Disentangling diabatic and adiabatic drivers during the life cycle of a jet streak — A Lagrangian PV-gradient perspective

— EMS Meeting 2022 —

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Thursday, September 8th 2022

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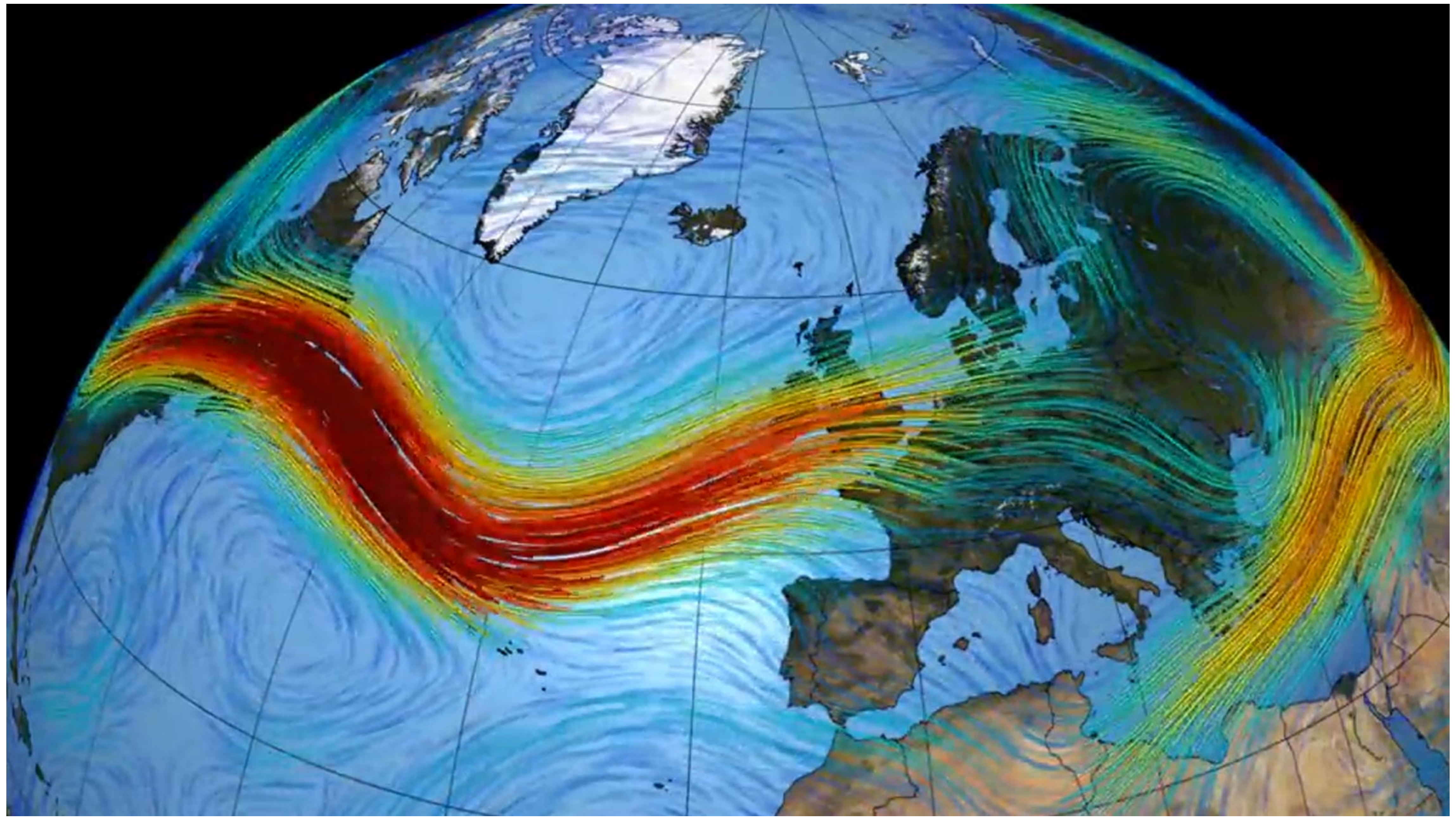
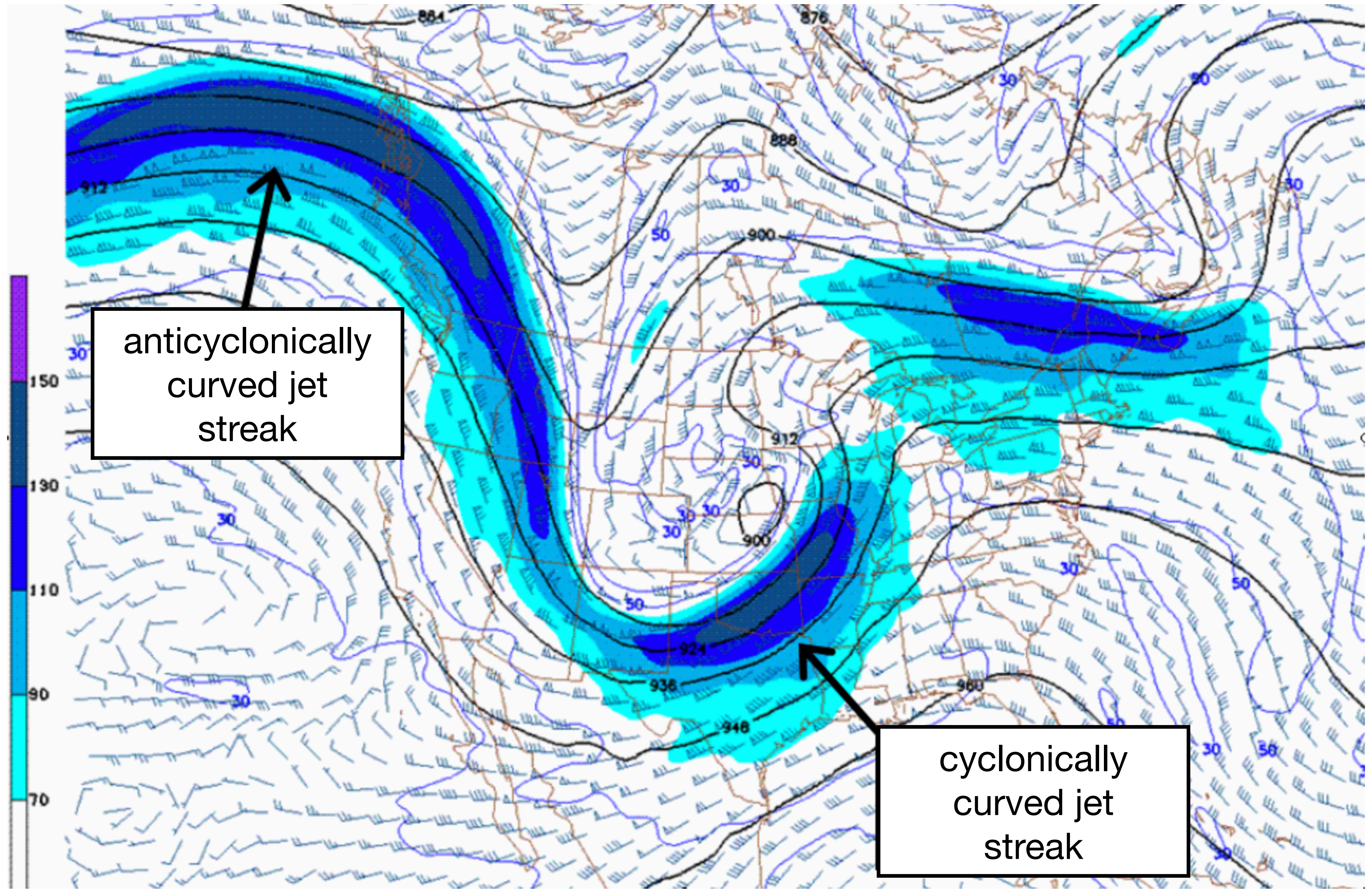
The jet stream



jet streaks



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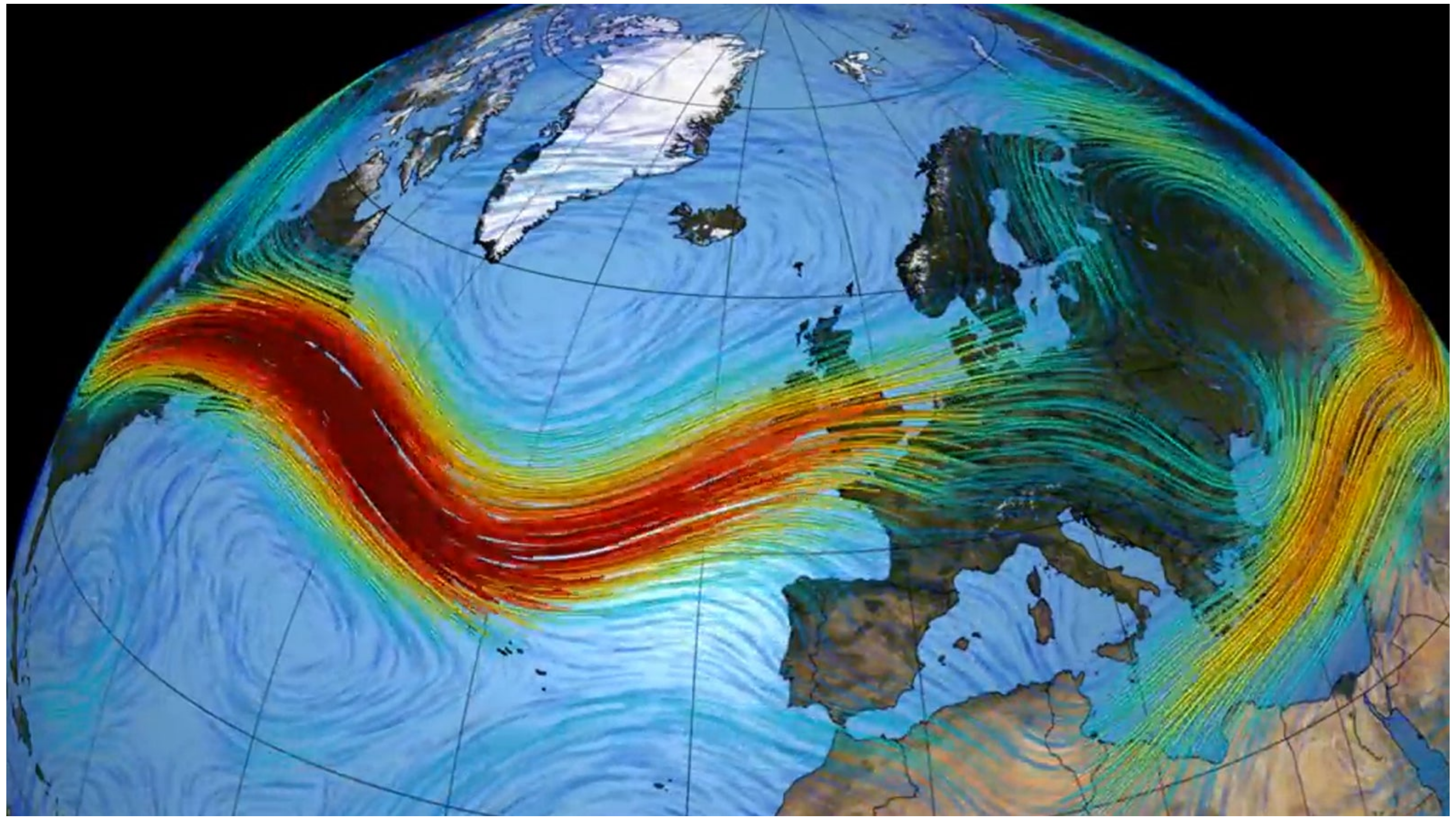

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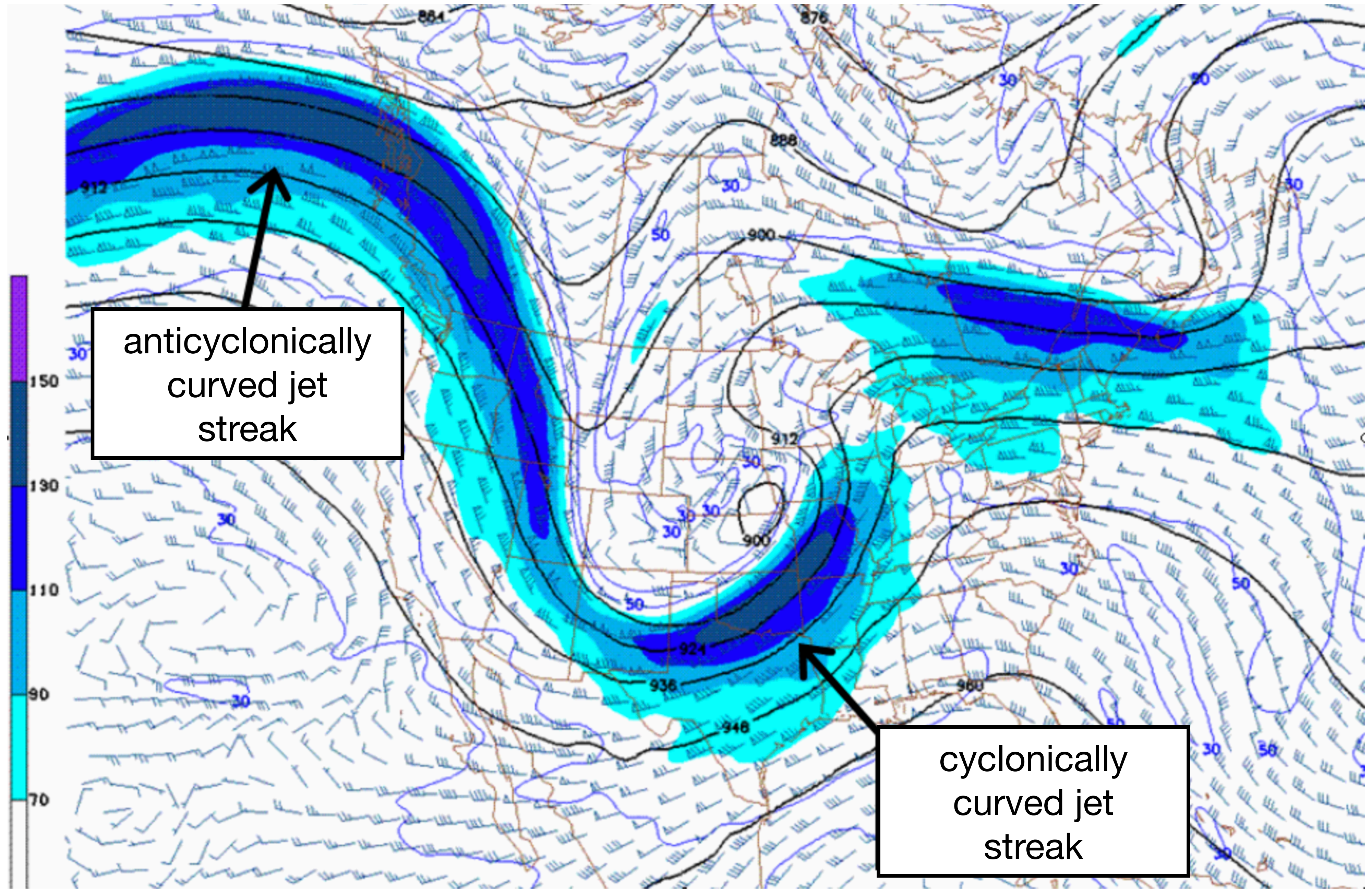
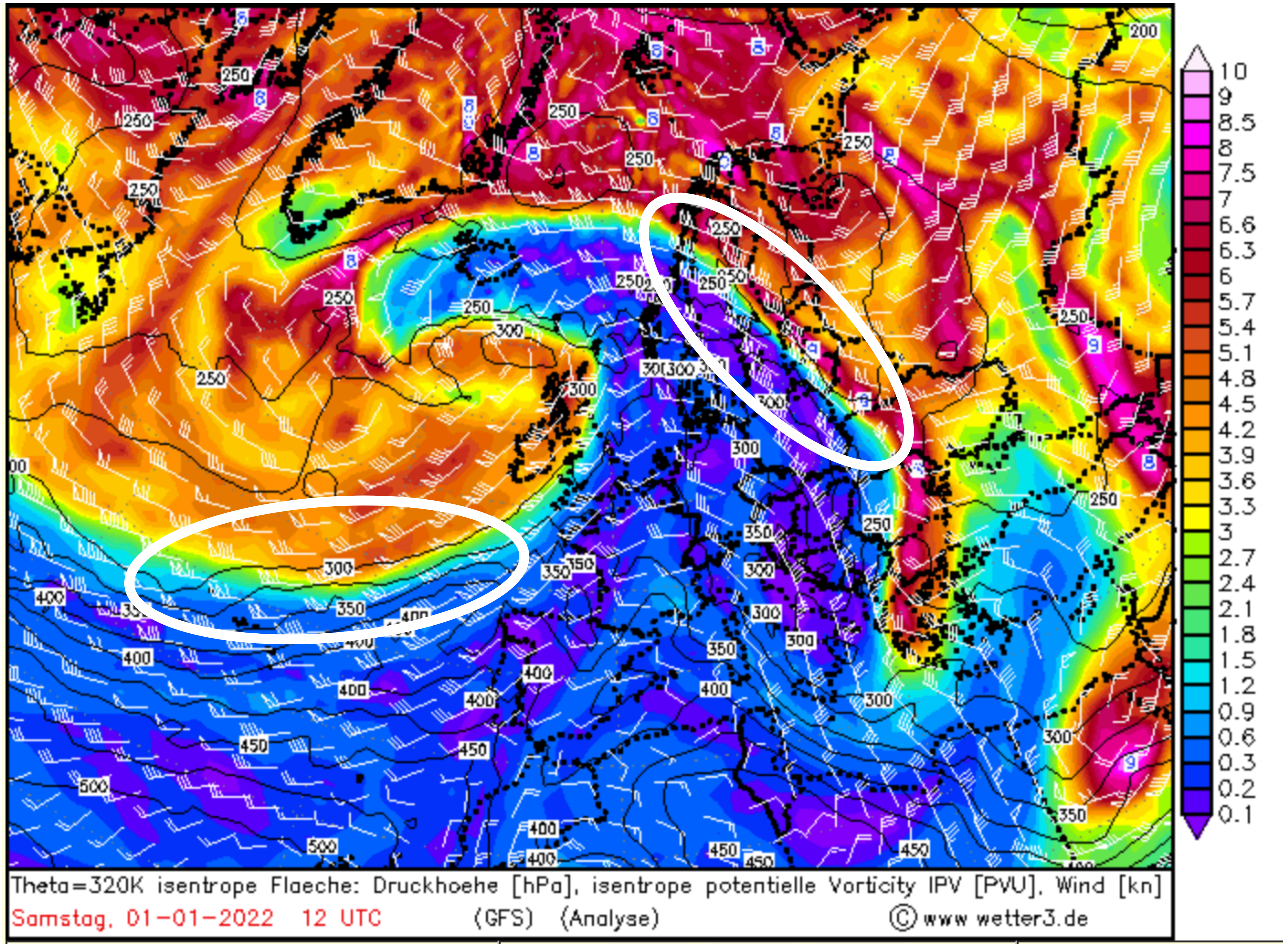


Future evolution and mechanistic understanding?

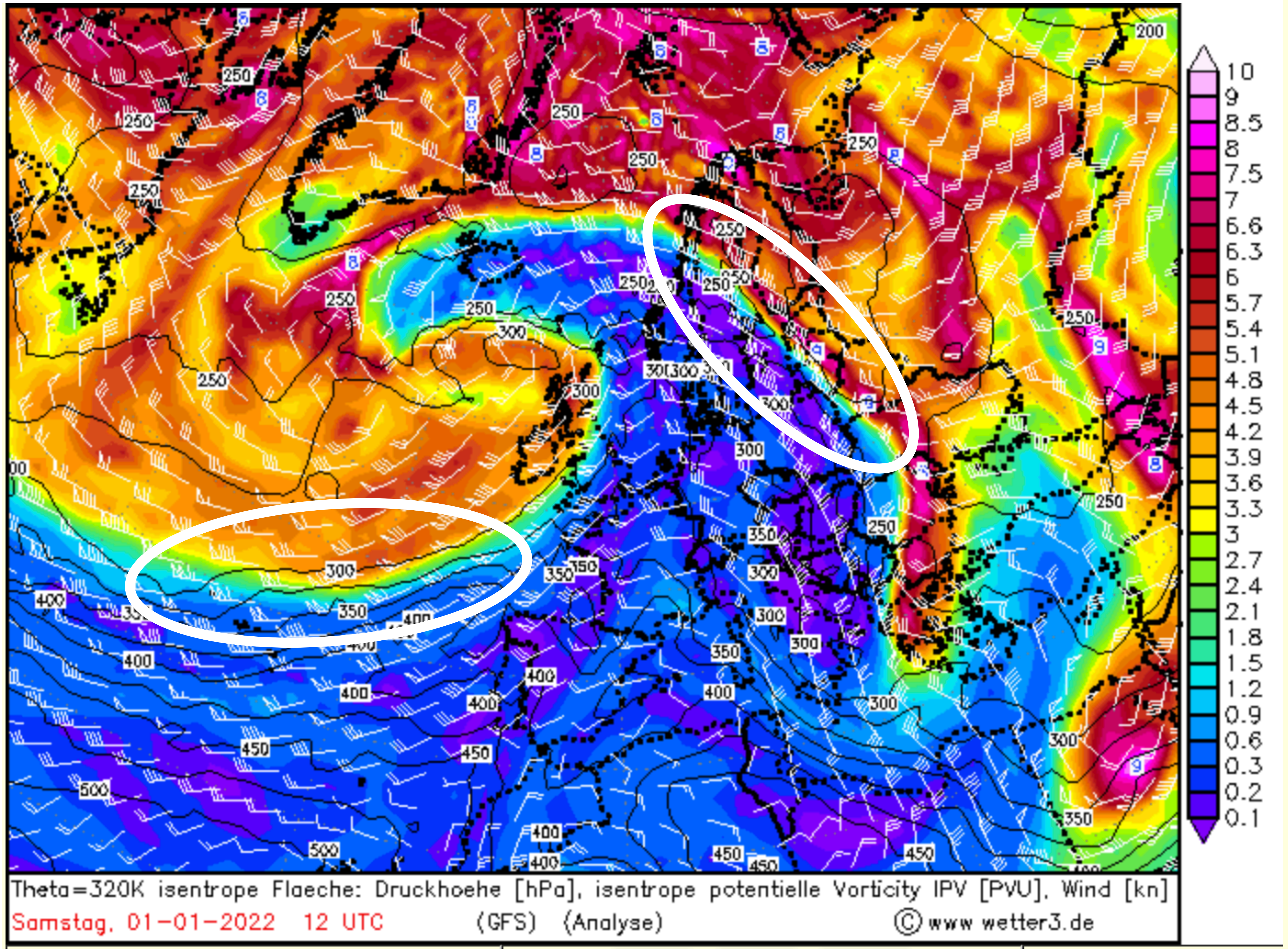
Diabatic-adiabatic coupling

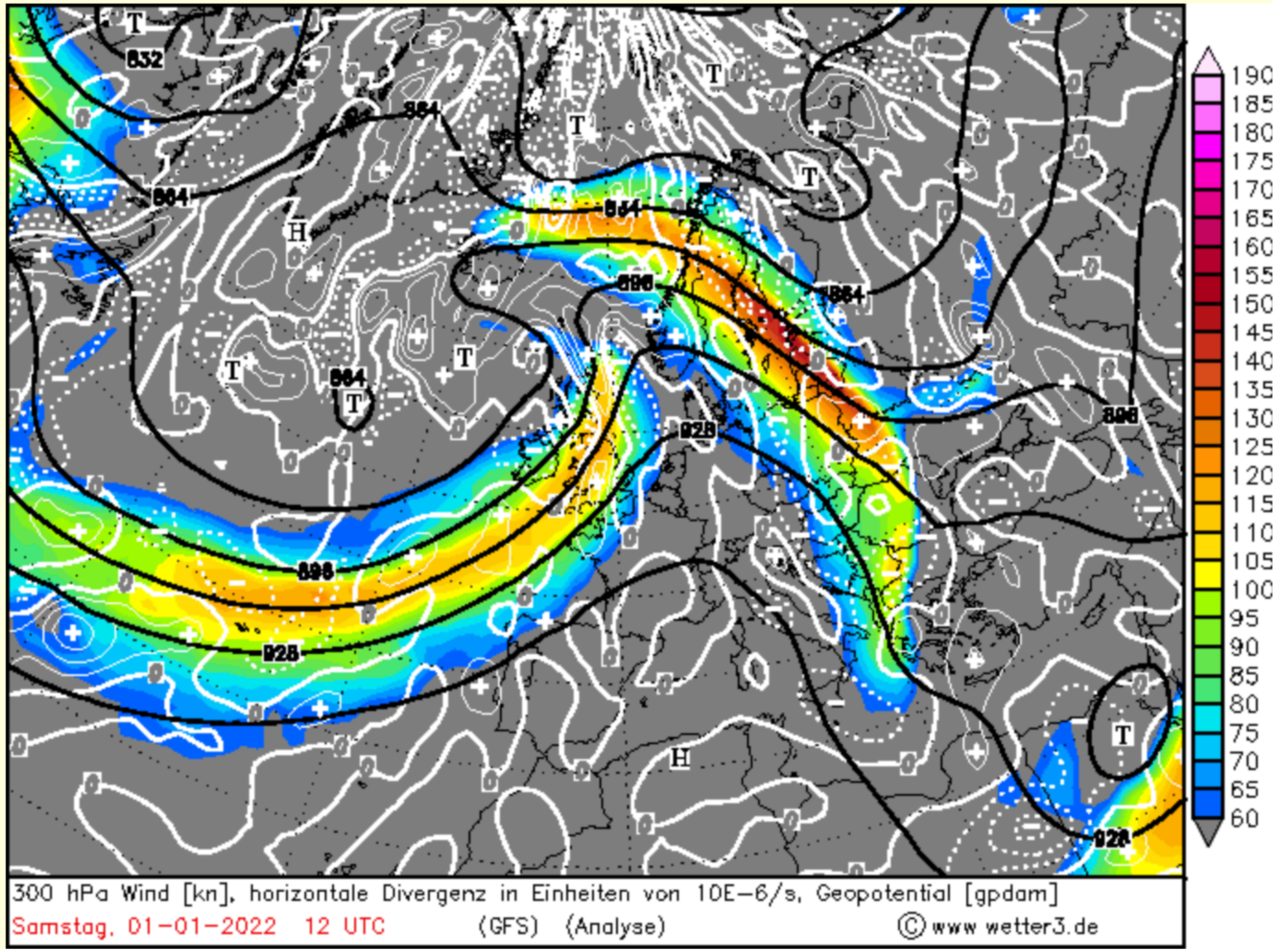
PV gradients and large-scale flow



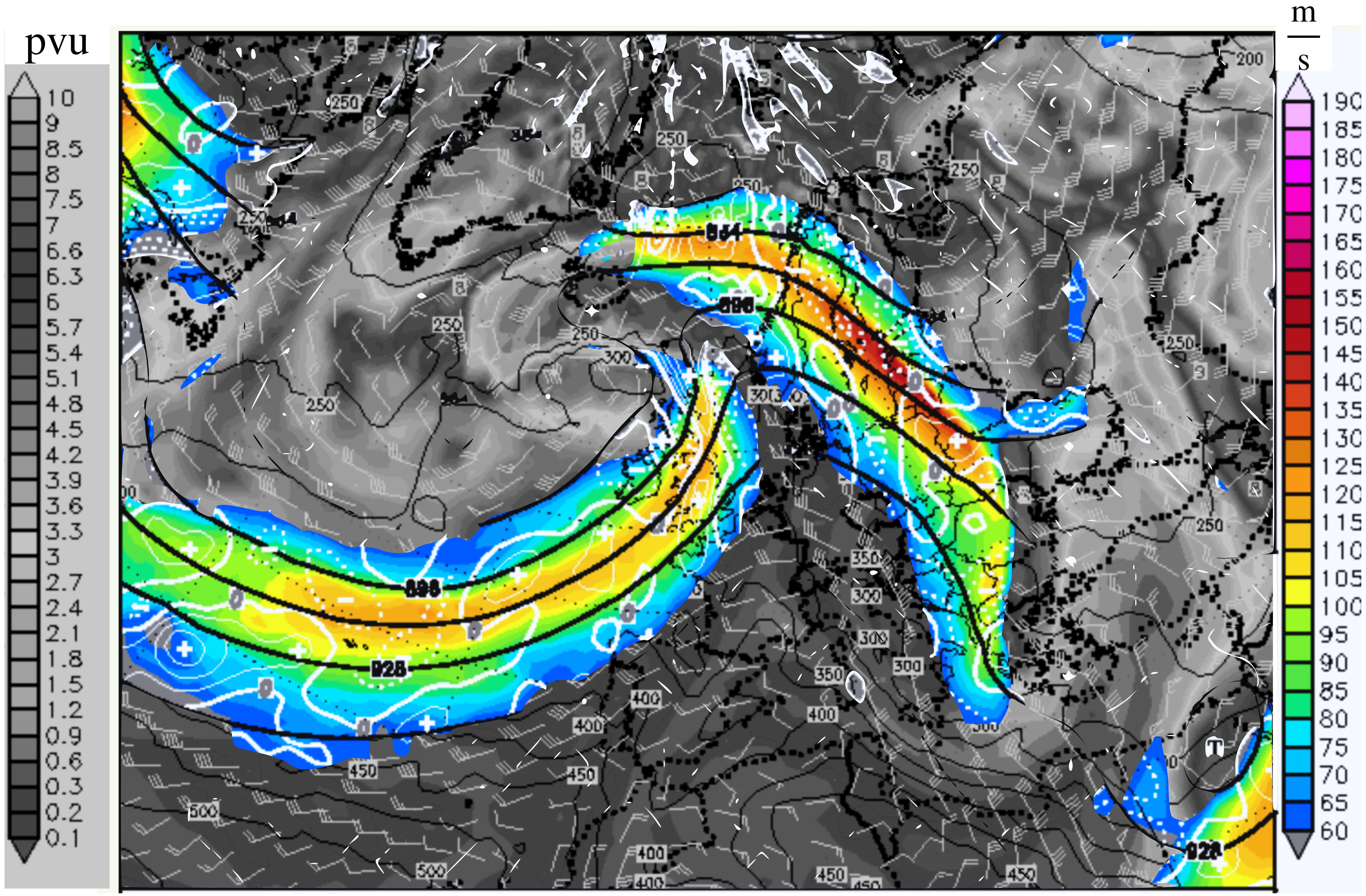
- PV@320K on 01 Jan. 2022, 12:00 UTC
- Two regions with large PV anomalies

PV gradients and large-scale flow



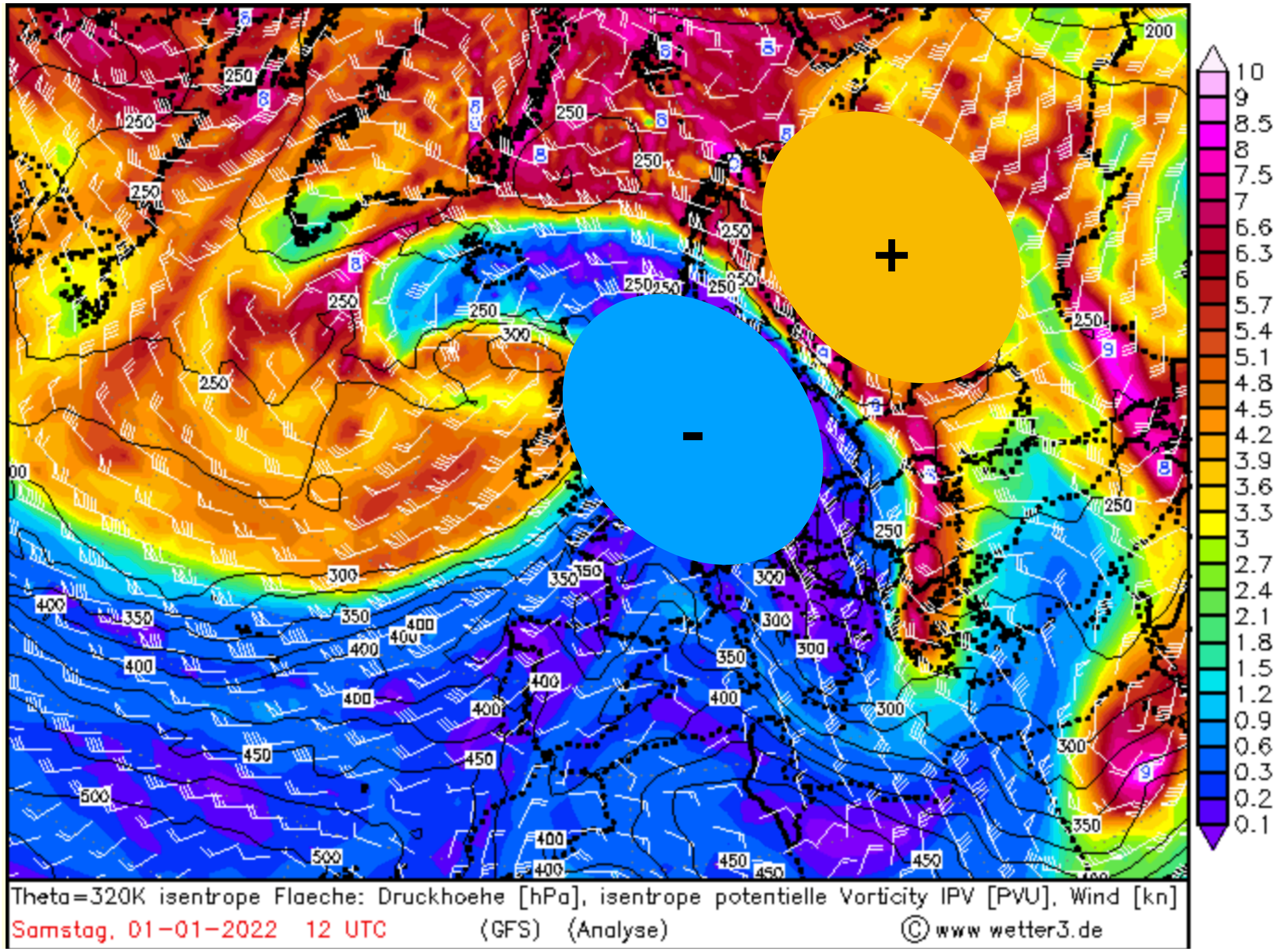


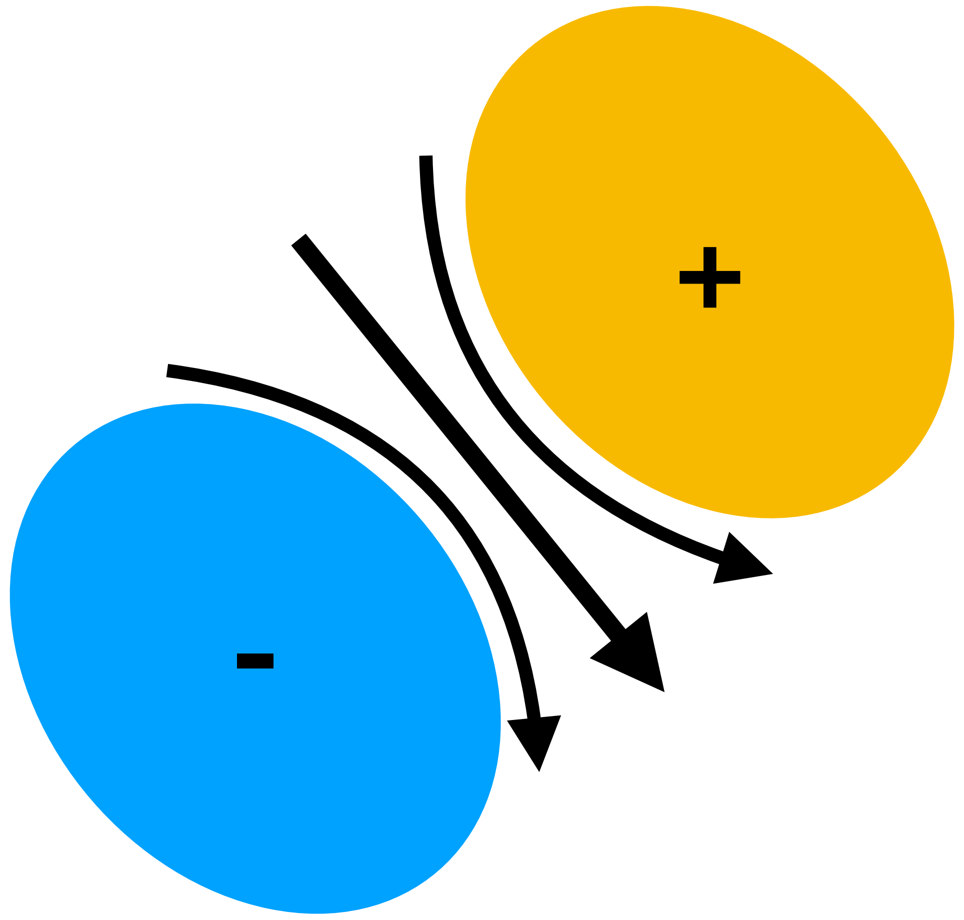
PV gradients and large-scale flow



- Jet aligns with regions of large PV anomalies

PV gradients and large-scale flow



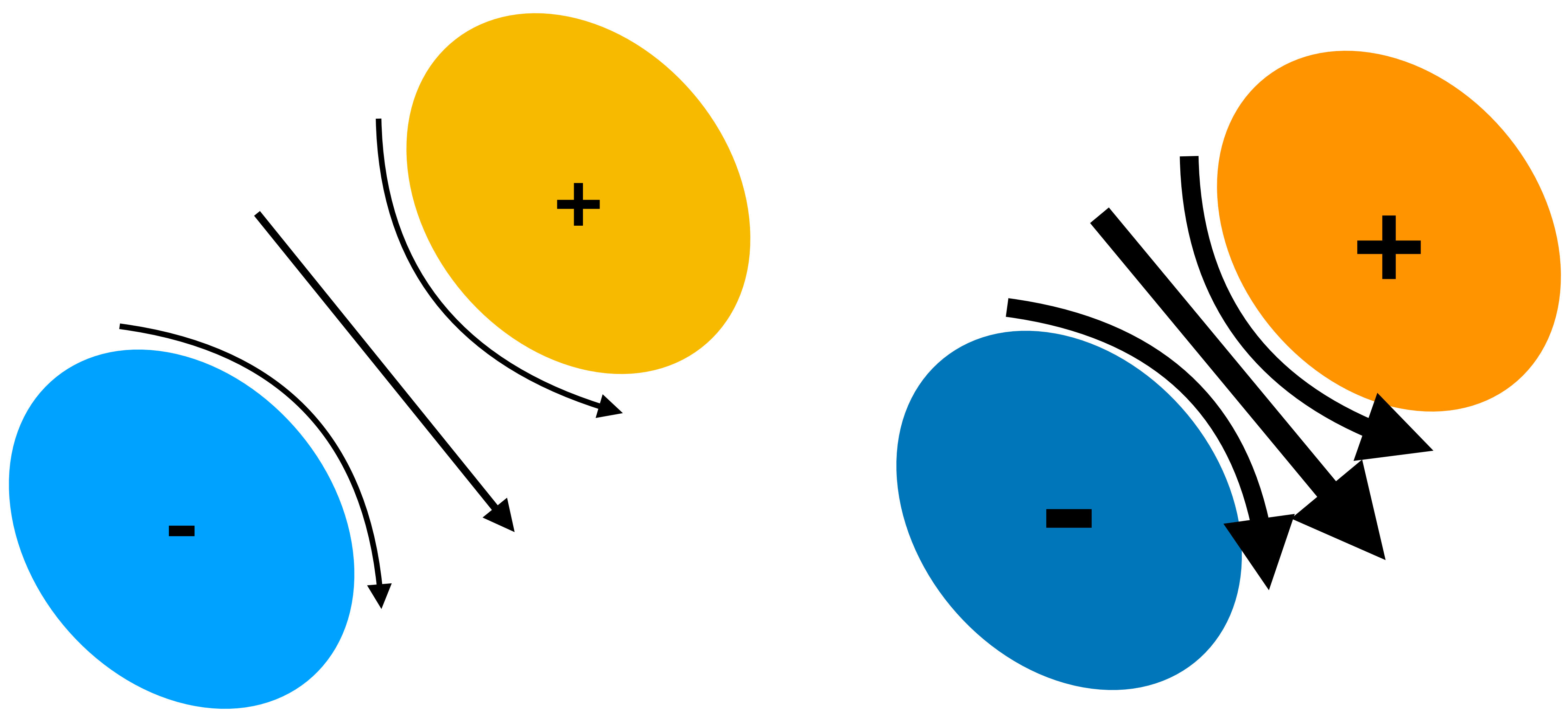


Hoskins and McIntyre, 1985
Thorpe and Bishop, 1989
etc.

PV gradients and large-scale flow

Principle of PV inversion:

PV anomalies ⇔ Flow anomalies



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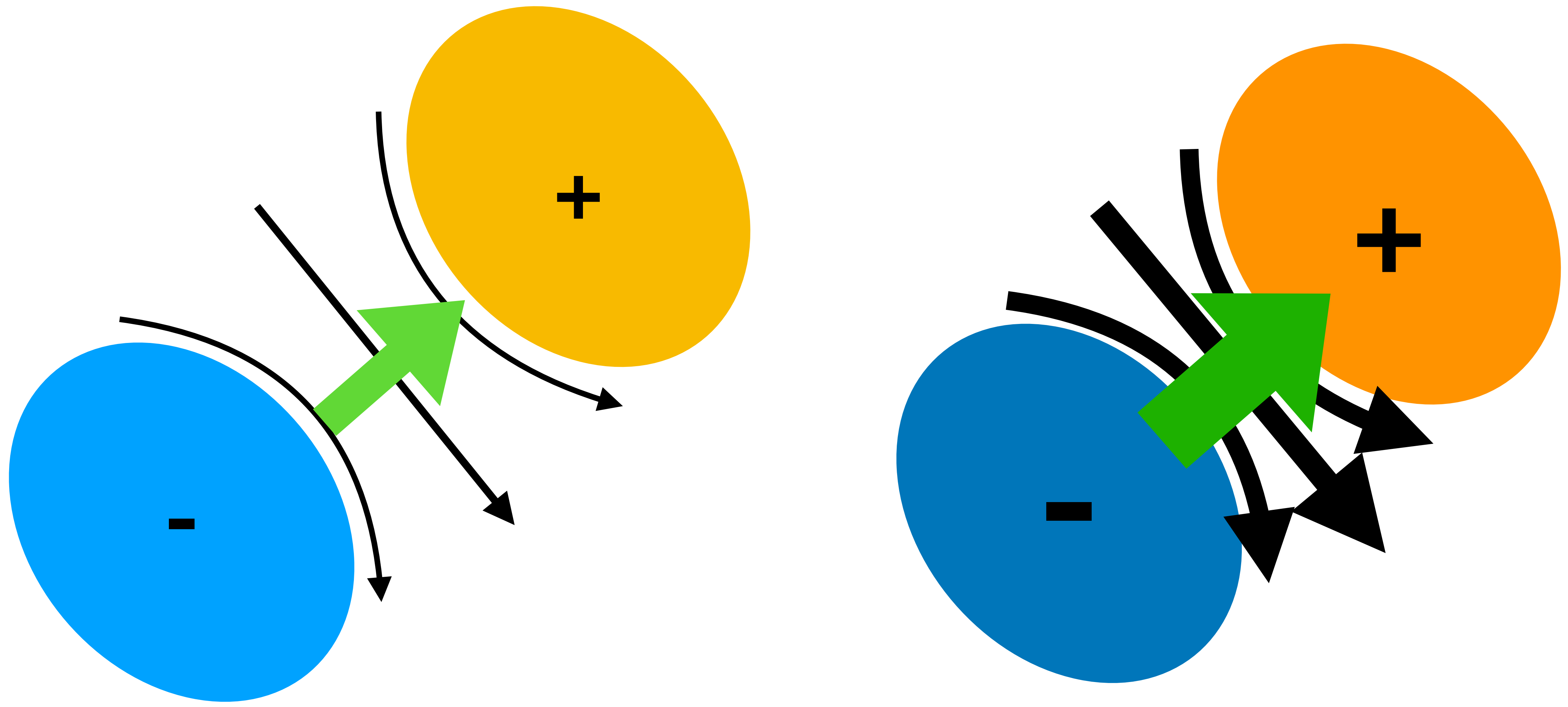
Large PV gradients ⇔ strong flow



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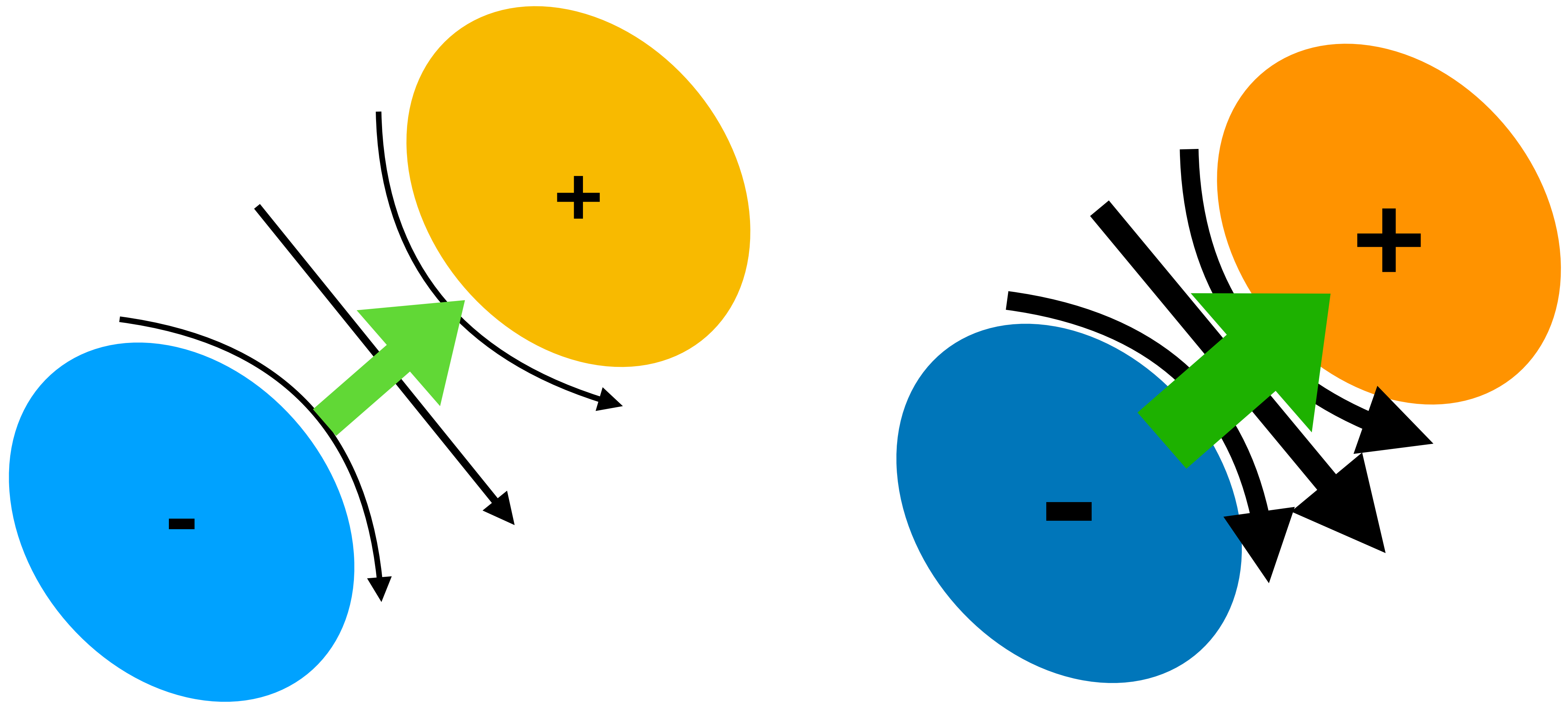

On **large scales** and for **quasi-geostrophic flow**:

- $\| \nabla_\theta \ln \mathrm{PV} \| \sim \mathrm{U},$
- $\| \nabla_\theta \mathrm{PV} \|$ related to horizontal flow, stratospheric displacement

Davies and Rossa, 1998
Martius et al, 2009

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PV gradients and diabetic-adiabatic coupling

$$\frac{D}{Dt}(\mathrm{PV}) = \frac{1}{\rho}\left(\nabla \times \vec{F} \cdot \nabla\theta + \vec{\eta} \cdot \nabla\dot{\theta}\right)$$

$\Longrightarrow$ PV conserved for adiabatic and frictionless motion

↓

PV tendency : **diabatic-adiabatic** coupling

$$\left\| \nabla_{\theta} \ln \mathrm{PV} \right\| \sim \mathrm{U}$$

$\Longrightarrow$ PV-gradient related to horizontal wind speed

↓

PV gradient: **Jet** (streaks)

PV gradients and diabetic-adiabatic coupling

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PV tendency : **diabatic-adiabatic** coupling

PV gradient: **Jet** (streaks)

Use **PV gradient tendency** to analyze **diabatic influence** on **jet streak** life cycles

The Lagrangian perspective

$$\frac{D}{Dt}\nabla_\theta \mathrm{PV}_\theta = \nabla_\theta\left(\frac{D}{Dt}\mathrm{PV}_\theta\right) - \mathrm{J}\cdot\nabla_\theta \mathrm{PV}_\theta$$

caused by diabatic processes

caused by deformation

The Lagrangian perspective

$$\frac{D}{Dt} \left\| \nabla_\theta \mathrm{PV}_\theta \right\| = \frac{\left\langle \frac{D}{Dt}\left(\nabla_\theta \mathrm{PV}_\theta\right),\ \nabla_\theta \mathrm{PV}_\theta \right\rangle}{\left\| \nabla_\theta \mathrm{PV}_\theta \right\|}$$

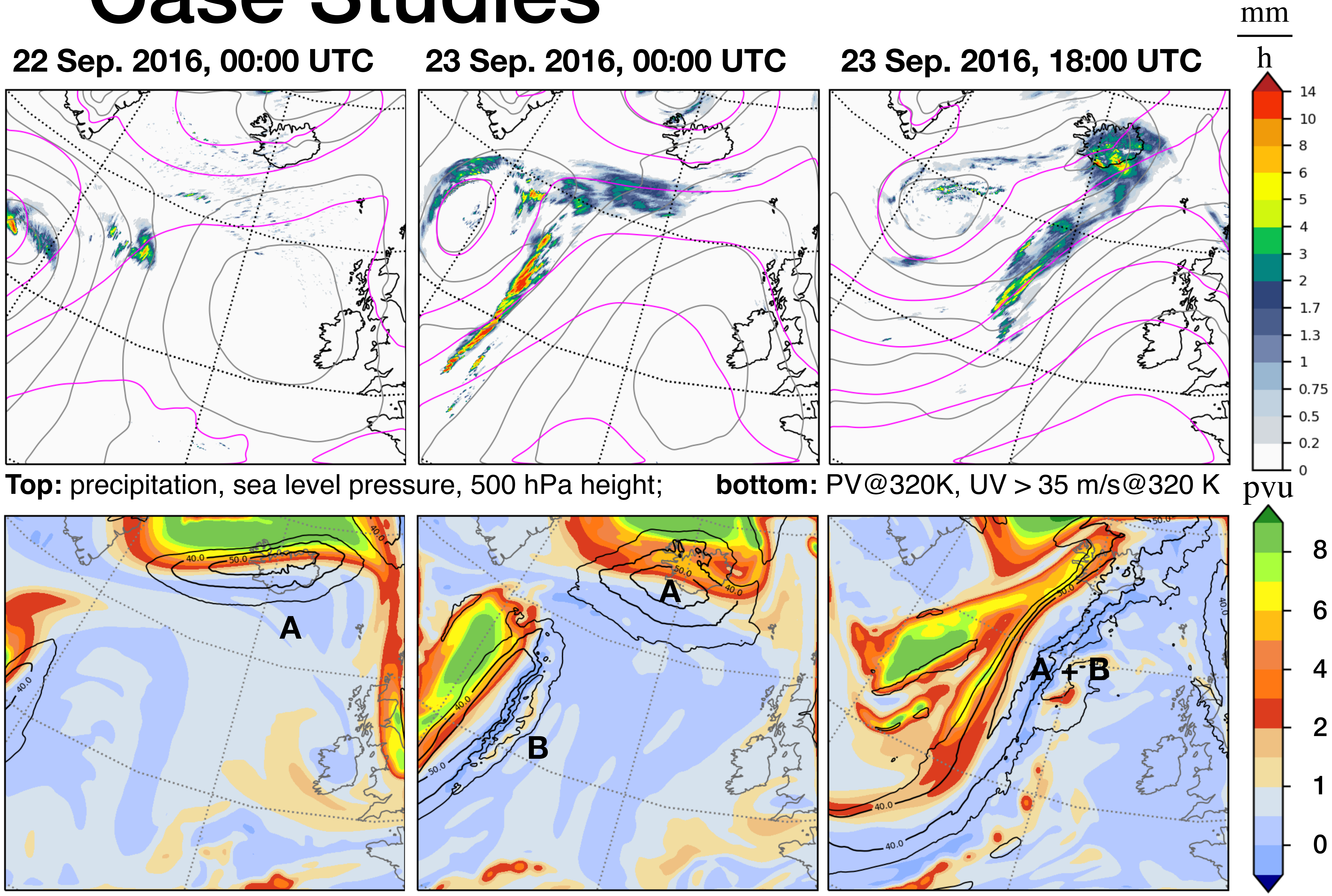
Decomposition of total PV gradient change:

$$\delta \|\nabla_\theta \mathrm{PV}_\theta\| = \delta \mathrm{PVG}_{\mathrm{ADIA}} + \delta \mathrm{PVG}_{\mathrm{DIAB,dir}} + \delta \mathrm{PVG}_{\mathrm{DIAB,ind.}}$$

Case Studies

Simulation

- COSMO v6.0 (GPU) 1.1km grid(2601x2441x80), 7.5 s time step, fully explicit convection
- Eastern North Atlantic (NAWDEX), 20-23 Sep. 2016
- 235,128 Online trajectories started every 3 h (20x) on 27.5 km grid (101x97x24)



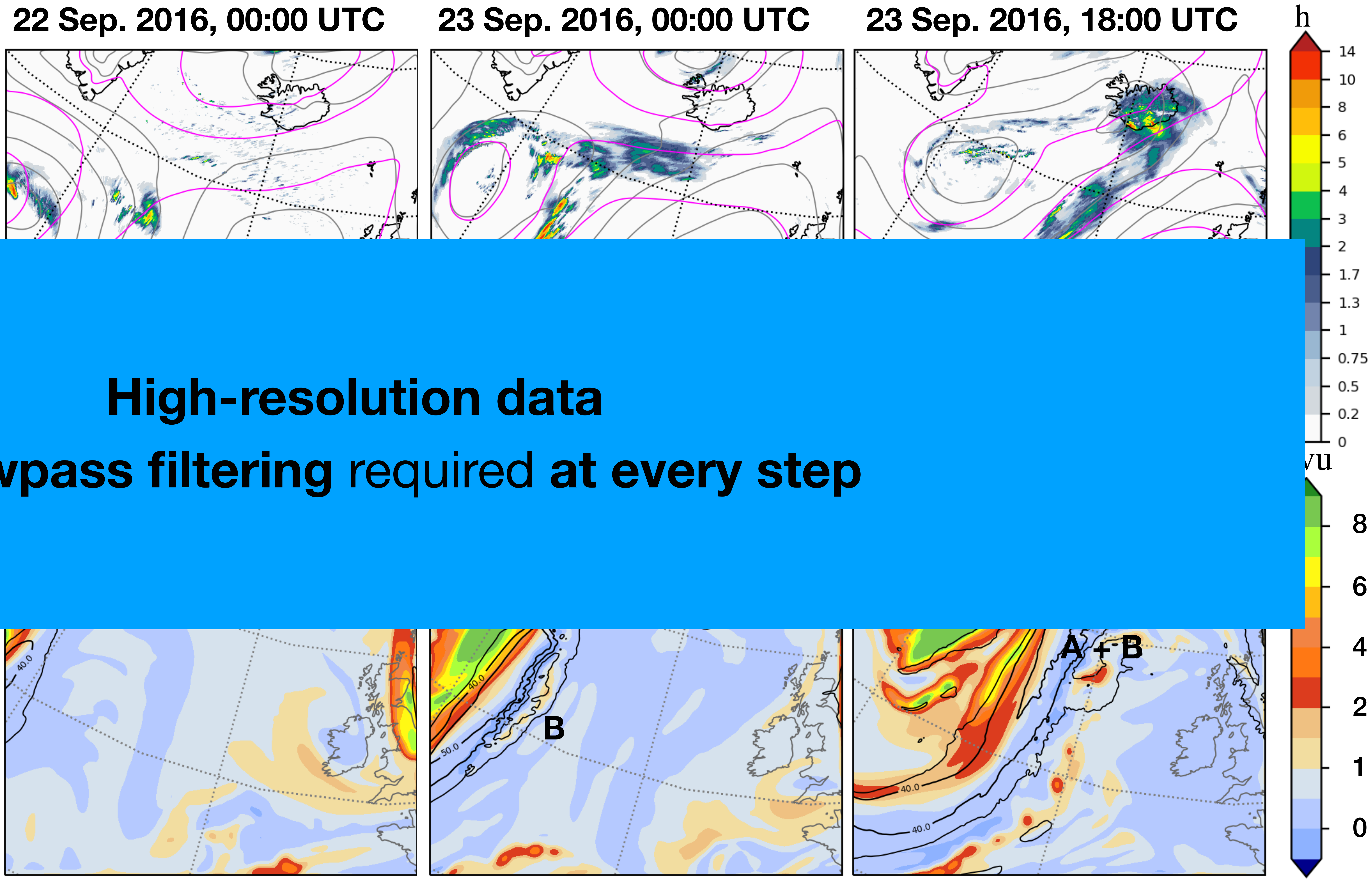
Case Studies

Simulation

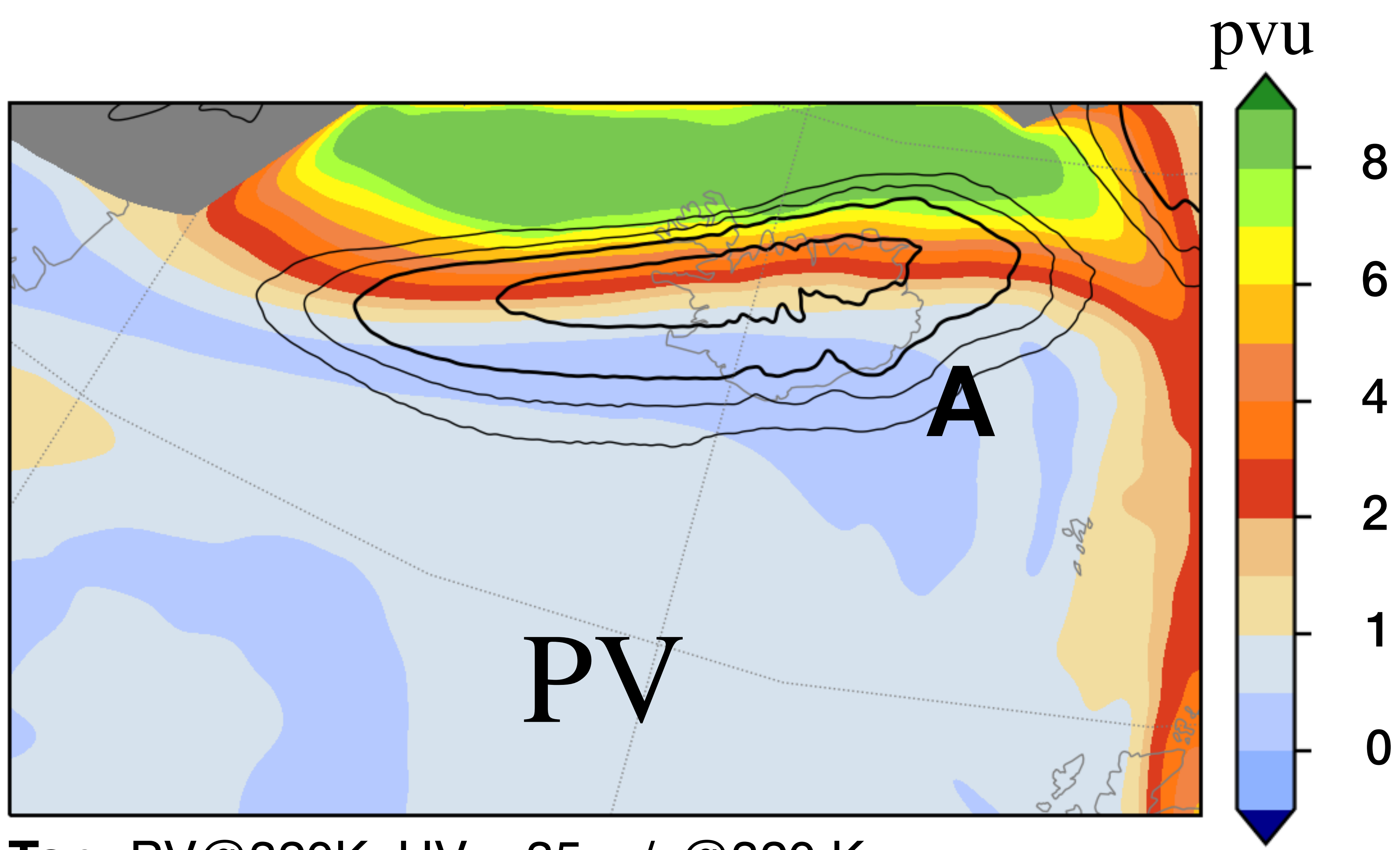
- COSMO v6.0 (GPU) 1.1km
-
- started every 3 h (20x) on 27.5 km grid (101x97x24)

High-resolution data

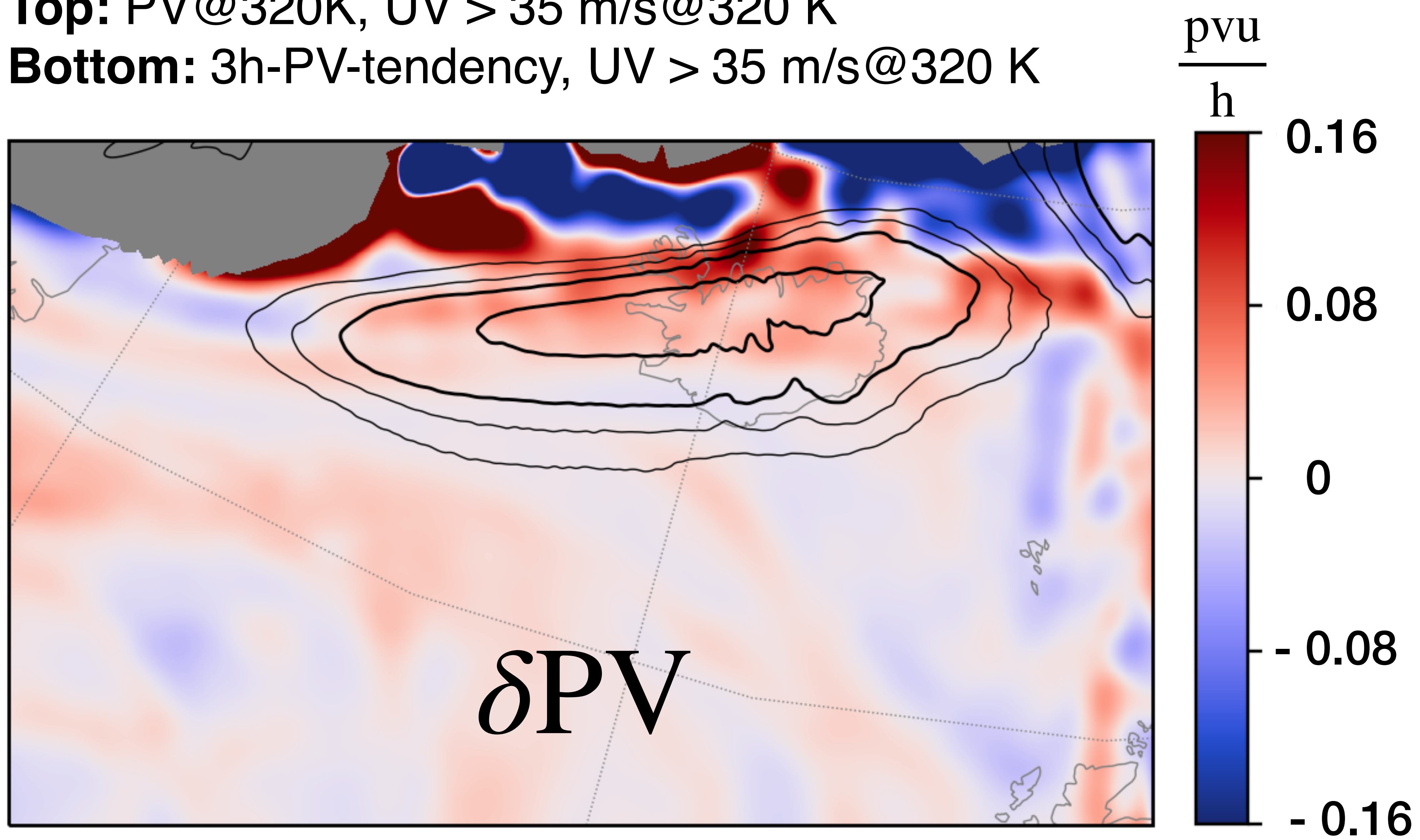
⇒ **lowpass filtering** required **at every step**



Results — case study 22.9.2016, 00:00UTC



Top: PV@320K, UV > 35 m/s@320 K
Bottom: 3h-PV-tendency, UV > 35 m/s@320 K



- Overall small PV changes
- δPV increases from tropospheric towards stratospheric side of jet streak

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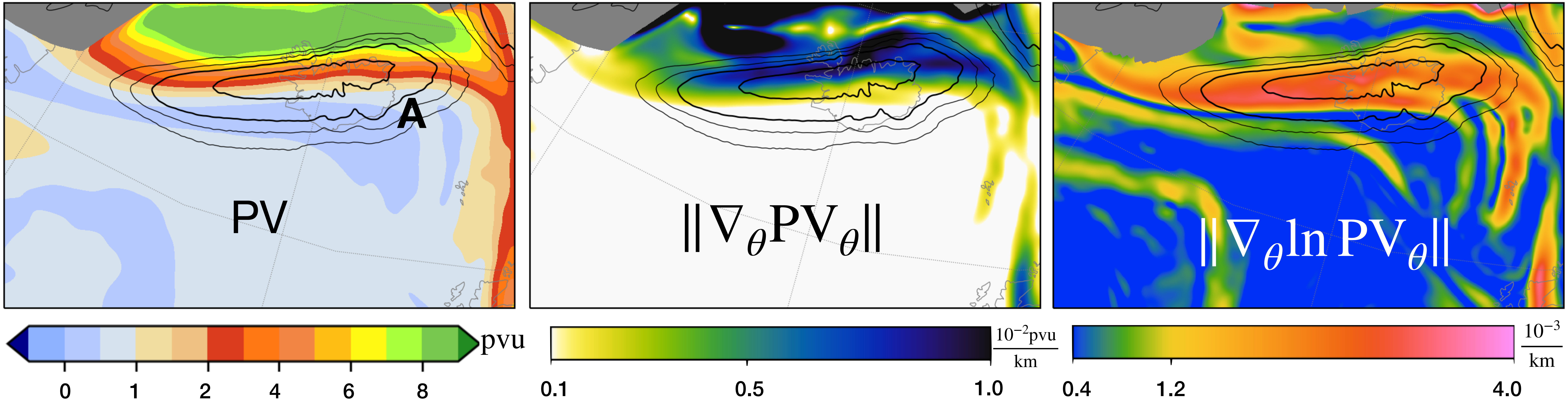
Large-scale fields

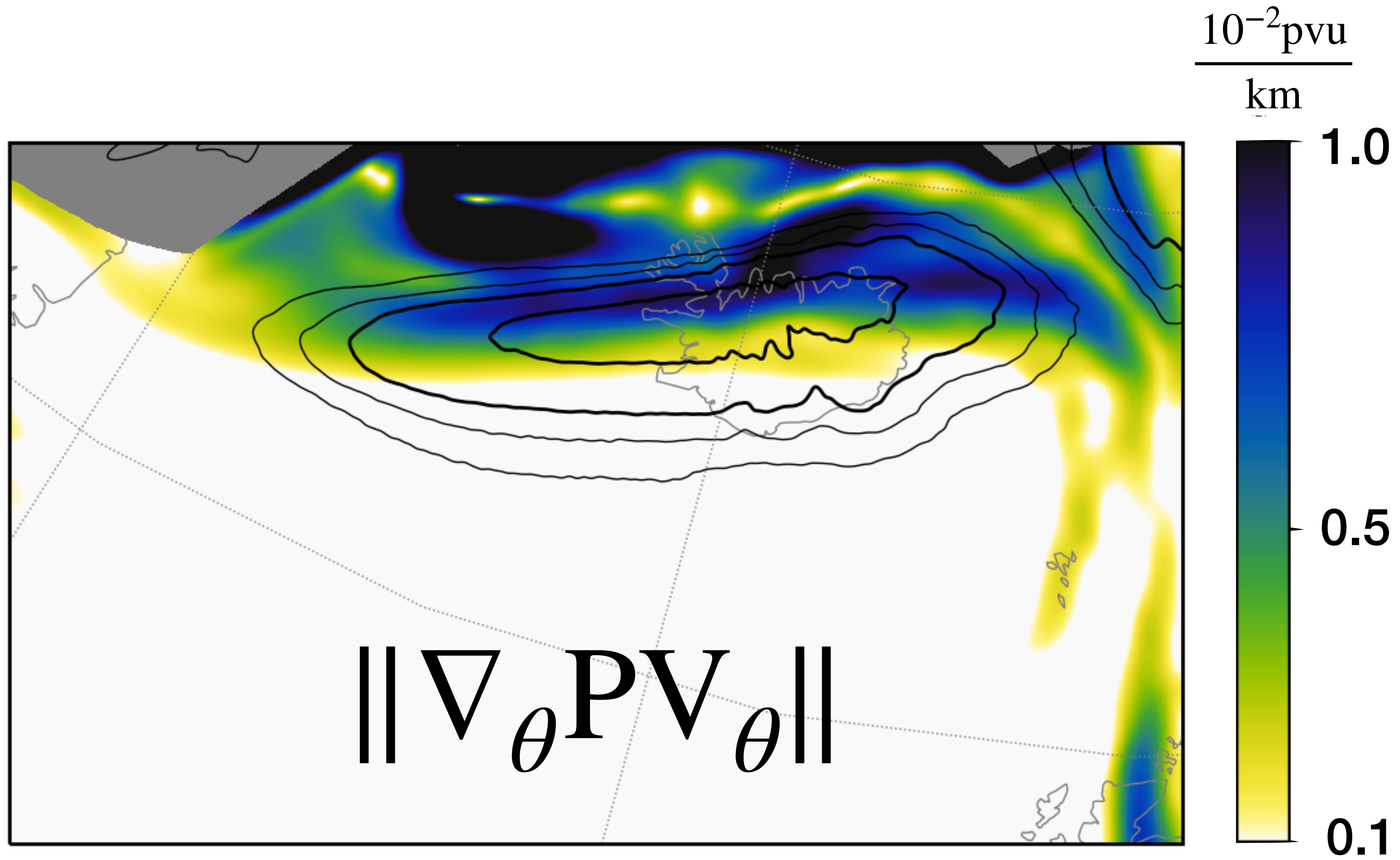


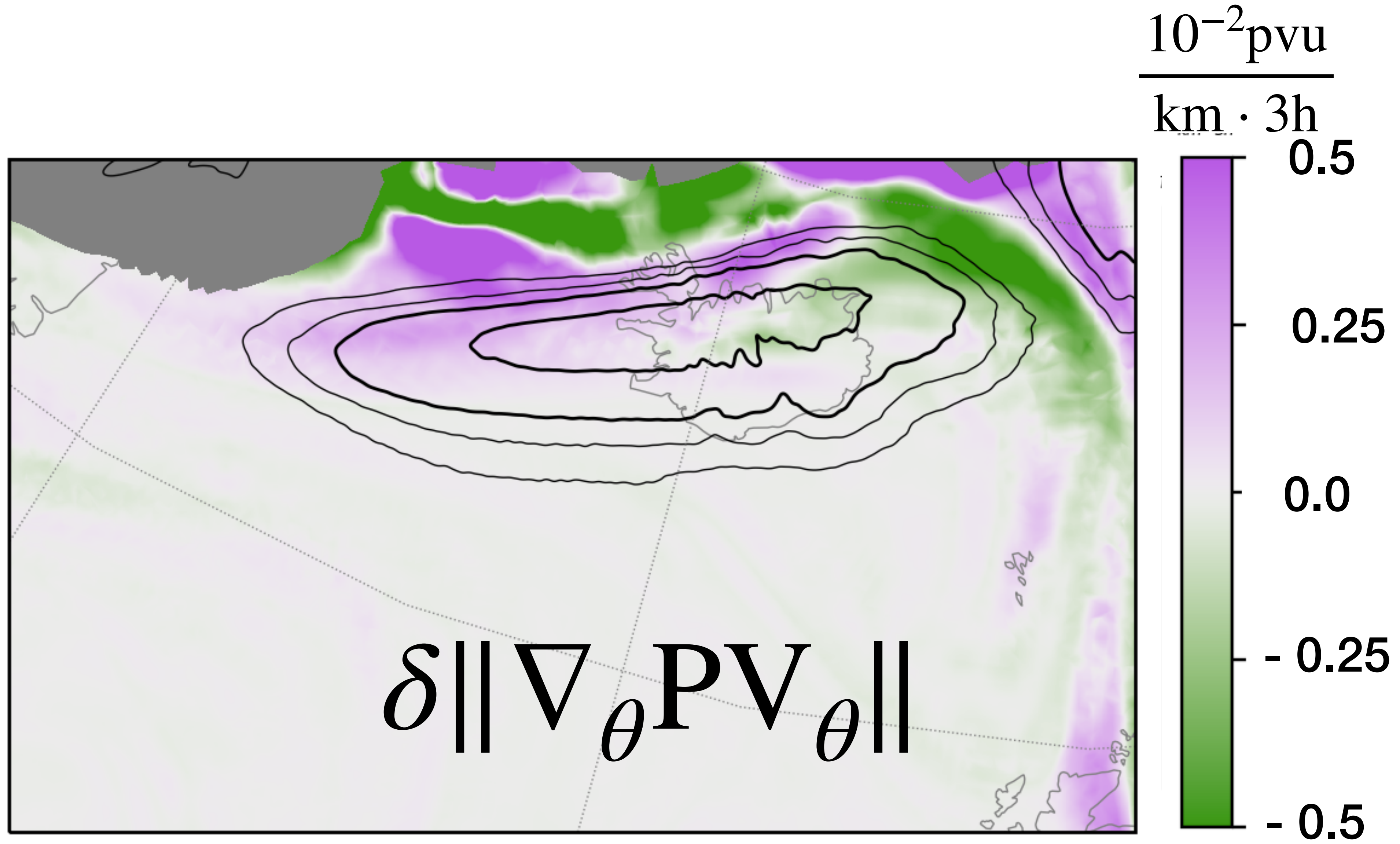
All Figures Contours:
UV > 35 m/s@320 K

- $\| \nabla_\theta \ln PV \| \sim U$: regions align
- Elongated band of large $\| \nabla_\theta PV \|$: stratospheric side of jet streak

PV gradient change

All Figures Contours:
UV > 35 m/s@320 K

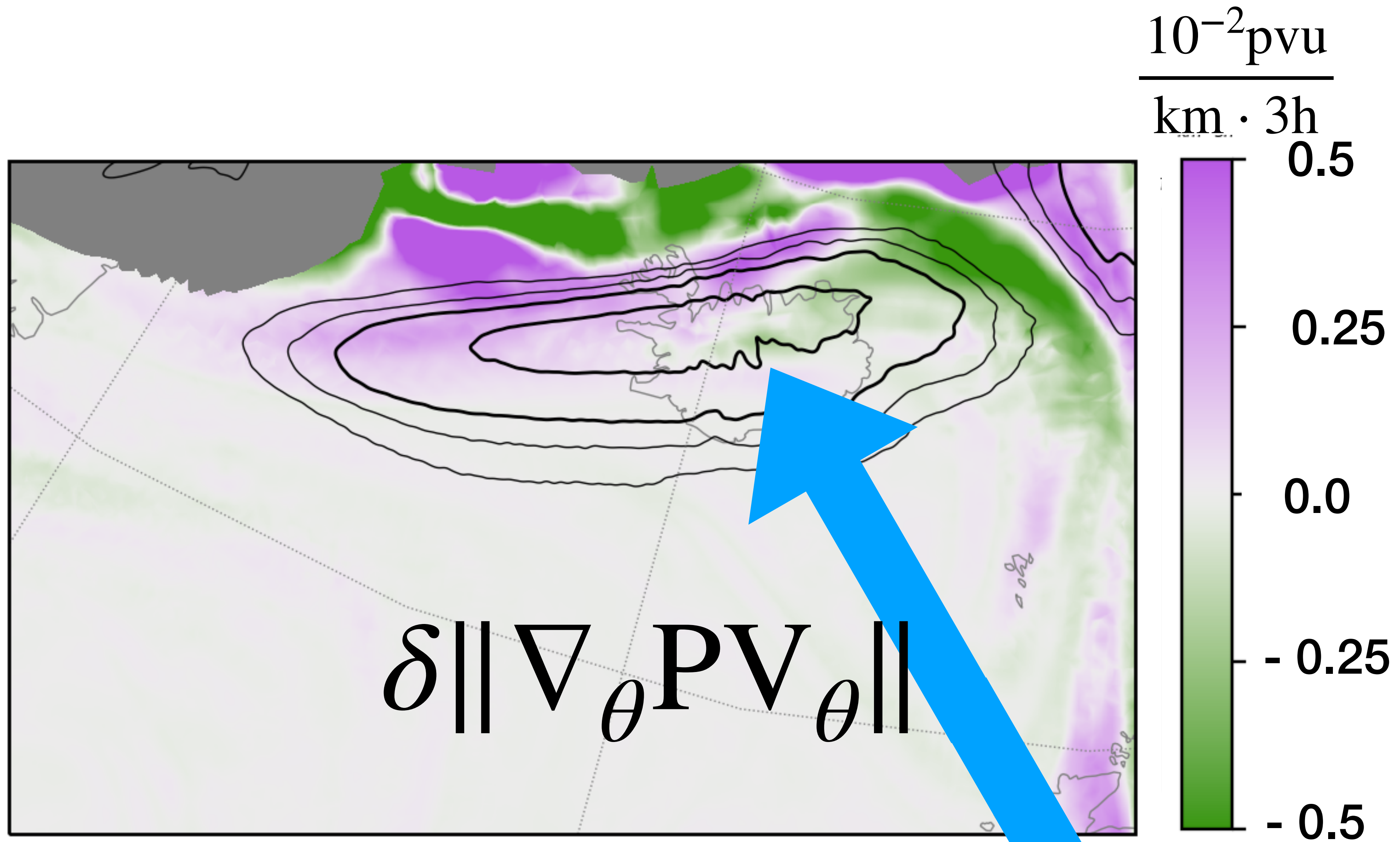


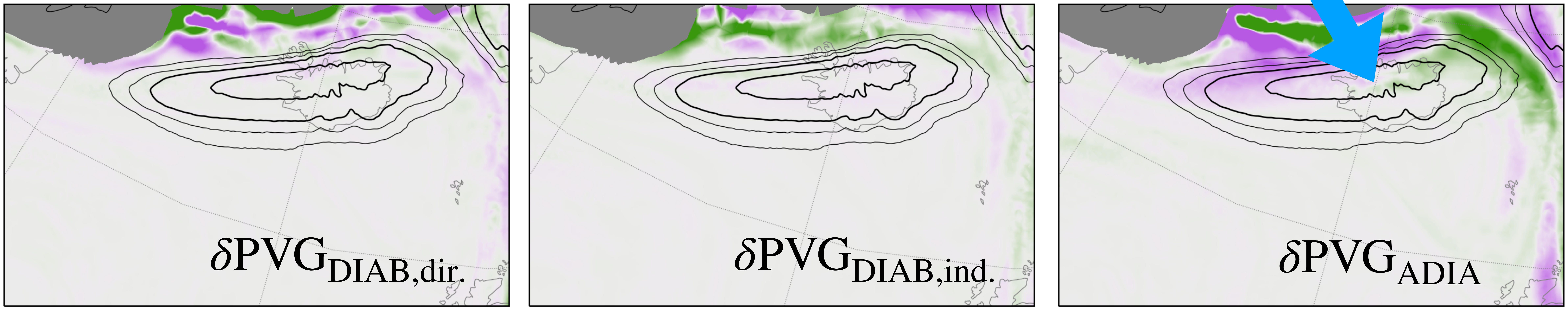


- Jet streak almost stationary, but PV gradient change large
- Positive at jet streak entrance
- Negative at exit

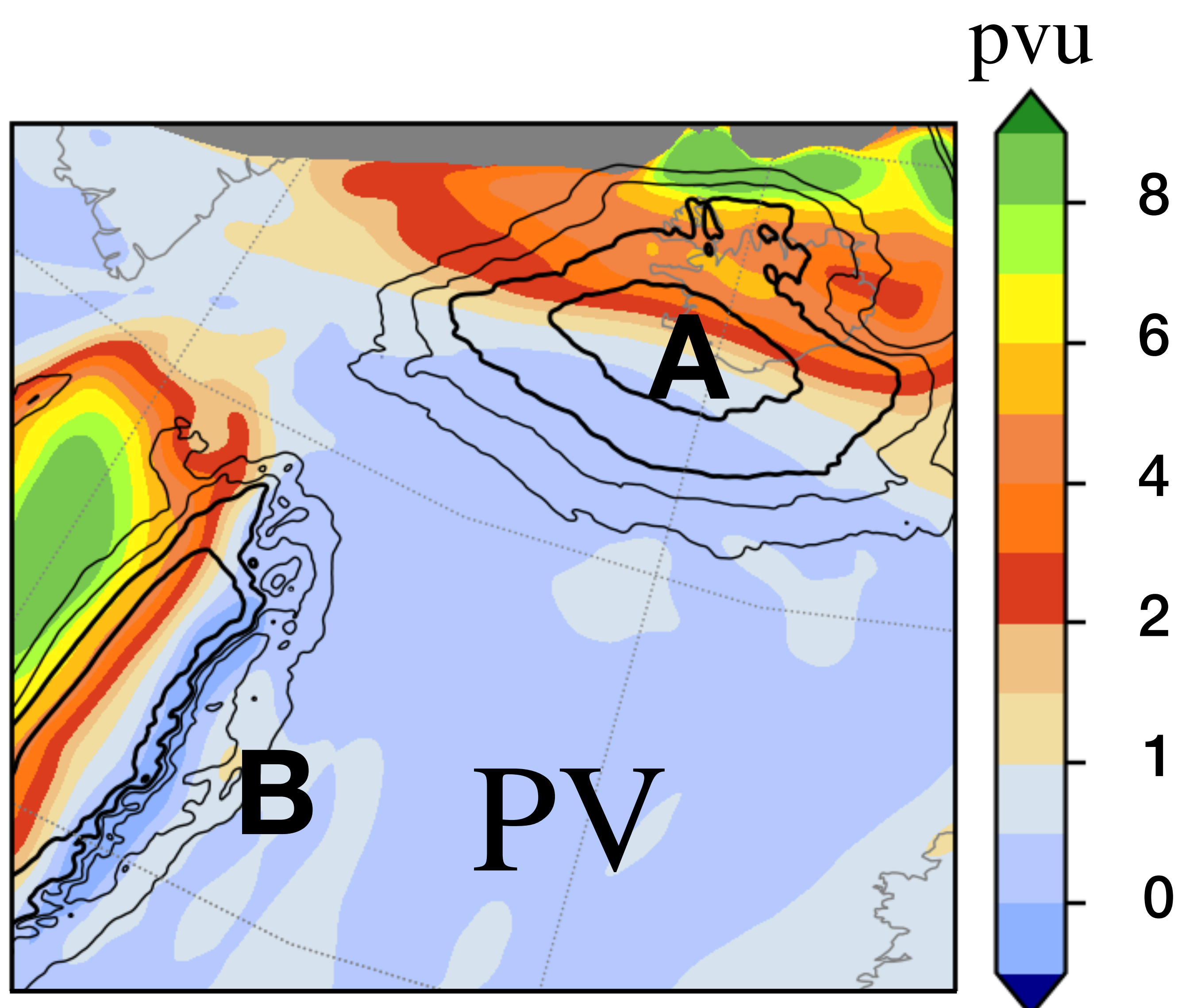
Contributions to PV gradient change

- Dominated by adiabatic deformation:
  - Convergence at jet entrance $\Rightarrow$ positive change
  - Divergence at jet streak exit $\Rightarrow$ negative change
- Direct and indirect diabatic contribution negligible

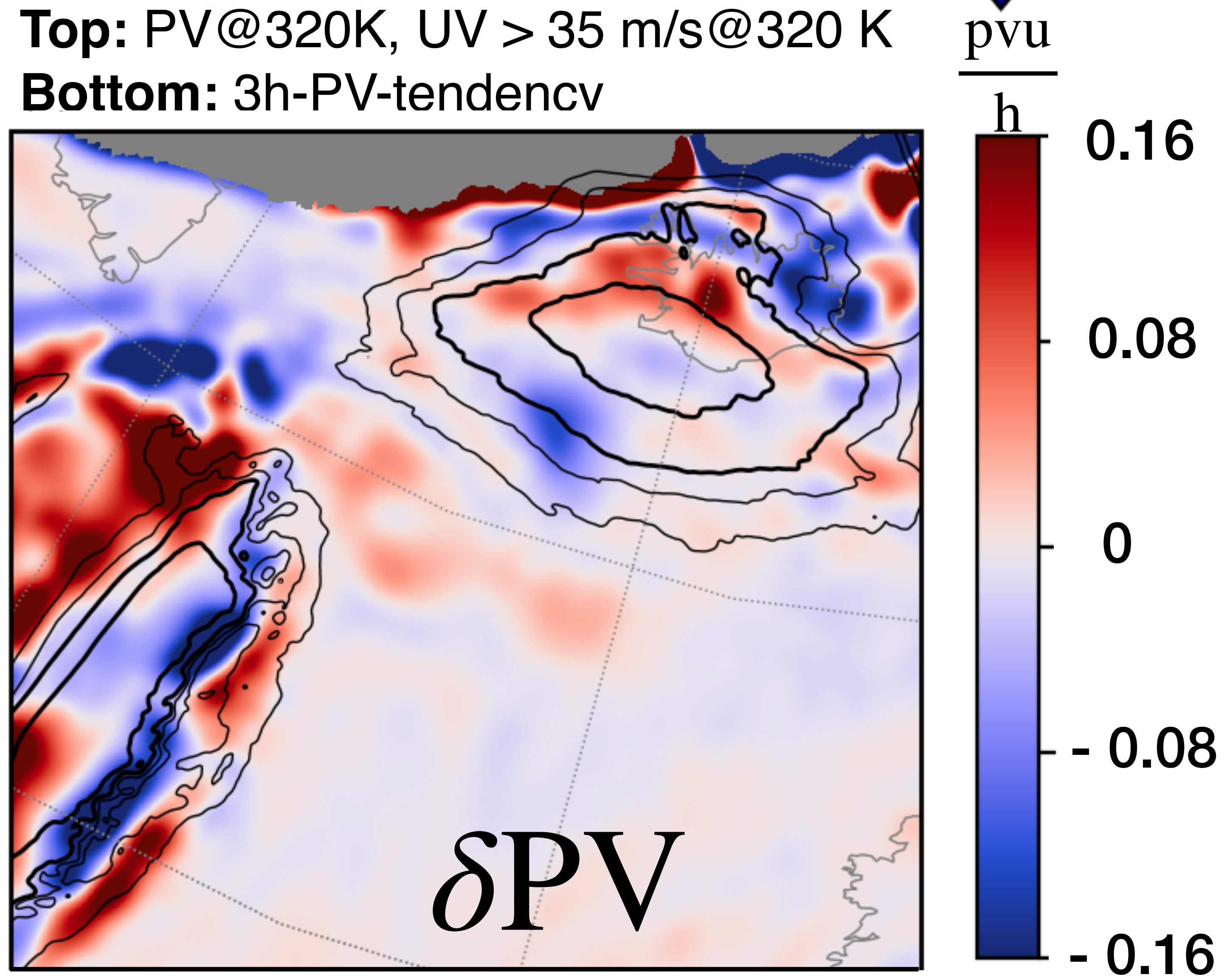




Results — case study 23.9.2016, 00:00UTC



Top: PV@320K, UV > 35 m/s@320 K
Bottom: 3h-PV-tendency



- Jet streak A: pattern similar as for first case study
- Jet streak B:
  - Larger absolute $\delta\mathrm{PV}$
  - Dipole in $\delta\mathrm{PV}$ at tropospheric boundary

    ⇒ larger diabatic influence on PV gradient

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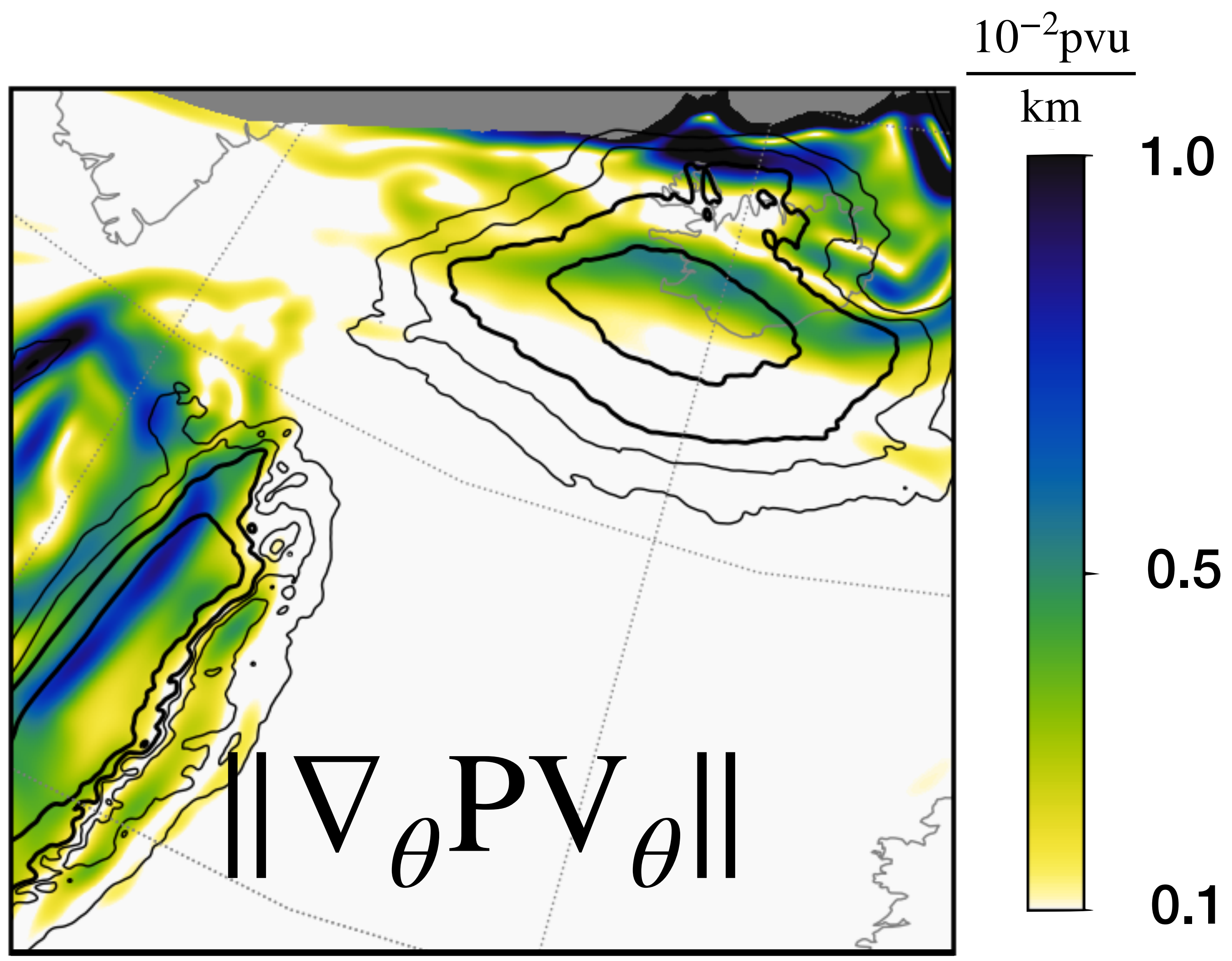
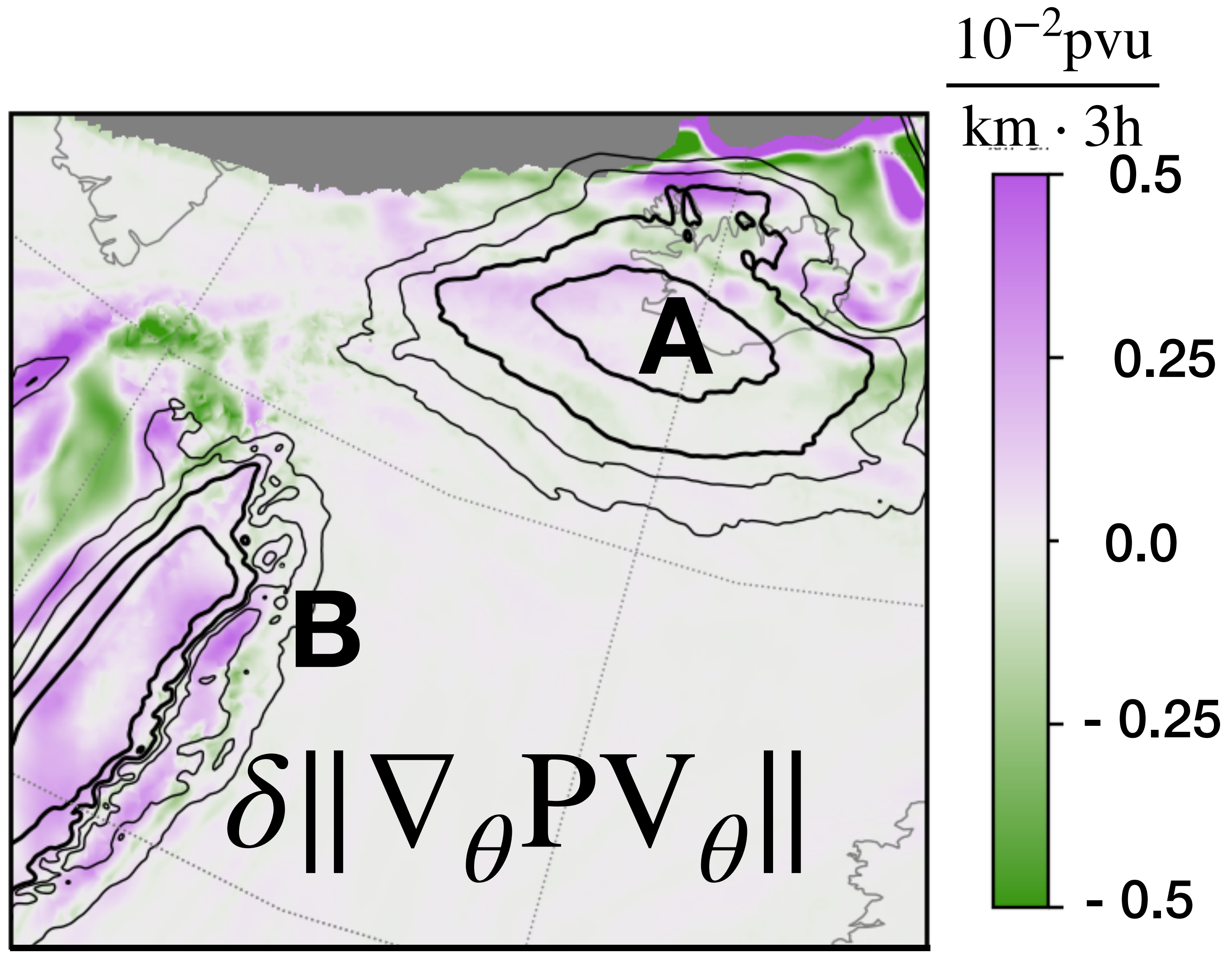
PV gradient change

All Figures Contours:
UV > 35 m/s@320 K



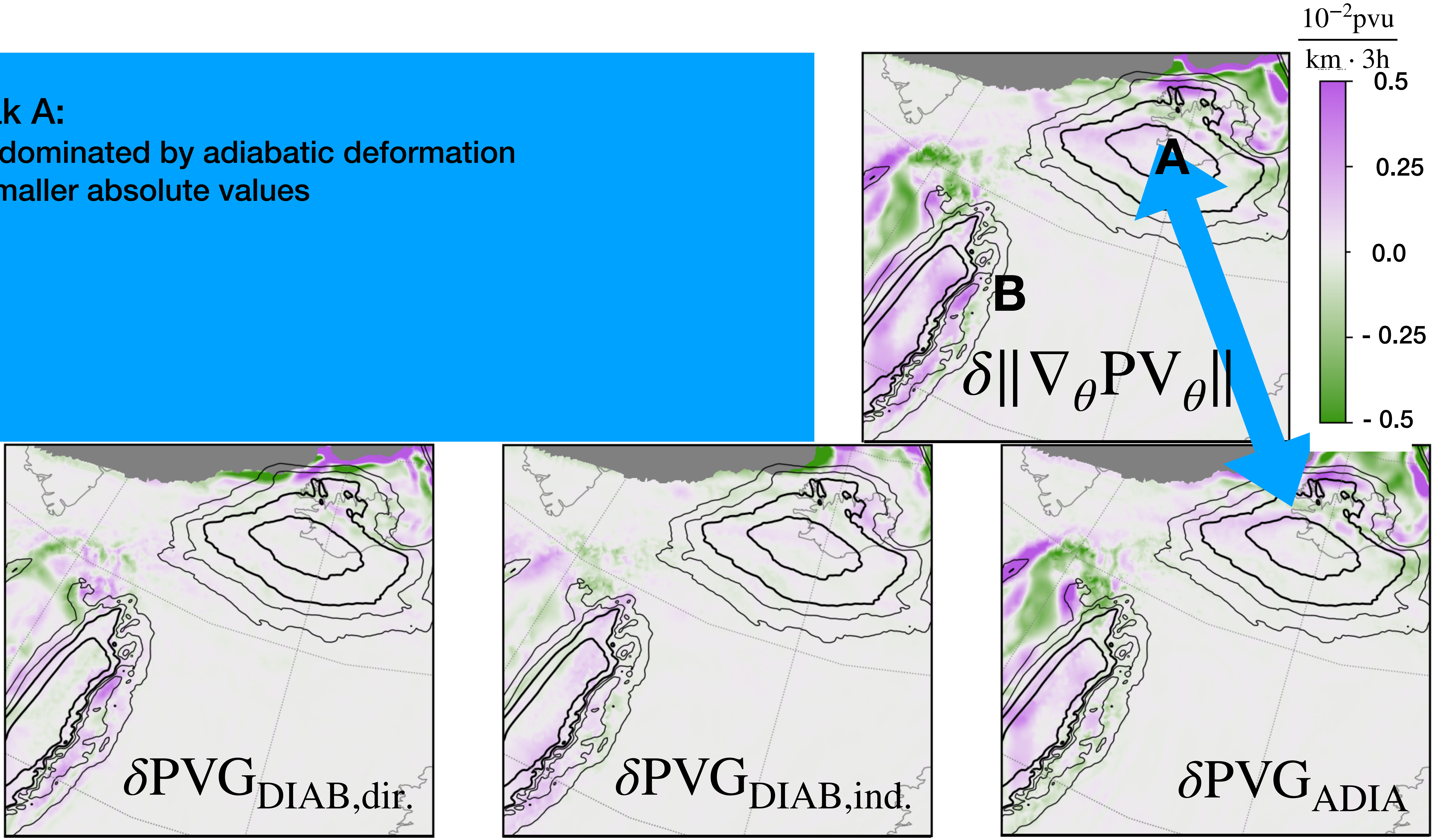


- Jet streak A: Pattern as before, smaller absolute values
- Jet streak B: Positive changes everywhere

$\Rightarrow$ Intensification fingerprint

Contributions to PV gradient change

- Jet streak A:
  - Again dominated by adiabatic deformation
  - But: smaller absolute values



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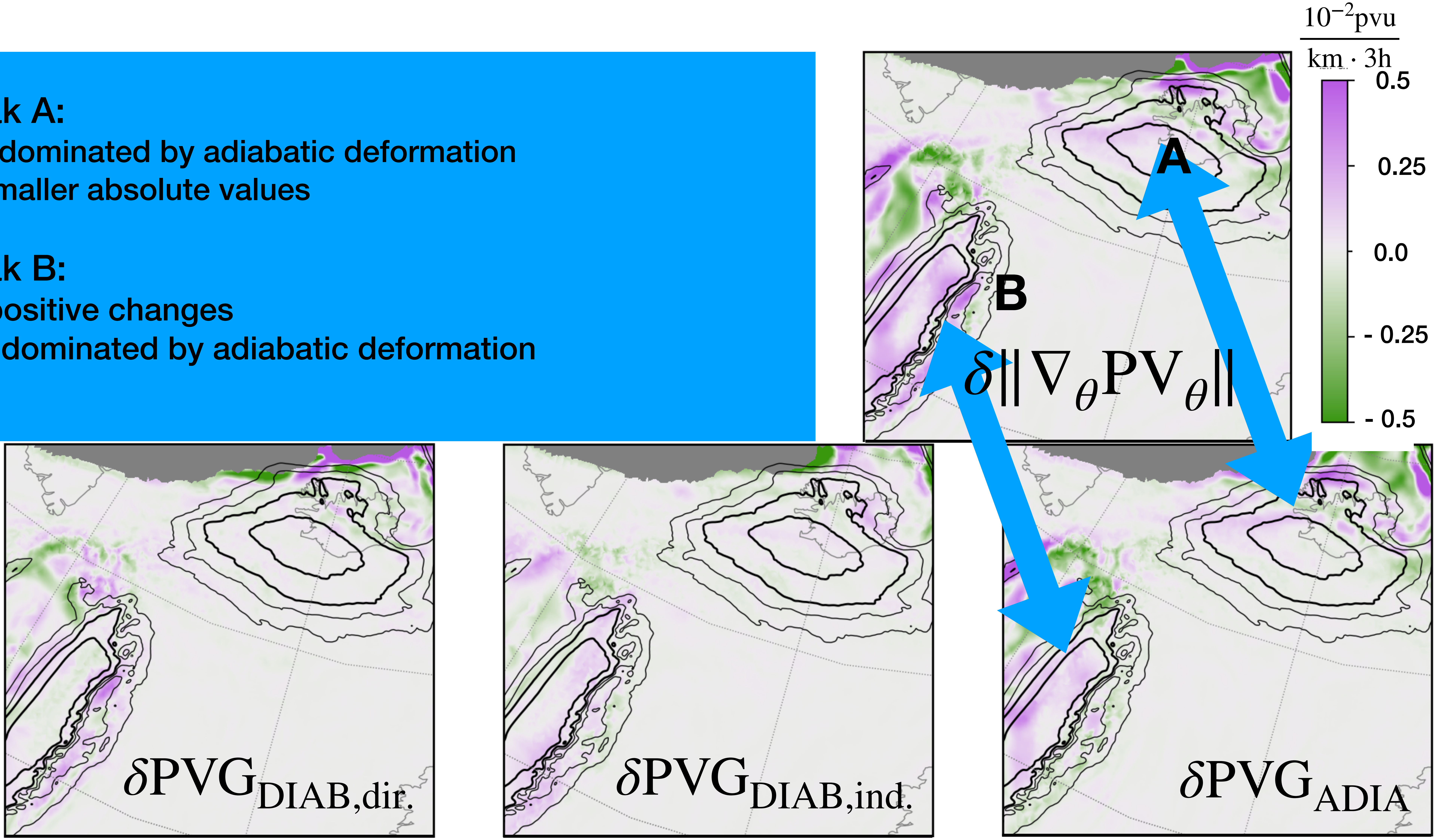
Contributions to PV gradient change

- Jet streak A:
  - Again dominated by adiabatic deformation
  - But: smaller absolute values
- Jet streak B:
  - Only positive changes
  - Again dominated by adiabatic deformation



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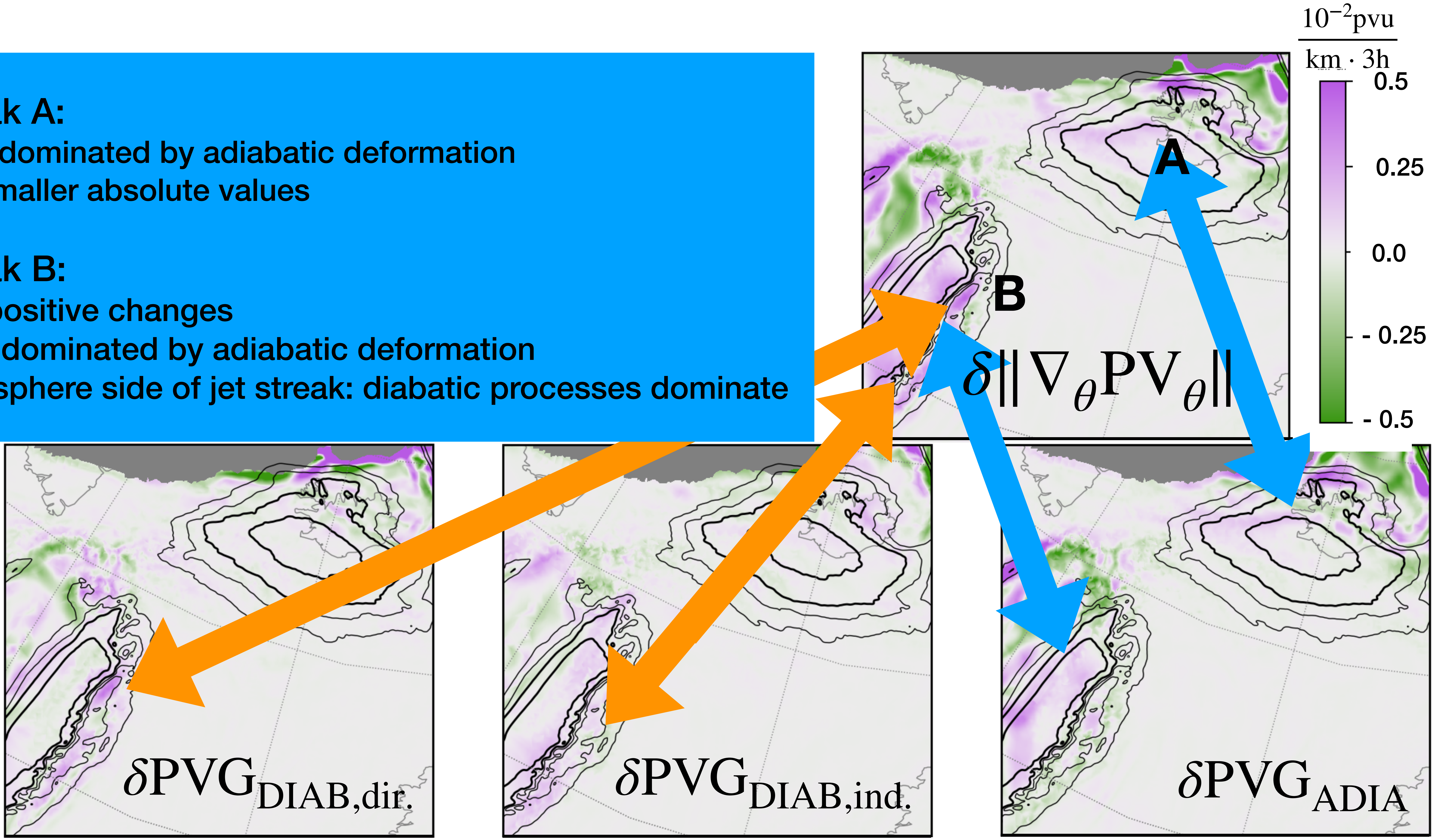
Contributions to PV gradient change

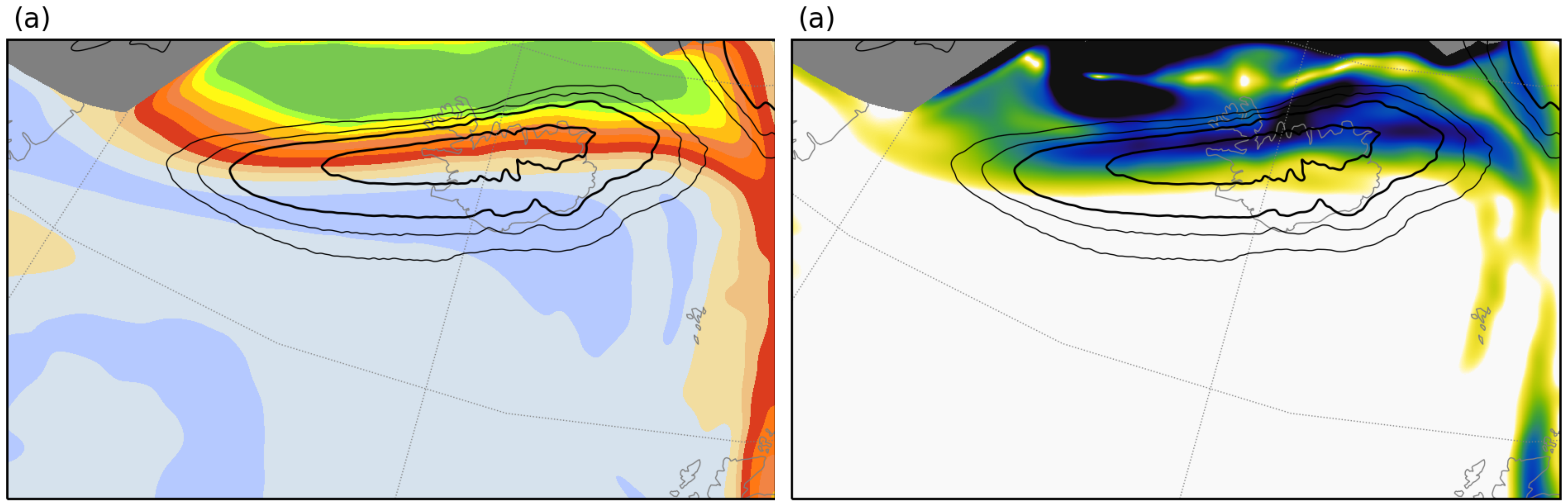
- Jet streak A:
  - Again dominated by adiabatic deformation
  - But: smaller absolute values
- Jet streak B:
  - Only positive changes
  - Again dominated by adiabatic deformation
  - Troposphere side of jet streak: diabatic processes dominate

All Figures Contours:
UV > 35 m/s@320 K



Conclusion

- **Methods:**
  Lagrangian framework for link between PV gradient and large-scale flow



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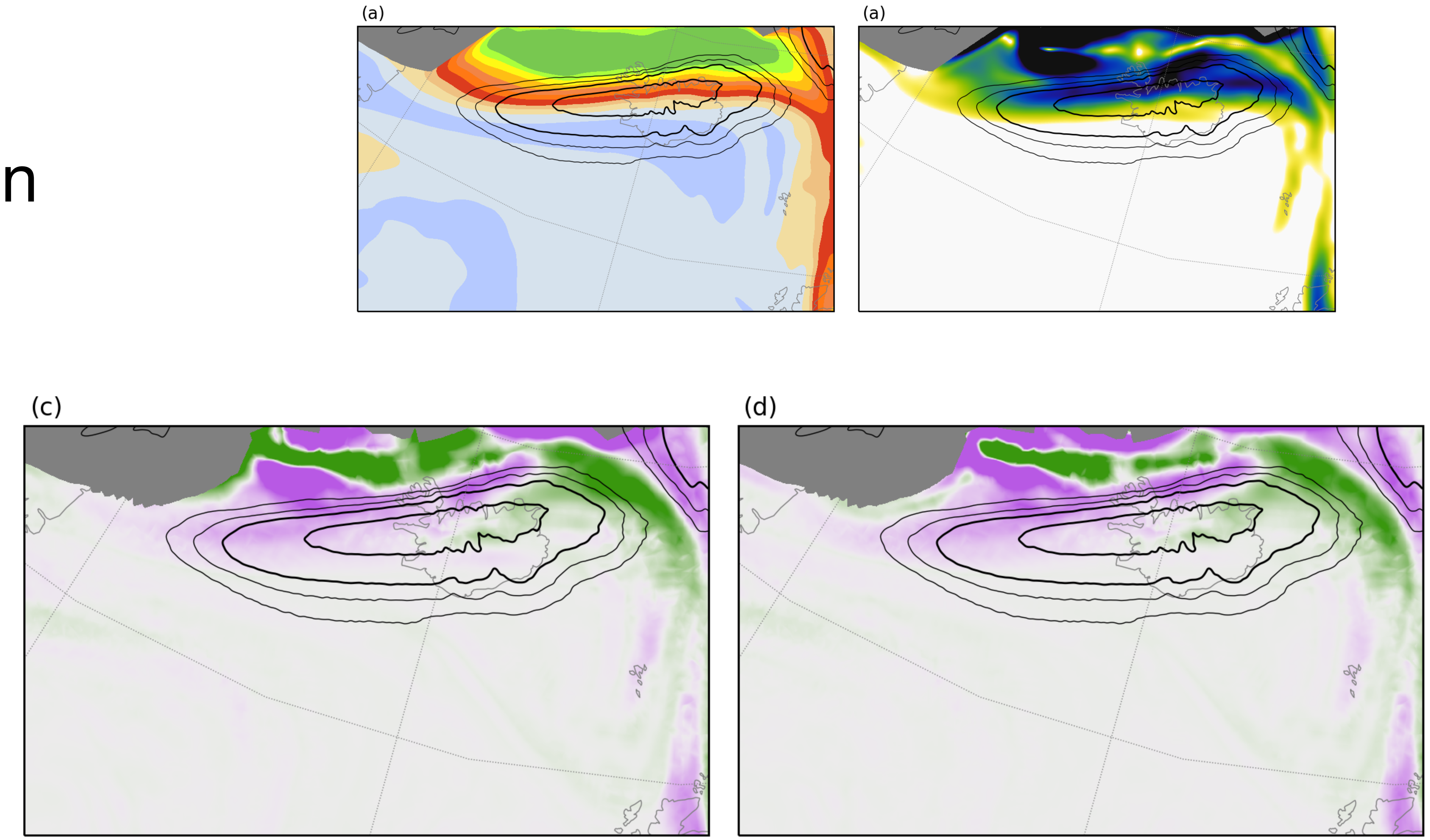
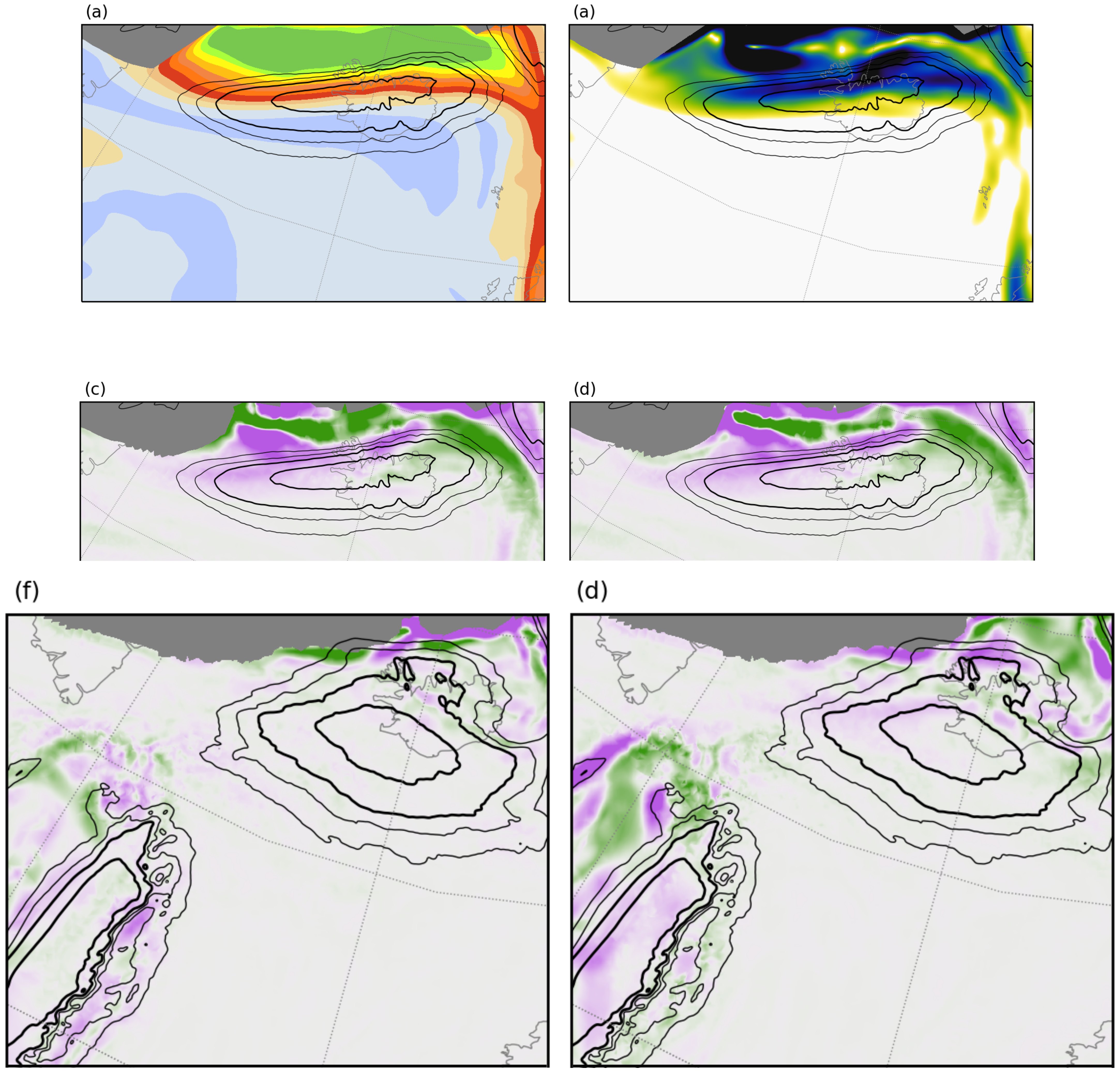
- **Methods:**
  Lagrangian framework for link between PV gradient and large-scale flow

- **First case:**
  Adiabatic deformation dominates PV gradient



Conclusion

- **Methods:**
  Lagrangian framework for link between PV gradient and large-scale flow
- **First case:**
  Adiabatic deformation dominates PV gradient
- **Second case:**
  Diabatic processes important and of the same order of magnitude as adiabatic deformation



Limitations

- **Large scale approximation**
  $\Rightarrow$ Lowpass filtering required

- **Complete decomposition**
  requires sufficient air parcel coverage

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  ⇒ Lowpass filtering required

- **Complete decomposition** requires sufficient air parcel coverage

Outlook

- Identify **jet streaks as object**

- Study evolution of **extreme events** and **trends** under climate change

References

- **Davies, H. C. and Rossa, A. M. (1998)**
  PV frontogenesis and upper-tropospheric fronts, Monthly Weather Review
- **Martius, O., Schwierz, C. and Davies, H. C. (2009)**
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- **Thorpe and Bishop (1985)**,
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