The effect of clouds, radiation and turbulence on upper-level PV

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Heini Wernli[1], and Hanna Joos[1]

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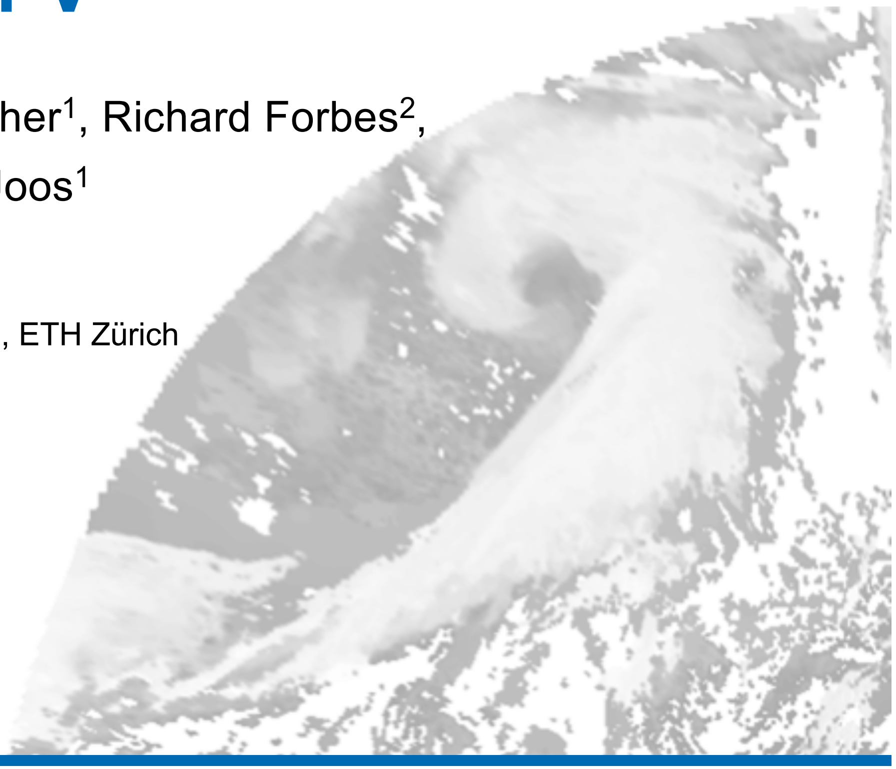
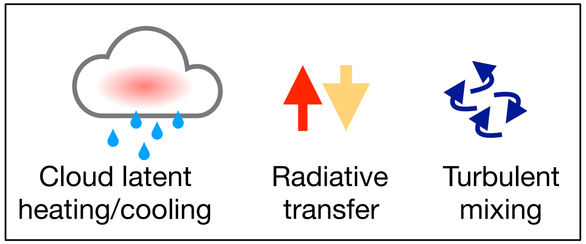
2 ECMWF, Reading



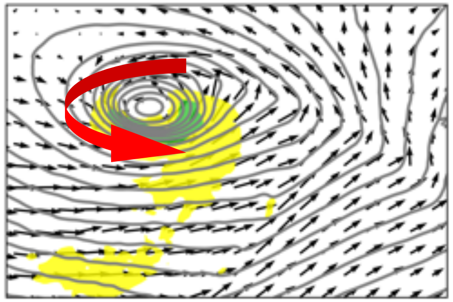
WCB Workshop
11 March 2020

Introduction



- Intensification of extratropical cyclones

  e.g., Davis and Emanuel (1991, MWR); Stoelinga (1996, MWR); Binder et al. (2016, JAS)



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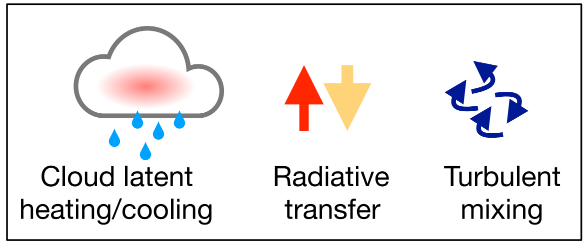

- Evolution of surface fronts

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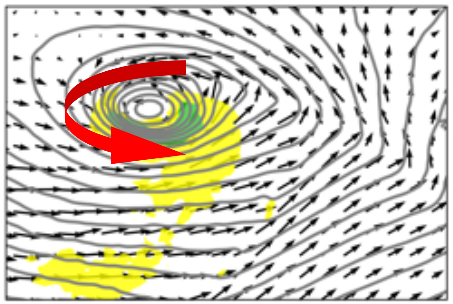

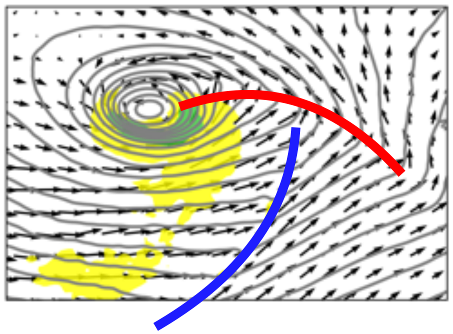

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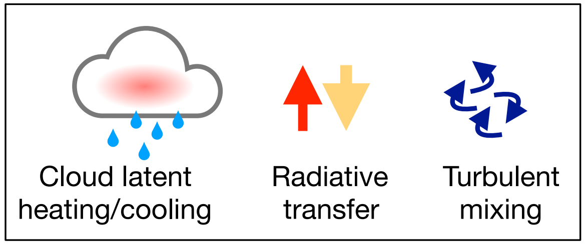

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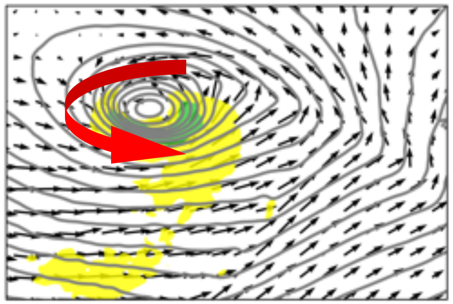

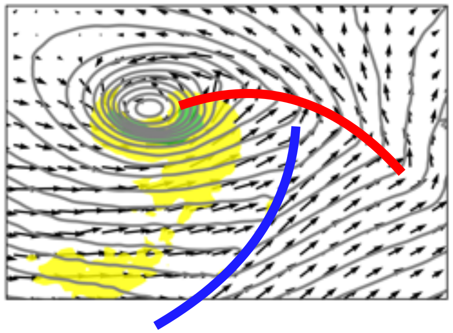

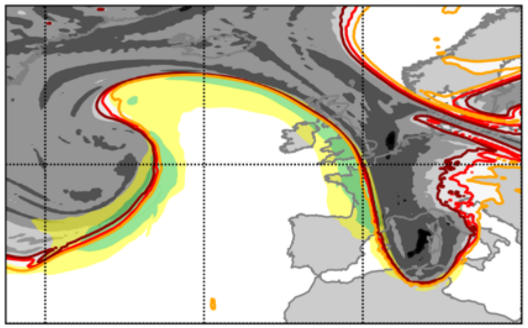

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How do individual physical processes modify potential vorticity near the tropopause?

Methods: Diabatic PV modification

$$\mathrm{PVR} = \frac{\mathrm{D}}{\mathrm{D}t}\mathrm{PV} = \frac{1}{\rho}\left(\boldsymbol{\eta} \cdot \underline{\nabla\dot{\theta}} + \nabla \times \underline{\boldsymbol{F}} \cdot \nabla\theta\right)$$

tendencies of
temperature &
momentum

Direct diabatic PV modification

Potential vorticity (PV)

$$\mathrm{PV} = \frac{1}{\rho}\boldsymbol{\eta} \cdot \nabla\theta$$

vorticity

gradient of potential temperature

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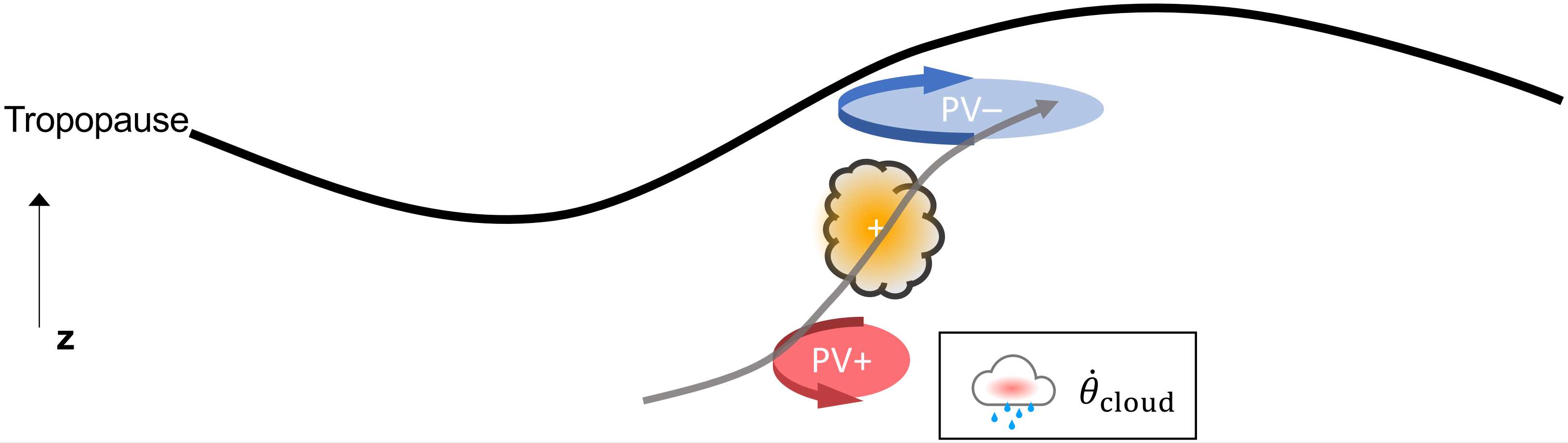

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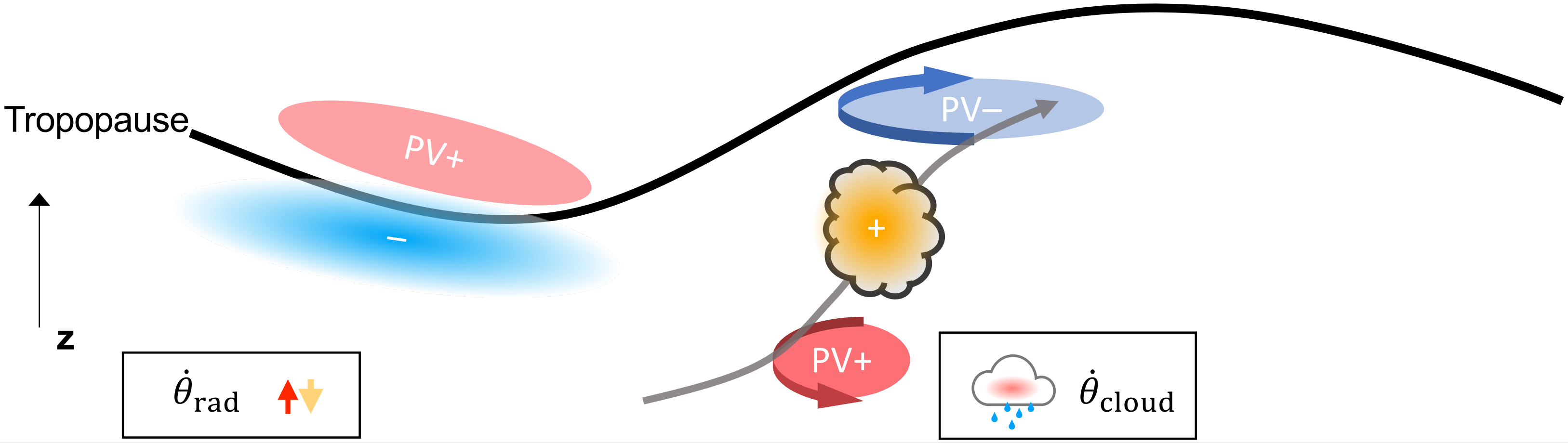

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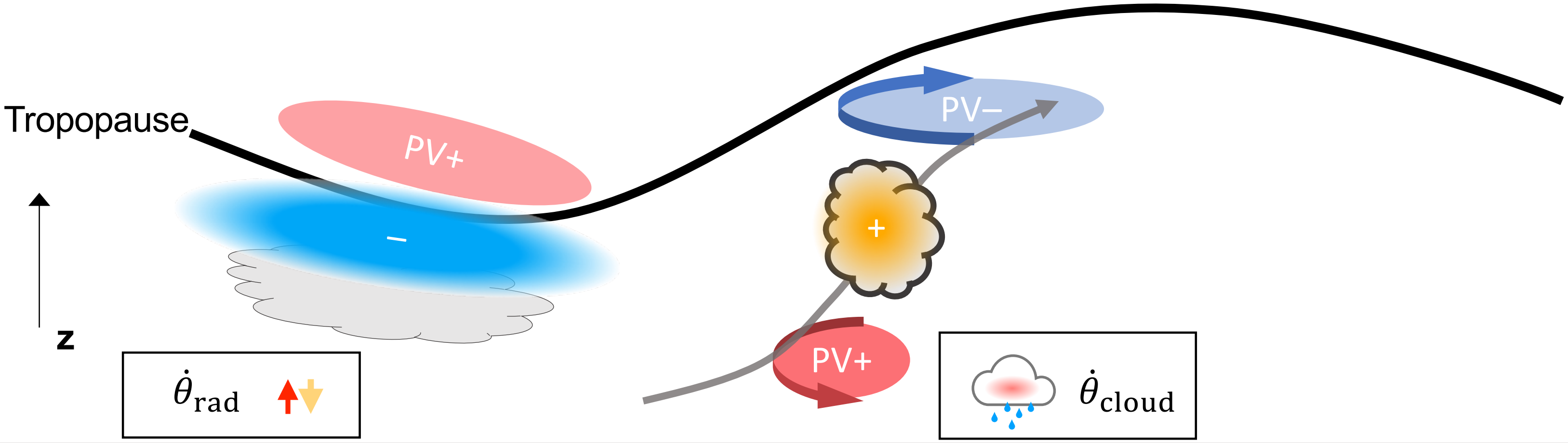

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tendencies of **temperature** & **momentum**

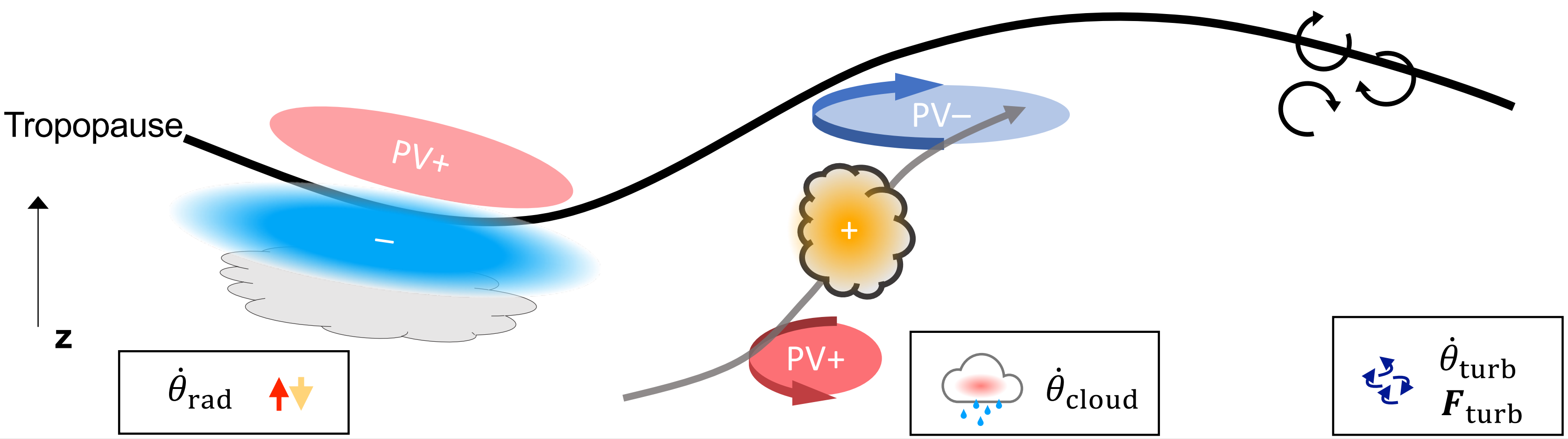
Direct diabatic PV modification

Potential vorticity (PV)

$$\mathrm{PV} = \frac{1}{\rho}\boldsymbol{\eta}\cdot\nabla\theta$$

vorticity ($\boldsymbol{\eta}$); gradient of potential temperature ($\nabla\theta$)

e.g., Shapiro (1976, MWR)



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tendencies of **temperature** & **momentum**

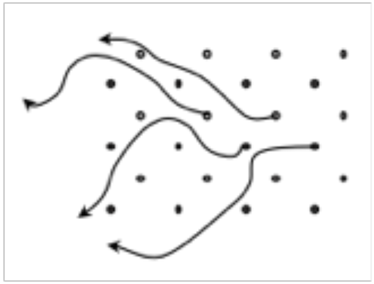
Direct diabatic PV modification

Lagrangian accumulated PV along trajectories:
following Crezee et al. (2017, JAS)

$$\mathrm{APV}(\mathbf{x}(t_0),t) = \int_t^{t_0}\mathrm{PVR}(\mathbf{x}(\tau),\tau)\,\mathrm{d}\tau$$

→ for each parametrized process

Reverse domain filling: Backward trajectories from each grid point
→ 3D-field of APV



Methods: Model simulations

Simulations with the global model of the ECMWF

- Horizontal resolution ~16 km

- Output of all instantaneous **temperature** & **momentum tendencies** from parametrized physics

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- Horizontal resolution ~16 km
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Physical tendencies:
Large-scale cloud
Moist convection
Long-/short-wave radiation
Vertical diffusion and gravity wave drag

→ complete physical budget

Methods: Model simulations

Simulations with the global model of the ECMWF

- Horizontal resolution ~16 km

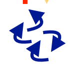
- Output of all instantaneous **temperature** & **momentum tendencies** from parametrized physics

> One case study simulation

> Three monthly simulations (DJF)

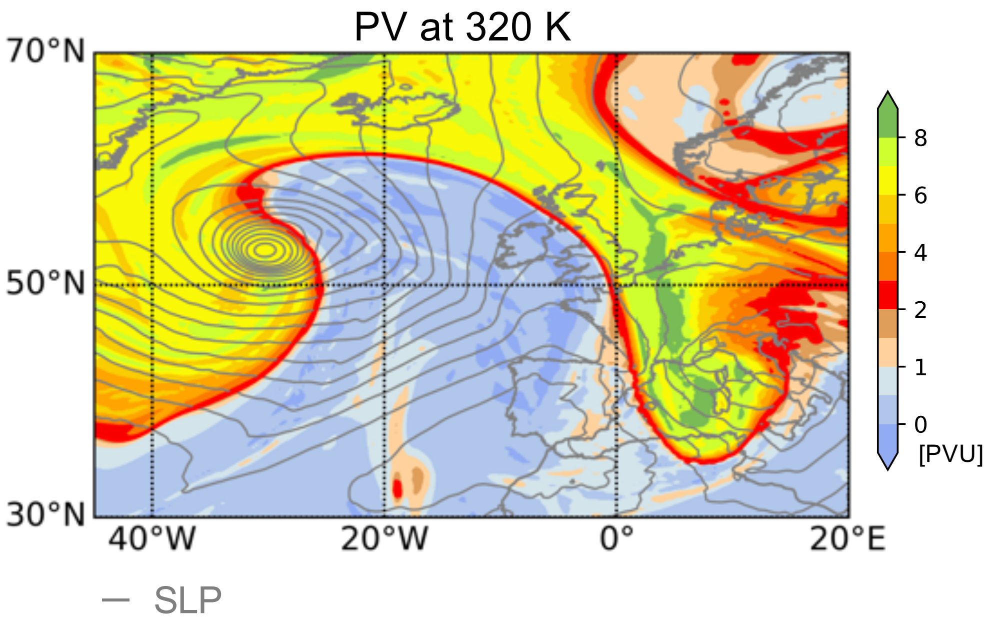
Physical tendencies:
Large-scale cloud

Moist convection
Long-/short-wave radiation

Vertical diffusion and gravity wave drag


> Complete physical budget

I. Near-tropopause PV modification: Case study



Spreitzer et al. (2019, JAS)

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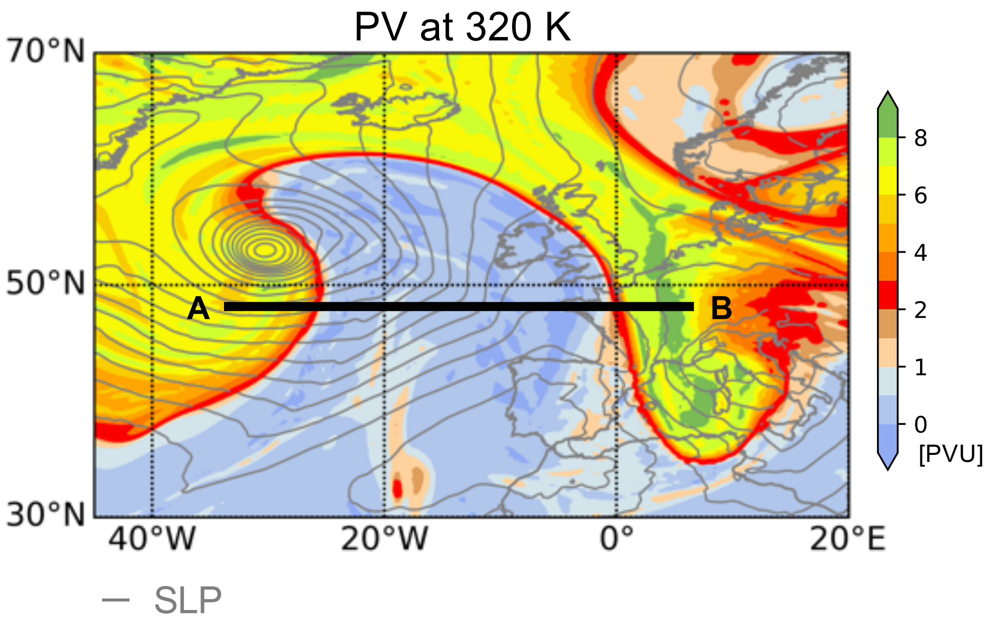

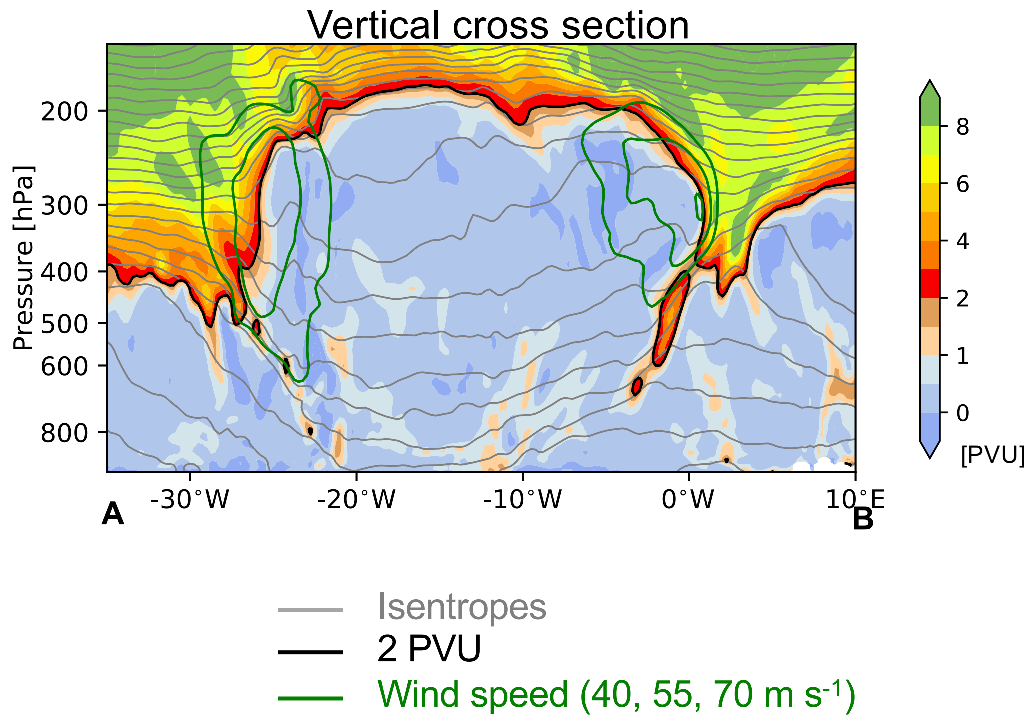

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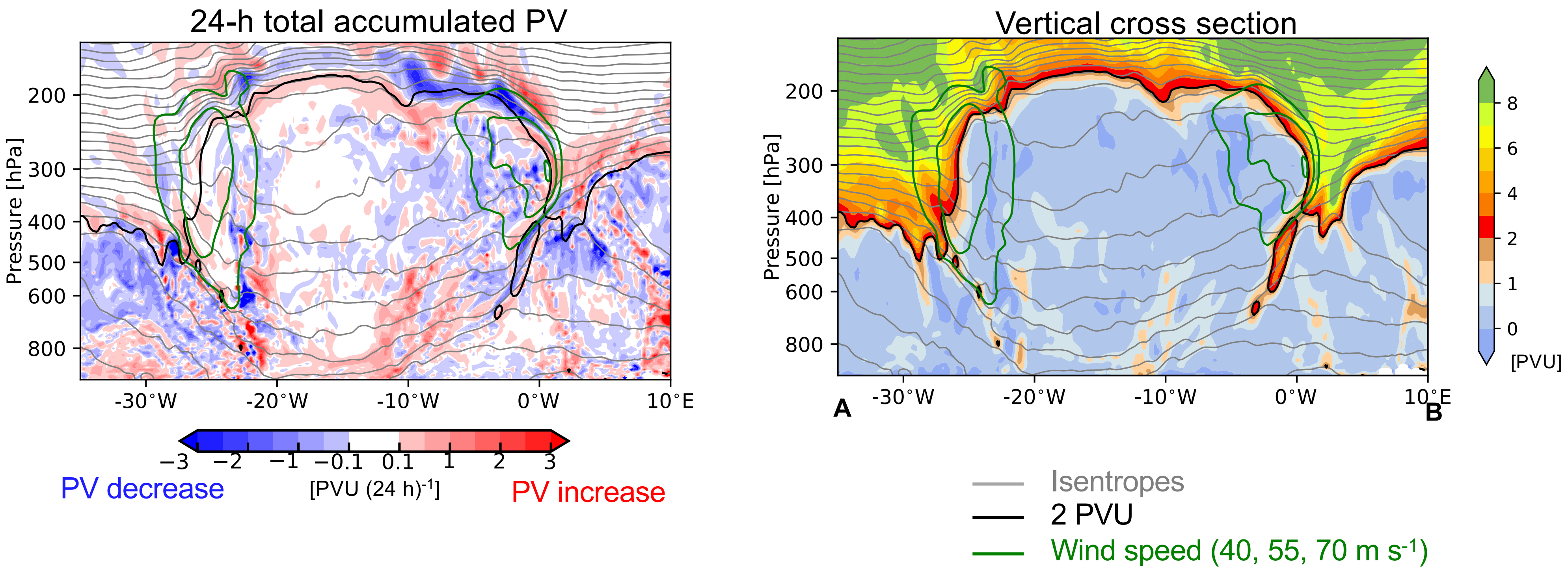
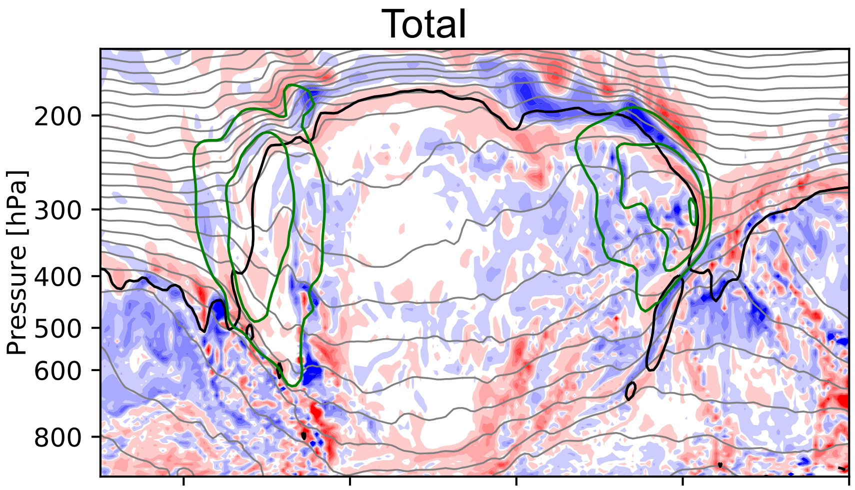
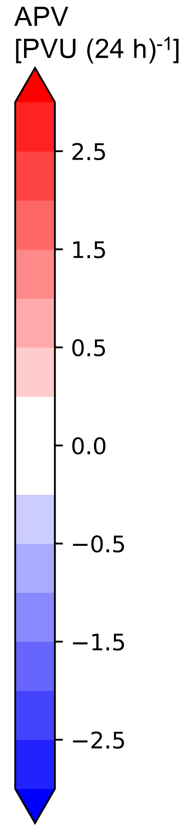


I. Near-tropopause PV modification: Case study

24-h accumulated PV





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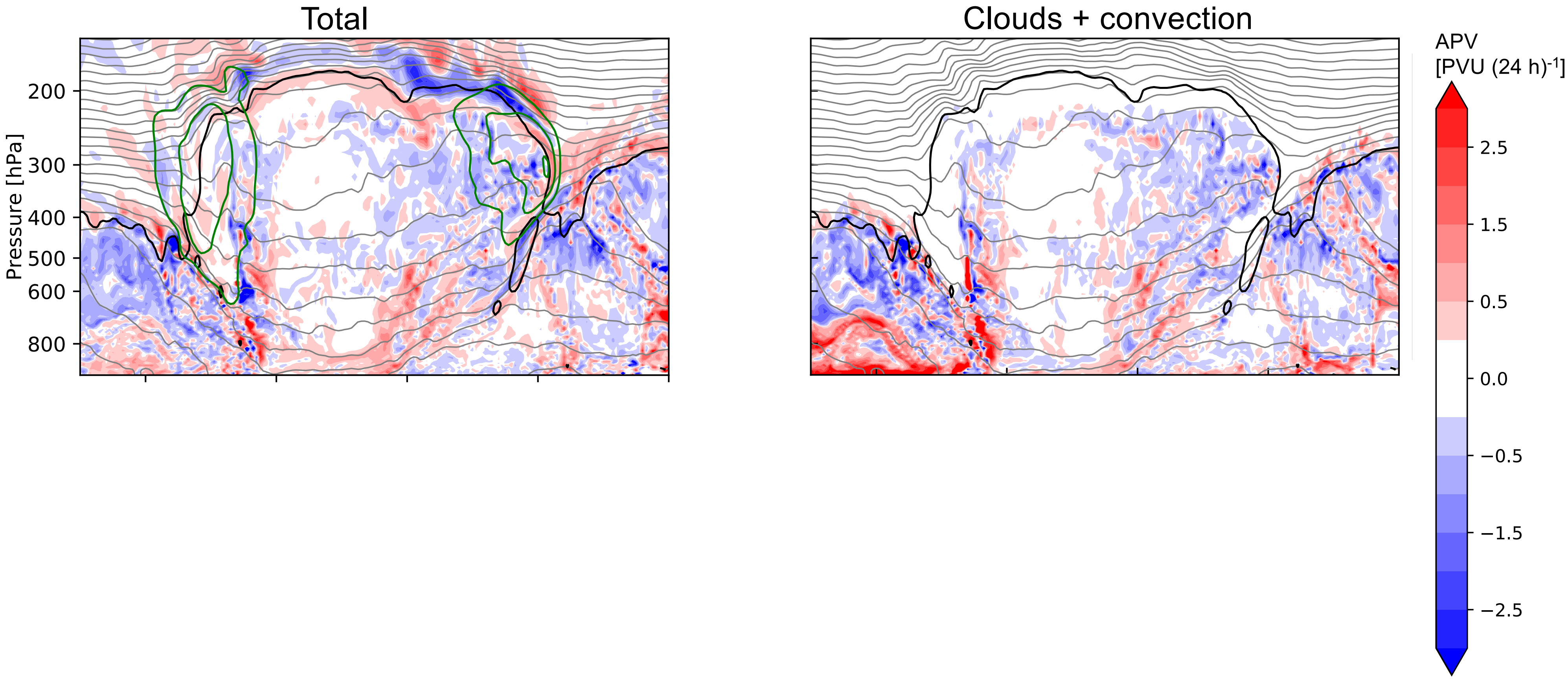

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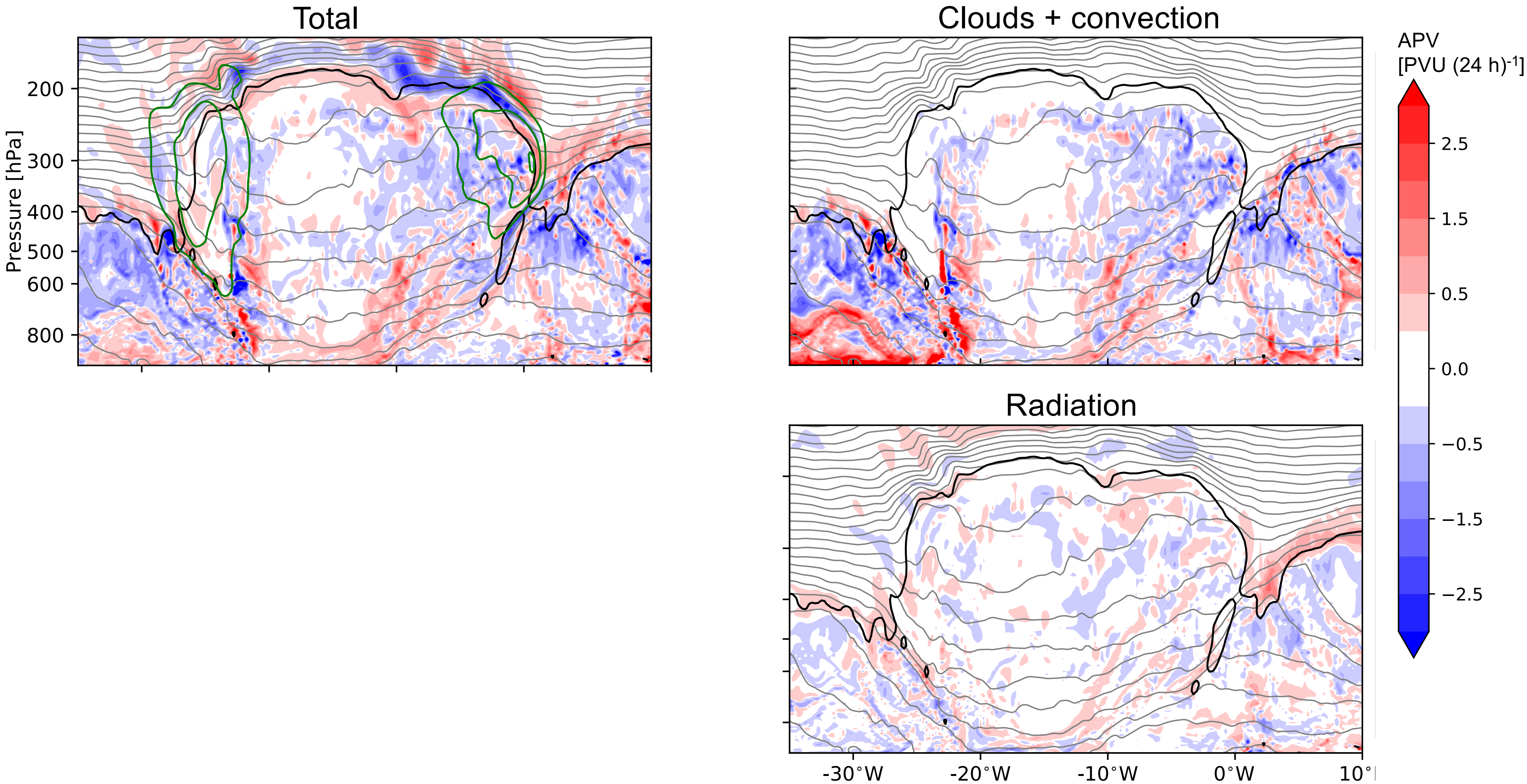

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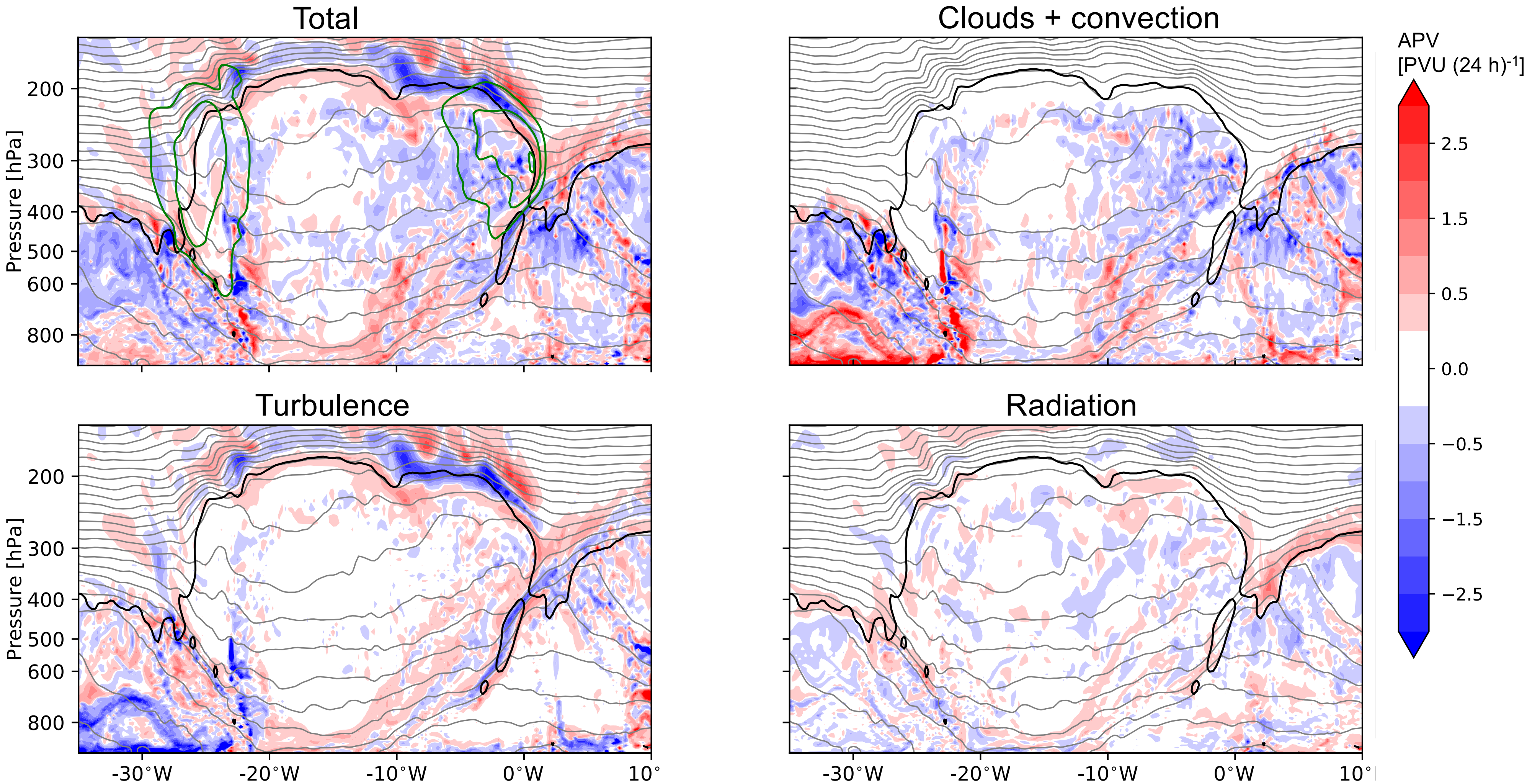

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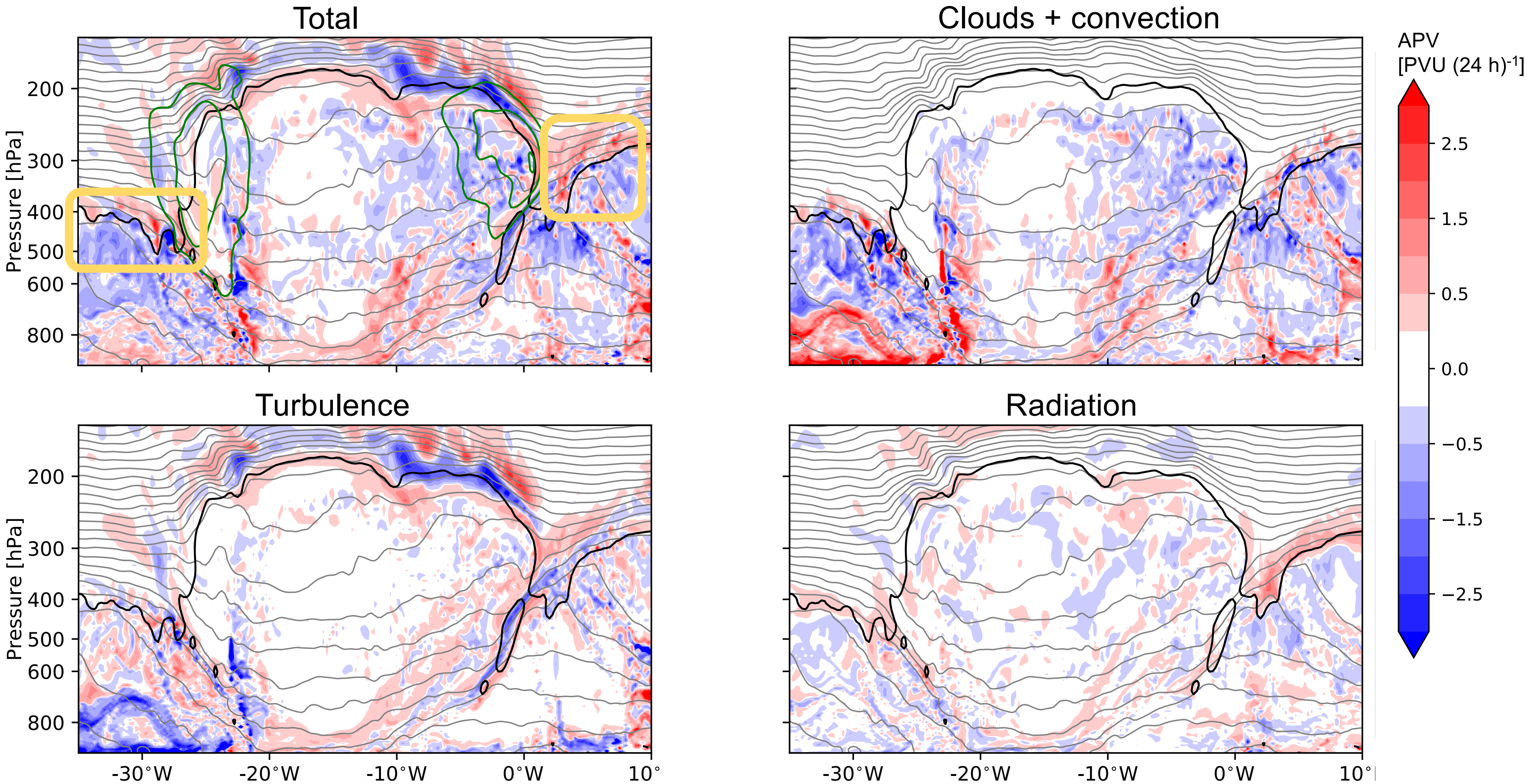

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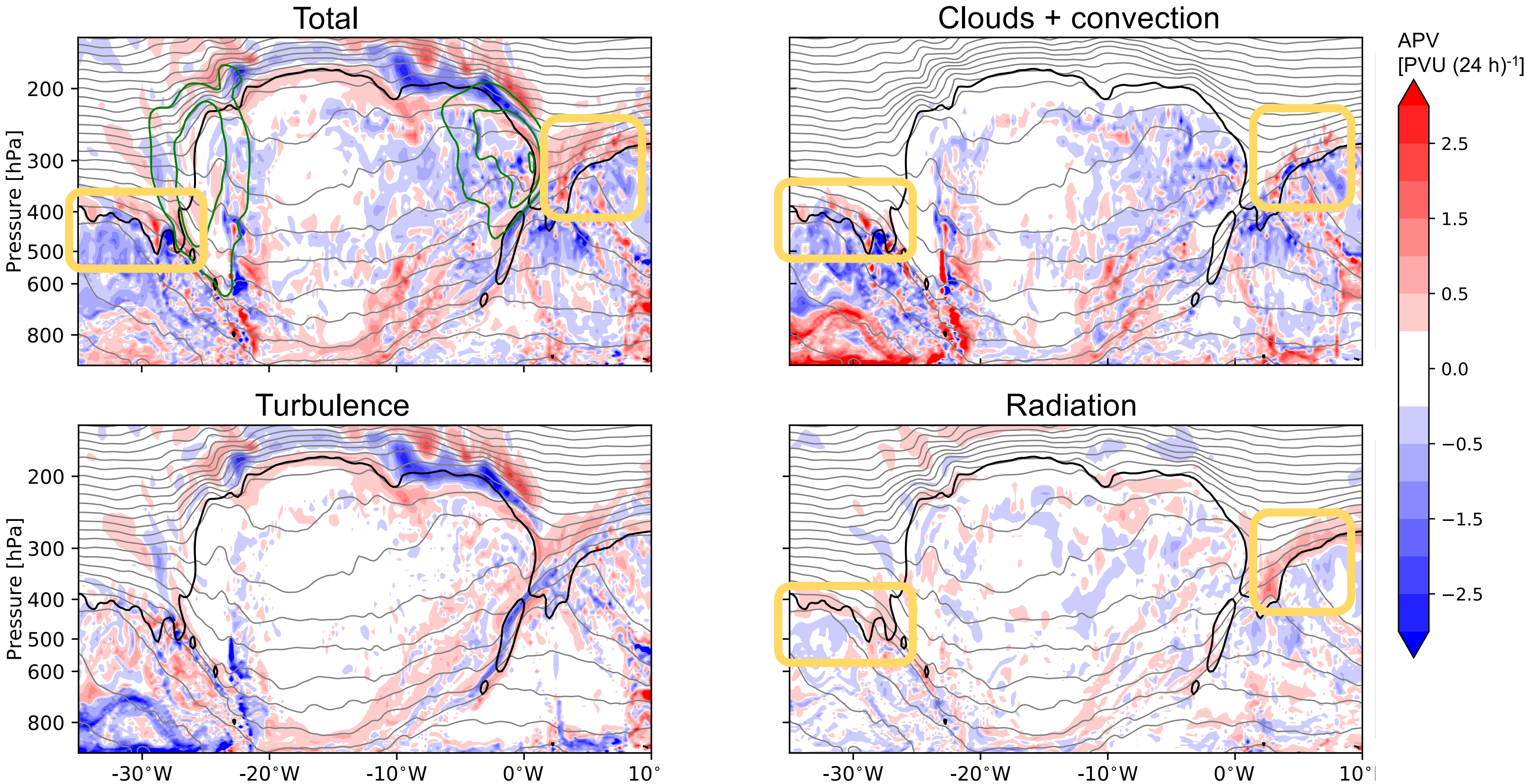

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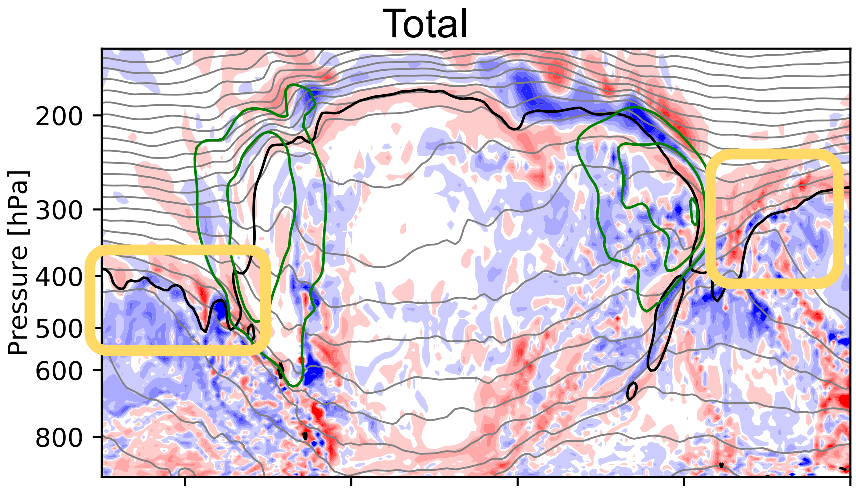
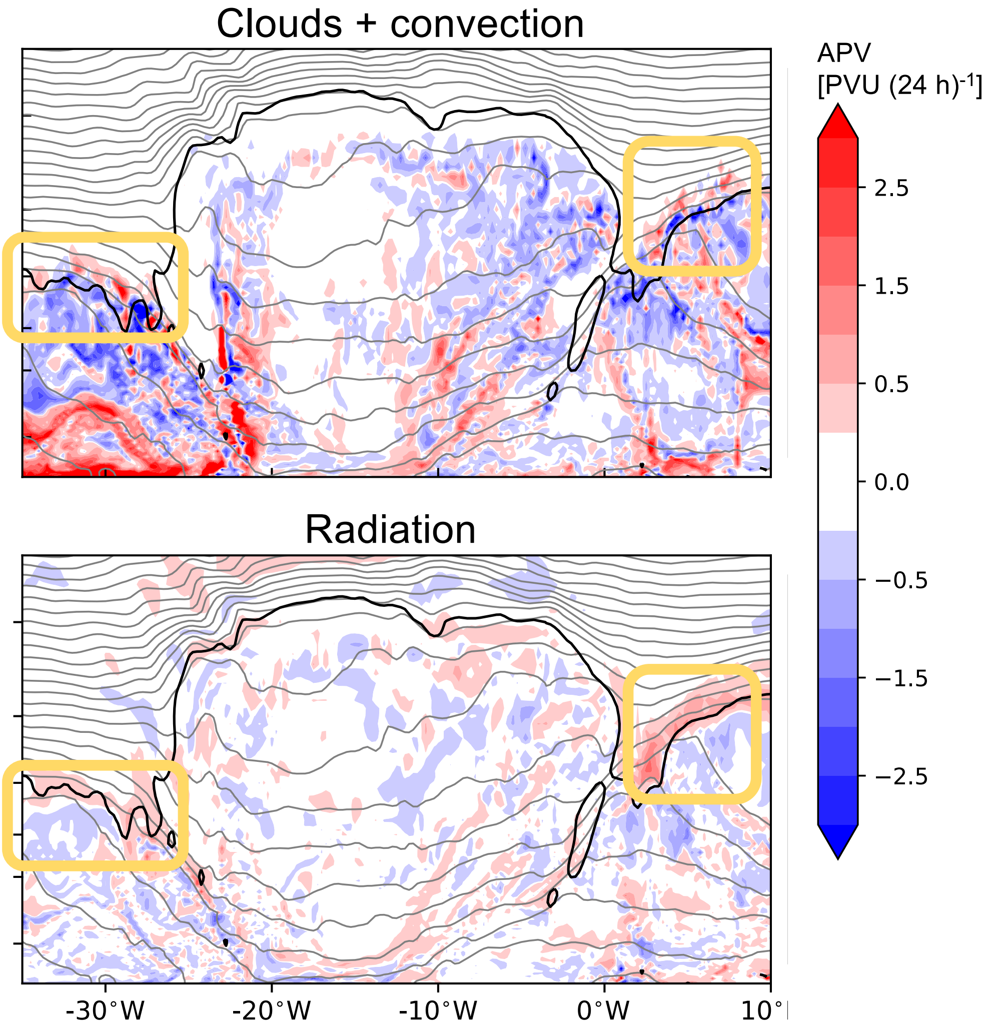
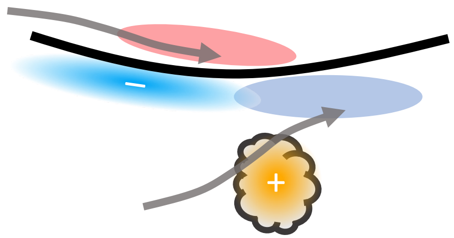




Vertical PV dipole



Consistent with
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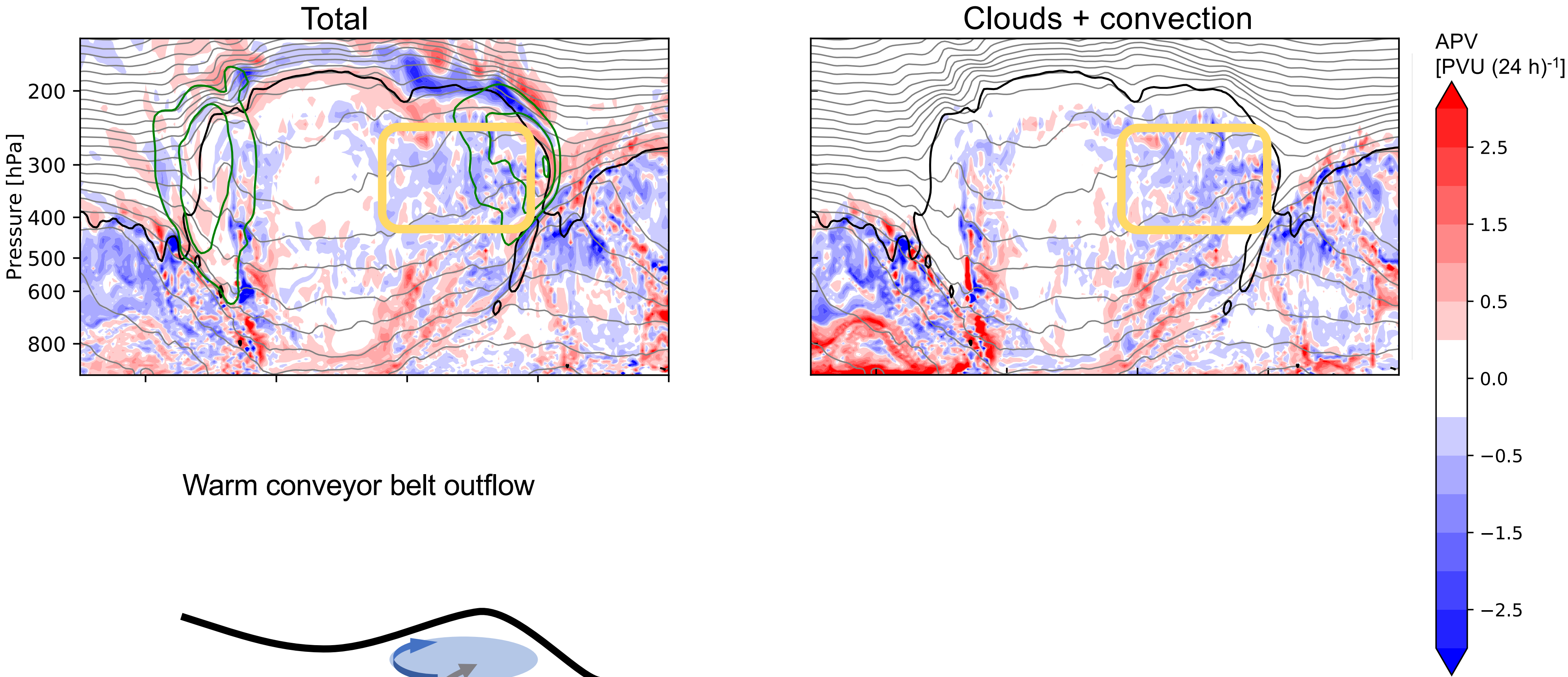
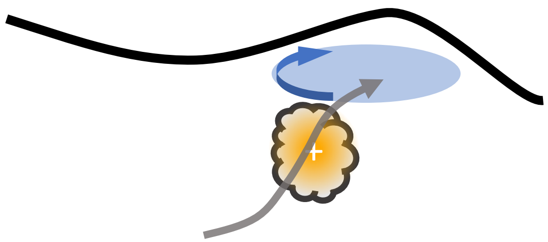


Warm conveyor belt outflow



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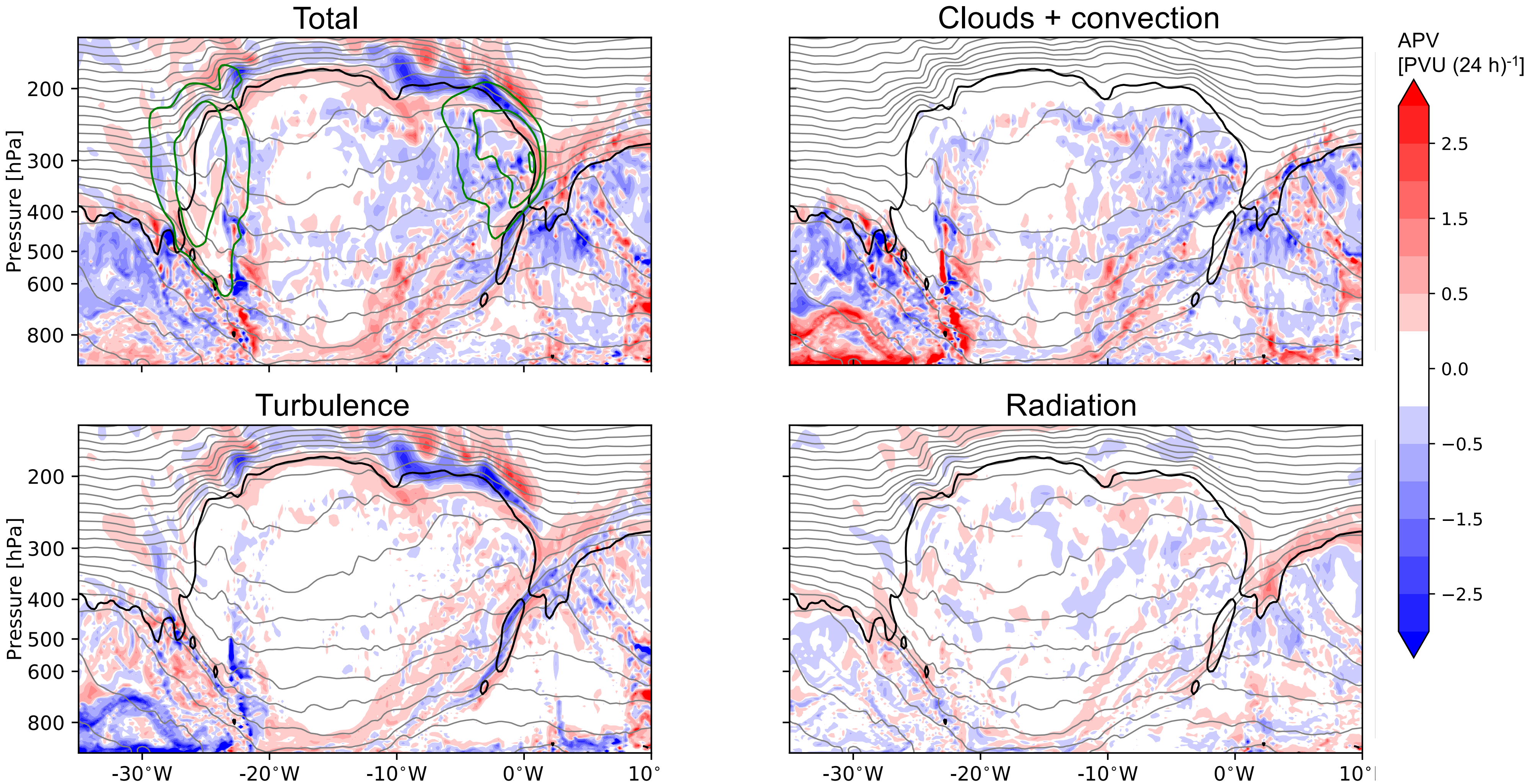

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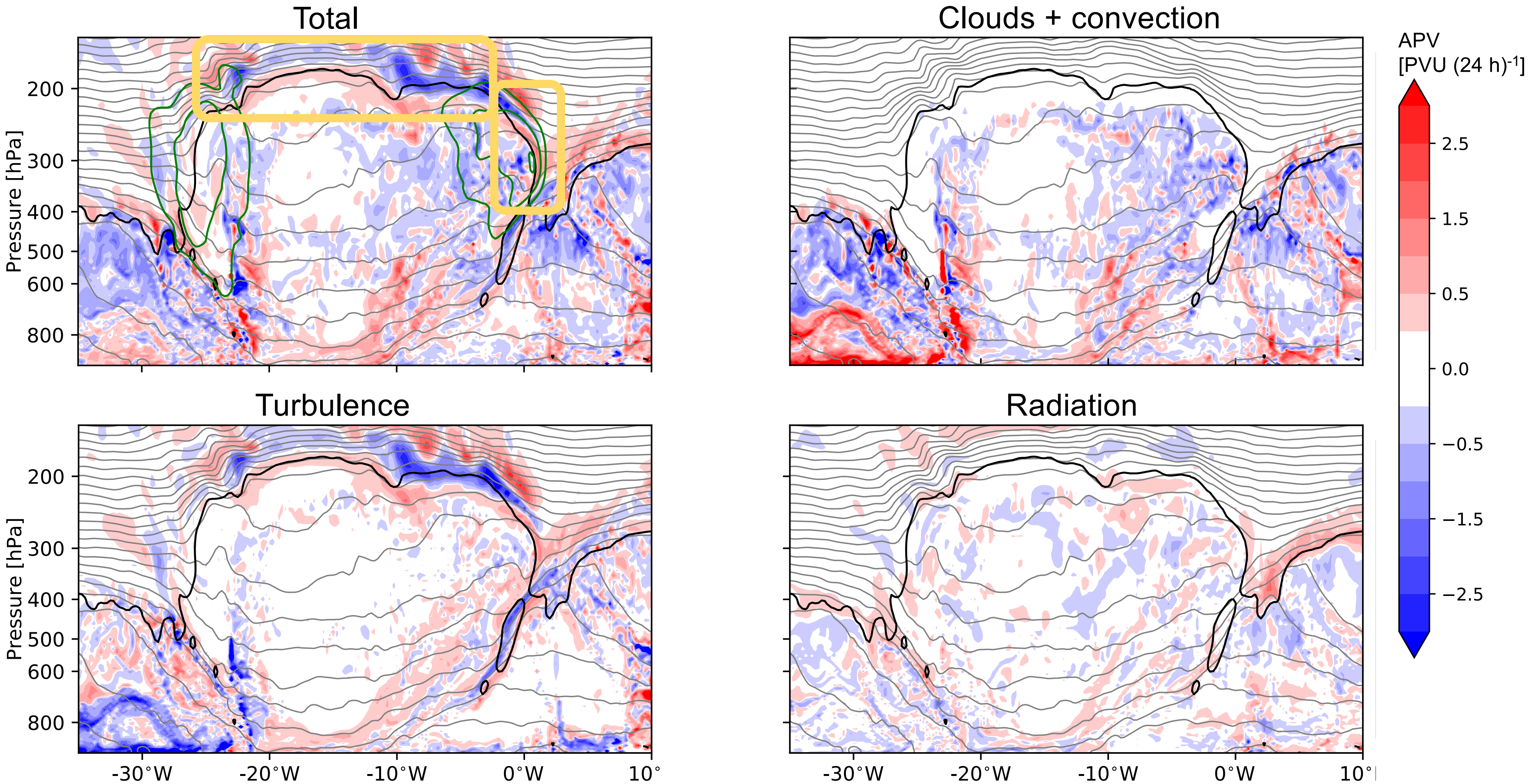

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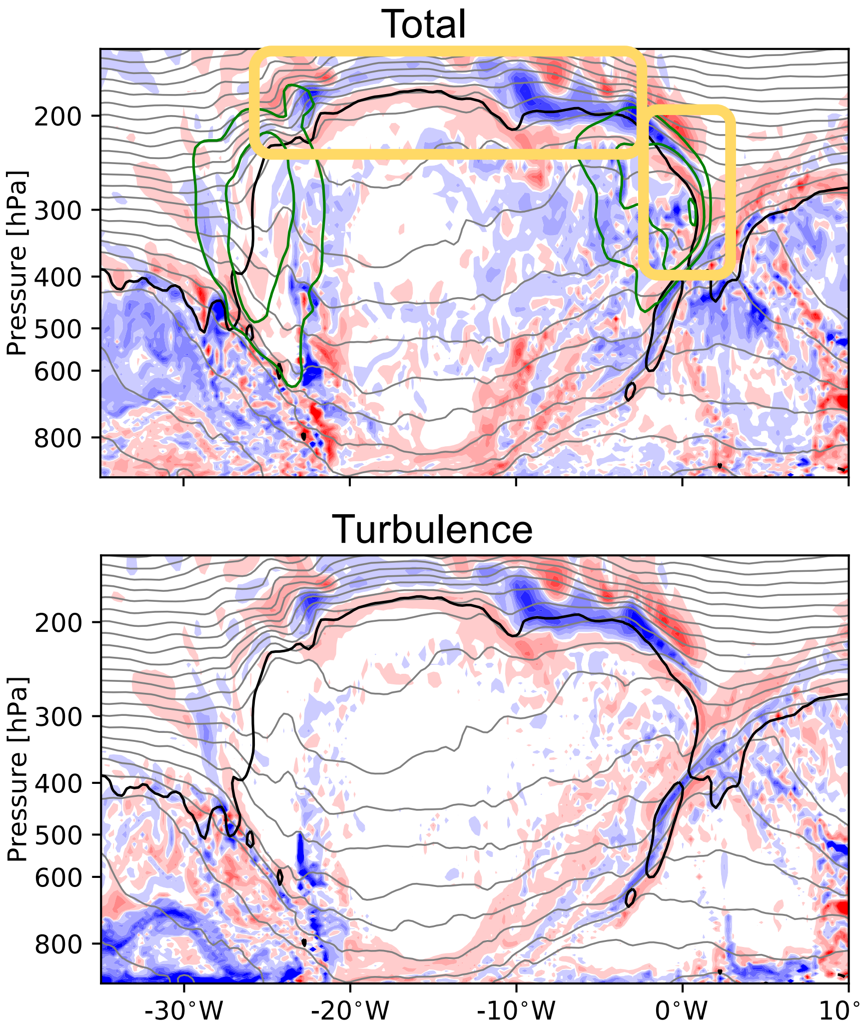

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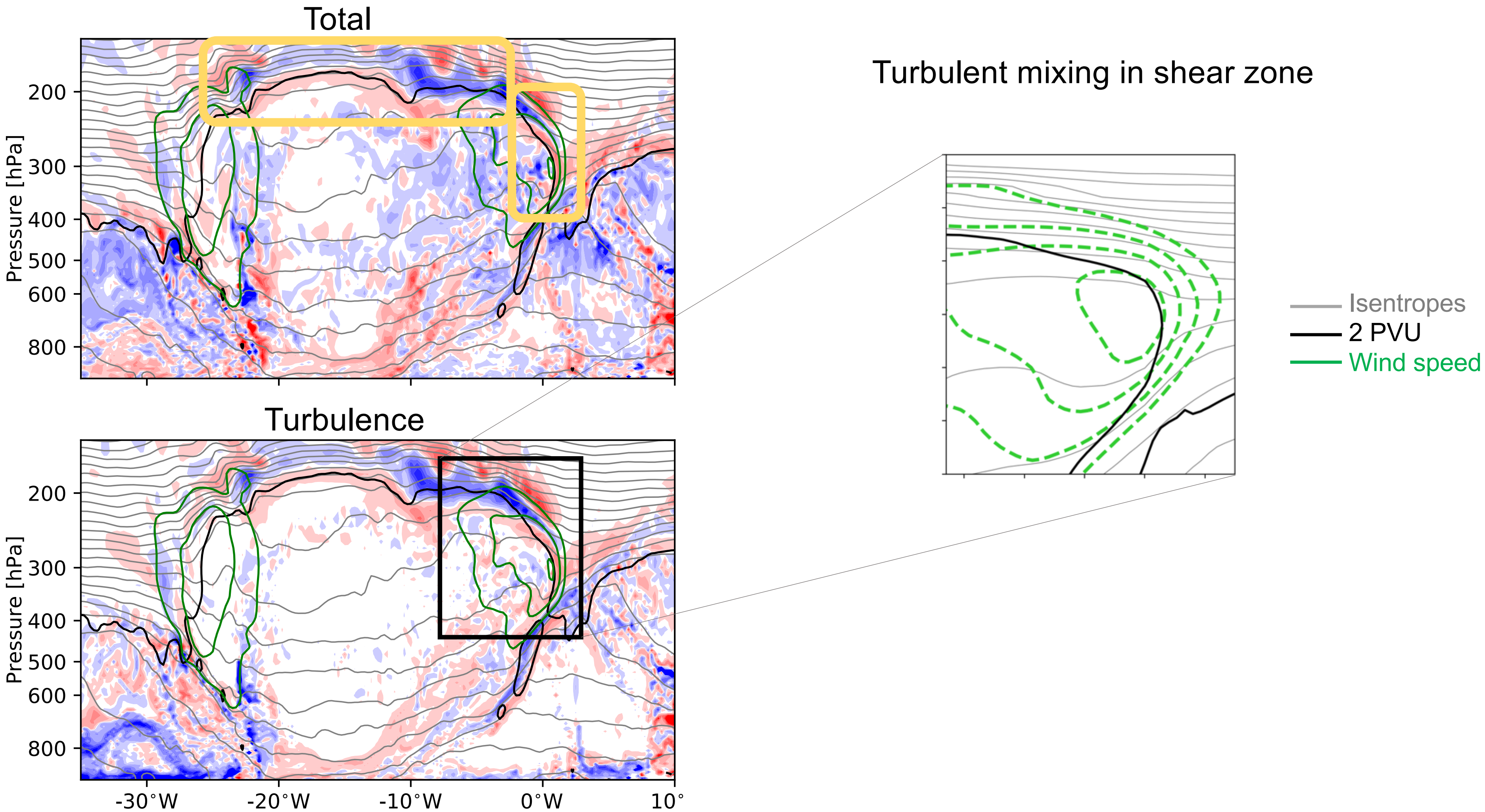

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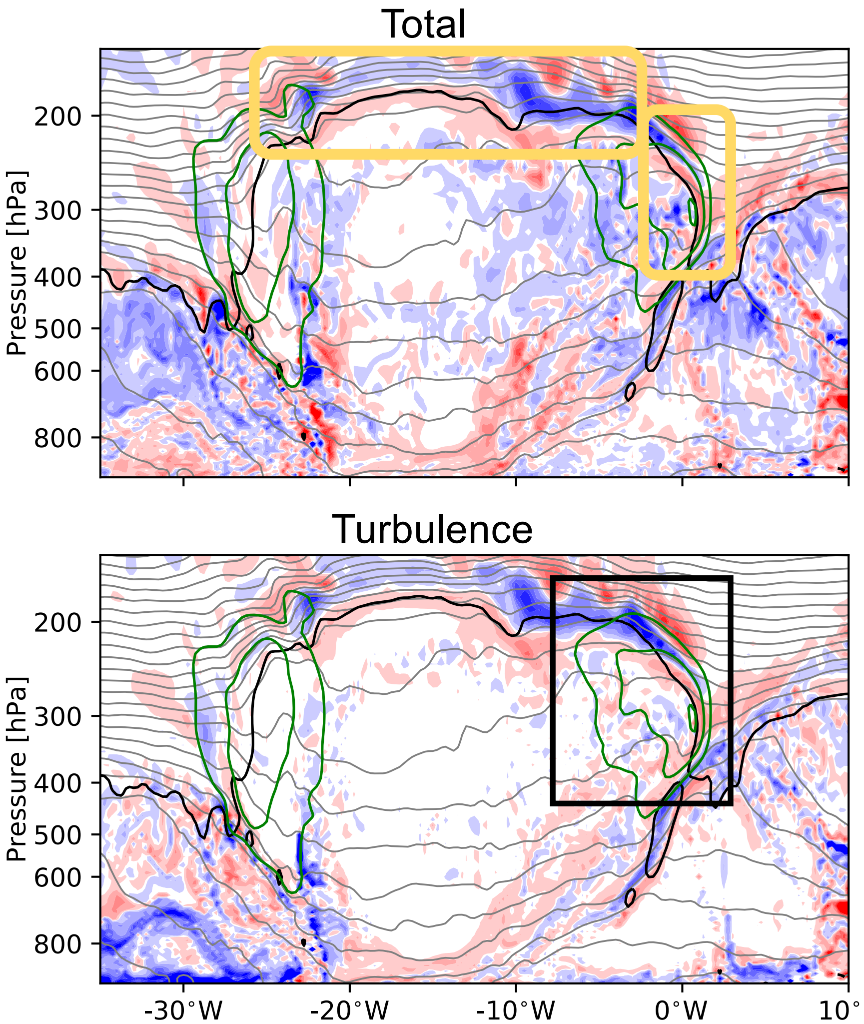
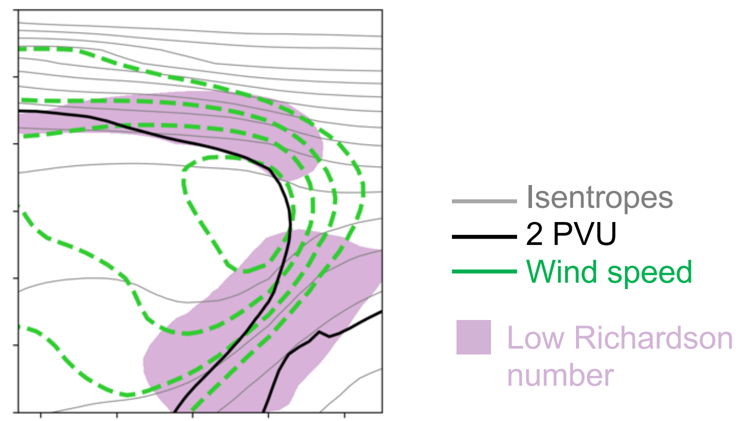


Turbulent mixing in shear zone



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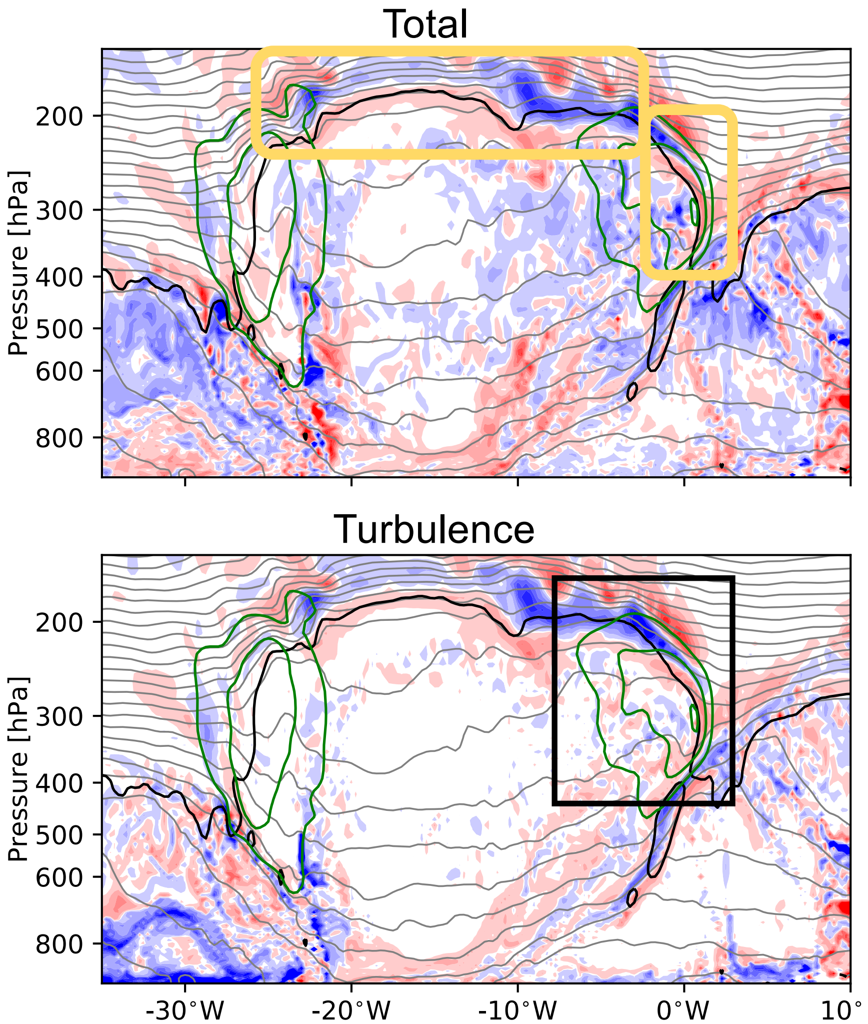

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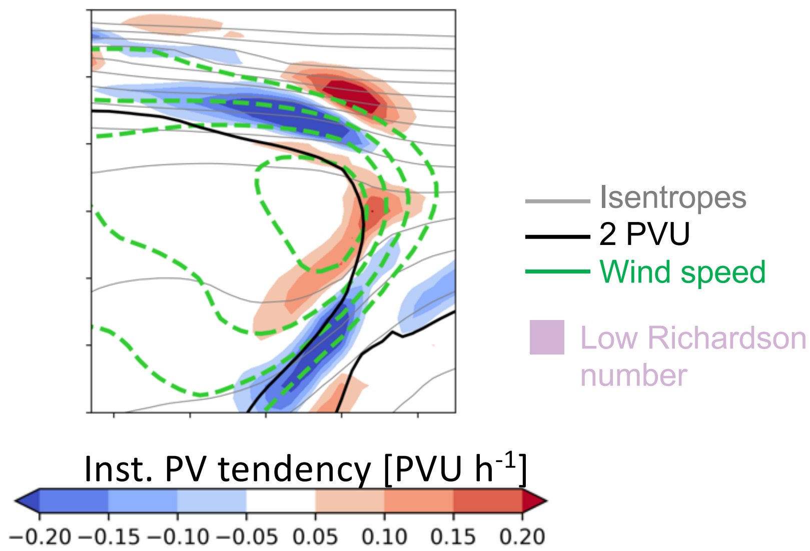

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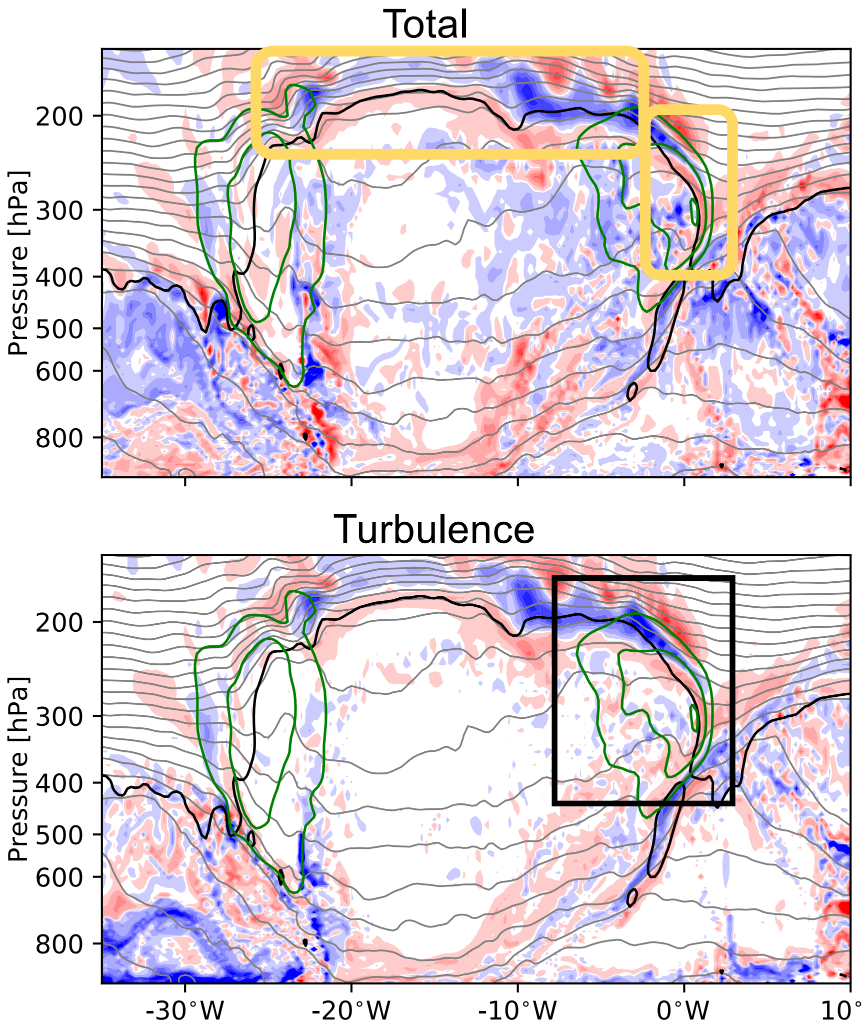

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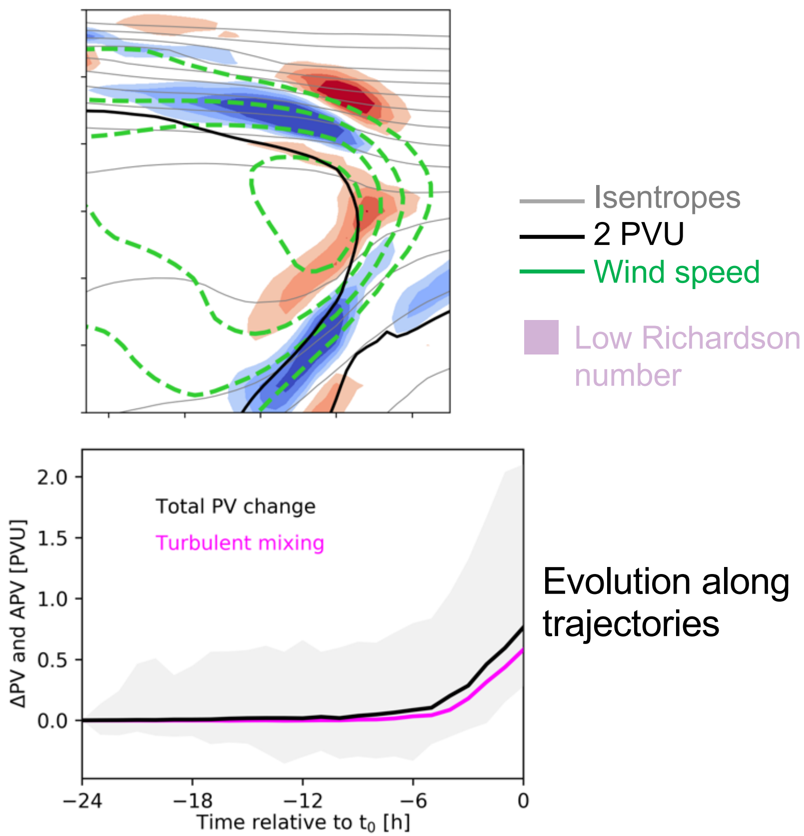

Evolution along trajectories

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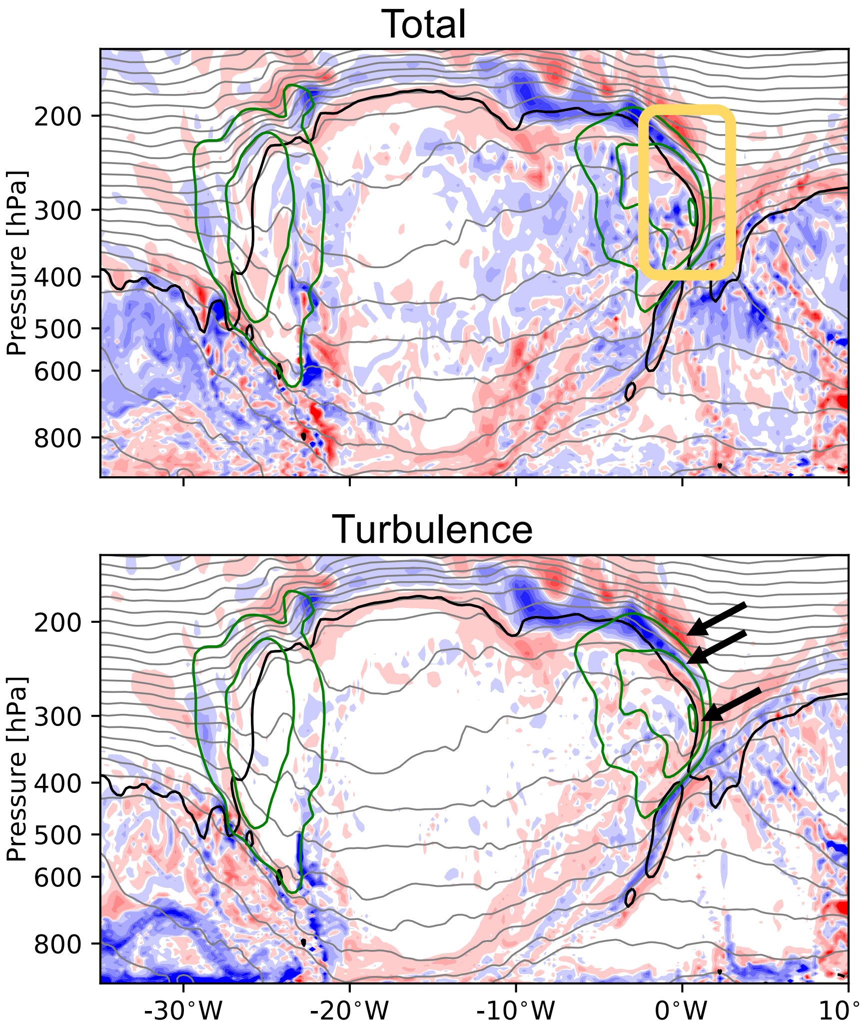

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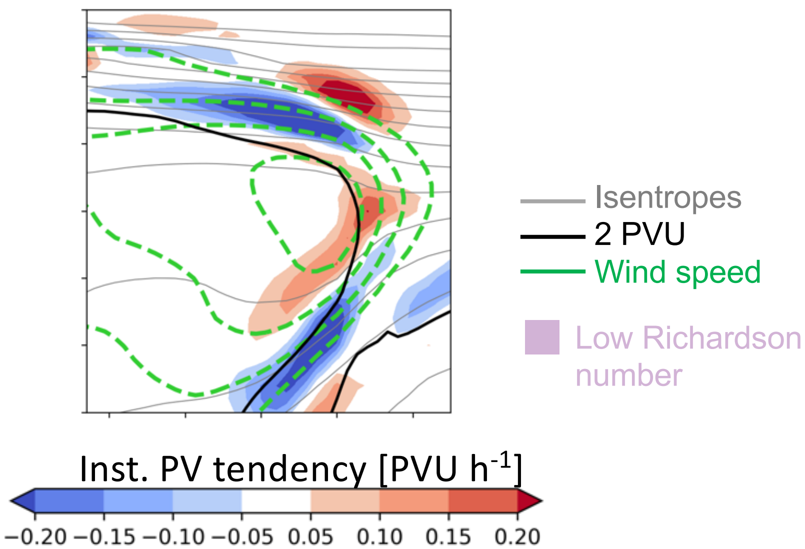

PV anomalies
cf. observational studies by
Staley (1960, JM)
Shapiro (1976, MWR)

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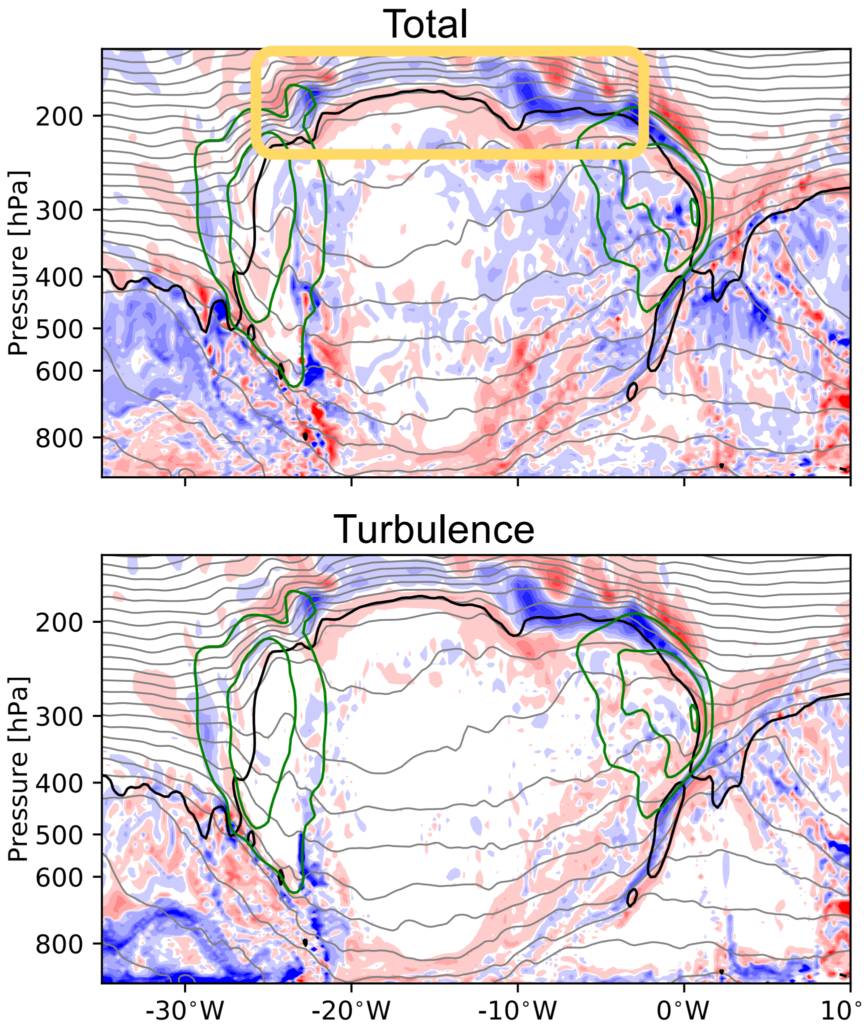

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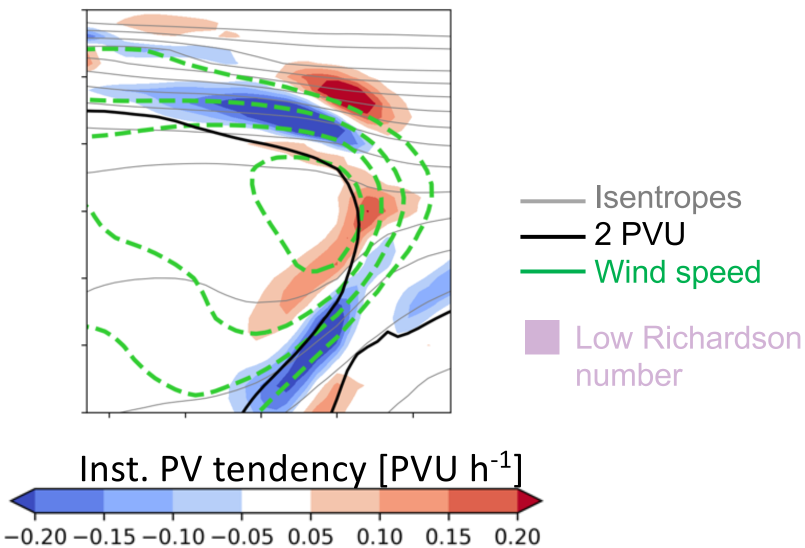

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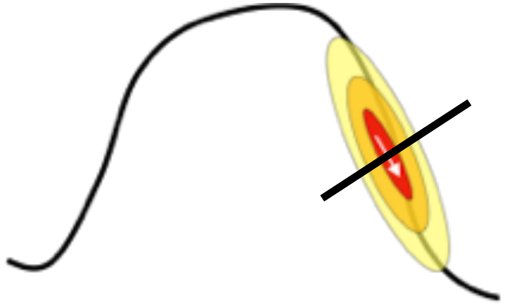
II. Systematic analysis: Jet streaks

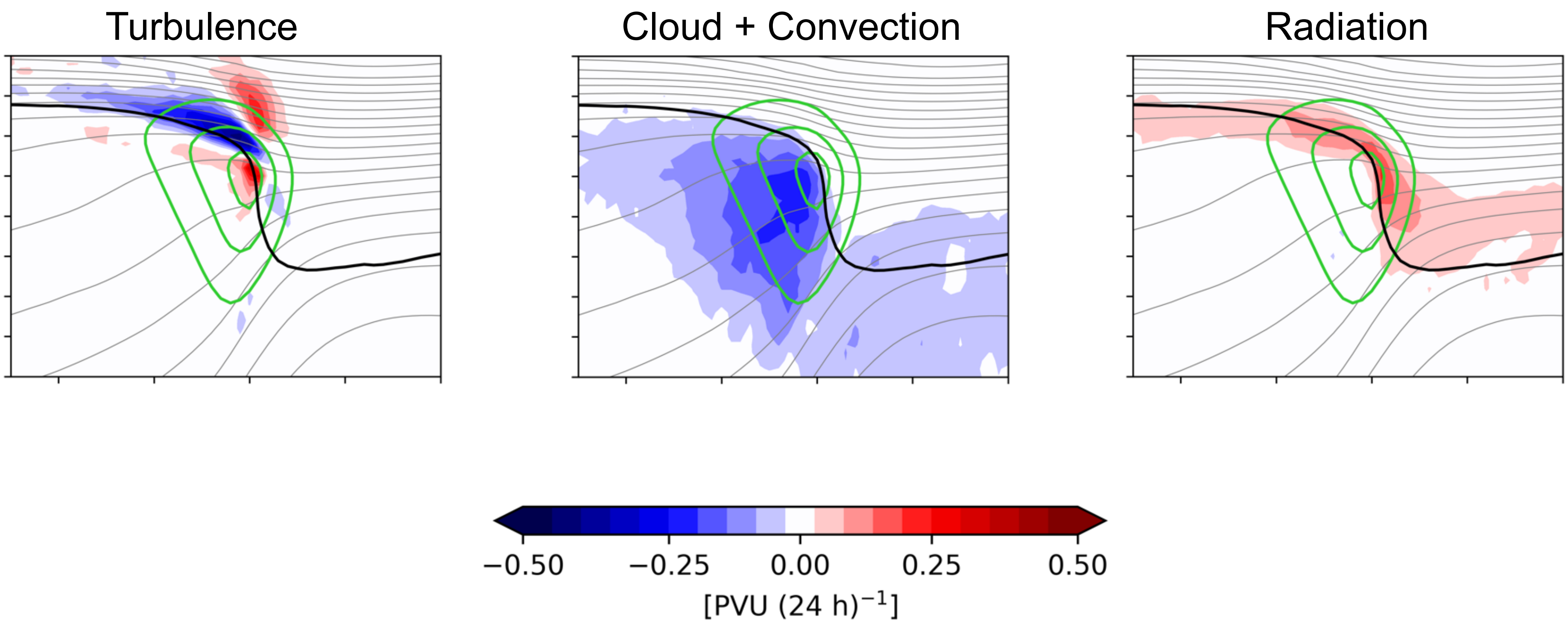
- Three monthly simulations
- Identification of jet streaks
- Composite cross sections across jet streaks



II. Systematic analysis: Jet streaks

Composite cross section across jet streaks

Accumulated PV:

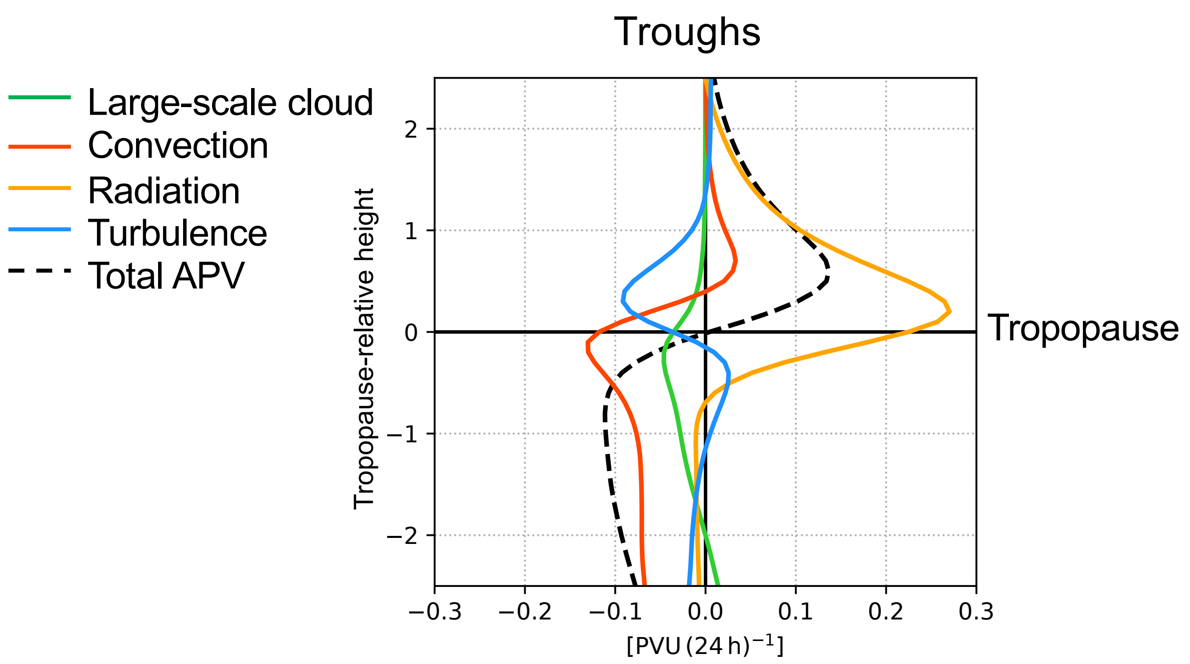


II. Systematic analysis: Vertical profiles

- Three monthly simulations
- Identification of ridge/trough area
- Tropopause-relative vertical composites of accumulated PV (similar to Saffin et al. (2017; JGR))

II. Systematic analysis: Vertical profiles

Composite vertical profiles of accumulated PV



Troughs: PV dipole → tropopause sharpening
Consistent with
Chagnon et al. (2013, QJRMS);
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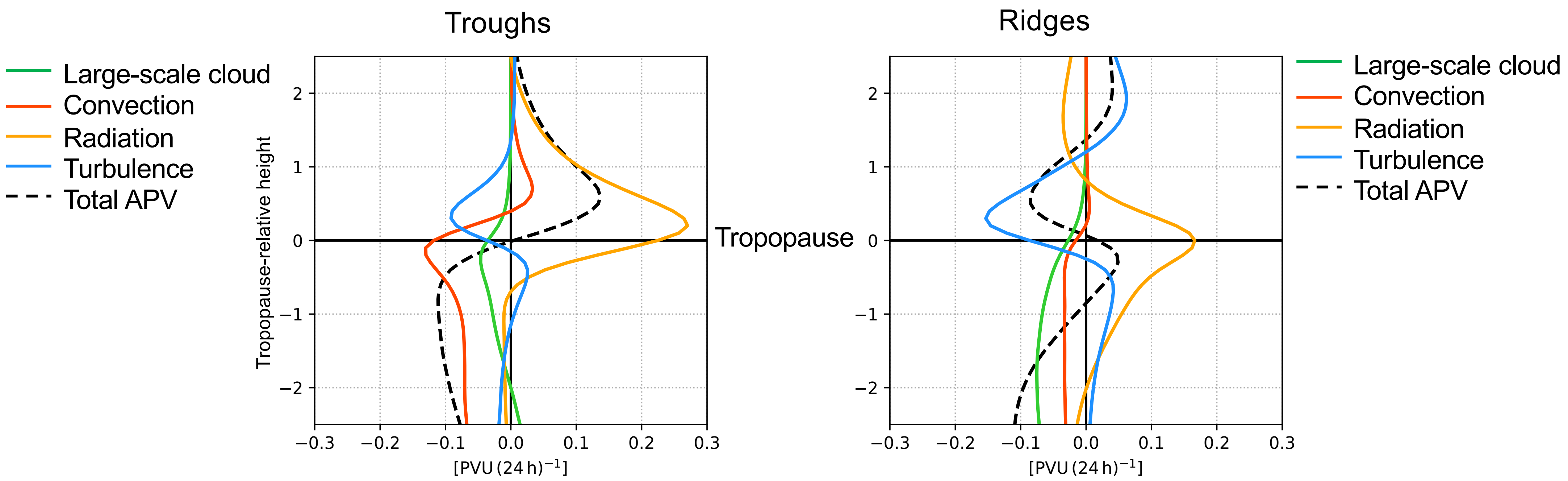
Composite vertical profiles of accumulated PV



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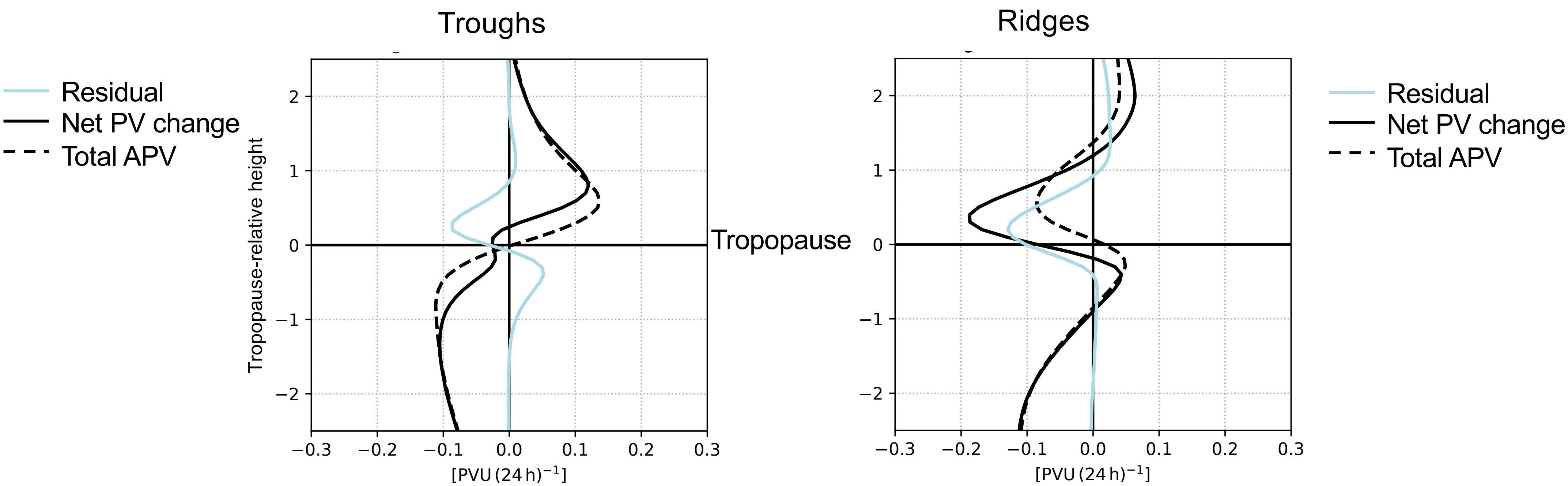
Ridges:
Turbulent PV erosion in lower stratosphere
→ weaker vert. PV gradient
Contradicting Saffin et al. (2017; JGR)

II. Systematic analysis: Vertical profiles

Composite vertical profiles of accumulated PV: Residual



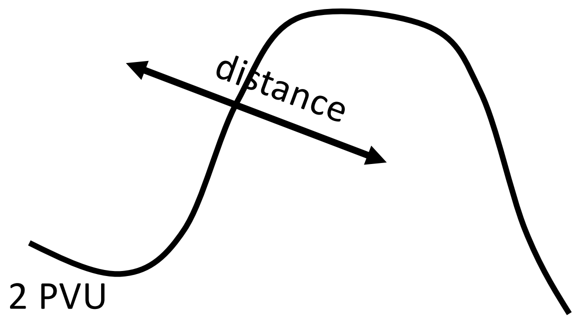
PV budget not closed: ΔPV = APV + RES

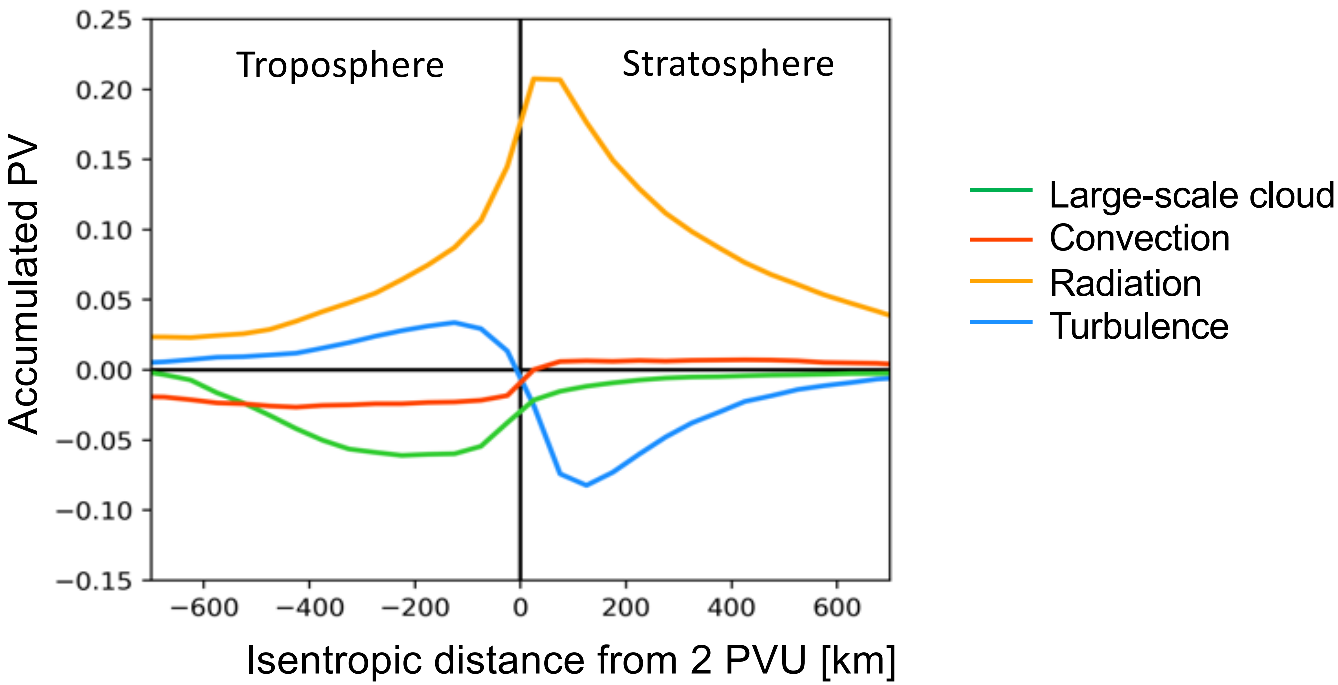
Large Residual → partly due to non-conservation of PV by the model

Consistent with Saffin et al. (2017; JGR)

II. Systematic analysis: Isentropic profiles

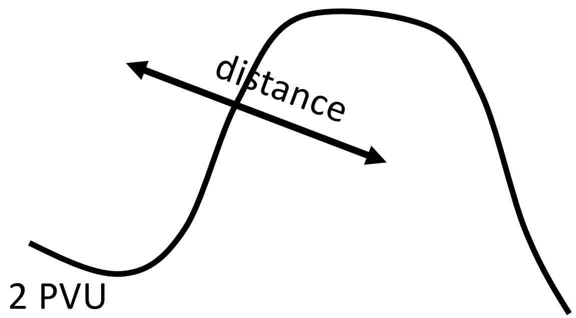
- Three monthly simulations
- Identification of waveguide on isentropes (2 PVU)
- Average isentropic profiles of APV

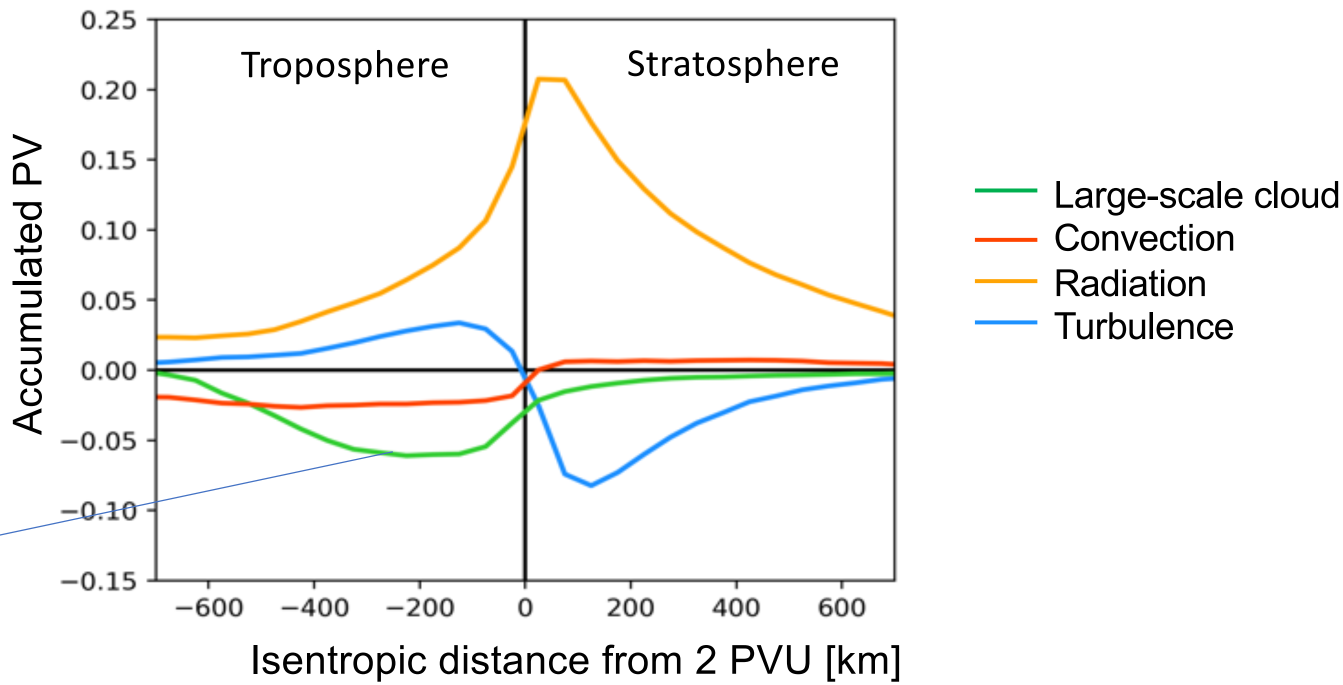




II. Systematic analysis: Isentropic profiles

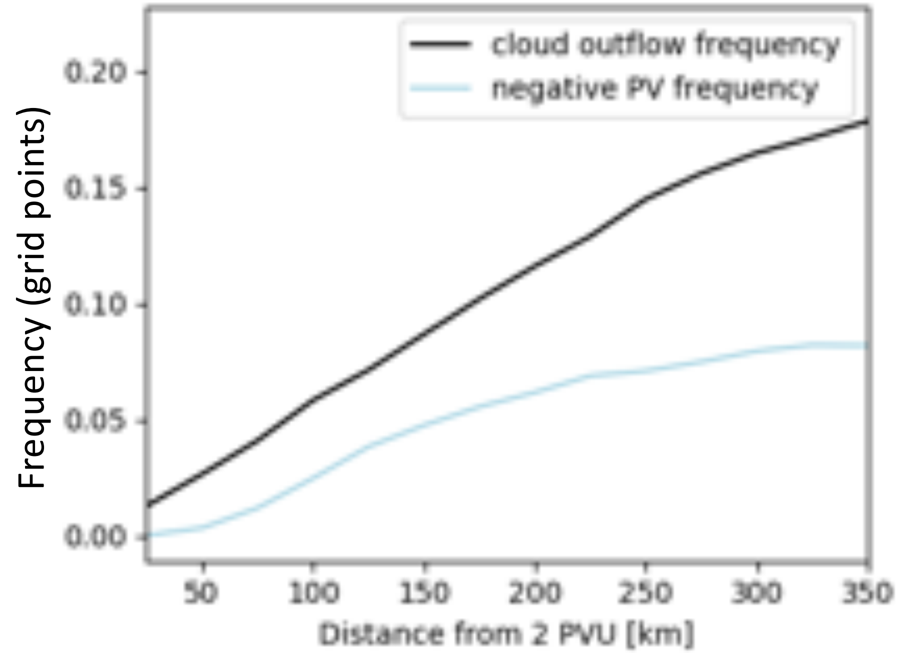
- Three monthly simulations
- Identification of waveguide on isentropes (2 PVU)
- Isentropic profiles of APV

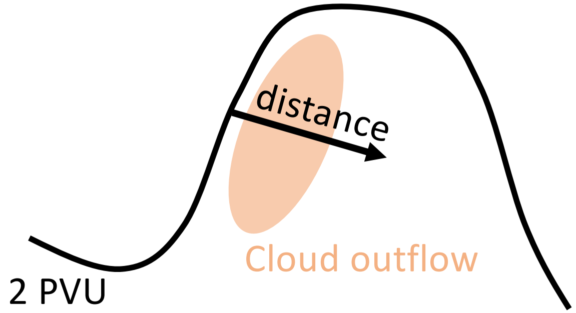




Tropospheric side:
Negative PV due to clouds?
cf. Pomroy and Thorpe (2000)

“WCB” outflow near the waveguide



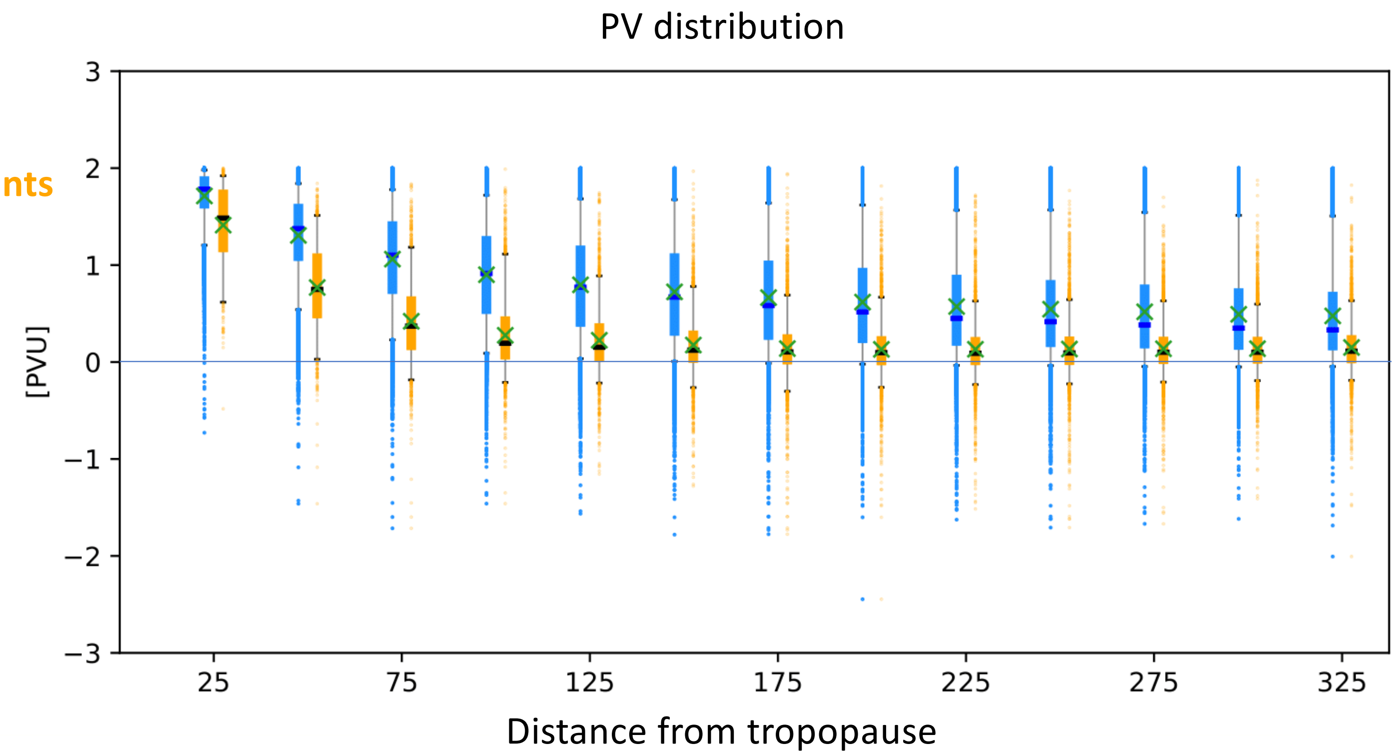


Cloud outflow region: Cloud-diabatic heating of > 5 K in 24 h

“WCB” outflow near the waveguide

Cloud outflow grid points

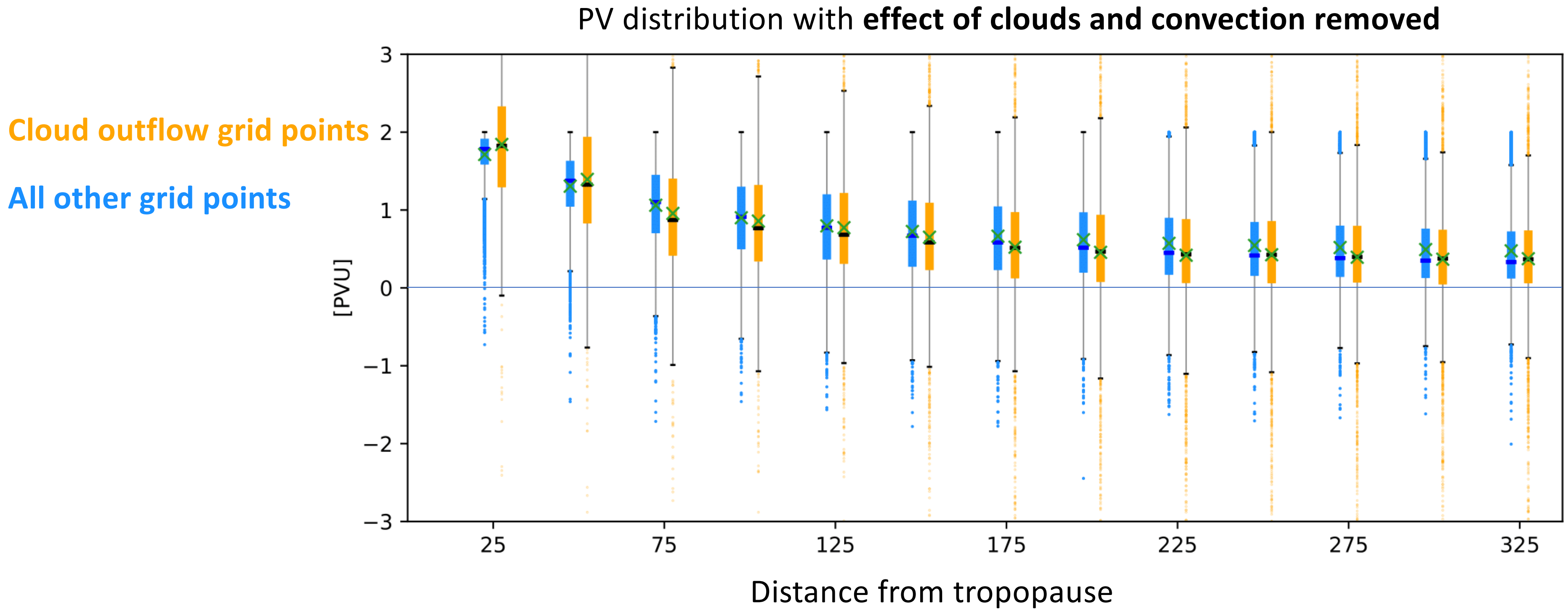
All other grid points



Cloud outflow: Cloud-diabatic heating of > 5 K in 24 h

Significantly lower PV in cloud outflow regions,
cf. Pomroy and Thorpe (2000)

“WCB” outflow near the waveguide



Cloud outflow: Cloud-diabatic heating of > 5 K in 24 h

Significantly lower PV in cloud outflow regions >> **caused by direct cloud PV modification**

cf. Pomroy and Thorpe (2000)

Summary

- Lagrangian PV-tendency diagnostics: PV budget and process attribution

  >> Case study

  >> Systematic analysis:

- Mesoscale PV anomalies near jet streaks
- Turbulent mixing in ridges relevant for vertical PV structure
- PV dipole in troughs (clouds and radiation)
- Direct PV modification due to clouds enhances negative PV anomaly in WCB outflows

Thank you