Karlsruhe Institute of Technology

WAVES TO WEATHER

WORKSHOP ON ATMOSPHERIC BLOCKING & EXTREME WEATHER IN A CHANGING CLIMATE
18 - 20 MARCH 2024, BOULDER

Contradictory results concerning the relative importance of dry and moist processes in blocking dynamics:

Is it the perspective that matters?

Seraphine Hauser

with valuable contributions from Christian M. Grams, Michael Riemer, Franziska Teubler, Jan Wandel, Dominik Büeler, Julian F. Quinting, Peter Knippertz, Daniel Steinfeld, Volkmar Wirth, Christopher Polster, …

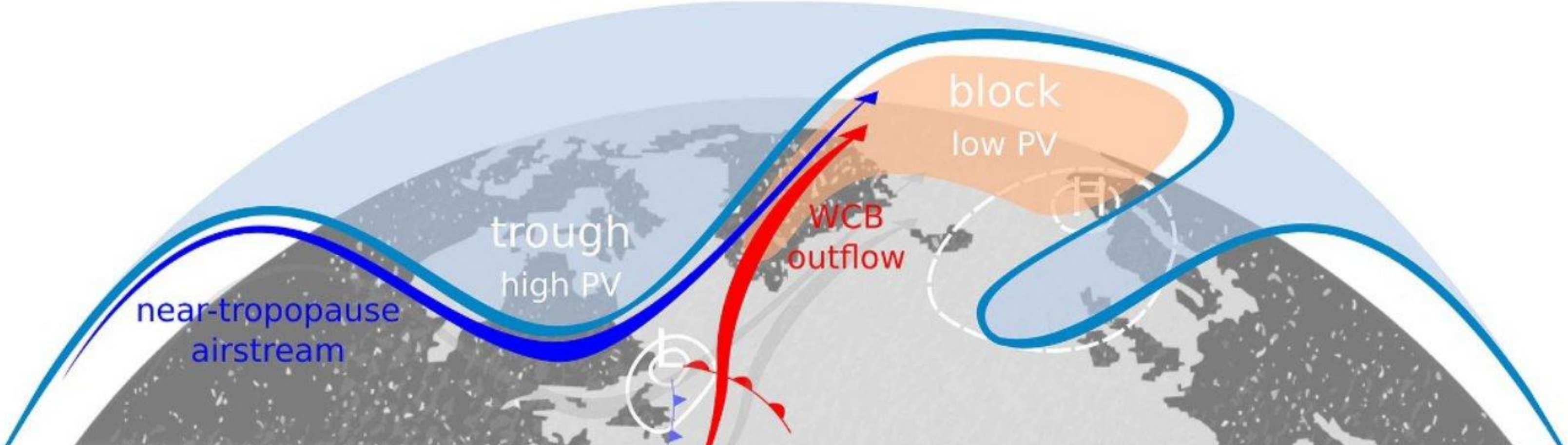
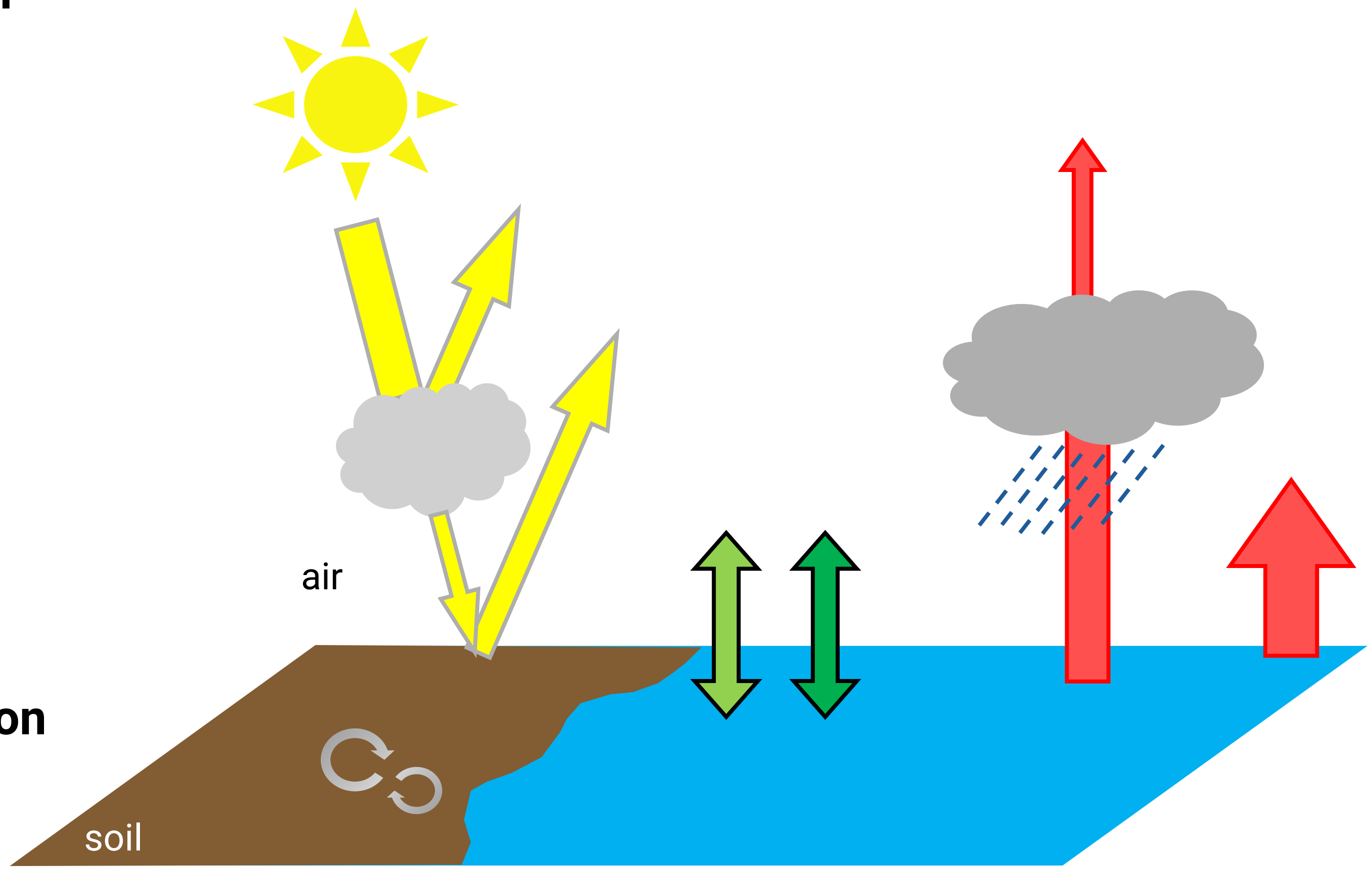


Figure by Steinfeld et al. (2022)

SESSION | Diabatic processes and feedbacks



Solar & terrestrial radiation

Phase changes of water species (i.e., clouds & precipitation)

Surface sensible & latent heat fluxes

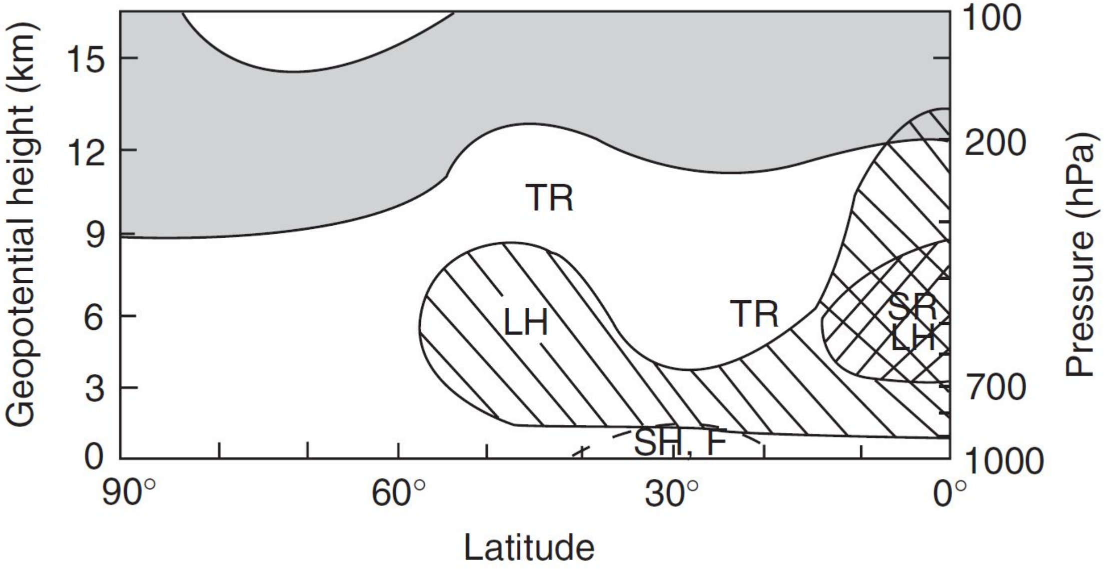
Turbulence & friction

Effects of diabatic processes on blocking

Solar & terrestrial radiation

(e.g., Zierl and Wirth, 1997; Chagnon et al., 2013; Teubler and Riemer, 2016)

Lubis et al.



R. Grotjahn, in Encyclopedia of Atmospheric Sciences, 2003

Phase changes of water species (i.e., clouds & precipitation)

Liu and Wang

Surface sensible & latent heat fluxes

(e.g. Fischer et al., 2007; Wenta et al., 2024; Yamamoto et al., 2021)

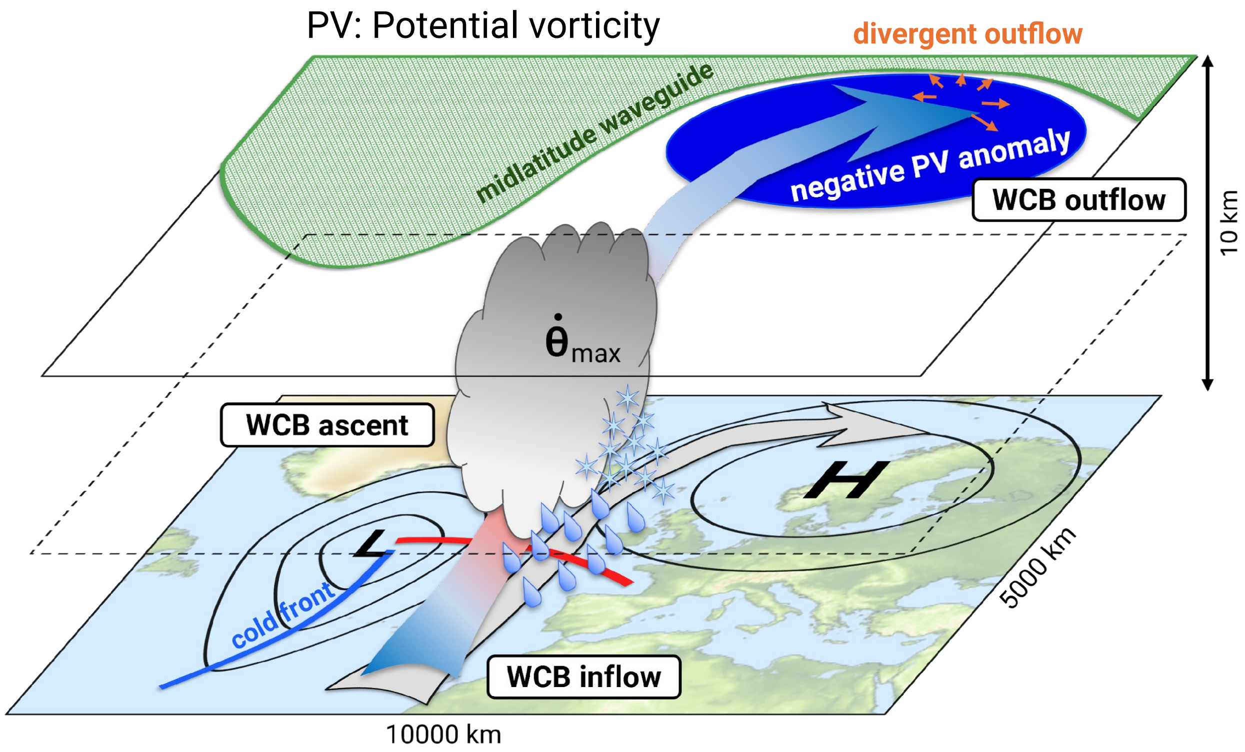
Neal and Nakamura

Turbulence & friction

predominantly neglected

🟩 subsequent talks

Latent heat release in mid-latitudes



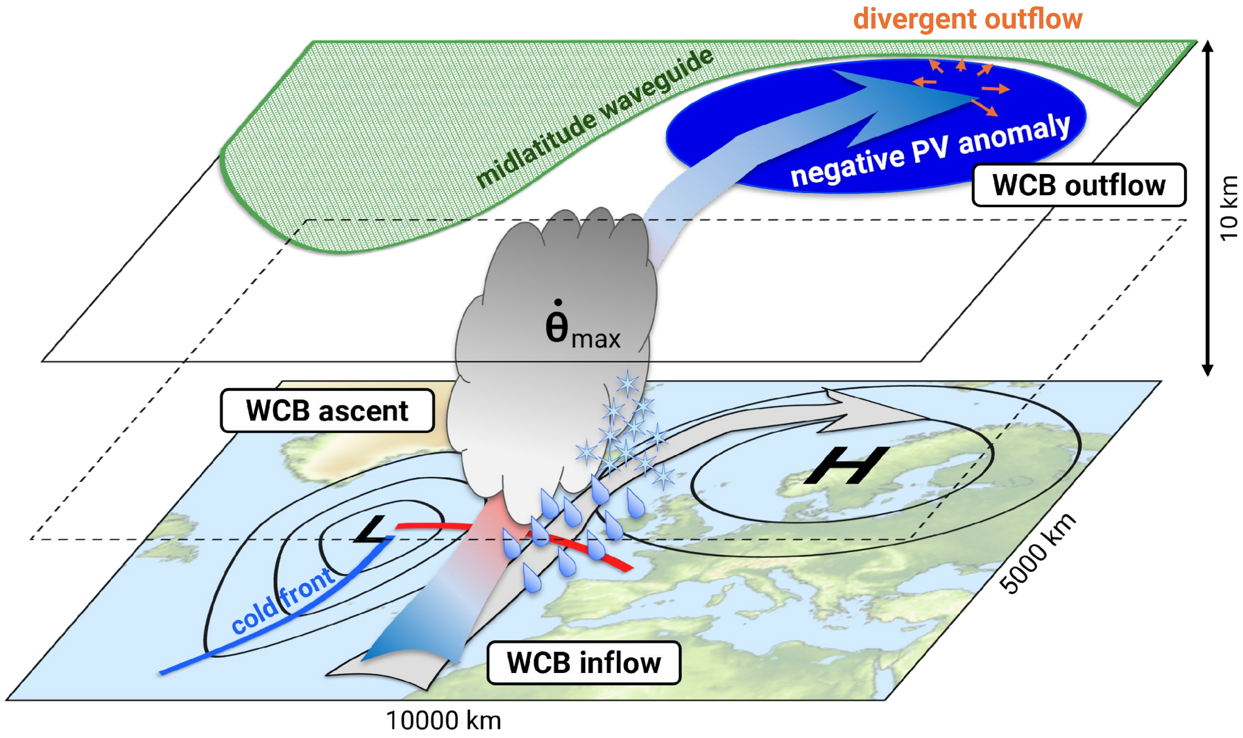
adjusted figure from Quinting and Grams (2022, JAS)

Warm conveyor belt (WCB)

- strongly ascending air stream in the vicinity of extratropical cyclones (Wernli and Davies, 1997)
- formation of large amounts of precipitation (Pfahl et al. 2014)
- latent heat release through cloud formation processes (Madonna et al. 2014)
- large-scale flow modification through ridge amplification (Grams et al. 2011)

Hot spots of WCBs: midlatitude storm-track region (Madonna et al. 2014)

Latent heat release in mid-latitudes



adjusted figure from Quinting and Grams (2022, JAS)

Warm conveyor belt (WCB)

- Identification traditionally with trajectory analysis (Wernli and Davies, 1997)

$$\Delta p_{48h} > 600 \text{ hPa}$$

WCB inflow	**WCB ascent**	**WCB outflow**
$p > 800$hPa	400hPa $< p < 800$hPa	$p < 400$hPa

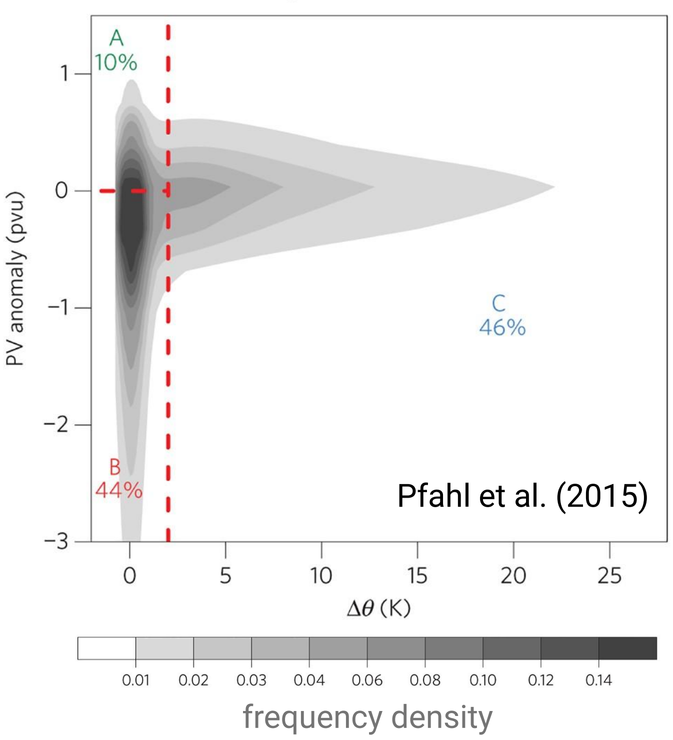
- Novel Eulerian identification using deep learning (Quinting and Grams, 2022)

WCB footprints from Eulerian fields

WCB inflow | **WCB ascent** | **WCB outflow**

Importance of latent heat release for blocking

Key work done by Stephan Pfahl and colleagues, mainly from a Lagrangian perspective



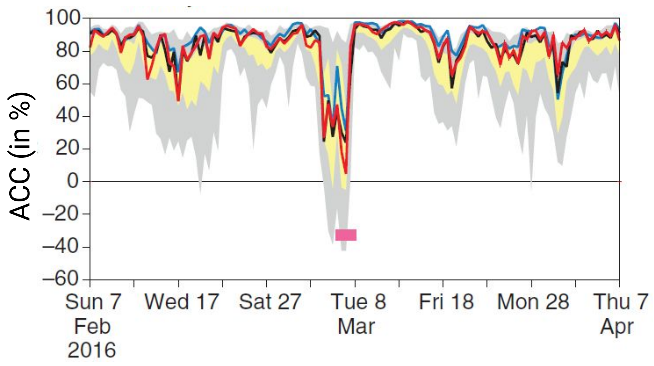
Pfahl et al. (2015)

Main findings

- Up to 46% of air masses involved in blocking (NH) are heated in the days before their arrival in the block (Pfahl et al., 2015)
- Moist-diabatic blocks develop faster than dry-adiabatic blocks, are more intense and larger in extent, and often long-lived (Steinfeld and Pfahl, 2019)
- Switching off latent heat release upstream of blocking leads to a functional weakening up to the elimination of blocking (Steinfeld et al., 2020)
- With climate change, stronger latent heating (+1K) points to an increased importance of moist processes for future blocks (Steinfeld et al., 2022)

Do moist processes limit predictability?

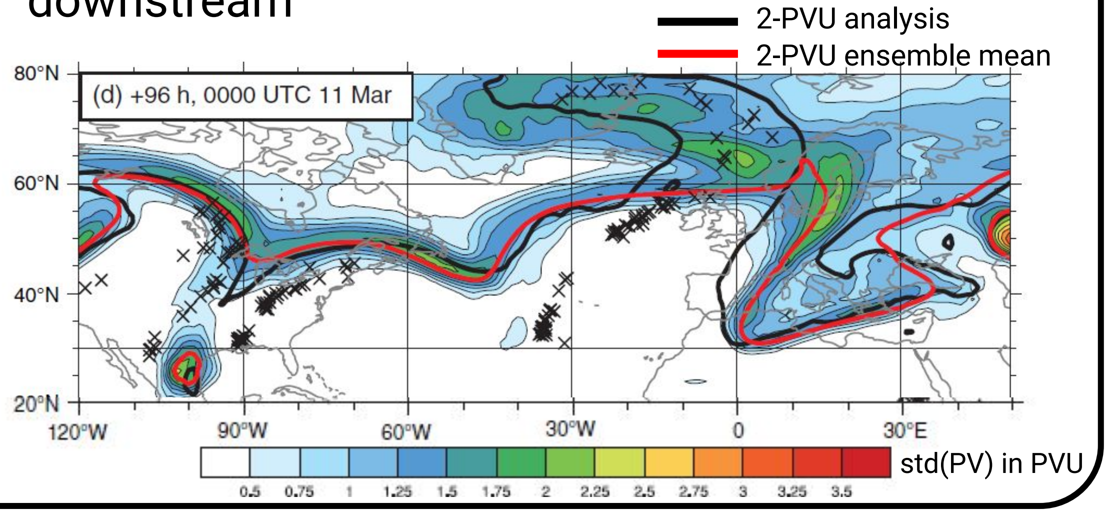
European Blocking “forecast bust” (March 2016)



Forecast bust associated with onset of strong blocking over Europe

Misrepresentation of the WCB upstream of Europe

☐ amplification and propagation of forecast error downstream

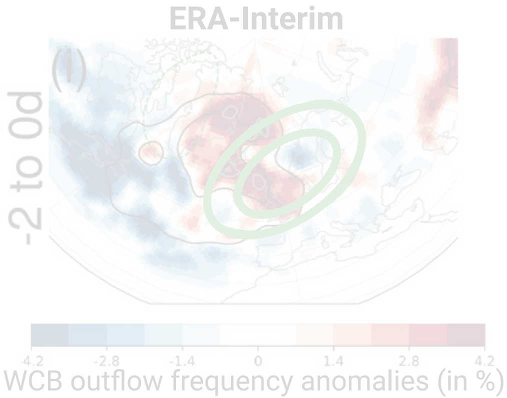


Magnusson (2017), Grams et al. (2018)

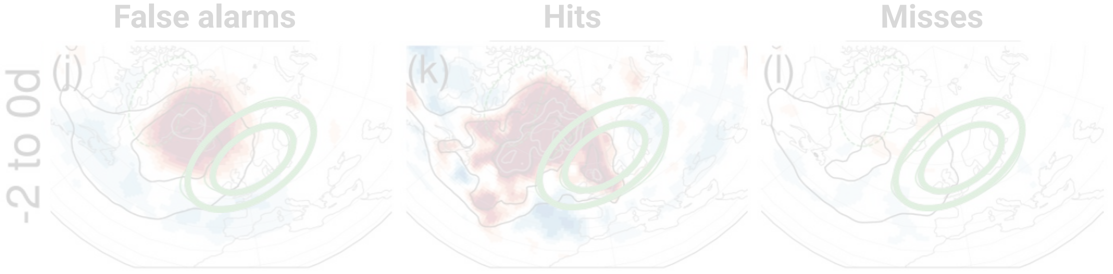
WCB activity and European blocking predictability

ECMWF IFS reforecasts (1997-2017), winter

Blocking onset between lead time 10-15 days



Above-average WCB outflow upstream of blocking region shortly before onset



Forecasts that miss blocking onset over Europe don’t have the increased WCB activity upstream

Wandel et al., in review

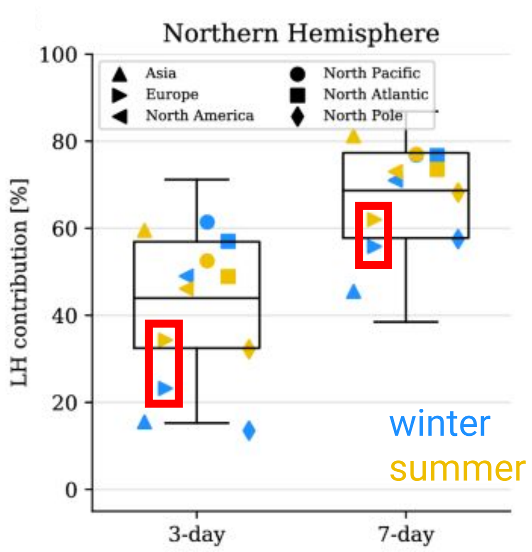
A joint consideration of dry and moist dynamics

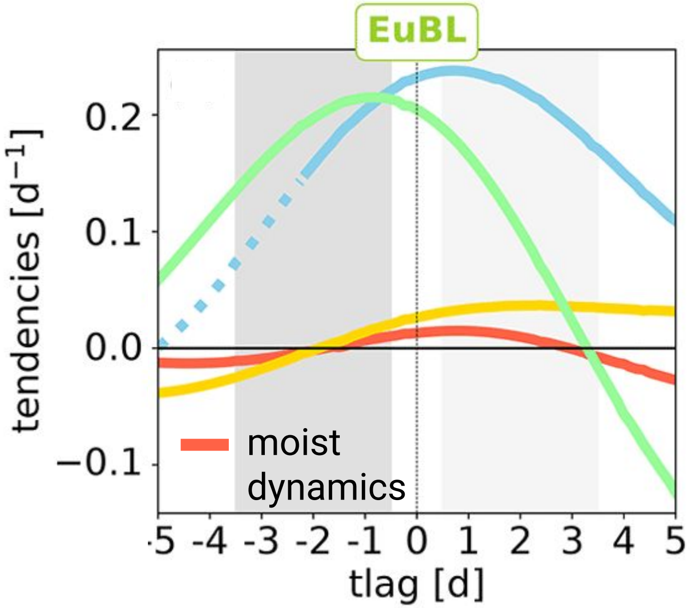
Eulerian vs. Lagrangian perspectives

Many studies investigating the role of <u>either dry or moist dynamics</u>, often resulting in “contradictory” results

Lagrangian

Steinfeld and Pfahl, 2019





Teubler et al., 2023

Eulerian

Only very few studies on the role of both, dry and moist dynamics (e.g., Miller and Wang, 2021)

How can we bridge the gap between pure Lagrangian and Eulerian perspectives?
Which puzzle piece is missing to combine the two approaches in a joint analysis?

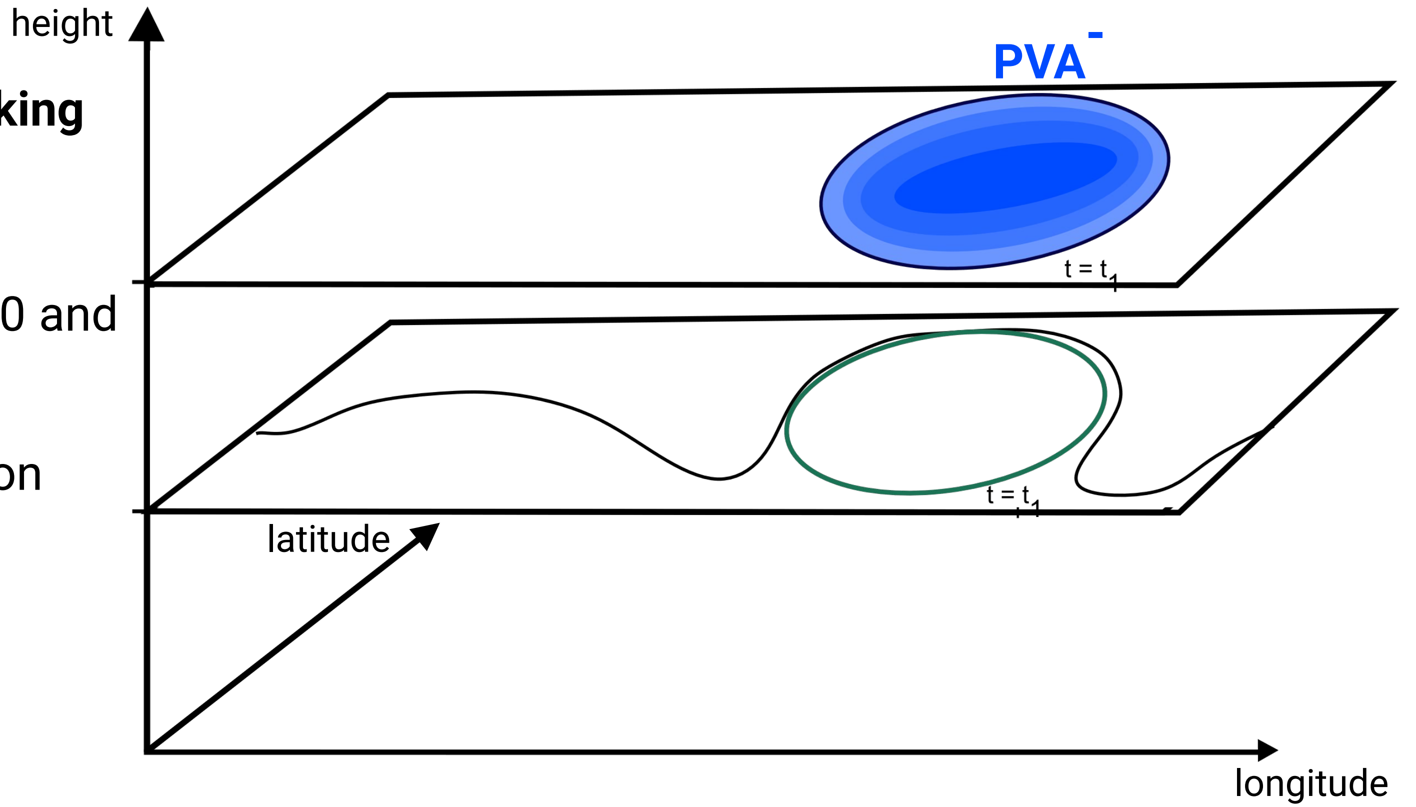
ERA5 reanalysis (1979-2021)

A quasi-Lagrangian framework

Basic idea | Use Eulerian PV tendencies (Eulerian), but follow the movement of the PV anomaly linked to the block (Lagrangian)

① **Identification of PV anomalies linked to blocking**
(Schwierz et al., 2004, Grams et al., 2017)

- negative PV anomalies in the upper troposphere (vertical average between 500 and 150hPa) □ PVAs$^-$
- percentile threshold that varies with season



Hauser et al., 2023 (WCD)

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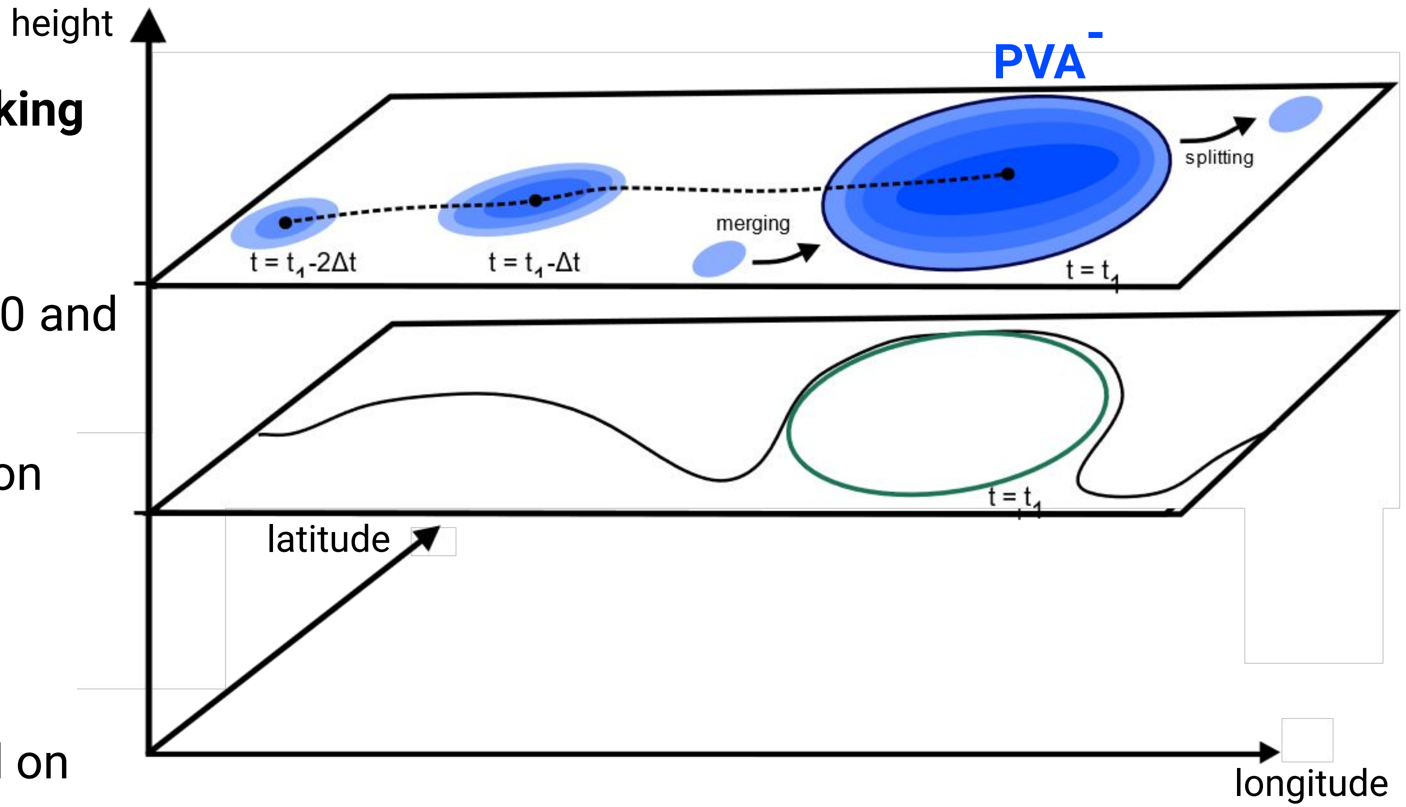

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② Tracking of PVAs$^-$

(Schwierz et al., 2004)

- novel tracking algorithm developed based on contour overlap
- detection and handling of splitting and merging

Hauser et al., 2023 (WCD)

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③ Amplitude evolution of PVAs$^-$

(Teubler and Riemer, 2016/2021)

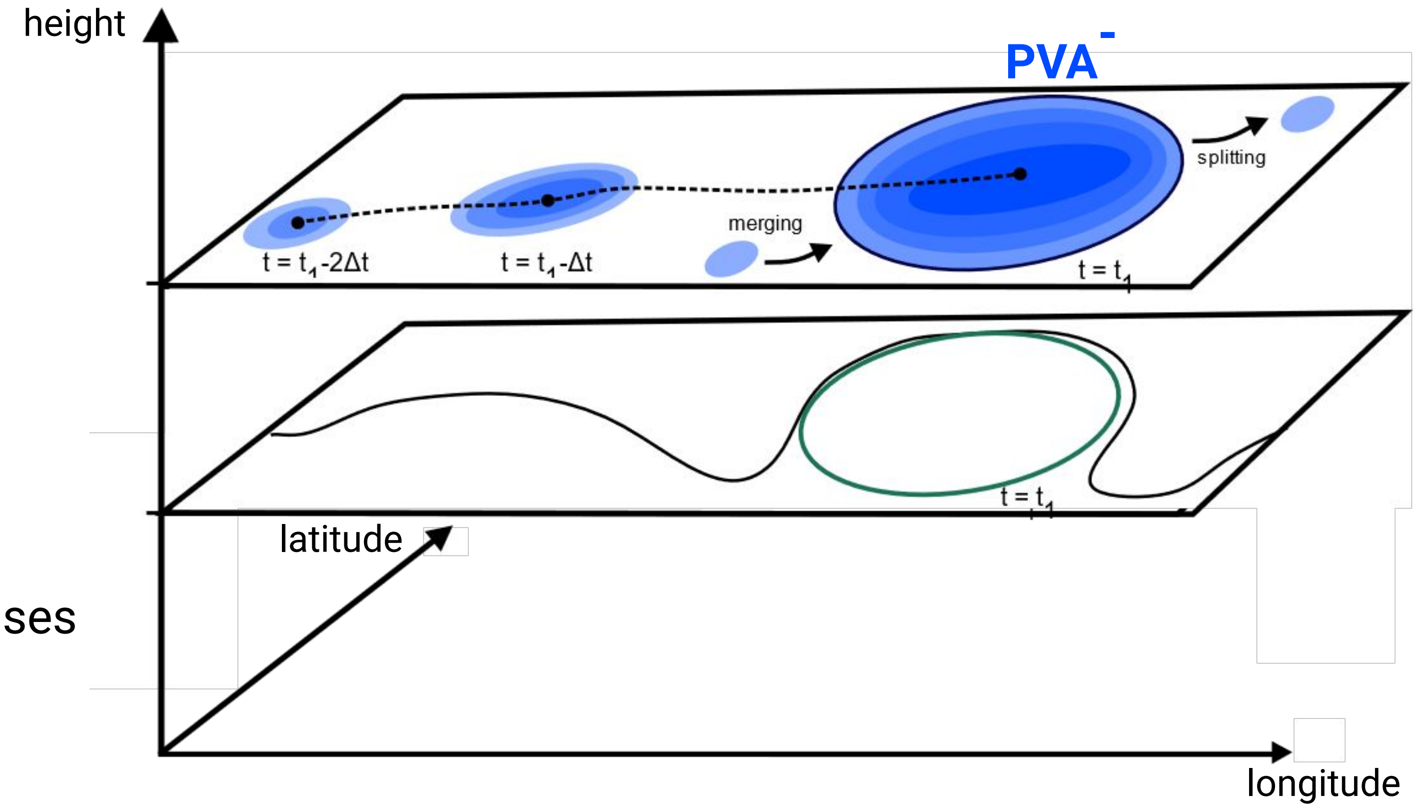
PV (q) tendency equation

non-conservative processes

$$\frac{\partial q}{\partial t} = \underbrace{-\vec{v}\cdot\vec{\nabla} q}_{\text{advection of PV}} + \underbrace{\mathcal{N}}$$

Partition wind field to look at different processes

$$\mathbf{v} = \mathbf{v}_0 + \underbrace{\mathbf{v}'_{div}}_{\text{Helmholtz partitioning}} + \underbrace{\mathbf{v}'_{up} + \mathbf{v}'_{low}}_{\text{piecewise PV inversion}} + \mathbf{v}'_{res}$$



Hauser et al., 2023 (WCD)

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③ Amplitude evolution of PVAs$^-$

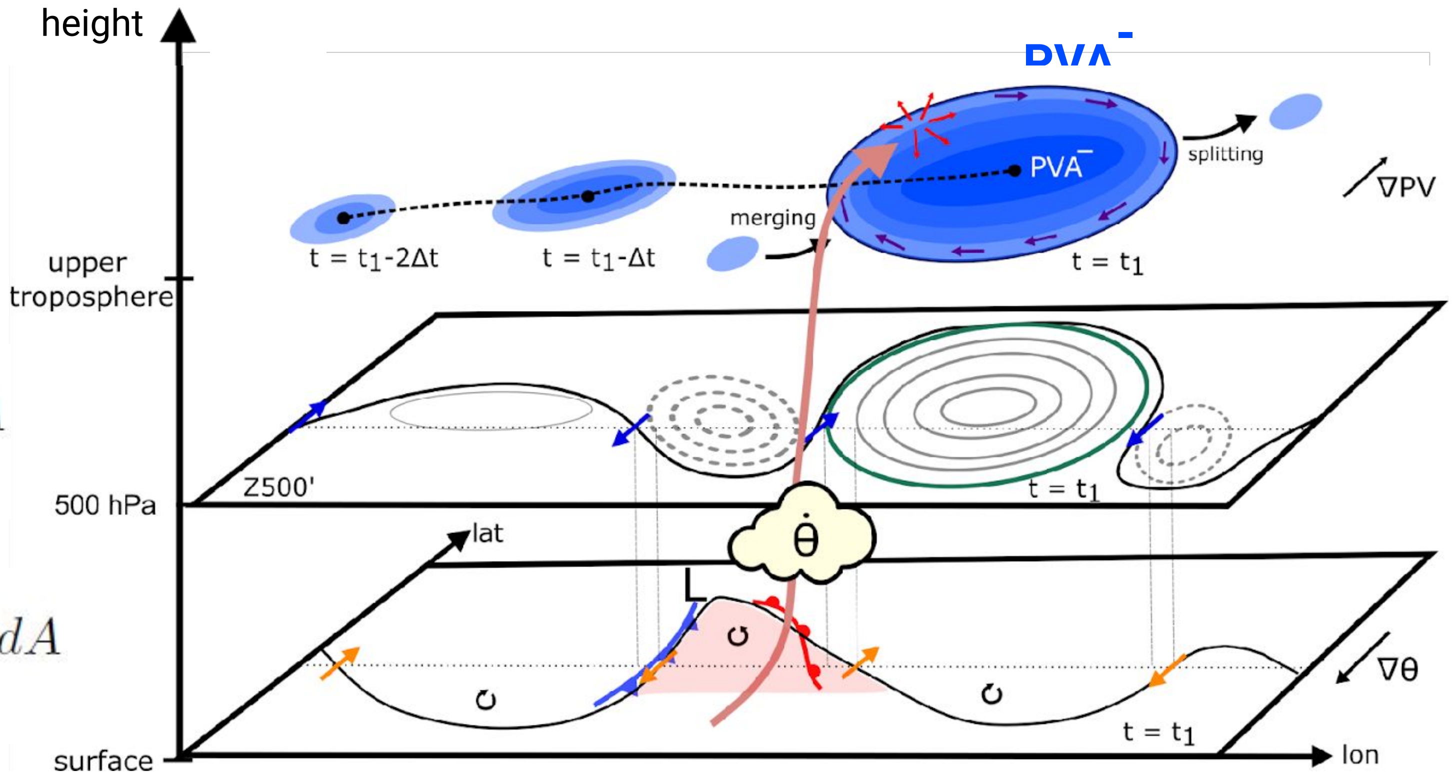
(Teubler and Riemer, 2016/2021)

Area-integrated PV anomaly (q’) amplitude change (on isentropic levels)

$$\frac{d}{dt}\int_{A(t)} q'\,dA = \int_{A(t)} \Big[\underbrace{-\mathbf{v}'_{up}\cdot\nabla q_0}_{\text{UP}}\ \underbrace{-\,\mathbf{v}'_{low}\cdot\nabla q_0}_{\text{LOW}}\Big]\,dA$$

$$= \int_{A(t)} \Big[\underbrace{-\,\mathbf{v}'_{div}\cdot\nabla q_0}_{\text{DIV}_{adv}} + \underbrace{q'(\nabla\cdot\mathbf{v}'_{div})}_{\text{DIV}_{div}}\Big]\,dA$$

$$= \int_{A(t)} \Big[\underbrace{-\,\mathbf{v}'_{res}\cdot\nabla q_0}_{\text{RES}} + \underbrace{\mathcal{N}}_{\text{NON-CONS}}\Big]\,dA + \oint_{S(t)} \underbrace{q'(\mathbf{v}_s-\mathbf{v})\,d\mathbf{S}}_{\text{BND}}$$



Hauser et al., 2023 (WCD)

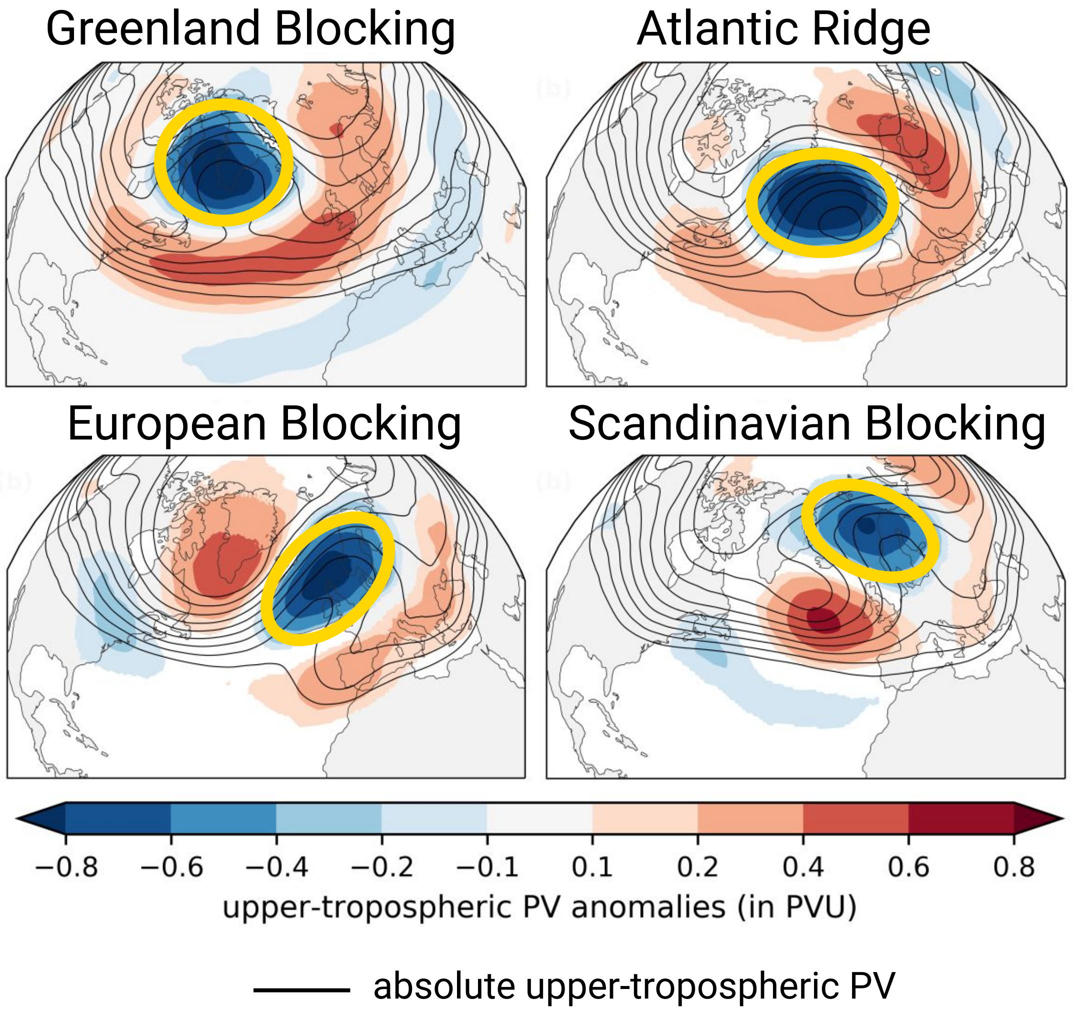
Blocking from a weather regime perspective

Investigate blocking dynamics in different sub-regions over North Atlantic-European sector

Seven year-round weather regime definition in the North Atlantic-European region
(Grams et al., 2017)

➡ ERA5 reanalysis (1979-2021), Z500

Link PVA$^-$ tracks to different blocked regime life cycle stages (onset, maximum, decay) via spatial overlap with **regime mask**



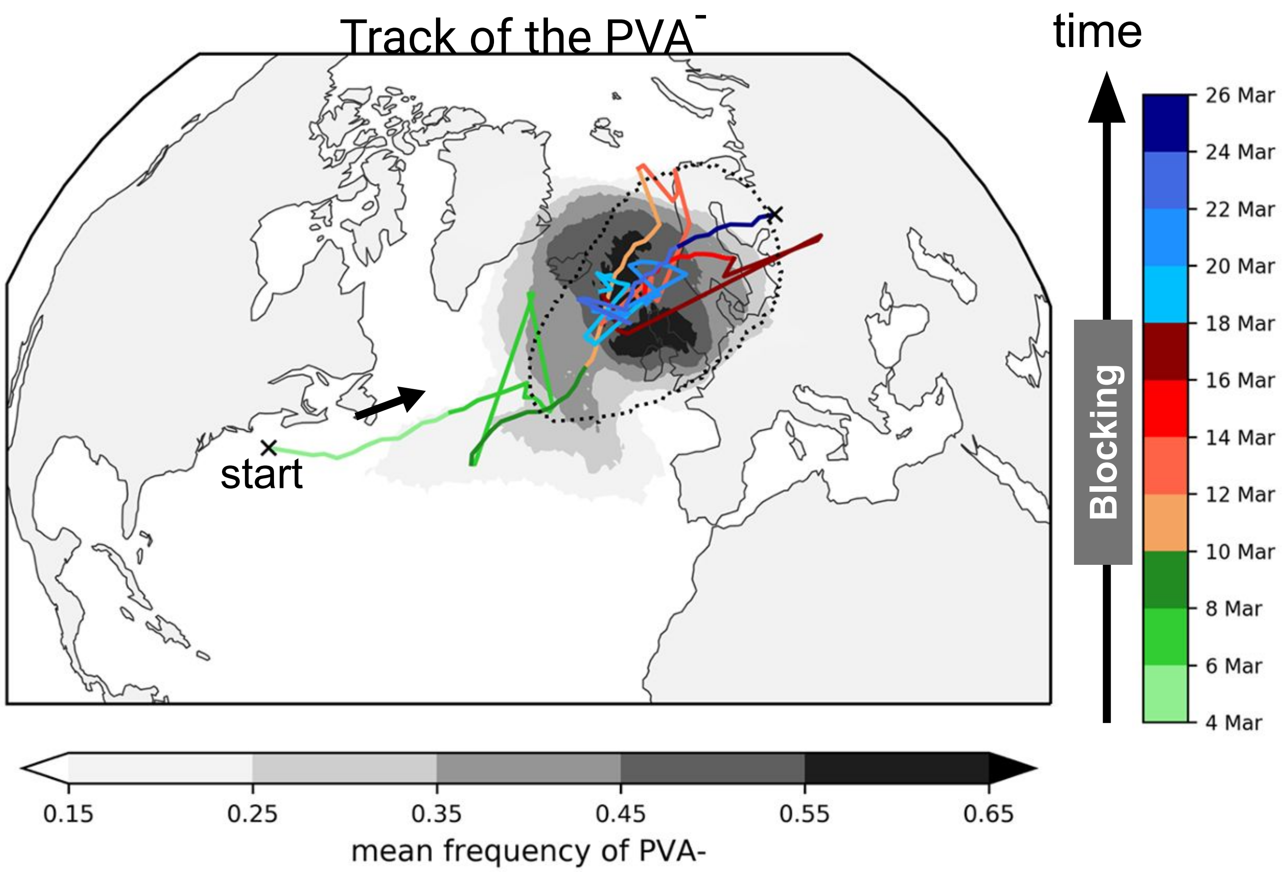
The European blocking “bust case” in March 2016

Role of moist processes and direct diabatic modifications

9-day blocking episode with block over the United Kingdom

Origin of the PVA$^-$

- PVA$^-$ formed five days before blocking onset
- non-local development of the PVA$^-$ over western North Atlantic



Hauser et al., 2023 (WCD)

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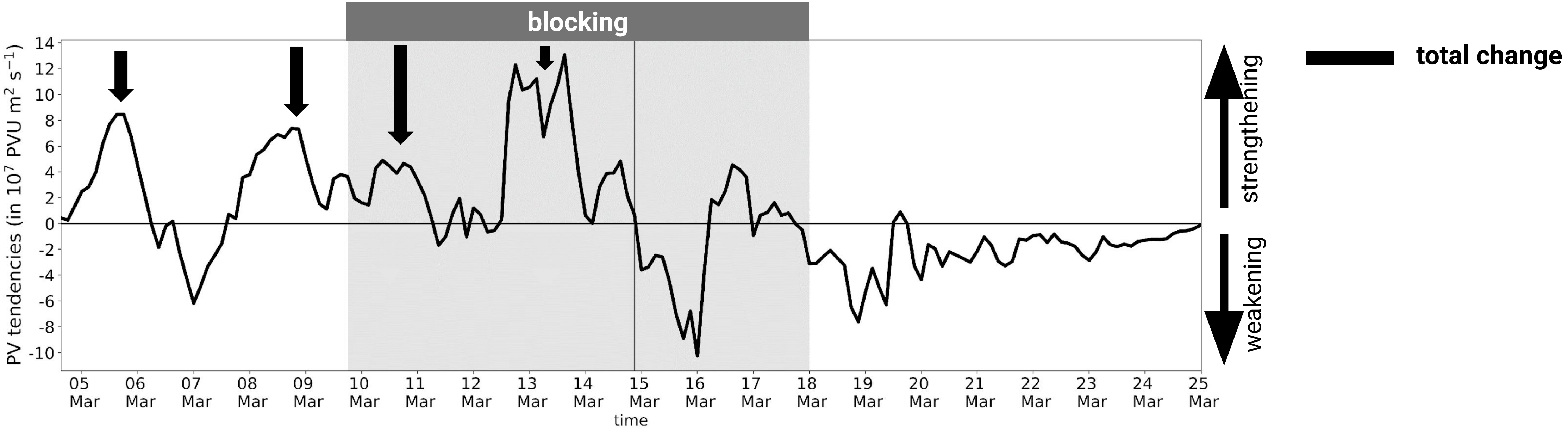
Role of moist processes and direct diabatic modifications

Amplitude evolution of the negative PV anomaly

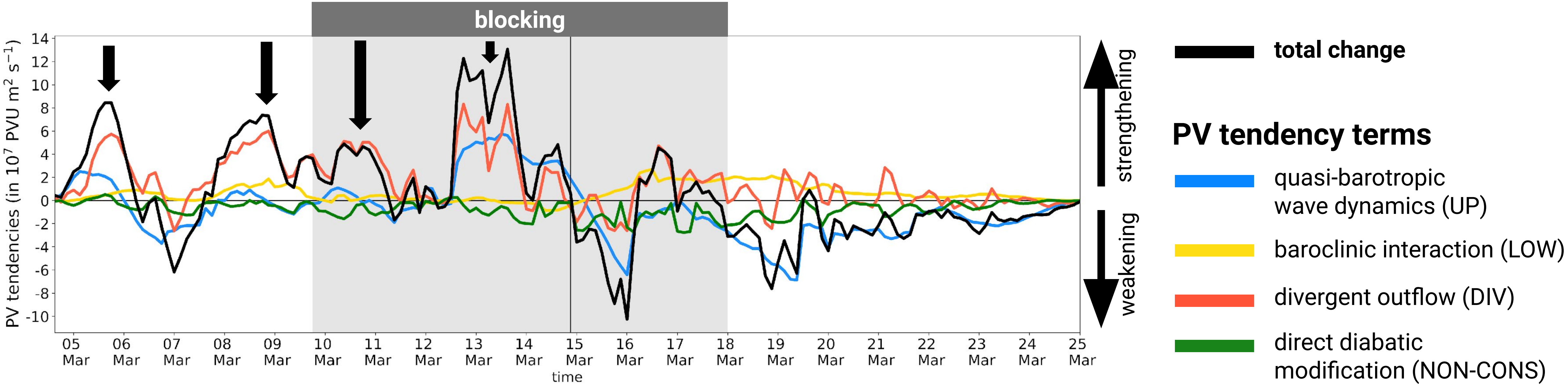


pulses of amplification before and during blocking → which processes?

Hauser et al., 2023 (WCD)

The European blocking “bust case” in March 2016

Role of moist processes and direct diabatic modifications

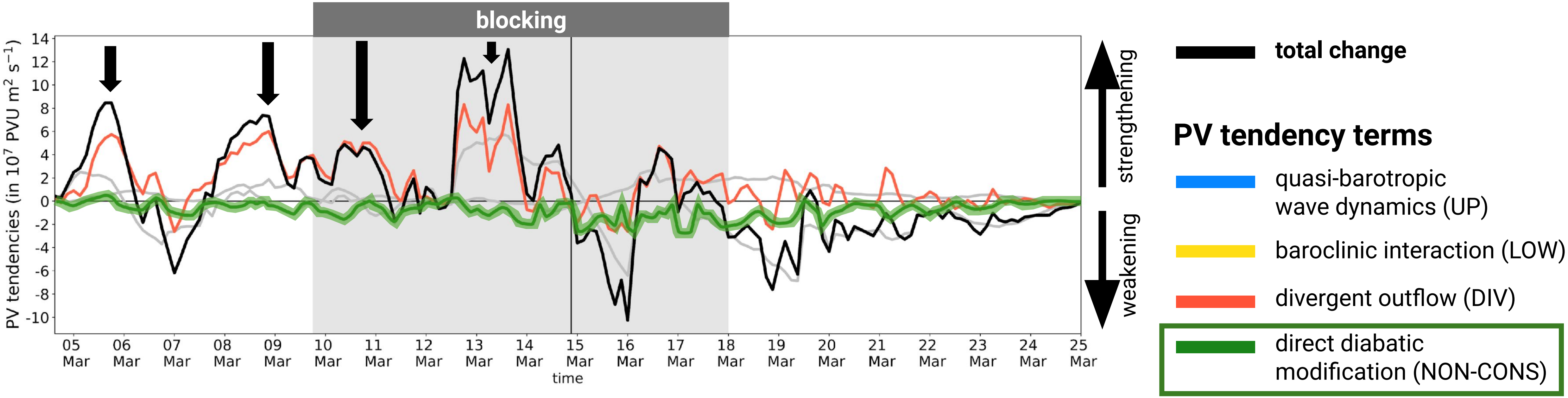


Moist processes? Let’s look at the direct diabatic modification term!

Hauser et al., 2023 (WCD)

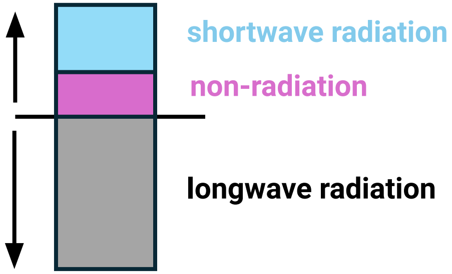
The European blocking "bust case" in March 2016

Role of moist processes and direct diabatic modifications



Direct diabatic modification (NON-CONS)

Small contribution to weakening of PVA^{-} amplitude (dominated by longwave-radiative cooling)



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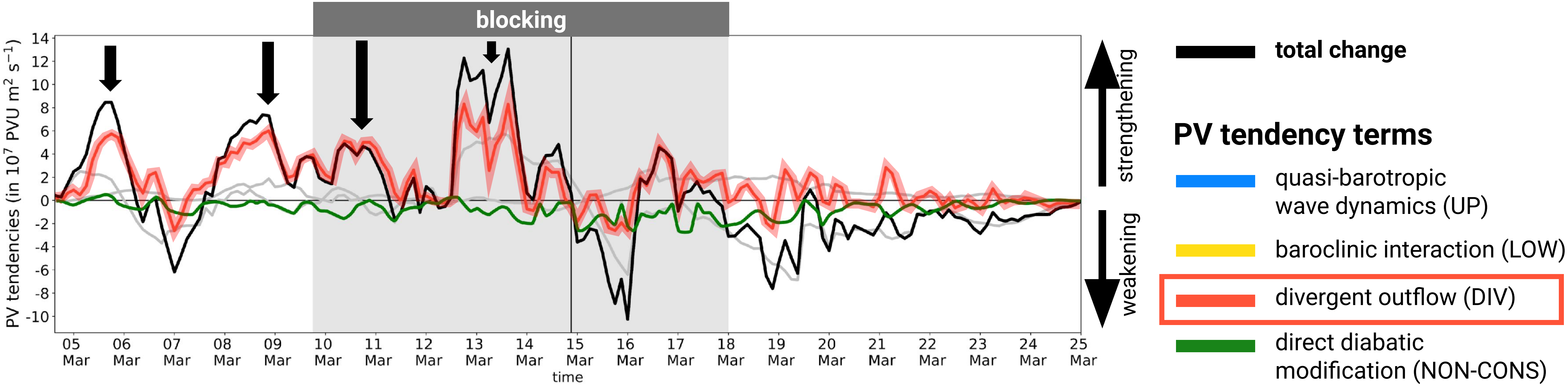


Divergent outflow (indirect moist processes)
Leads the pulses of amplification and points to importance of moist processes

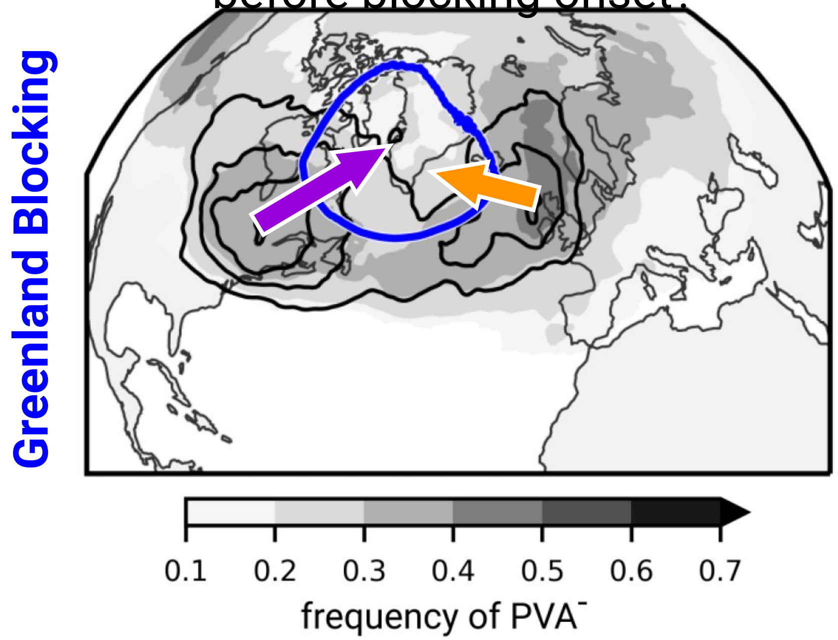
“moist process played a role for blocking development in the March 2016 case” (Grams et al., 2018)

Hauser et al., 2023 (WCD)

From case study to systematic investigation

Key finding #1

Where are PVAs$^-$ located 4 days before blocking onset?

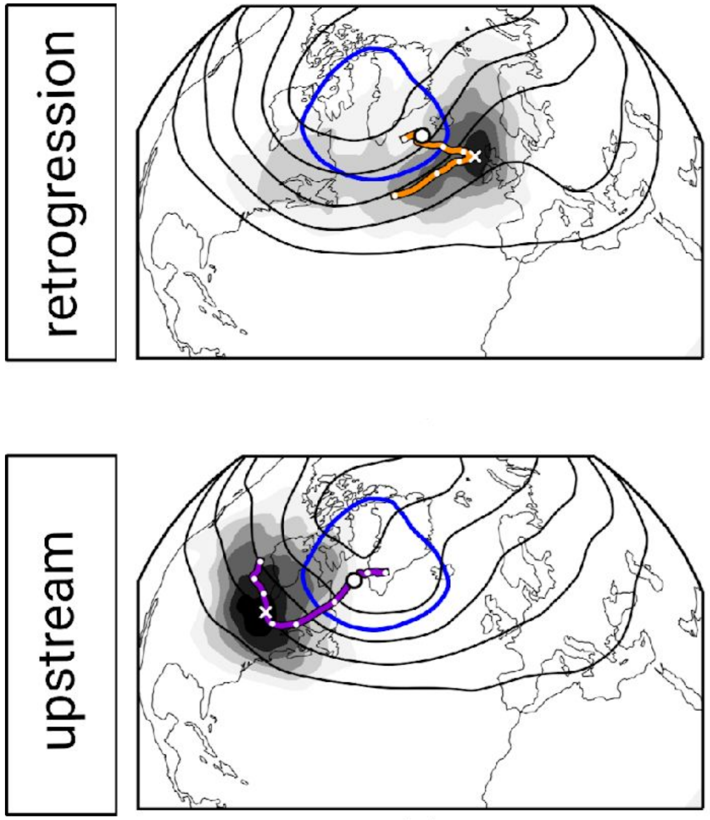


—— block-related PVAs$^-$

two pathways?

—— upper-tropospheric PV

grey shading: PVA$^-$ frequency at t = -4 days before blocking onset

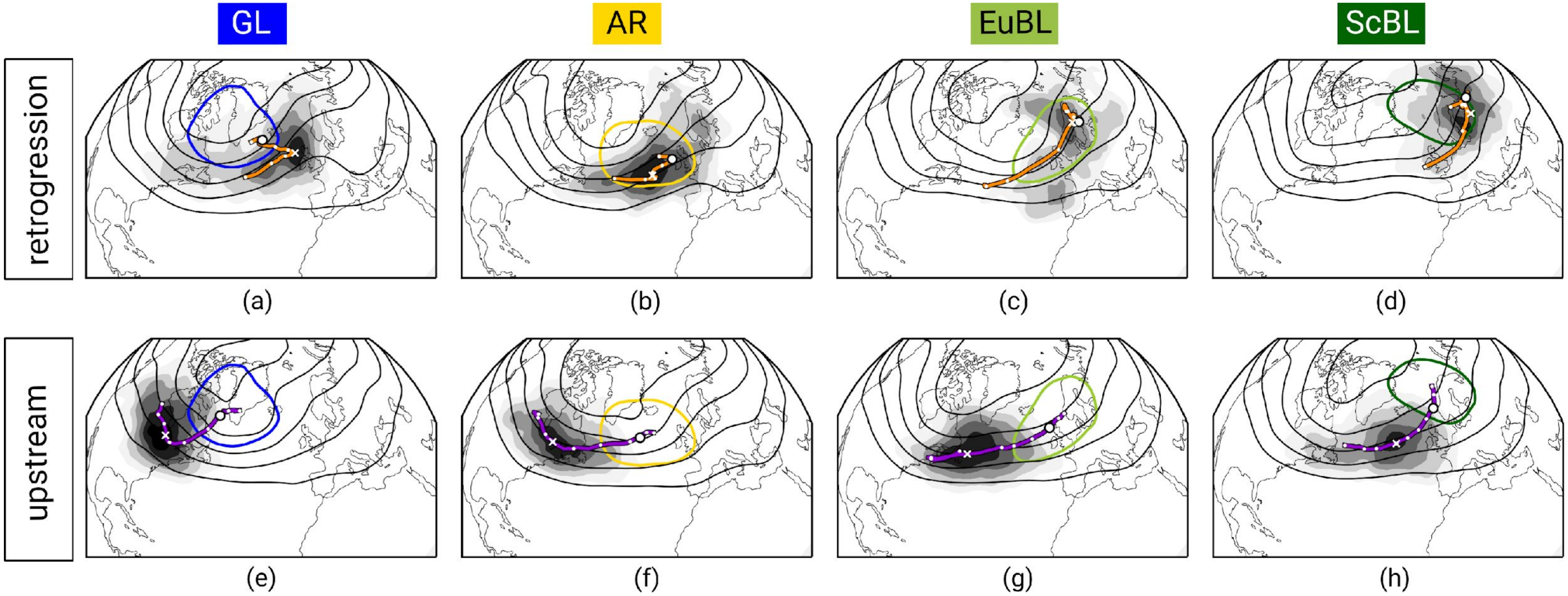


Hauser et al., 2024 (WCD, in review)

From case study to systematic investigation

Key finding #1

PVAs$^-$ linked to blocking over North Atlantic-European region develop remotely with two pathways into the blocking region



— upper-tropospheric PV

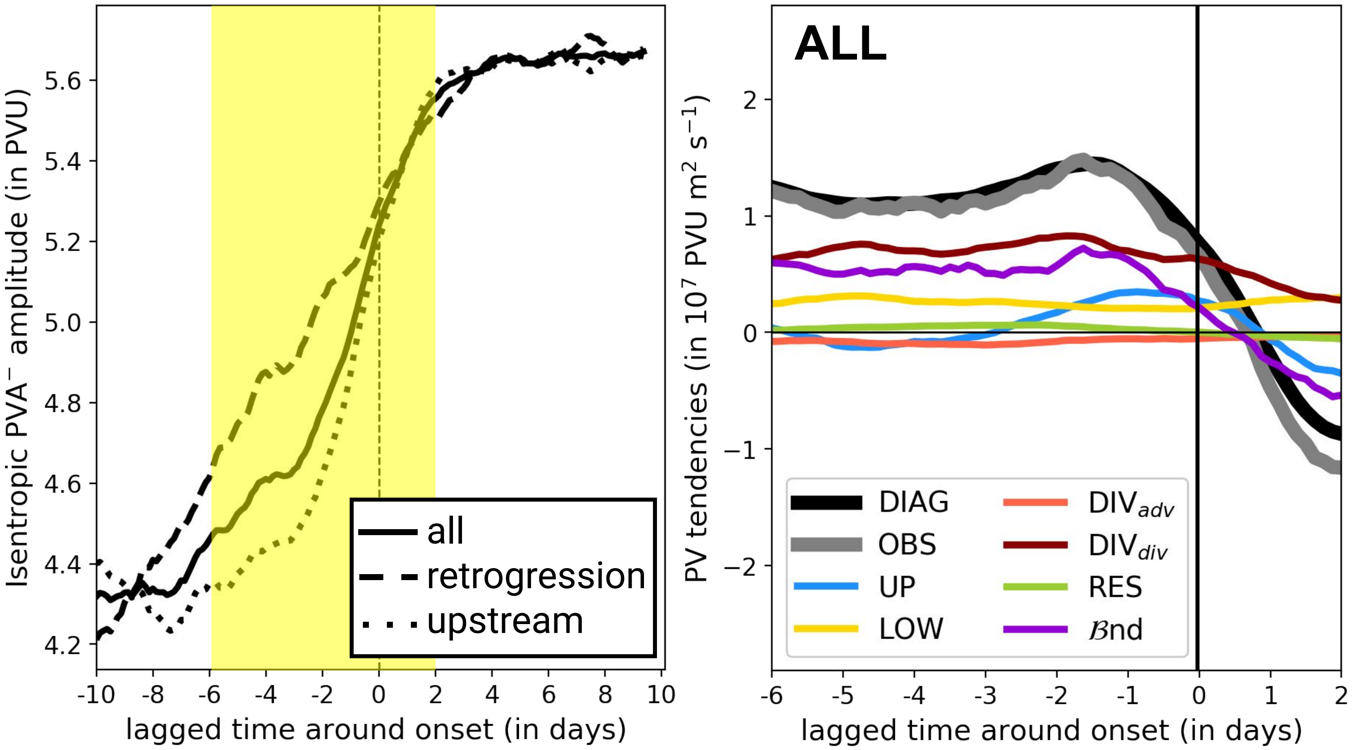
grey shading: PVA$^-$ frequency at t = -4 days before blocking onset

Hauser et al., 2024 (WCD, in review)
Hauser et al., *in preparation*

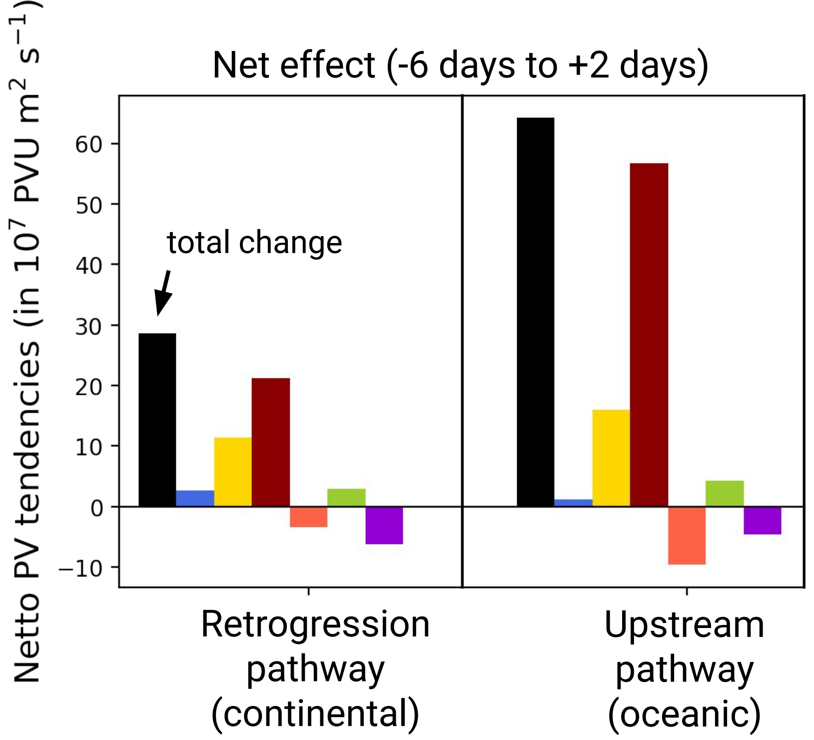
From case study to systematic investigation

Key finding #2

Amplification of PVAs$^-$ occurs already **before** blocking onset and is dominated by divergent PV tendencies pointing to moist contributions



Pathway differences for European blocking

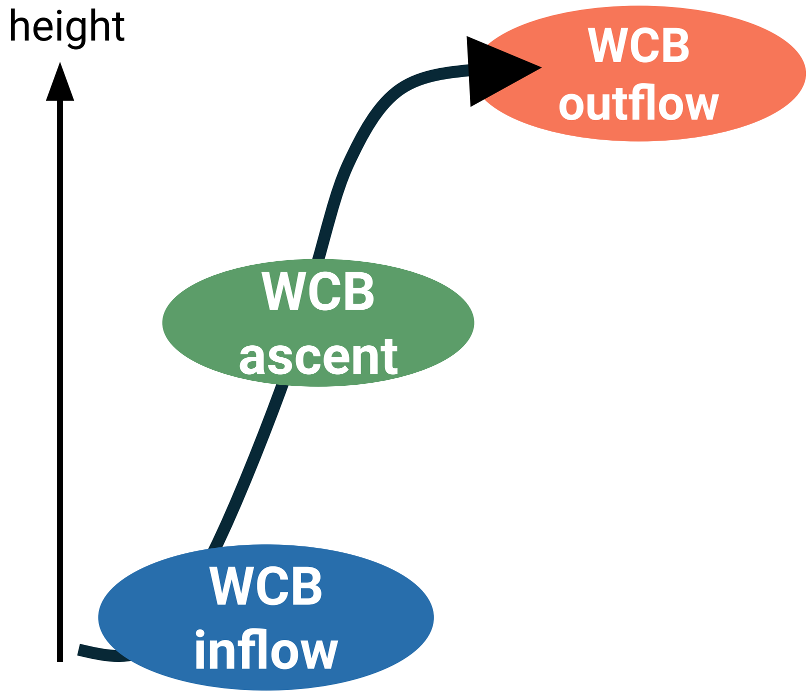


Hauser et al., 2024 (WCD, in review)
Hauser et al., *in preparation*

From case study to systematic investigation

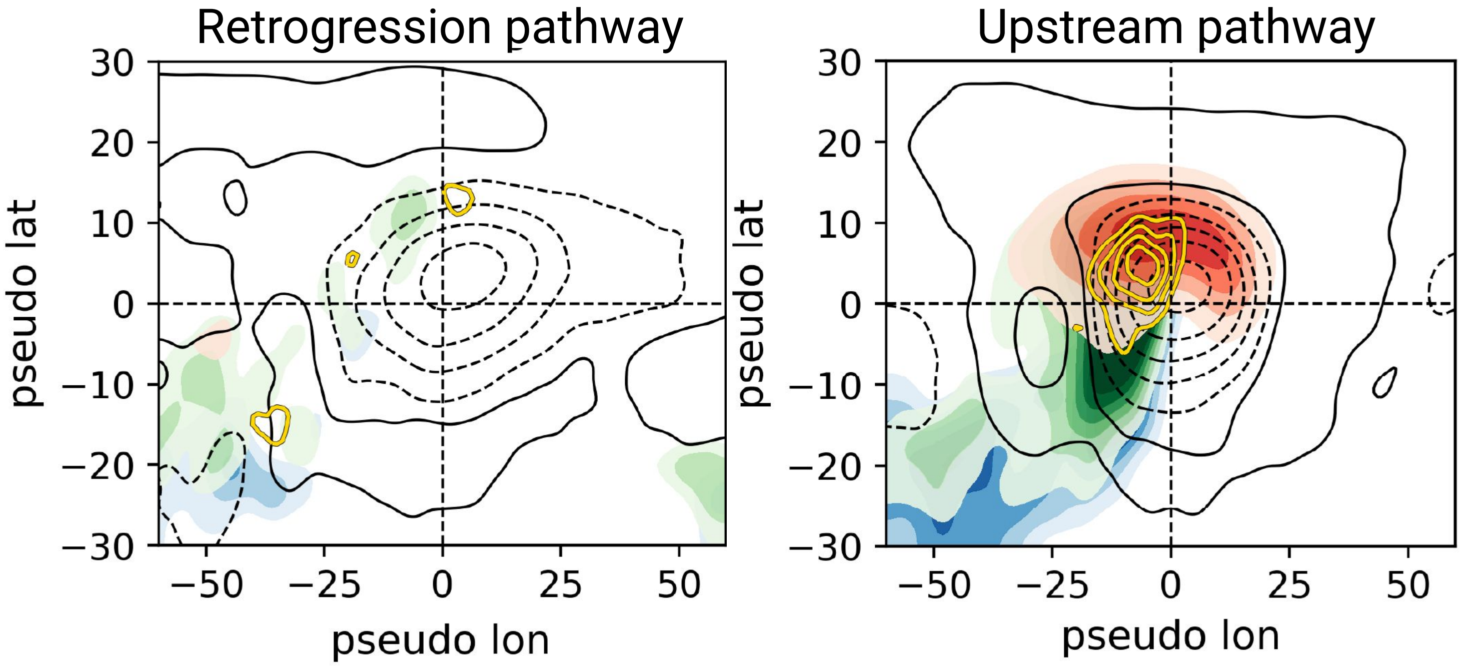
Key finding #3

PVAs$^-$ moving over midlatitude storm-track region amplify much stronger by divergent PV tendencies (linked to WCB activity)



▬ amplifying divergent PV tendencies

European blocking



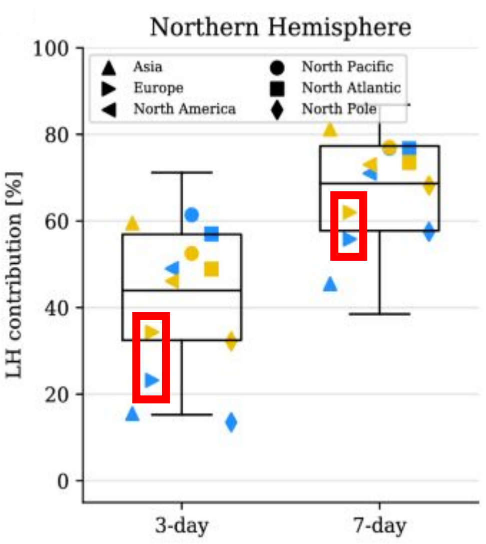
▬▬ positive PV anomalies
- - - negative PV anomalies

Hauser et al., 2024 (WCD, in review)
Hauser et al., *in preparation*

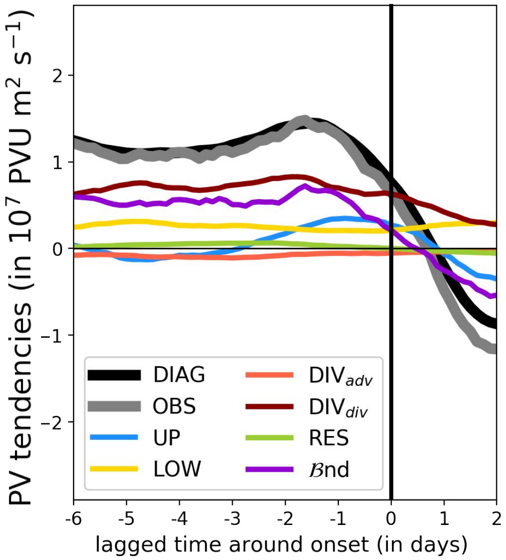
Connecting the different perspectives

Lagrangian

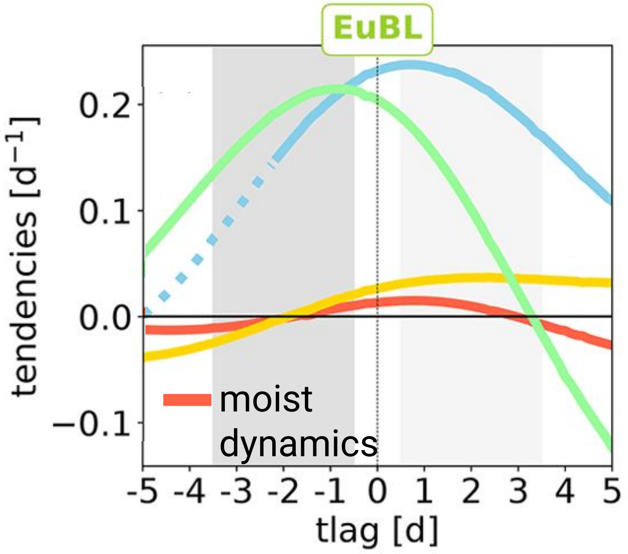
Steinfeld and Pfahl (2019)



Quasi-Lagrangian



Eulerian

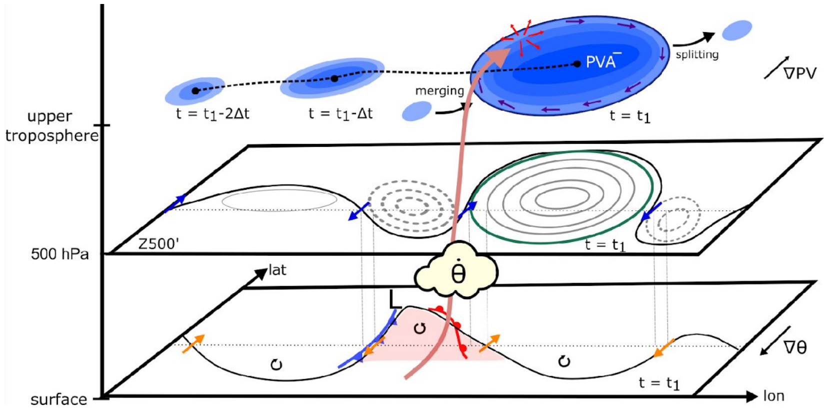


Teubler et al. (2023)

Good agreement with Lagrangian perspective (moist processes play a non-negligible role!)

“Disagreement” with Eulerian perspective because of remote moist-dynamical development of PVA^- outside of Europe (but hidden in dry-dynamical advection terms!)

Summary



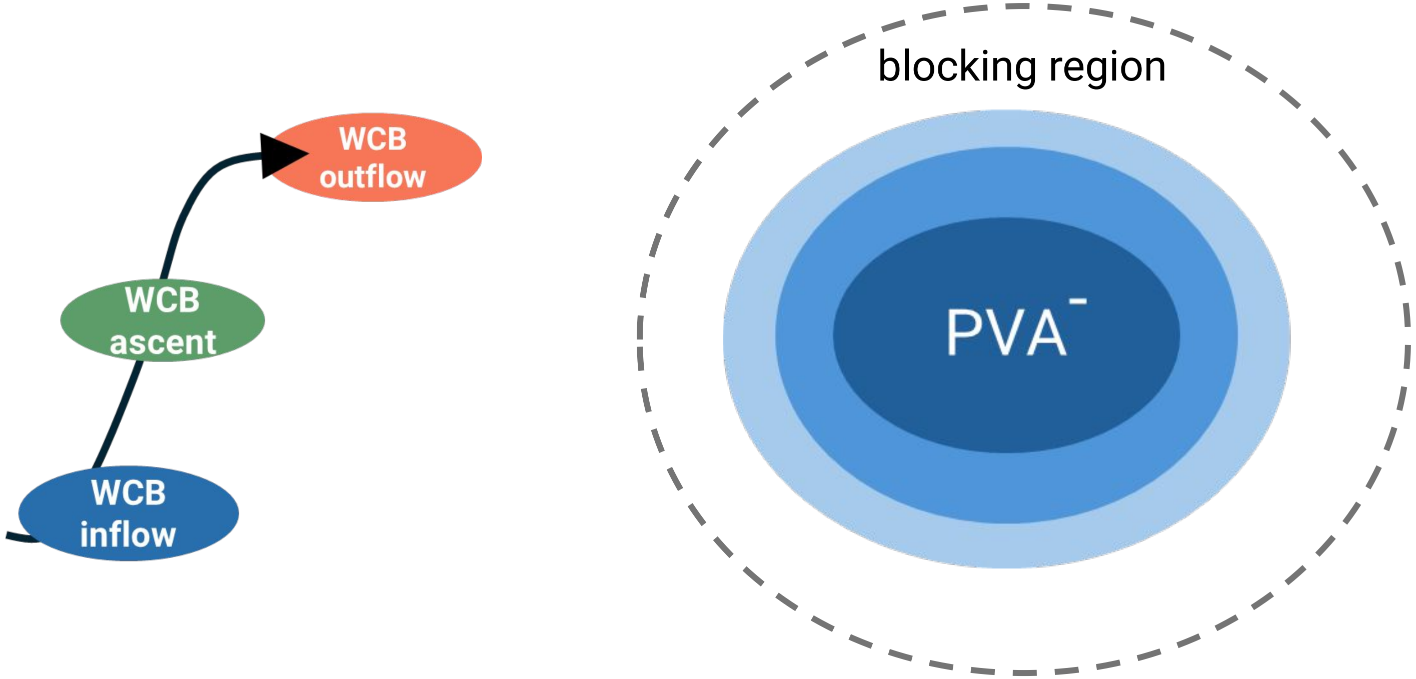
- Development of a novel quasi-Lagrangian PV framework to unify the separate Eulerian and Lagrangian perspectives on blocking dynamics

Key results from quasi-Lagrangian perspective

- Remote development of PVAs$^-$ linked to blocking over North Atlantic-European region and propagation along different pathways to blocking region
- Amplification of PVAs$^-$ takes place predominantly before the blocking onset and is dominated by moist dynamics (divergent PV tendencies)
- PVAs$^-$ moving over midlatitude storm-track region amplify much stronger by divergent PV tendencies (linked to WCB activity)

Summary

Is it the perspective that matters?



We need a combination of perspectives to yield a comprehensive understanding of blocking dynamics and the role of moist processes

THANK YOU!

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