Contradictory results concerning the relative importance of dry and moist processes in blocking dynamics: Is it the perspective that matters?

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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, …
SESSION | Diabatic processes and feedbacks

- Solar & terrestrial radiation
- Phase changes of water species (i.e., clouds & precipitation)
- Surface sensible & latent heat fluxes
- Turbulence & friction
- Soil
Effects of diabatic processes on blocking

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

Turbulence & friction
predominantly neglected

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

Introduction  Perspectives  Quasi-Lagrangian  Case study  Climatology  Summary

R. Grotjahn, in Encyclopedia of Atmospheric Sciences, 2003

Lubis et al.
Latent heat release in mid-latitudes

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

Warm conveyor belt (WCB)

- Identification traditionally with trajectory analysis (Wernli and Davies, 1997)
  \[ \Delta p_{48h} > 600 \text{ hPa} \]
  - **WCB inflow**: \( p > 800\text{hPa} \)
  - **WCB ascent**: \( 400\text{hPa} < p < 800\text{hPa} \)
  - **WCB outflow**: \( p < 400\text{hPa} \)

- Novel Eulerian identification using deep learning (Quinting and Grams, 2022)
  - WCB footprints from Eulerian fields

*adjusted figure from Quinting and Grams (2022, JAS)*

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**Introduction**

**Perspectives**

**Quasi-Lagrangian**

**Case study**

**Climatology**

**Summary**
Importance of latent heat release for blocking

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

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

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

Magnusson (2017), Grams et al. (2018)
A joint consideration of dry and moist dynamics
Eulerian vs. Lagrangian perspectives

Many studies investigating the role of either dry or moist dynamics, often resulting in “contradictory” results.

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?
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

ERA5 reanalysis (1979-2021)

Hauser et al., 2023 (WCD)
A quasi-Lagrangian framework

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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

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**ERA5 reanalysis (1979-2021)**
A quasi-Lagrangian framework

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**Amplitude evolution of PVAs**

(Peubler and Riemer, 2016/2021)

PV (q) tendency equation

\[
\frac{\partial q}{\partial t} = - \mathbf{v} \cdot \nabla q + \mathcal{N}
\]

- **Advection of PV**
- **Non-conservative processes**

Partition wind field to look at different processes

\[
v = v_0 + v_{\text{div}} + v_{\text{up}} + v_{\text{low}} + v_{\text{res}}
\]

- **Piecewise**
- **PV inversion**

Hauser et al., 2023 (WCD)
A quasi-Lagrangian framework

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Amplitude evolution of PVAs

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

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

$$= \int_{A(t)} \left[ -\mathbf{v}_{div}' \cdot \nabla q_0 + \mathbf{N}' \cdot \nabla \mathbf{v}_{div}' \right] \, dA$$

$$= \int_{A(t)} \left[ -\mathbf{v}_{res}' \cdot \nabla q_0 + \mathbf{N}' \right] \, dA + \int_{S(t)} q' (\mathbf{v}_s - \mathbf{v}) \, dS$$

ERA5 reanalysis (1979-2021)

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
The European blocking “bust case” in March 2016
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)

Hauser et al., 2023 (WCD)
The European blocking “bust case” in March 2016
Role of moist processes and direct diabatic modifications

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)
From case study to systematic investigation

Key finding

#1

Where are PVAs located 4 days before blocking onset?

Greenland Blocking

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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.

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.

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**Pathway differences for European blocking**

**Net effect (-6 days to +2 days)**

Hauser et al., 2024 (WCD, in review)
Hauser et al., in preparation
From case study to systematic investigation

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

Key finding #3

Hauser et al., 2024 (WCD, in review)
Hauser et al., in preparation
Connecting the different perspectives

**Lagrangian**

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

**Quasi-Lagrangian**

**Eulerian**

“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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