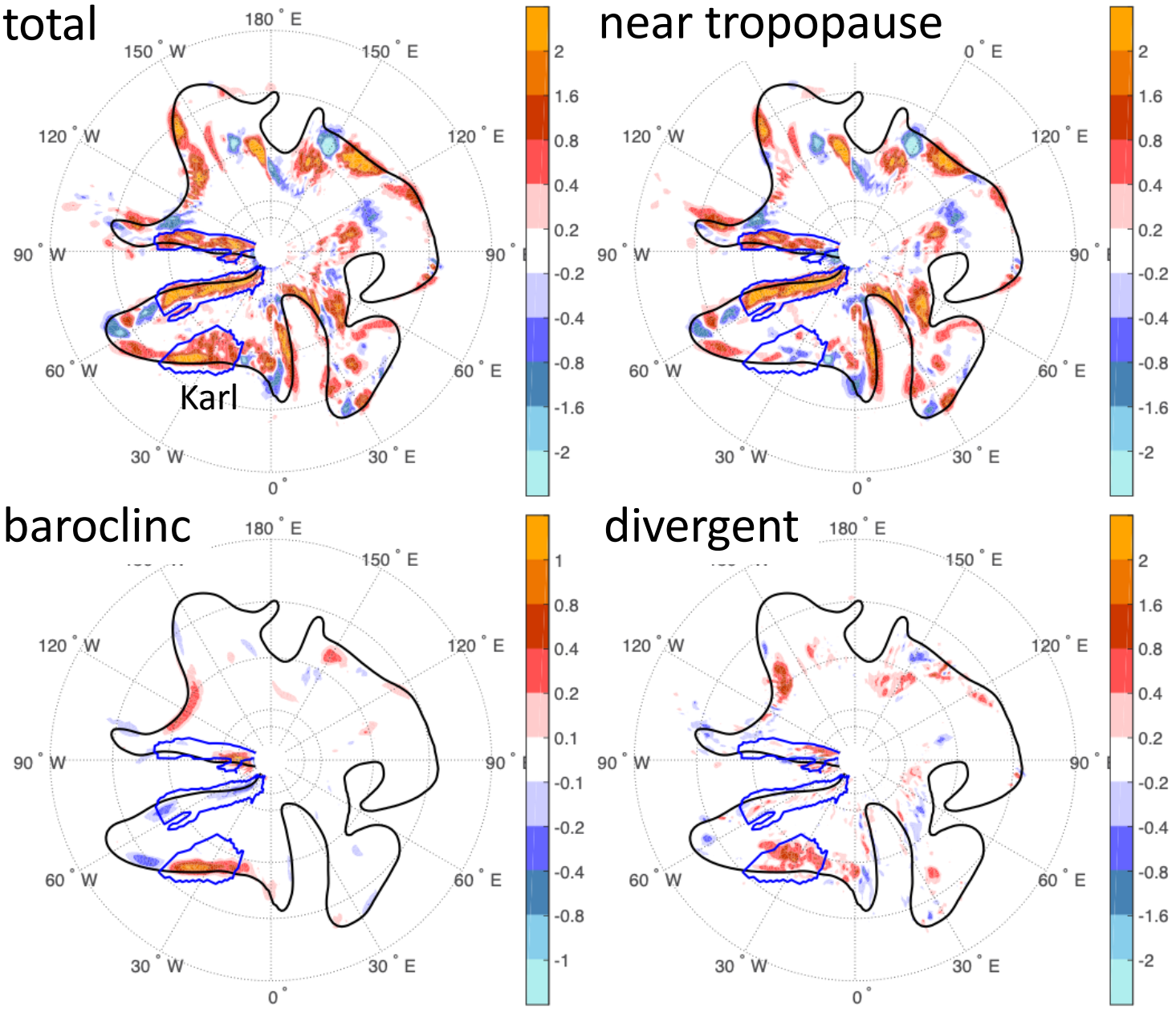
Individual PV-variance tendencies on 325K

(day 2)



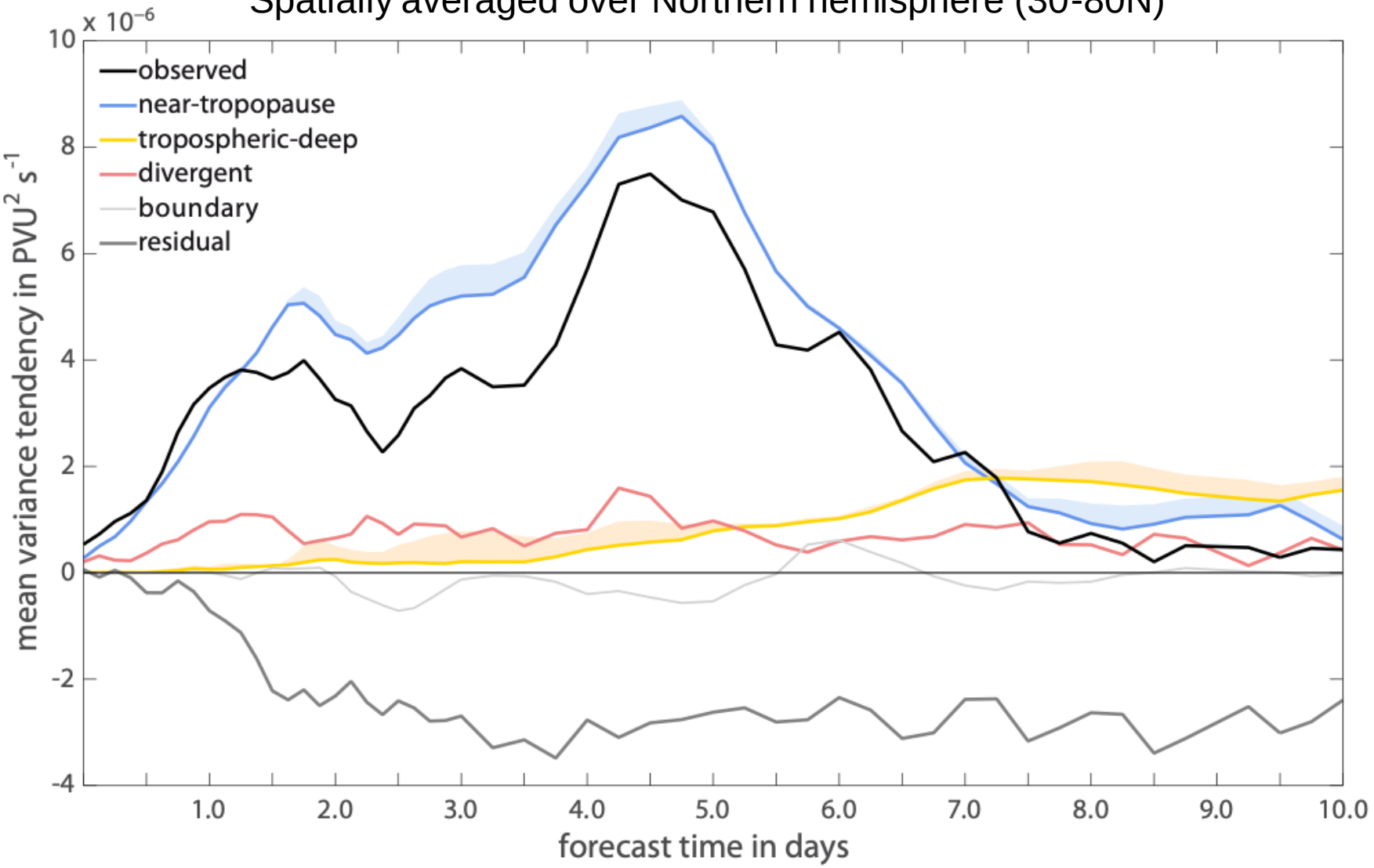
Individual PV-variance tendencies on 325K

(day 4.5)

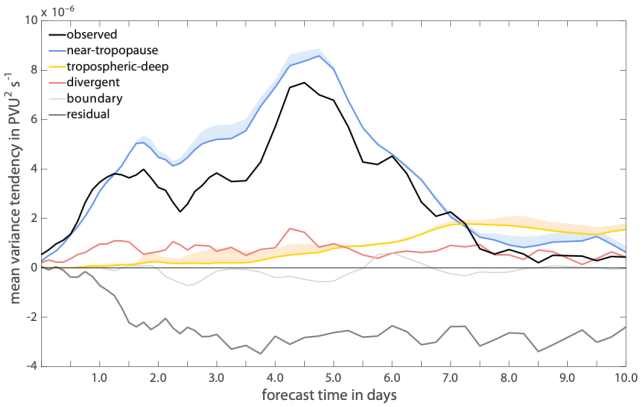


Individual contributions to spread amplification

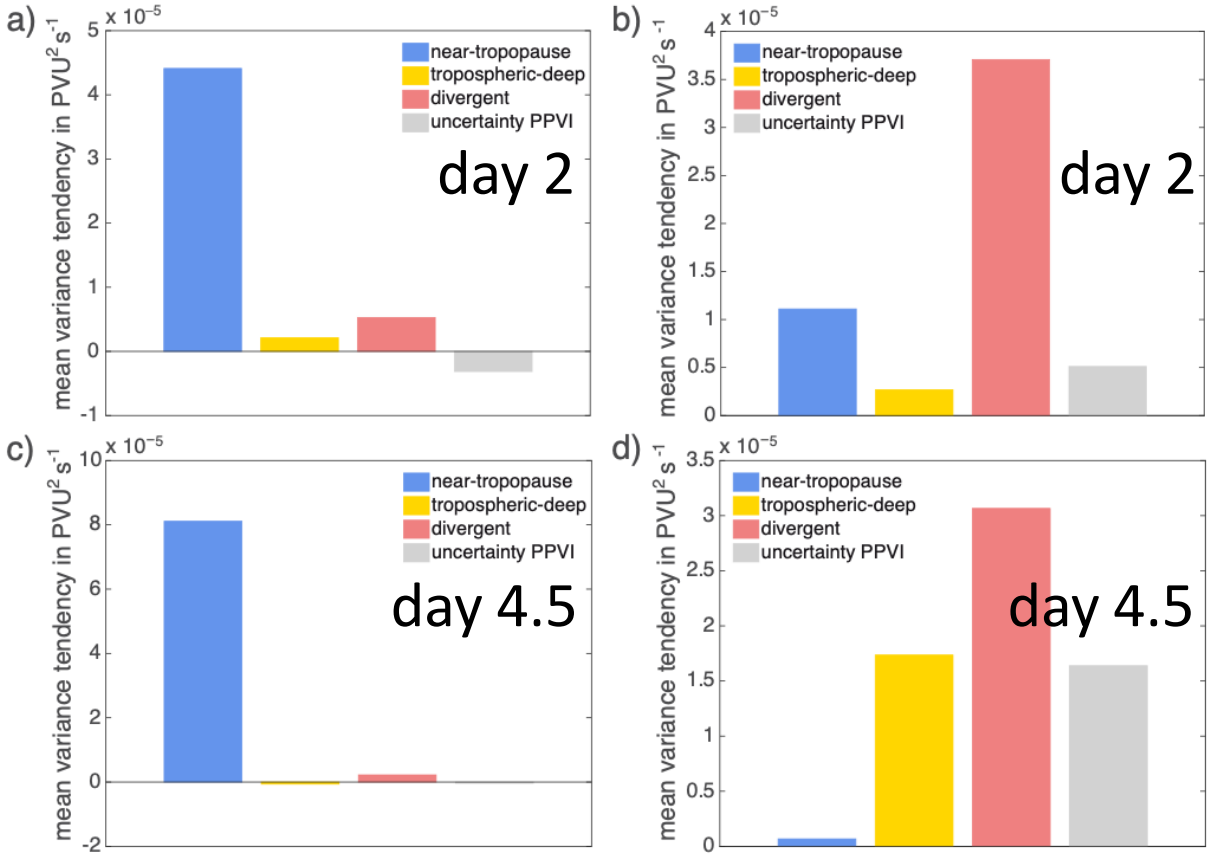
Spatially averaged over Northern hemisphere (30-80N)



Individual contributions to spread amplification



Local differences in the dominant processes



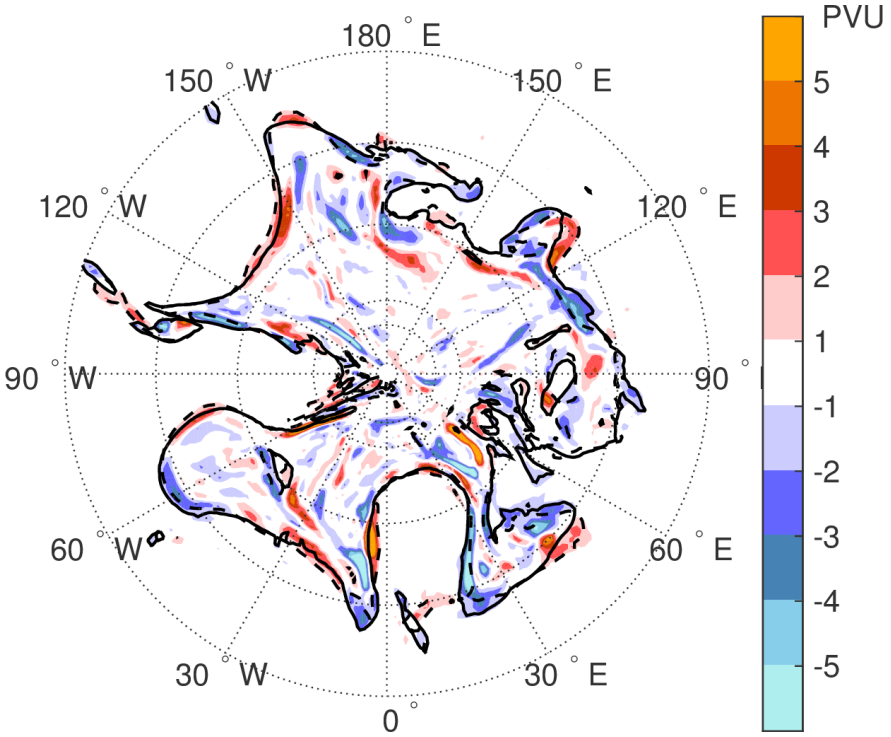
Cut off and high-amplitude ridge

Vladiana + Karl

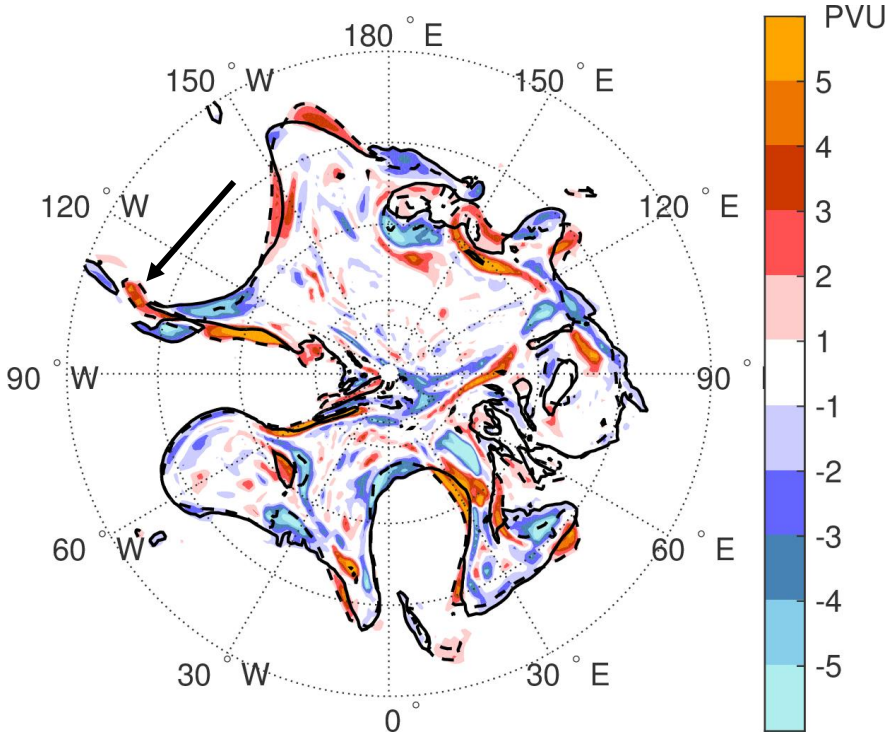
PV error on 325K for best and worst member

3.25-day forecast initialized on 00UTC 22 September 2016

member with best forecast



member with worst forecast

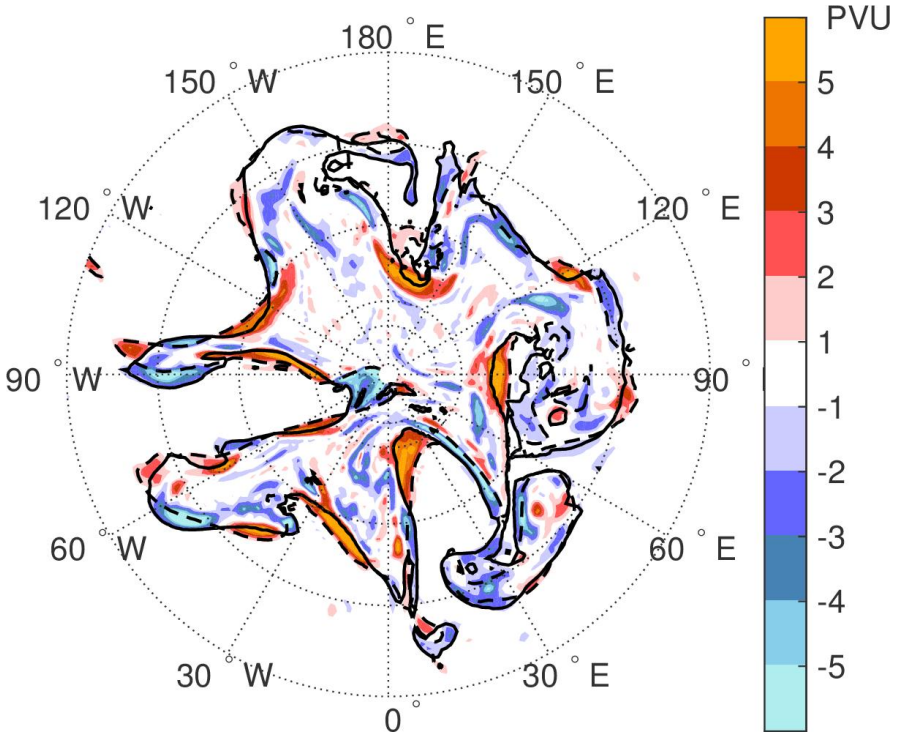


first large differences related to cut-off reabsorption around 105°W

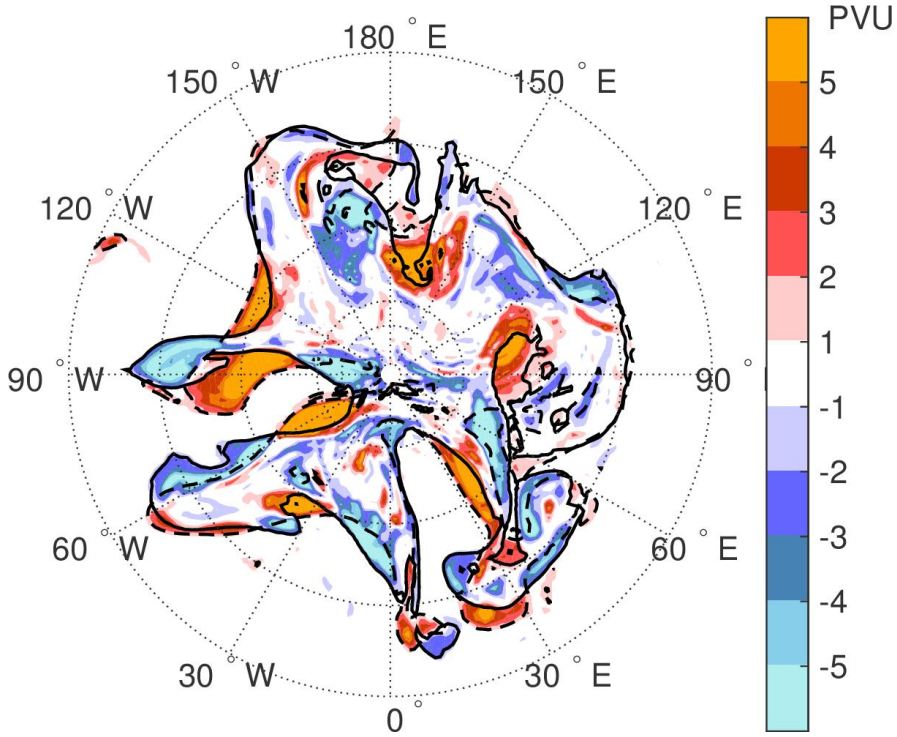
PV error on 325K for best and worst member

4.5-day forecast initialized on 00UTC 22 September 2016

member with best forecast



member with worst forecast



largest differences in ridge-trough pattern around 60-100°W

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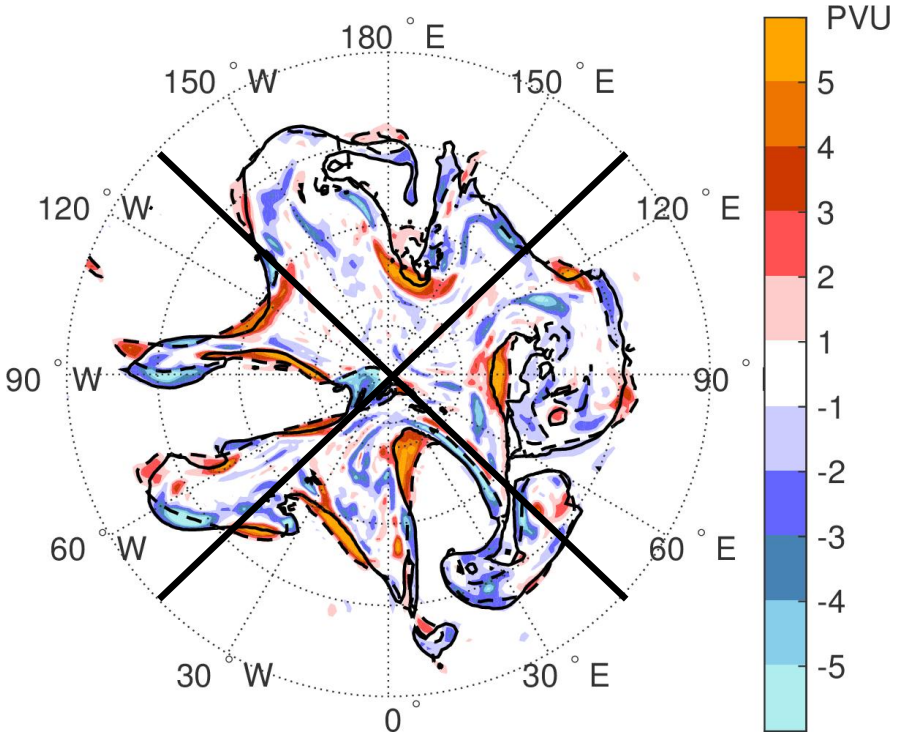

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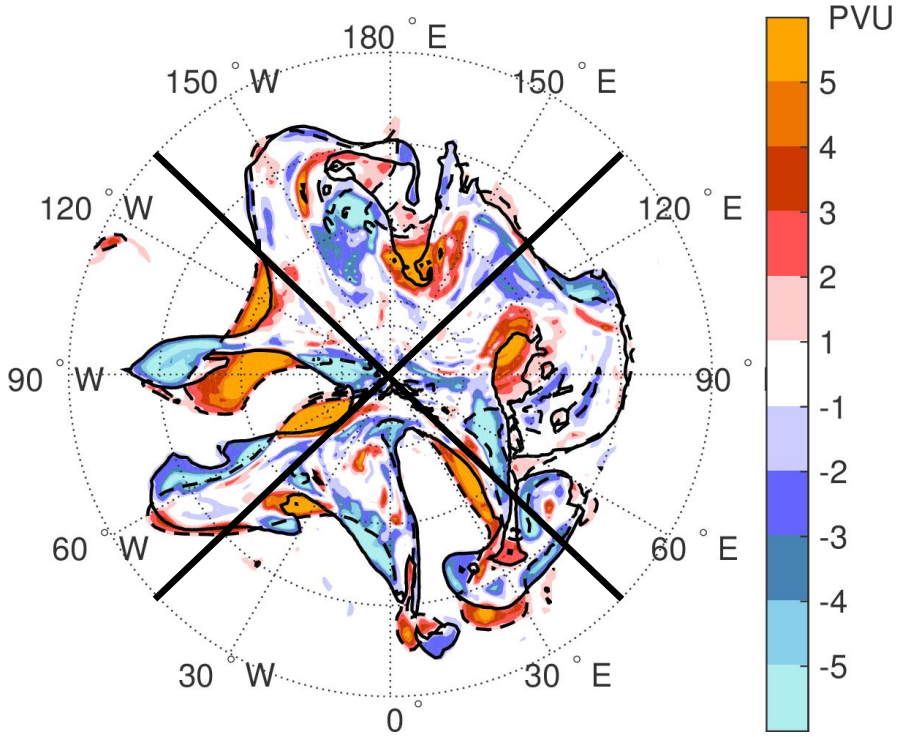

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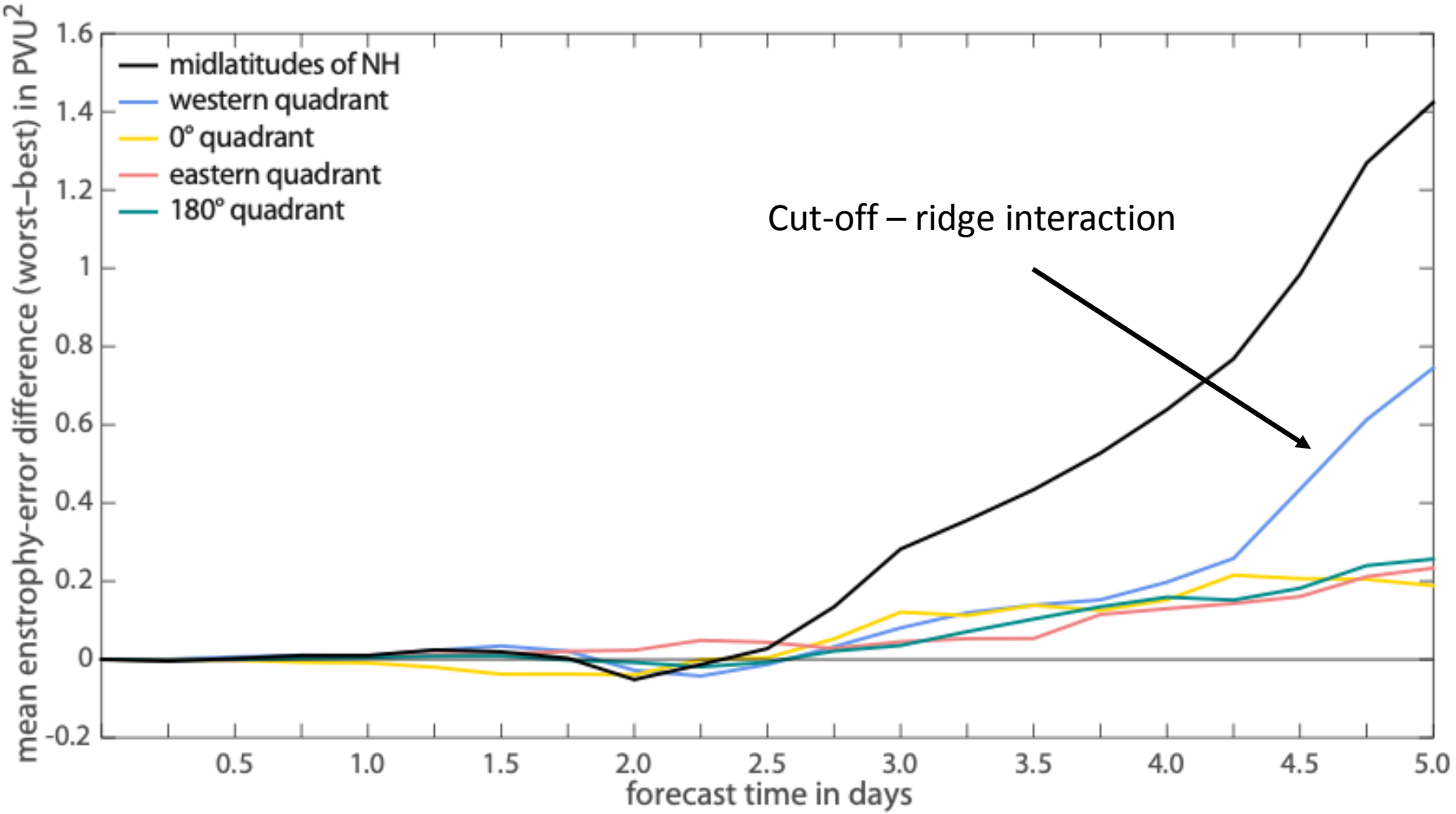
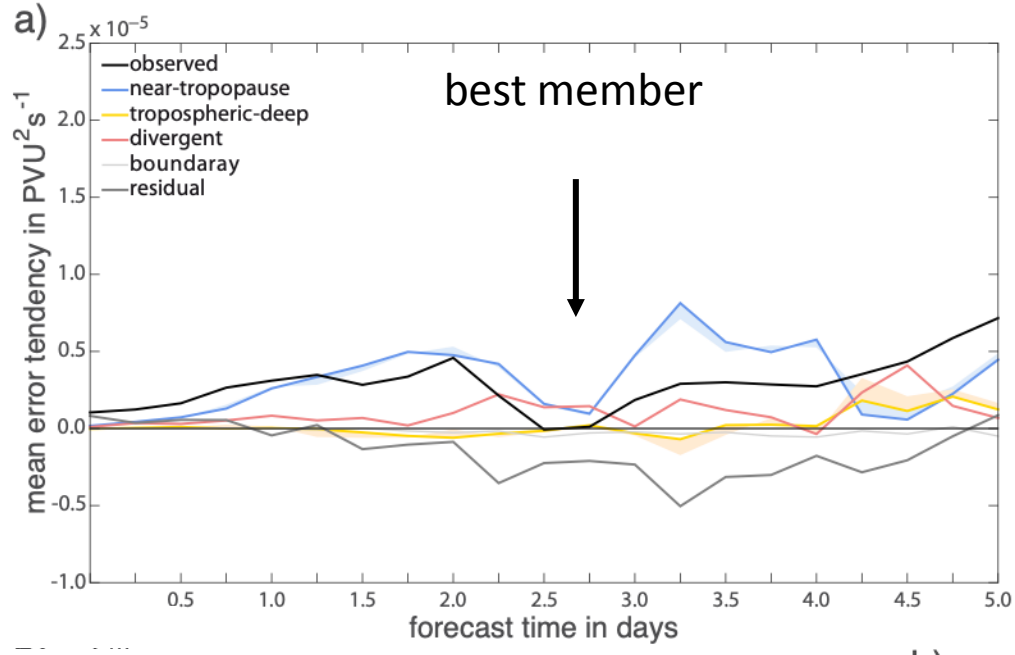
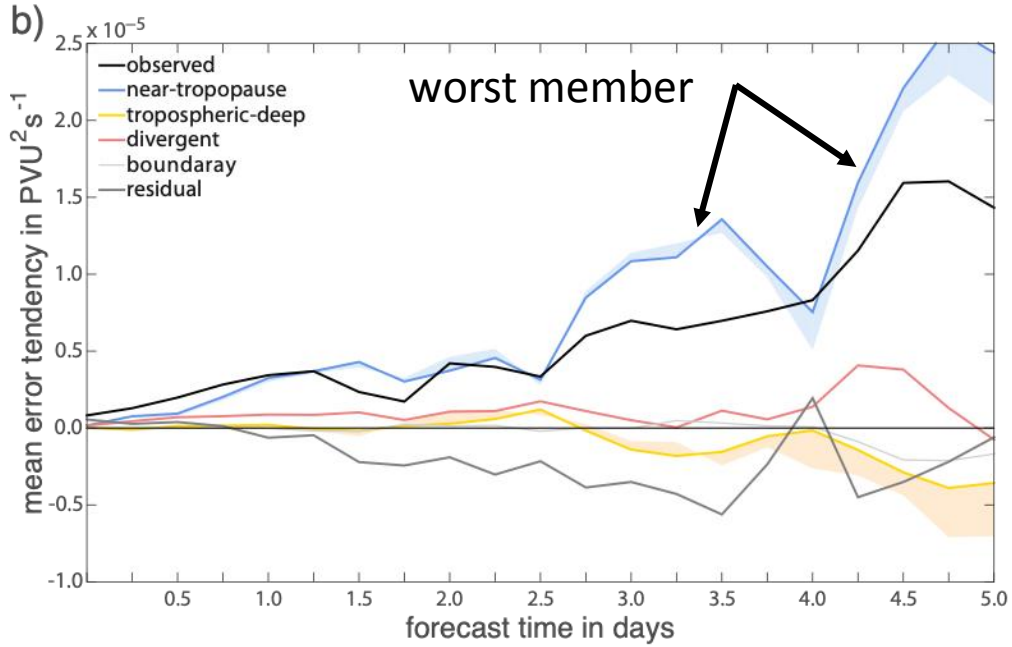
Difference of error evolution in individual quadrants



Individual contributions to error growth





Summary

- Derived tendency equation for ensemble PV variance
- “Spread” evolution, on average, dominated by nonlinear tropopause dynamics (as error growth)
- Important local differences in the mechanisms
- High-amplitude ridges: nonlinear trop. dynamics
- Cyclone development: divergent and baroclinic

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- Cyclone development: divergent and baroclinic

- Cyclones and cut-off: dominant sources of uncertainty

→ Vortex – wave interaction? [Tim Dunkerton]

EMS annual meeting
Copenhagen, 9-13 September

Session on Dynamics and Predictability

Conveners: Sebastian Schemm, Christian Grams, Michael Riemer, and Alessandro Dell'Aquila

Abstract Deadline: **12 April 2019**