The role of warm conveyor belts in the life cycle of Atlantic-European weather regimes

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Forecast busts

occasional poor forecasts still occur in modern NWP systems

+144h Z500 **ACC** - Europe

![Graph showing forecast initial time and model performance over time.](image-url)
Forecast busts

occasional poor forecasts still occur in modern NWP systems

**Onset of European Blocking**

ECMWF analysis  
PV@315K, wind@315K, and PMSL

→ WCB activity amplifies initial condition error and projects it on the large-scale extratropical circulation

Forecast busts

WCB error during EuBL onset

tram starting & pmsl 20160309_00  ECMWF analysis
tram ending & 2PVU@315K 20160311_00

→ WCB activity amplifies initial condition error and projects it on the large-scale extratropical circulation

Grams, Magnusson, and Madonna (2018), QJRMS, doi:10.1002/qj.3353
Forecast busts

WCB error during EuBL onset

Grams, Magnusson, and Madonna (2018), QJRMS, doi:10.1002/qj.3353
cloud-diabatic processes and blocking

>50% of air mass experiences LHR prior to arriving in blocking anticyclones

Why are regimes relevant?

Wind power variability

- Beerli et al. (2017) 10.1002/qj.3158
- Grams et al. (2017) 10.1038/nclimate3338

Modulation of heavy precipitation

- Piaget et al. (2015) 10.1002/qj.2496
- Grams et al. (2014) 10.5194/nhess-14-1691-2014
- Pasquier et al. (2019) 10.1029/2018GL081194

Heat waves

- Quinting and Reeder (2017) 10.1175/MWR-D-17-0165.1

Cold air outbreaks

  plot by L. Papritz
Relevance of weather regimes

What is the role of warm conveyor belts in the life cycle of Atlantic-European weather regimes?

WR describe multi-day variability of large-scale extratropical circulation over a specific region

- quasi-stationary (continent-size)
- persistent (> 5 days)
- recurrent

(e.g. Reinhold and Pierrehumbert 1983; Vautard, 1990, Molteni et al. 1990, Michelangeli and Vautard, 1995, Ferranti et al. 2015)
Atlantic-European weather regimes

- year-round 7 regimes & life-cycle definition
- Z500 ERA-Interim reanalysis (1979-2015)

Cyclonic regimes:
- Atlantic trough
- Zonal Regime
- Scandinavian trough

Blocked regimes:
- Atlantic ridge
- European blocking
- Scandinavian blocking
- Greenland blocking

Grams et al. (2017), doi:10.1038/nclimate3338
Weather regime life cycles

- Weather regime Index $I_{wr}$ following Michel and Rivière (2011), JAS, doi:10.1175/2011JAS3635.1
- Objective definition of onset, maximum, decay for individual weather regime
WCB activity during WR life cycles

- cyclone, **WCB inflow & outflow**, and **blocking** frequency anomalies during weather regime life cycle
  
  (Madonna et al. 2014, JCLI, Sprenger et al. 2017, BAMS)
Blocking during WR

Blocking frequency anomaly during active (on-dc) weather regime life cycles
(Schwierz et al., 2004)

Black contours: DJF mean frequency (contours every 0.02).
Shading: anomaly during active weather regime life cycle (onset to decay).
WCB outflow during WR

**WCB outflow** frequency anomaly during active (on-dc) weather regime life cycles (Madonna et al. 2014, Sprenger et al. 2017)

Black contours: DJF mean frequency (contours every 0.02). Shading: anomaly during active weather regime life cycle (onset to decay).
Chicken and egg problem

Blocking $\leftrightarrow$ WCB

$\rightarrow$ Lagged composites in period around onset

\begin{itemize}
  \item WCB inflow
  \item WCB outflow
  \item cyclone L
  \item blocking H
\end{itemize}
Lagged composites at EuBL onset

→ WCB activity supports onset and maintenance of European blocking

WCB inflow
-4d to -2d

WCB outflow
-2d to onset

blocking
onset to +2d

cyclones
-2d to onset

cyclone
L

blocking
H
All blocked regime variants

**WCB outflow** frequency anomaly at onset of blocked regimes (onset to +2d)

Black contours: DJF mean frequency (contours every 0.03).
Shading: anomaly during active weather regime life cycle (onset to decay).

<table>
<thead>
<tr>
<th>Region</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>9.7%</td>
</tr>
<tr>
<td>EuBL</td>
<td>10.9%</td>
</tr>
<tr>
<td>ScBL</td>
<td>6.5%</td>
</tr>
<tr>
<td>GL</td>
<td>11.7%</td>
</tr>
</tbody>
</table>

→ WCB activity during onset and maintenance of blocked weather regimes

**and this is critical for forecast busts**

(QJRMS, doi:10.1002/qj.3353)
WCB activity also present during cyclonic regimes!?

**WCB outflow** frequency anomaly during active (on-dc) weather regime life cycles (Madonna et al. 2014, Sprenger et al. 2017)

Black contours: DJF mean frequency (contours every 0.02).
Shading: anomaly during active weather regime life cycle (onset to decay).
WCB outflow at ScTr onset

- lags wrt. onset

Scandinavian Trough

Z500 ScTr

-4d to -2d

-2d to onset

onset to +2d

+2d to +4d

+4d to +6d

less frequent

WCB outflow

more frequent
300hPa zonal wind at ScTr onset

- lags wrt. onset

• 6d to -4d
• -4d to -2d
• -2d to onset

Scandinavian Trough

onset to +2d
• +2d to +4d
• +4d to +6d

300 hPa wind speed anomaly

-25 -23 -21 -19 -17 -15 -13 -11 -9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 [0-1]
WCB outflow at EuBL onset

• lags wrt. onset

European blocking

Z500 EuBL

-4d to -2d

-2d to onset

onset to +2d

+2d to +4d

+4d to +6d

[0-1]

less frequent

WCB outflow

more frequent
300hPa zonal wind at EuBL onset

- lags wrt. **onset**

-6d to -4d

-4d to -2d

-2d to **onset**

**onset** to +2d

+2d to +4d

+4d to +6d

**European blocking**

![300hPa wind speed anomaly](image)
300 hPa zonal wind during WR

300 hPa zonal wind speed anomaly during active (on-dc) weather regime life cycles

→ strong jet during cyclonic regimes hinders accumulation of WCB outflow air

(see also Riboldi et al. 2018, MWR, doi:10.1175/MWR-D-17-0219.1)
Summary

- WCB during WR life cycles are a predictability challenge due to upscale error growth
- Diabatic WCB outflow supports onset and maintenance of blocked regimes
- Absence of strong jet allows “accumulation” of outflow air mass

Ongoing work

- Eulerian WCB metric (talk Thu Julian Quinting)
- WR and diabatic outflow in S2S models (poster Dominik Büeler and talk Thu Jan Wandel)
- Sensitivity of WCBs on SPPT (poster Moritz Pickl)
Extra Slides
Challenges: Blocking and RWP in S2S models

- Subseasonal prediction models underestimate blocking frequency in the Atlantic/European region

  - Rossby waves propagate too far eastward
  - Strong lack of blocking during RWP decay

Slide by J. F. Quinting
Forecast opportunity: WR & large-scale extremes

- multiple pathways to regional extreme events via preferred weather regimes

Stratospheric modulation of WR frequencies

frequency in **strong** / **neutral** / **weak**
stratospheric conditions

frequency following weak stratospheric polar
vortex events (SSWs)

stratosphere provides window of S2S predictability up to 40 days

Limited forecast skill in S2S models

2m temperature anomaly 0-30d after weak stratospheric polar vortex

ECMWF extended-range reforecasts

ERA-Interim

A cooperation with aspo ETH Zürich

Slide by D. Büeler with R. Beerli