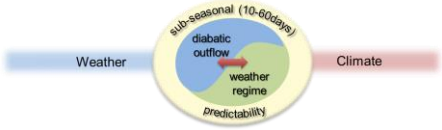
Karlsruhe Institute of Technology

*Young Investigator Group VH-NG-1243: "**S**ub-seasonal **PRE**dict**A**bility: understanding the role of **D**iabatic **OUT**flow" (SPREADOUT)*



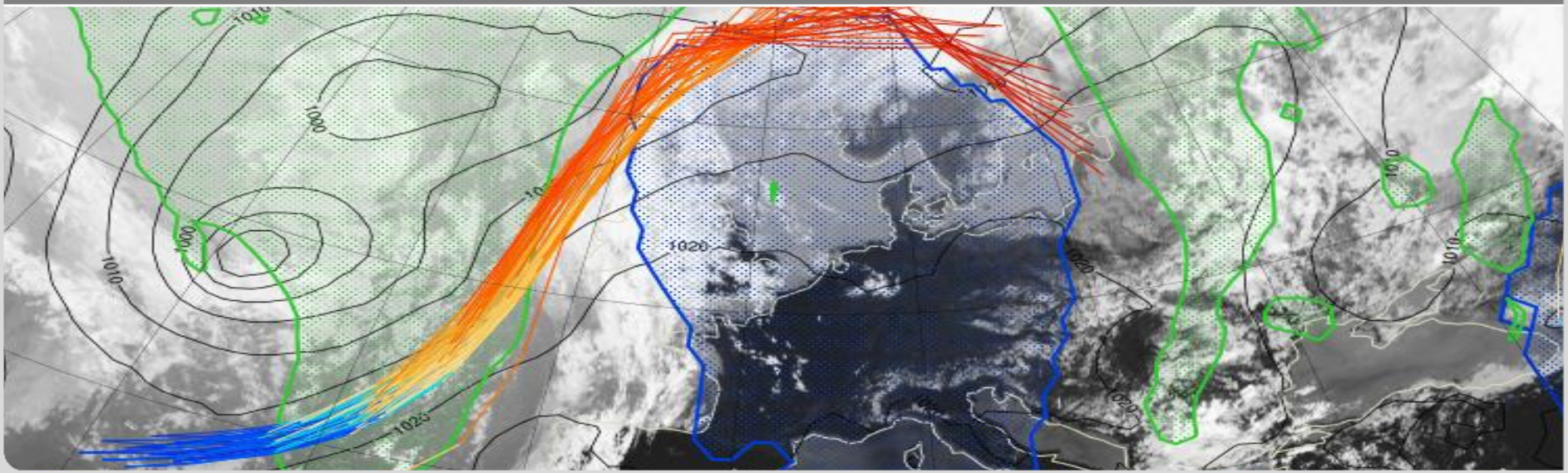
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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

Christian M. Grams - *Large-scale Dynamics and Predictability Group*

Acknowledgments: Maxi Böttcher, Dominik Büeler, Laura Ferranti, Erica Madonna, Linus Magnusson, Lukas Papritz, Stephan Pfahl, Julian Quinting, Michael Sprenger, Heini Wernli, and others

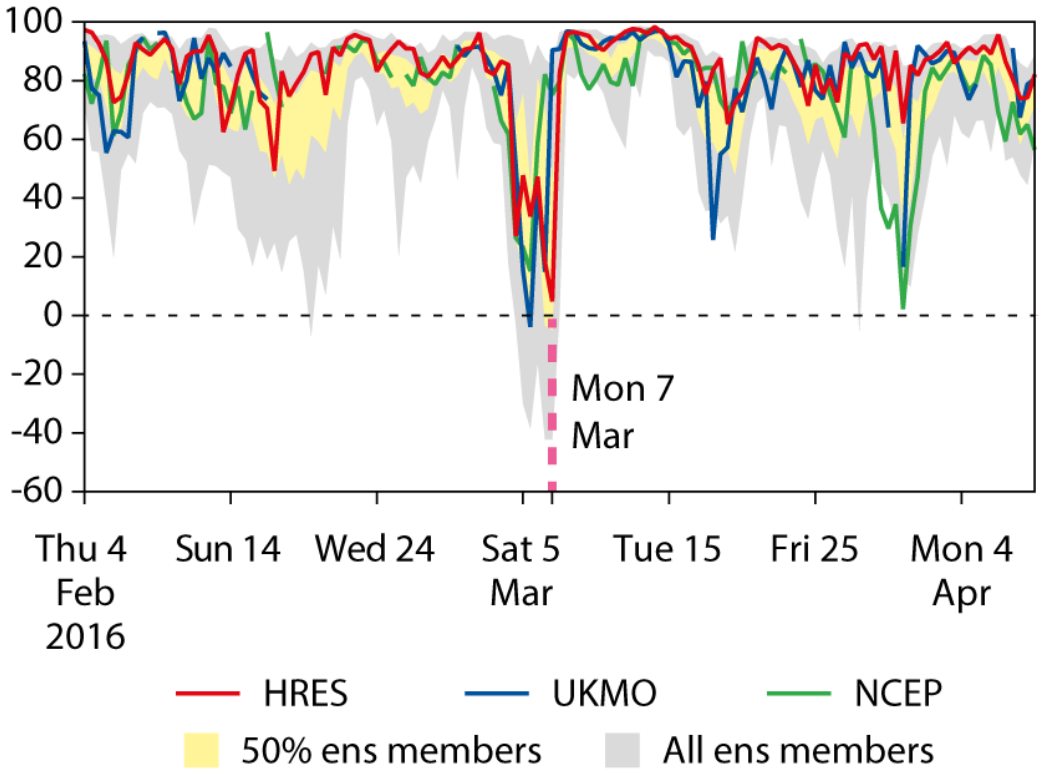
Institute of Meteorology and Climate Research – Department Troposphere Research



Forecast busts

occasional poor forecasts still occur in modern NWP systems

+144h Z500 **ACC** - Europe



forecast initial time

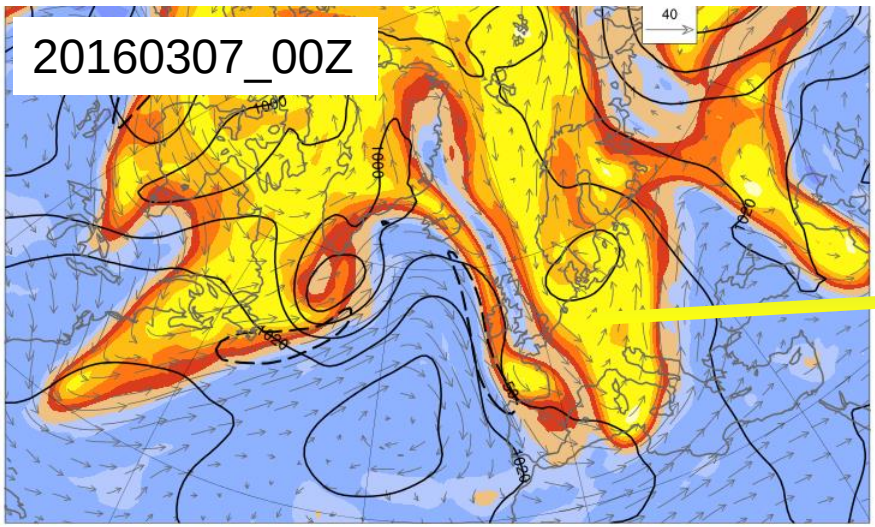
Forecast busts

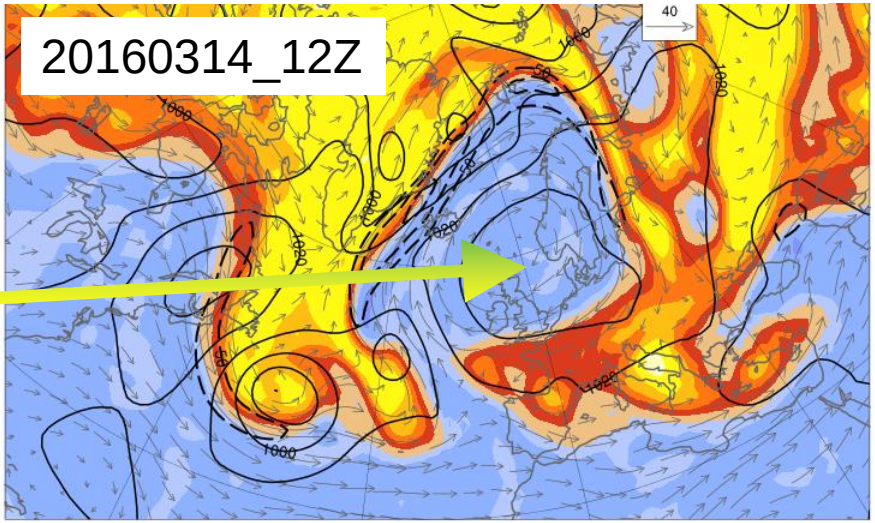
occasional poor forecasts still occur in modern NWP systems

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

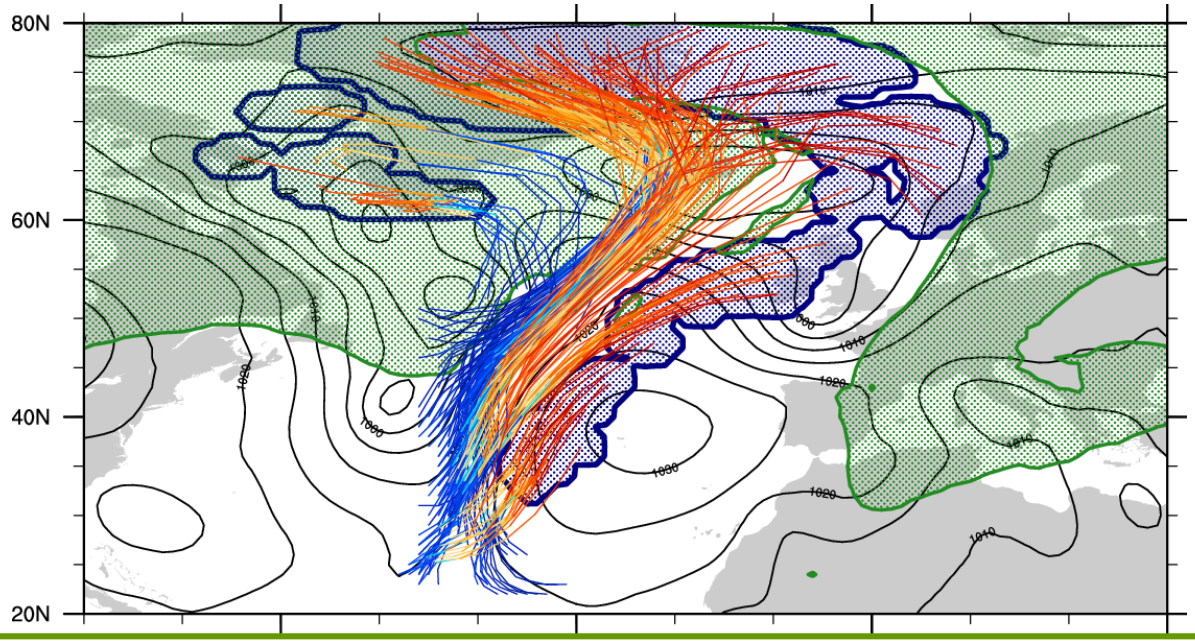
Grams, Magnusson, and Madonna (2018), *QJRMS,* doi:10.1002/qj.3353

Forecast busts

WCB error during **EuBL** onset

tra starting & pmsl 20160309_00 ECMWF analysis

tra 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

Grams, M

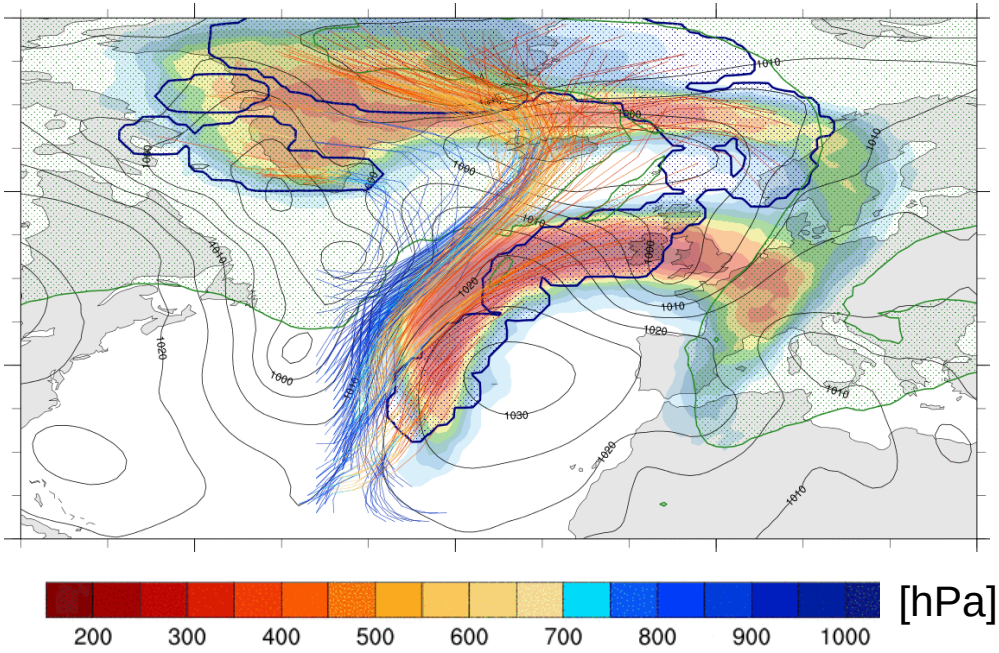
Forecast busts

WCB error during **EuBL** onset

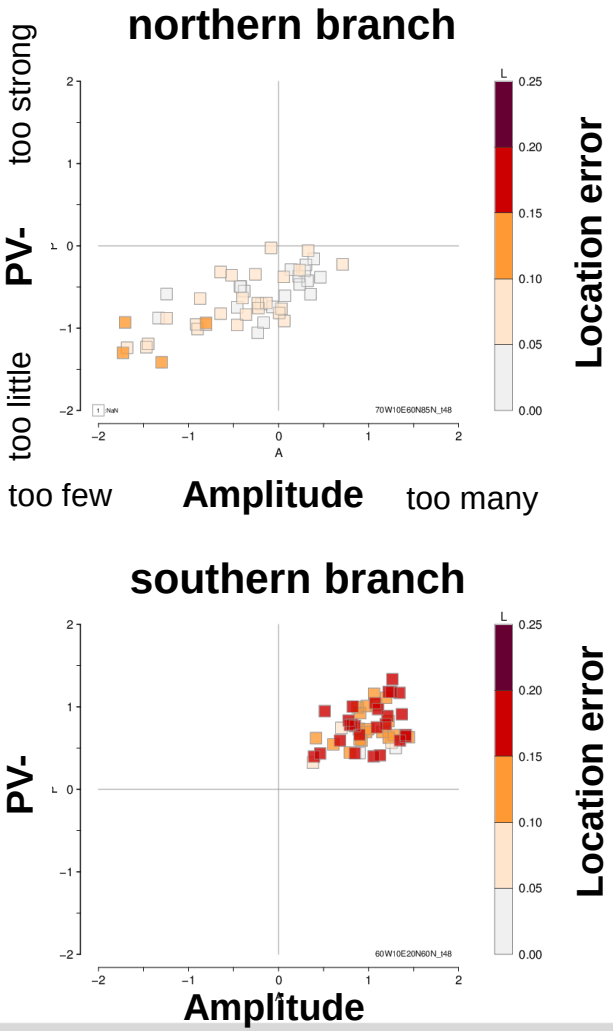
tra starting & pmsl 20160309_00

tra ending & 2PVU@315K 20160311_00

ECMWF analysis & ensemble

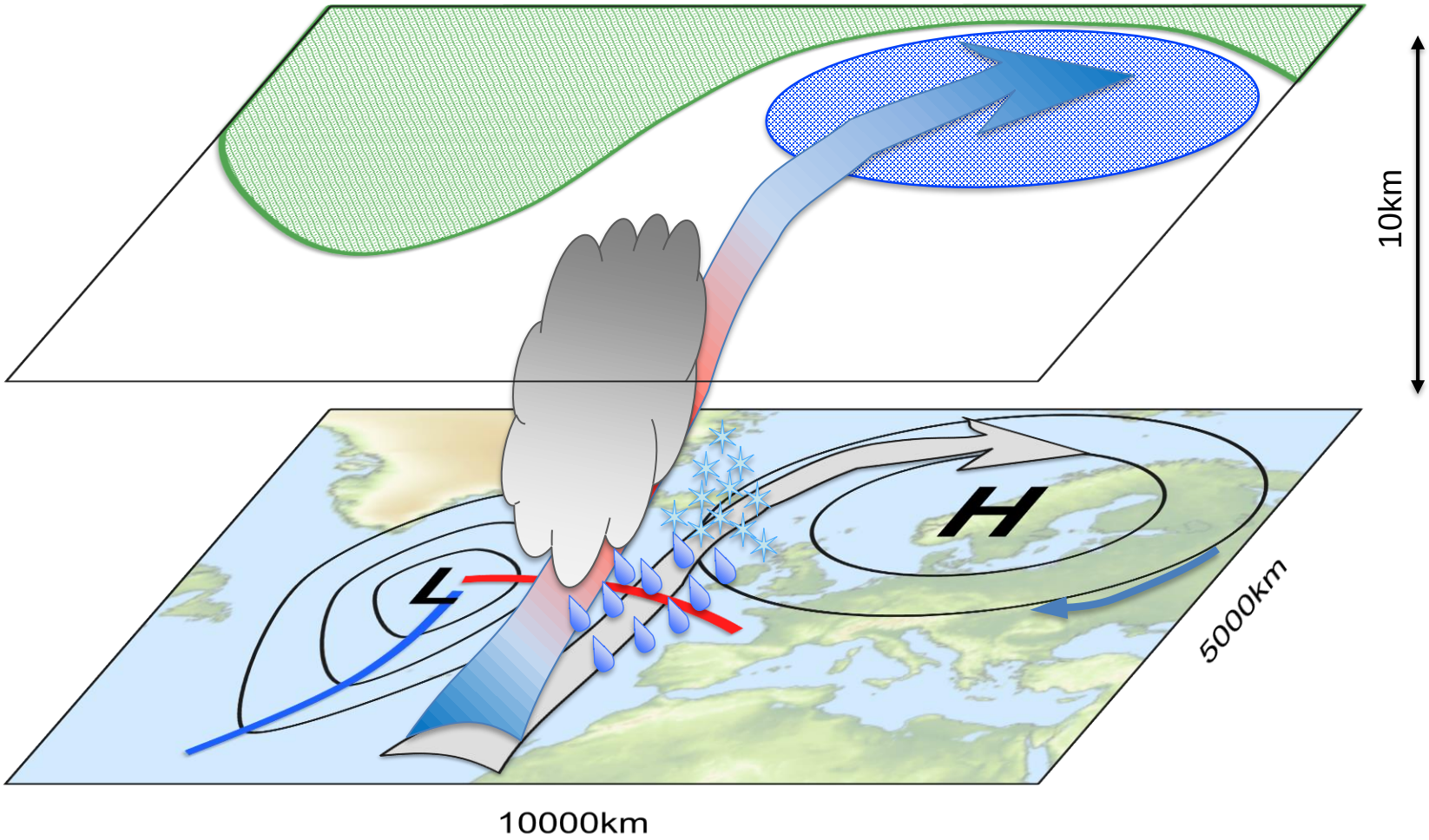


ECMWF ensemble



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

cloud-diabatic processes and blocking

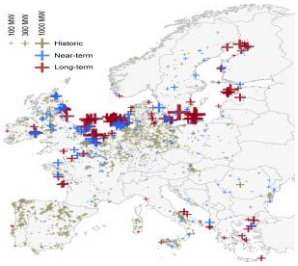


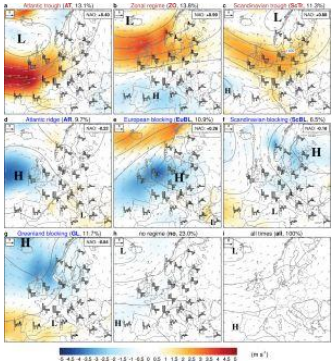
- **>50% of air mass** experiences **LHR** prior to arriving in **blocking anticyclones**

Pfahl et al (2015): *Nature Geosci*, doi:10.1038/ngeo2487.

Why are regimes relevant?

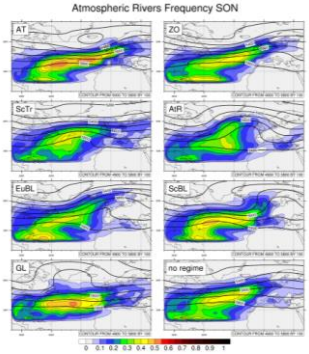
Wind power variability

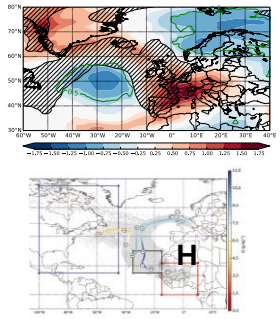




Beerli et al. (2017) 10.1002/qj.3158
Grams et al. (2017) 10.1038/nclimate3338

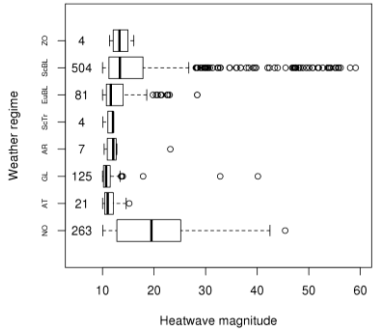
Modulation of heavy precipitation

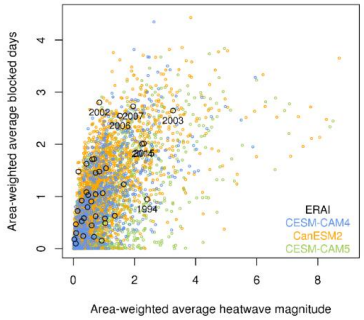




Piaget et al. (2015) 10.1002/qj.2496, Grams et al. (2014) 10.5194/nhess-14-1691-2014, Pasquier et al. (2019) 10.1029/2018GL081194

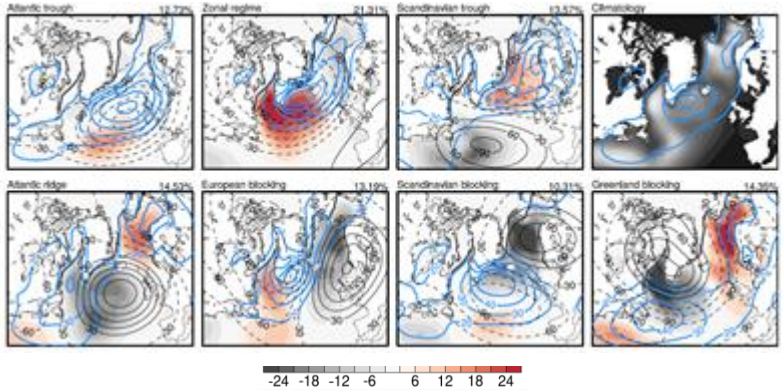
Heat waves





Quinting and Reeder (2017) 10.1175/MWR-D-17-0165.1
Schaller et al. (2018) 10.1088/1748-9326/aaba55

Cold air outbreaks

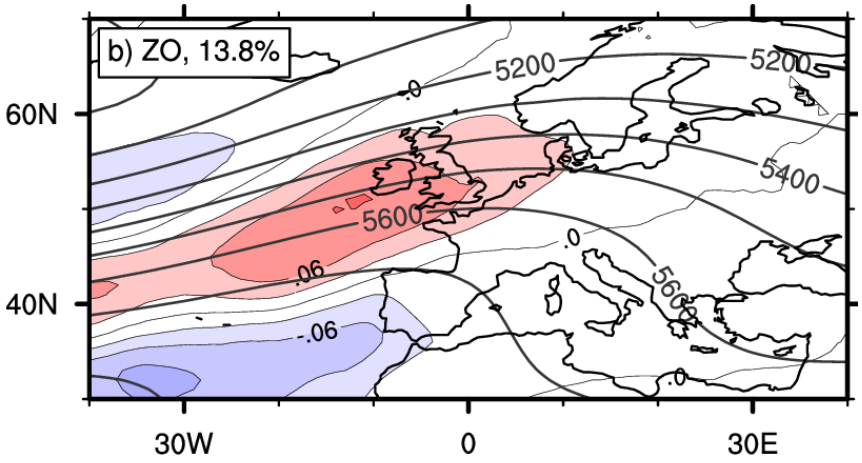


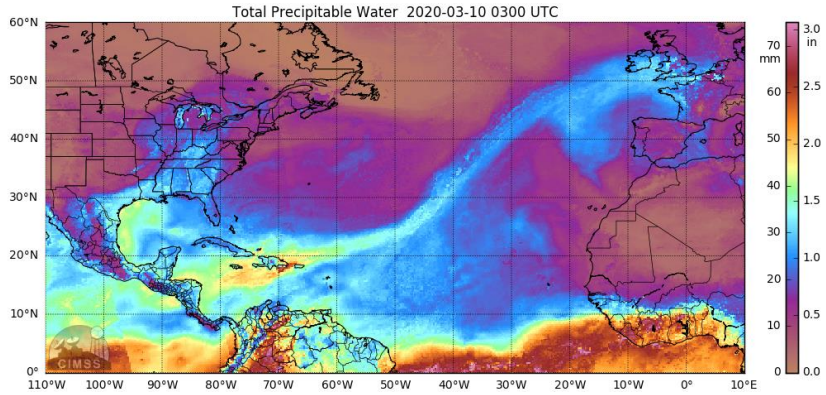
Papritz and Grams (2018) 10.1002/2017GL076921 plot by L. Papritz

Relevance of weather regimes

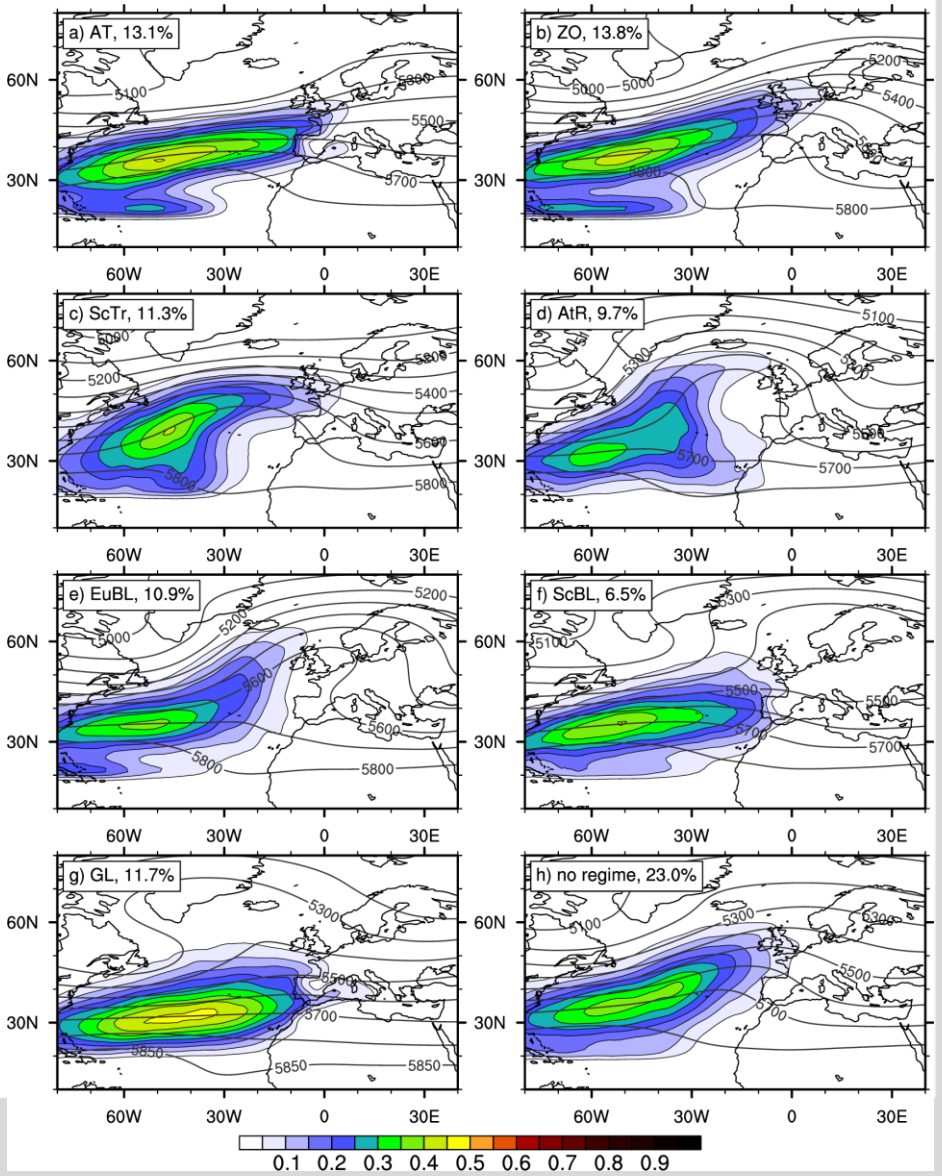
winter (DJF)

AR frequency during 7 regimes





ftp://ftp.ssec.wisc.edu/pub/mtpw2



Pasquier et al. (2019), *GRL*, doi:10.1029/2018GL081194

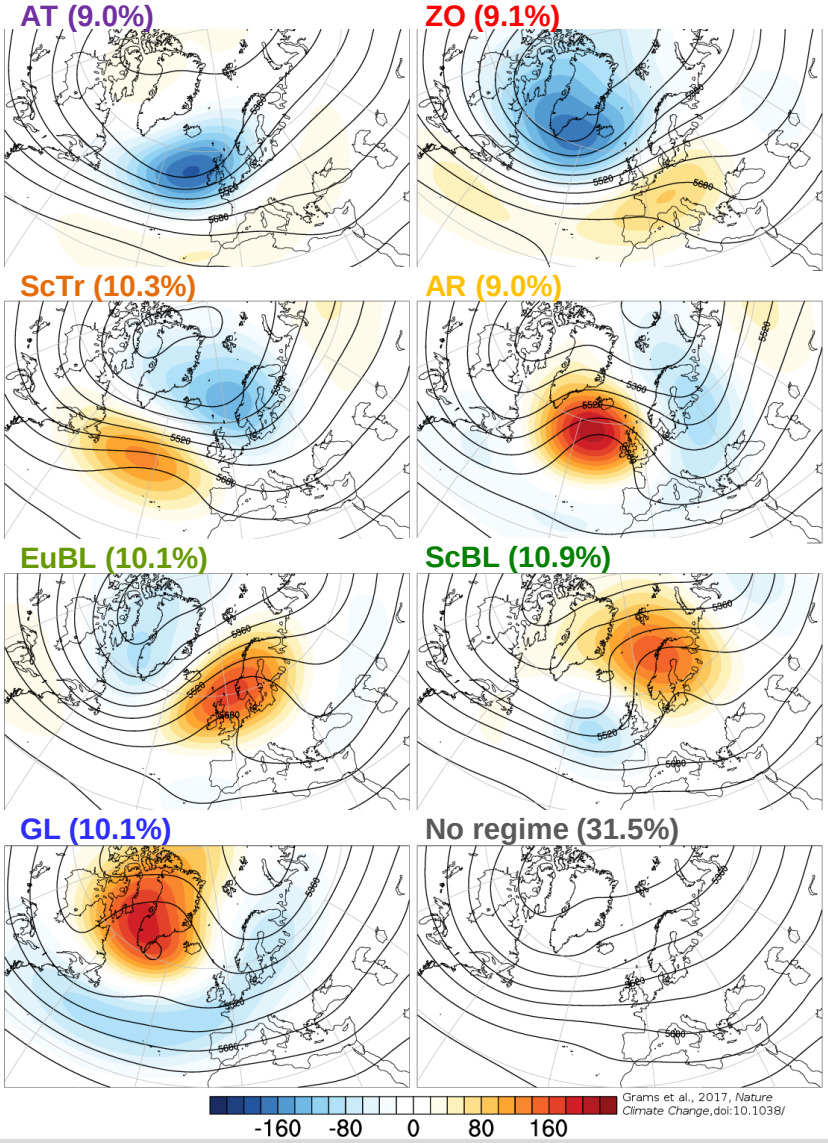
Christian M. Grams grams@kit.edu

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)

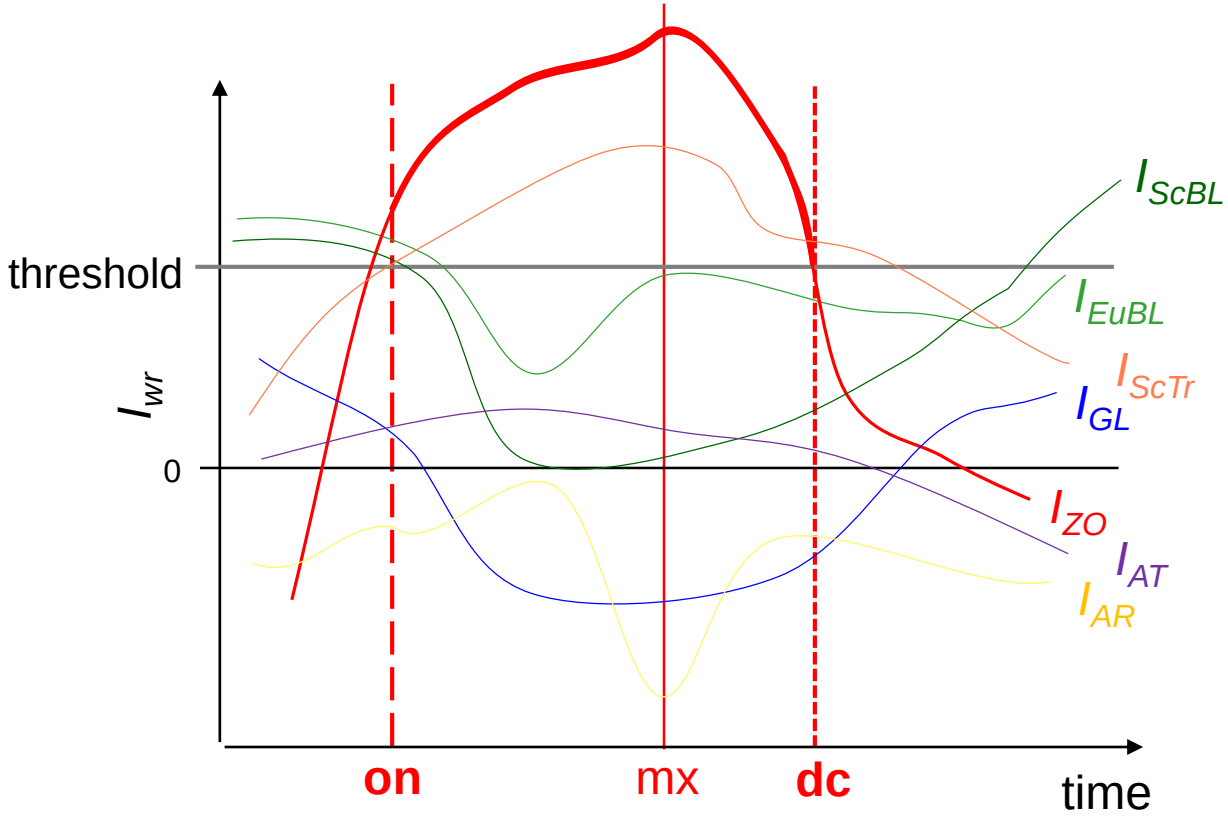
Cyclonic regimes:
- Atlantic trough
- Zonal Regime
- Scandinavian trough

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

Grams et al. (2017), doi:10.1038/nclimate3338

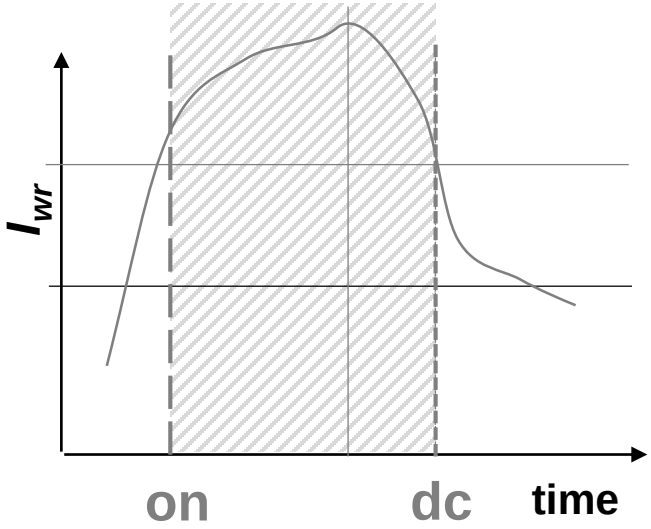
Weather regime life cycles

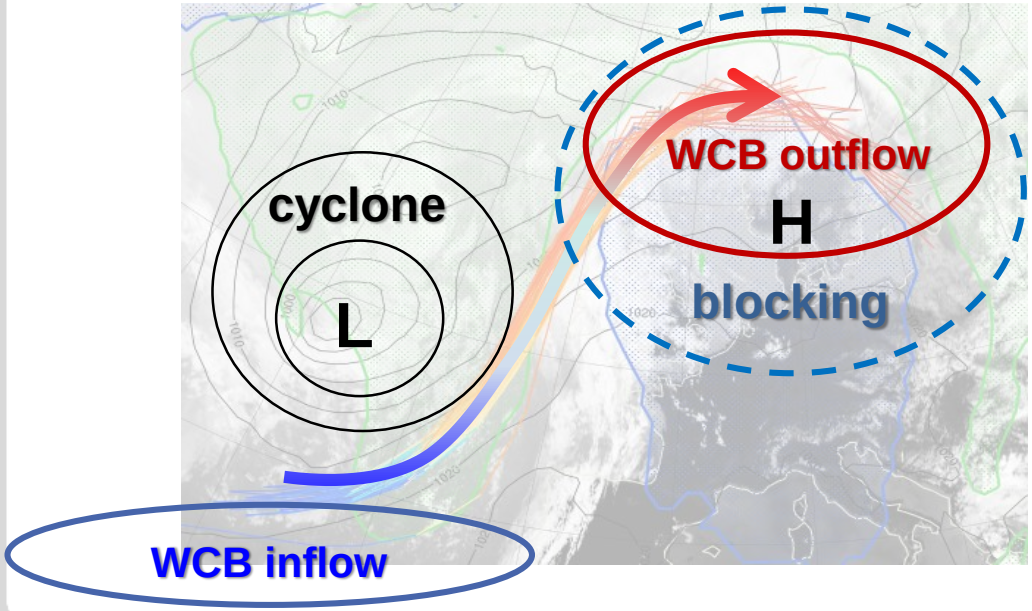
- Weather regime Index I_{wr} following Michel and Rivière (2011), *JAS,* doi:10.1175/2011JAS3635.1
- Objective definition of **onset,** maximum, **decay** for individual weather regime



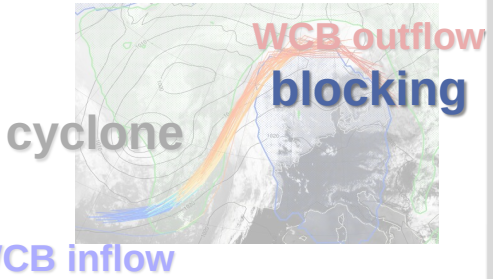
WCB activity during WR life cycles

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





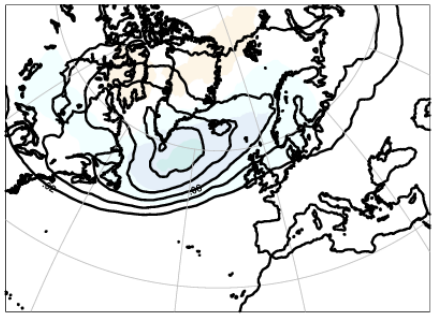
Blocking during WR



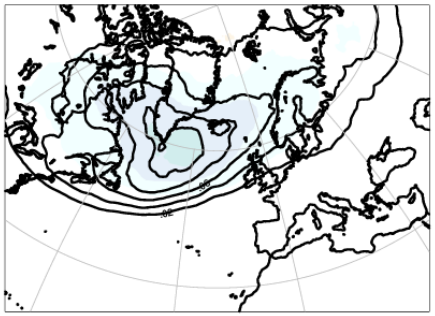
Blocking frequency anomaly during active (on-dc) weather regime life cycles
(Schwierz et al., 2004)

cyclonic

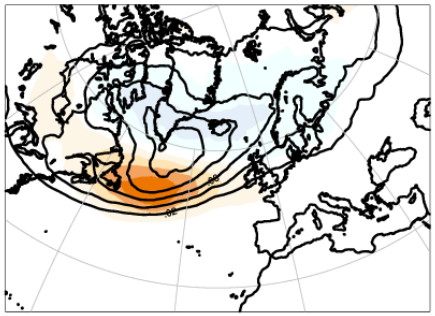
AT (13.1%)



ZO (13.8%)

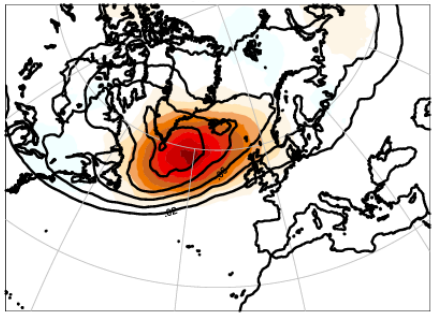


ScTr (11.3%)

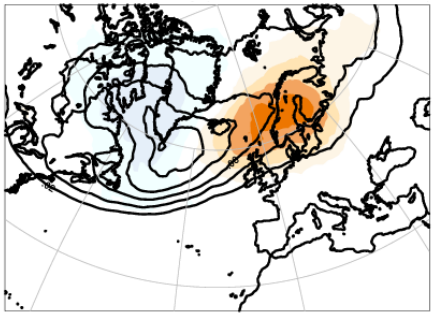


blocked

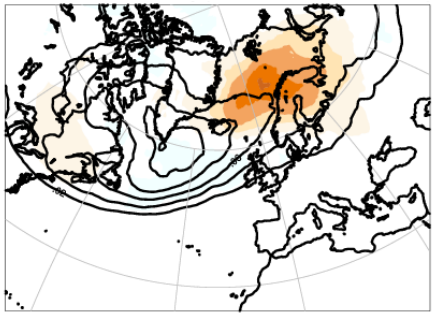
AR (9.7%)



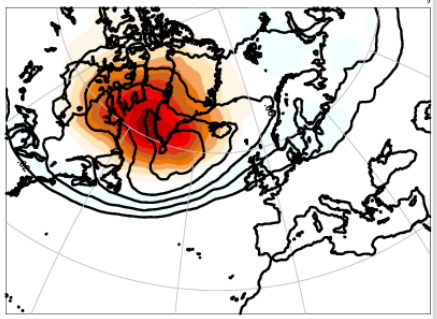
EuBL (10.9%)

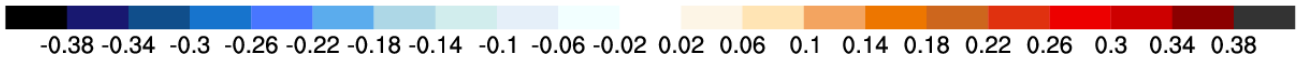


ScBL (6.5%)



GL (11.7%)



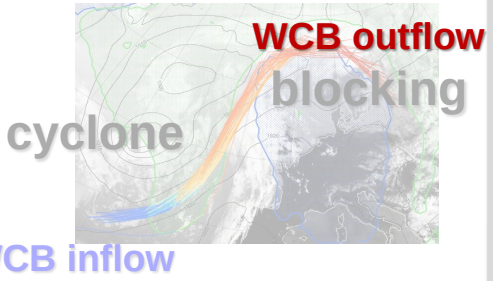


[0-1]

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

Christian M. Grams grams@kit.edu Institute of Meteorology and Climate Research (IMK-TRO)

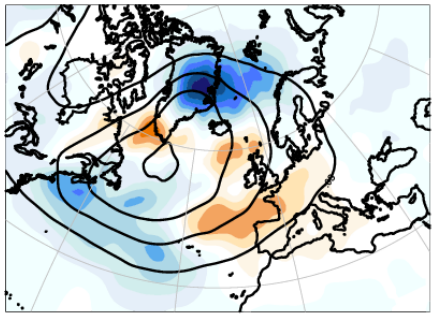
WCB outflow during WR



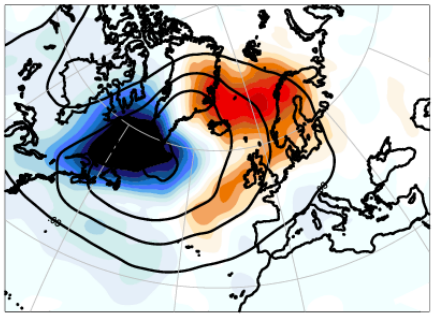
WCB outflow frequency anomaly during active (on-dc) weather regime life cycles
(Madonna et al. 2014, Sprenger et al. 2017)

cyclonic

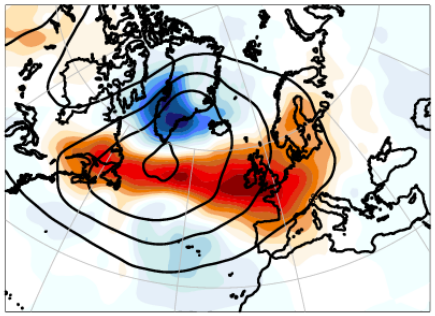
AT (13.1%)



ZO (13.8%)

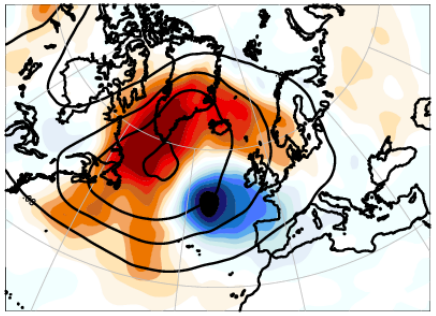


ScTr (11.3%)

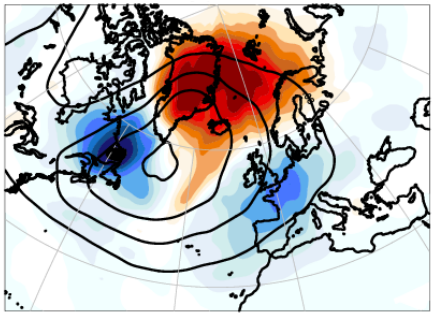


blocked

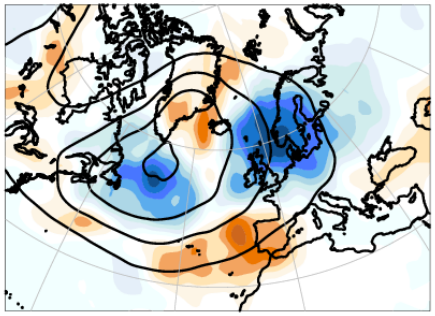
AR (9.7%)



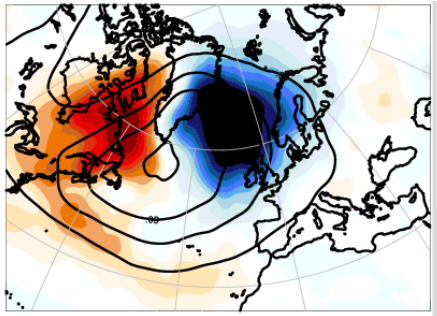
EuBL (10.9%)

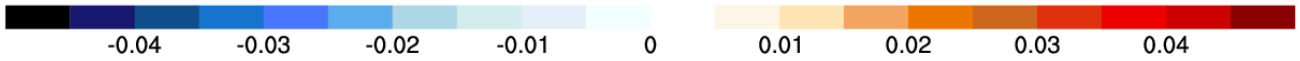


ScBL (6.5%)



GL (11.7%)





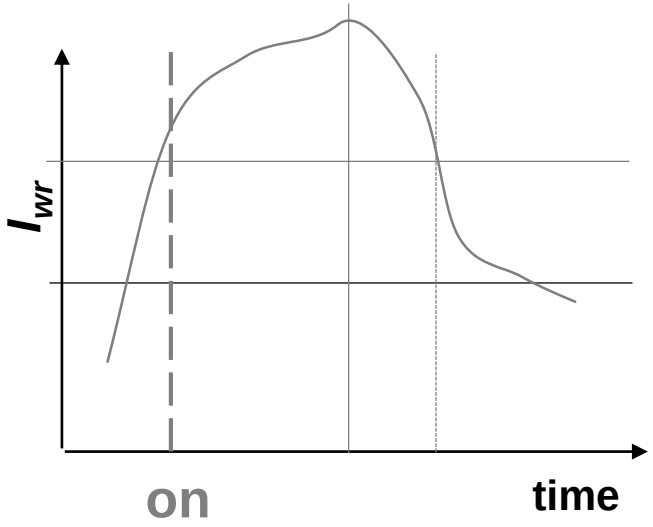
Black contours: DJF mean frequency (contours every 0.02).
Shading: anomaly during active weather regime life cycle (onset to decay).

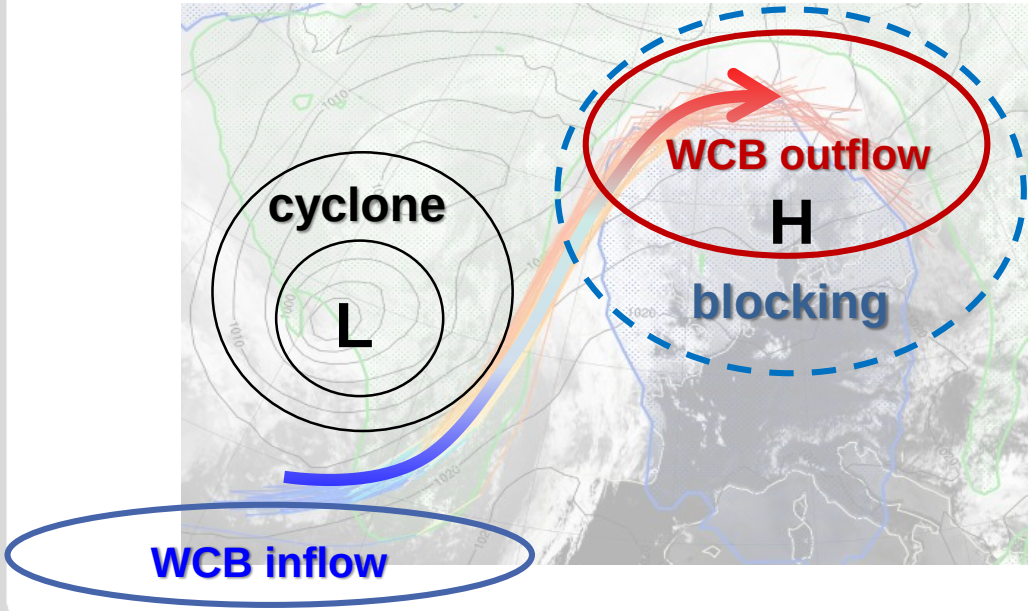
Christian M. Grams grams@kit.edu Institute of Meteorology and Climate Research (IMK-TRO)

Chicken and egg problem

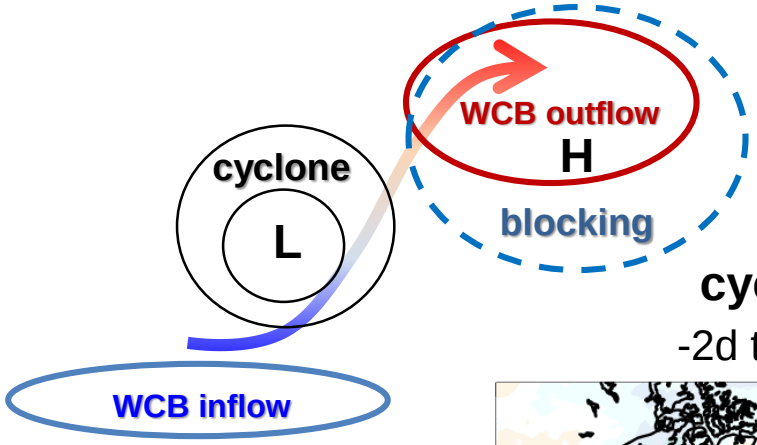
Blocking ↔ WCB

→ Lagged composites in period **around onset**



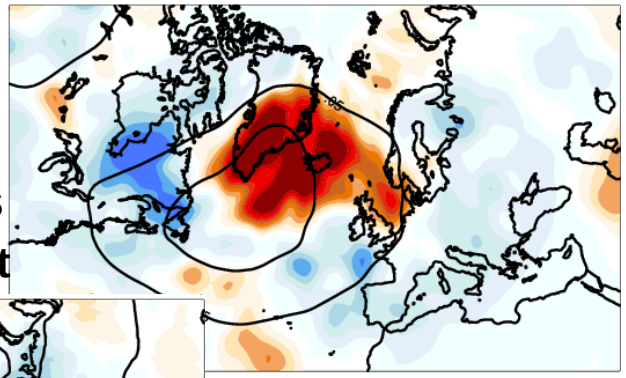


Lagged composites at EuBL onset



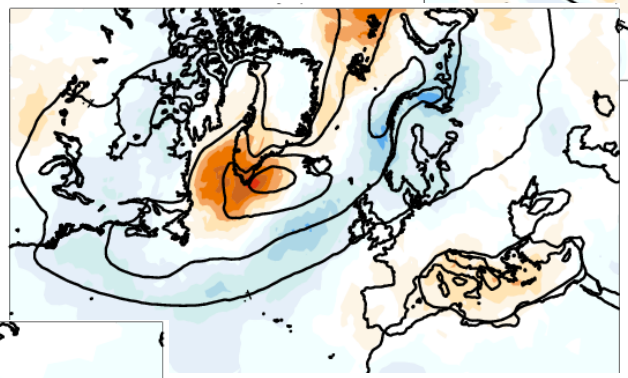
WCB outflow

-2d to **onset**



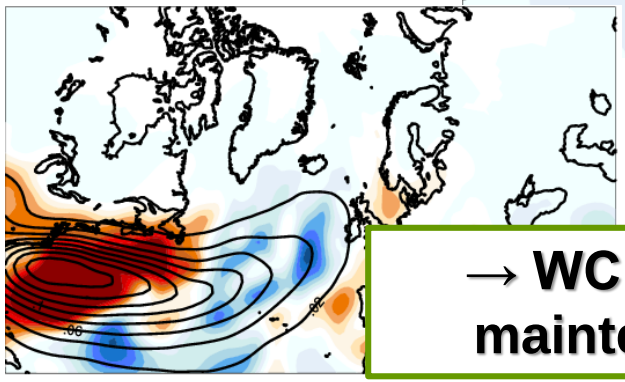
cyclones

-2d to **onset**



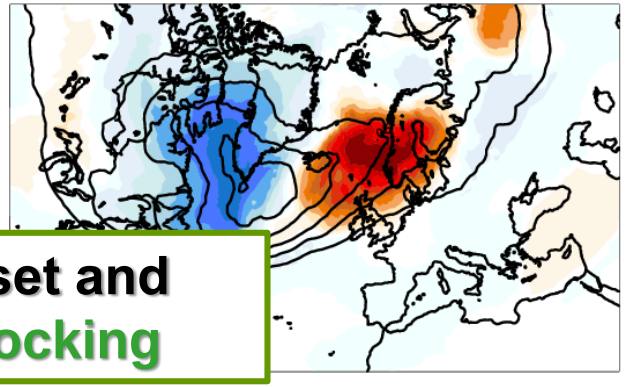
WCB inflow

-4d to -2d



blocking

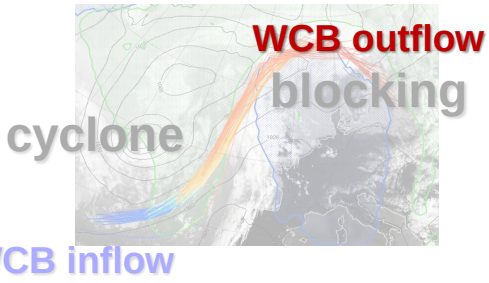
onset to +2d



→ **WCB activity supports onset and maintenance of European blocking**

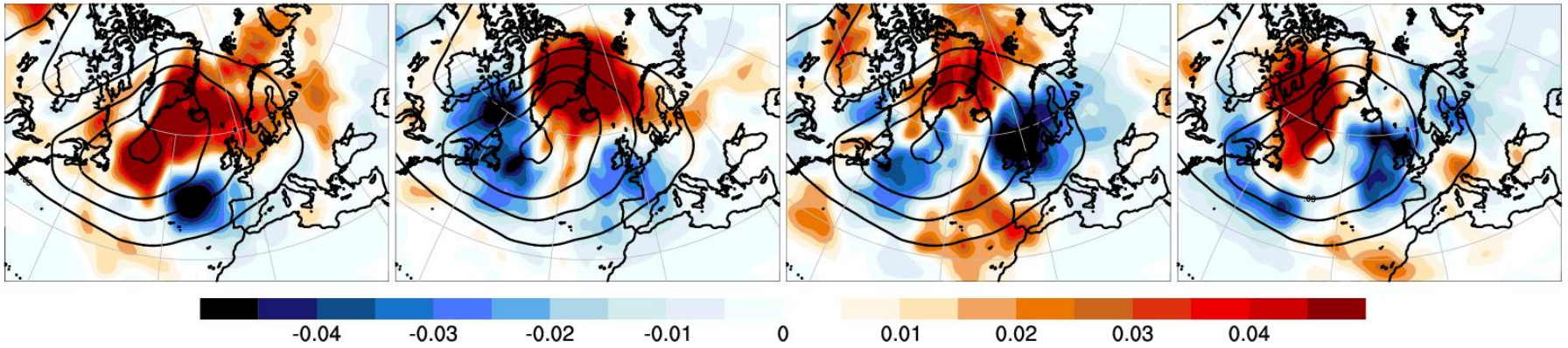
All blocked regime variants

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



blocked

AR (9.7%) EuBL (10.9%) ScBL (6.5%) GL (11.7%)



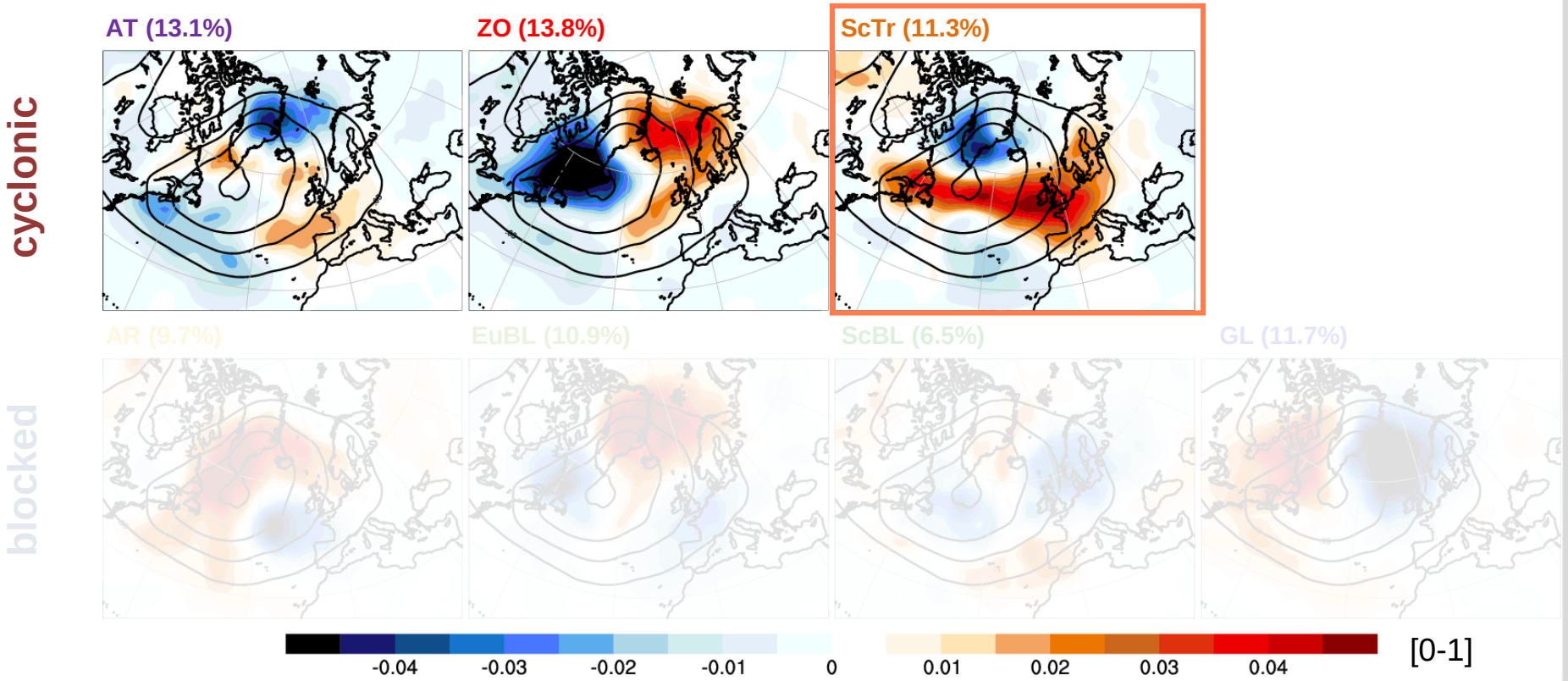
→ WCB activity during onset and maintenance of blocked weather regimes **and this is critical for forecast busts**

(*QJRMS*, doi:10.1002/qj.3353)

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

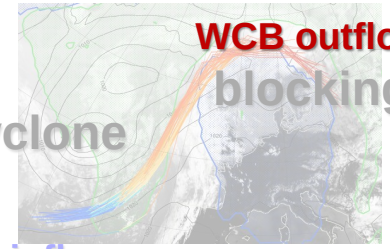
WCB activity also present during cyclonic regimes !?

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

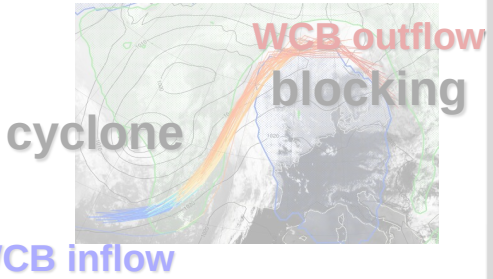
+4d to +6d

-0.04 -0.03 -0.02 -0.01 0 0.01 0.02 0.03 0.04 [0-1]

less frequent **WCB outflow** more frequent

Christian M. Grams grams@kit.edu Institute of Meteorology and Climate Research (IMK-TRO)

300hPa zonal wind at ScTr onset



- lags wrt. **onset**

Scandinavian Trough

-6d to -4d | -4d to -2d | -2d to **onset**

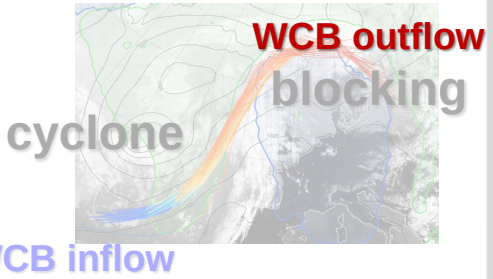
onset to +2d | +2d to +4d | +4d to +6d

-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]

300 hPa wind speed anomaly

Christian M. Grams grams@kit.edu Institute of Meteorology and Climate Research (IMK-TRO)

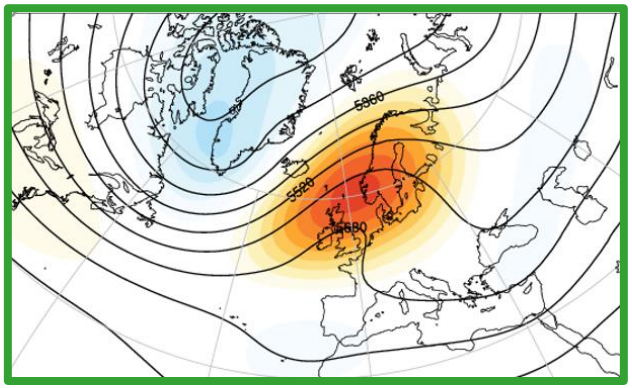
WCB outflow at EuBL onset



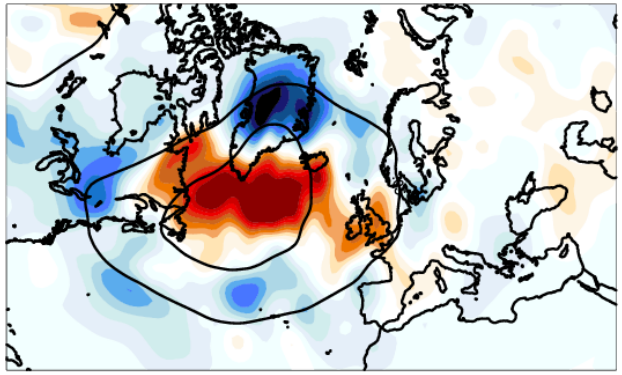
- lags wrt. **onset**

European blocking

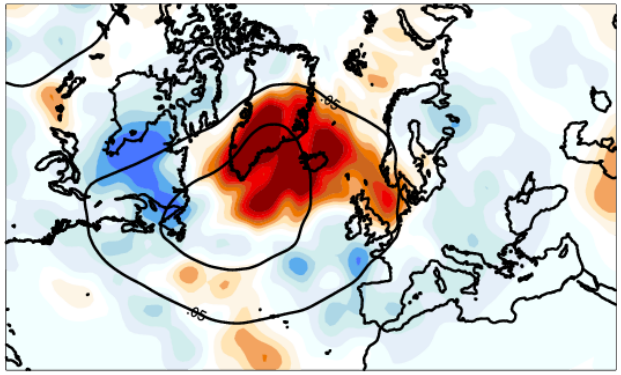
Z500 EuBL



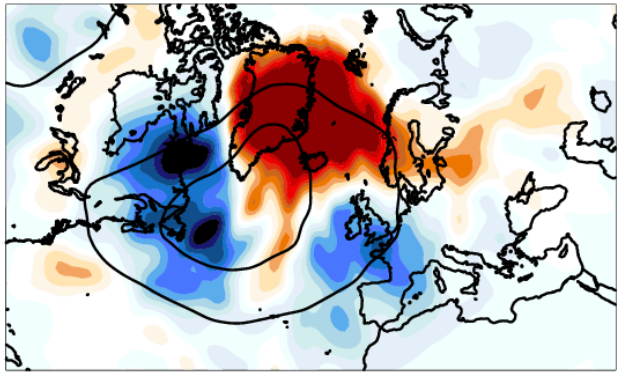
-4d to -2d



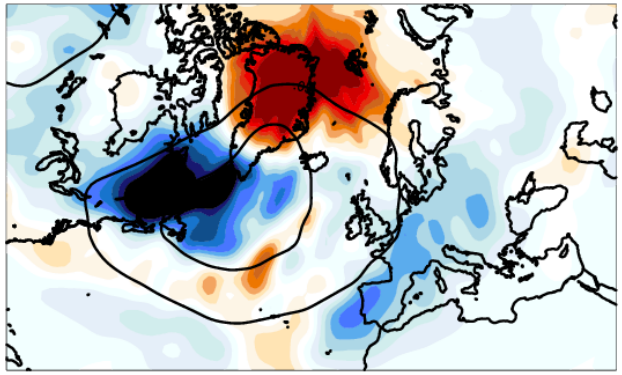
-2d to **onset**



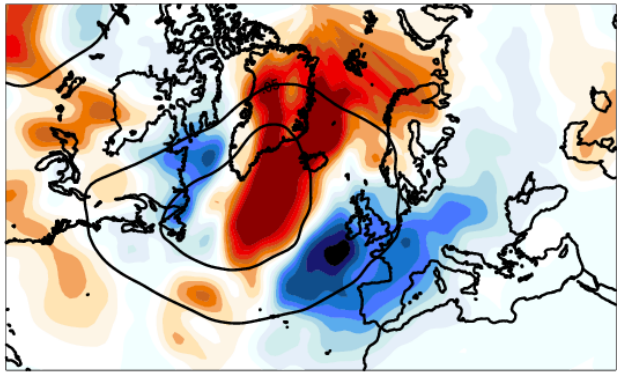
onset to +2d

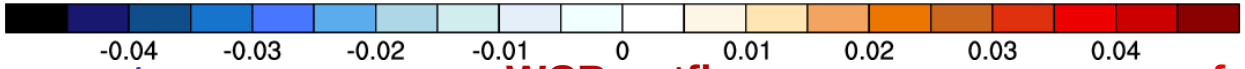


+2d to +4d



+4d to +6d

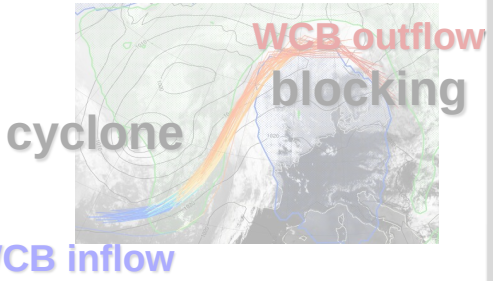




less frequent WCB outflow more frequent

Christian M. Grams grams@kit.edu Institute of Meteorology and Climate Research (IMK-TRO)

300hPa zonal wind at EuBL onset



- lags wrt. **onset**

European blocking

-6d to -4d | -4d to -2d | -2d to **onset**

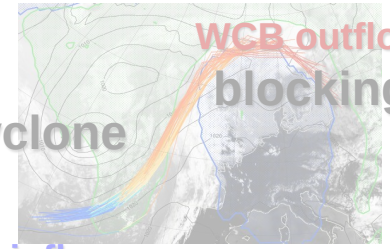
onset to +2d | +2d to +4d | +4d to +6d

-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]

300 hPa wind speed anomaly

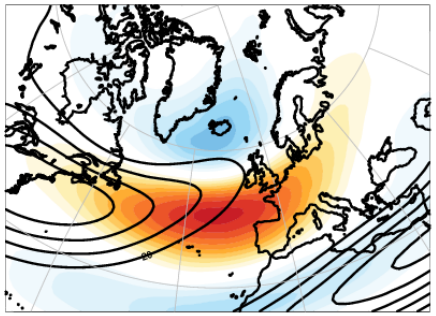
300 hPa zonal wind during WR

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

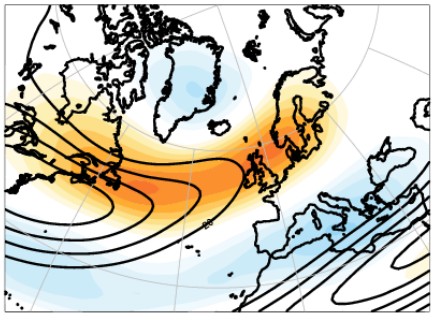


cyclonic

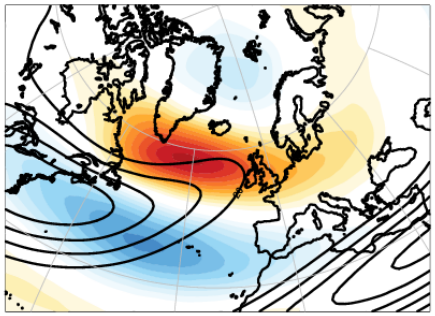
AT (13.1%)



ZO (13.8%)

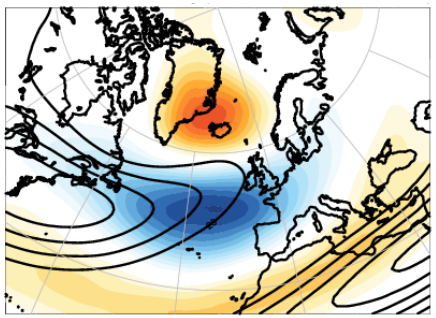


ScTr (11.3%)

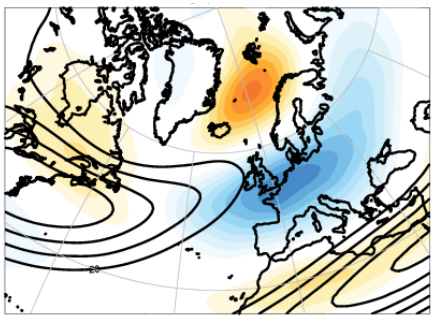


blocked

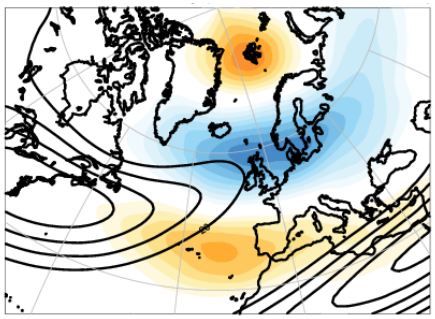
AR (9.7%)



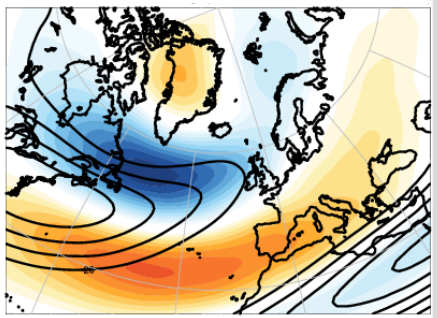
EuBL (10.9%)



ScBL (6.5%)



GL (11.7%)



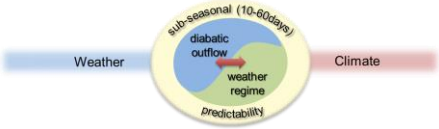
)-1]

Black contou
Shading: and

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

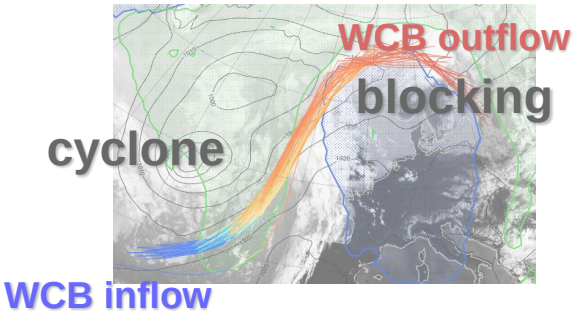
(see also Riboldi et al. 2018, *MWR*, doi:10.1175/MWR-D-17-0219.1)

MK-TRO)



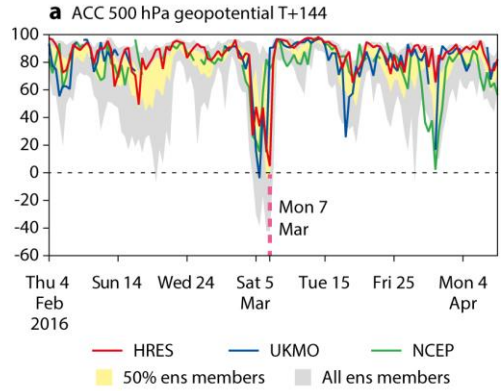
Summary

- 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

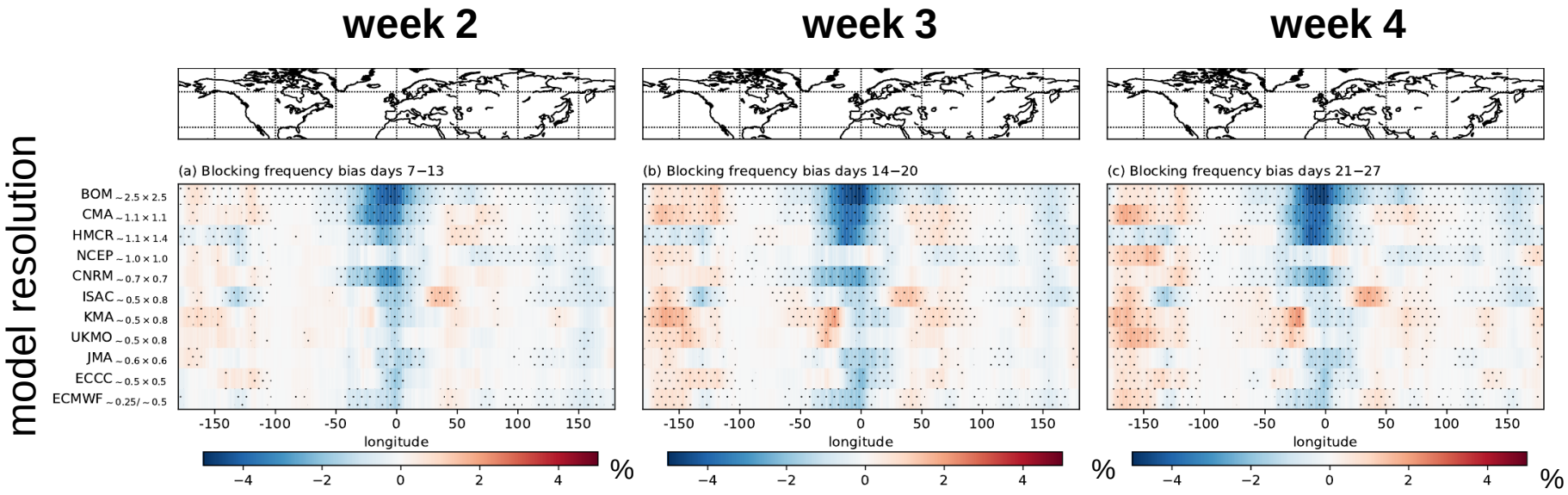
- Eulerian WCB metric (talk **Thu Julian Quinting**)
- WR and diabatic outflow in S2S models (poster **Dominik Büeler** and talk **Thu Jan Wandel**)
- Sensitivity of WCBs on SPPT (poster **Moritz Pickl**)



Extra Slides

Challenges: Blocking and RWP in S2S models

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

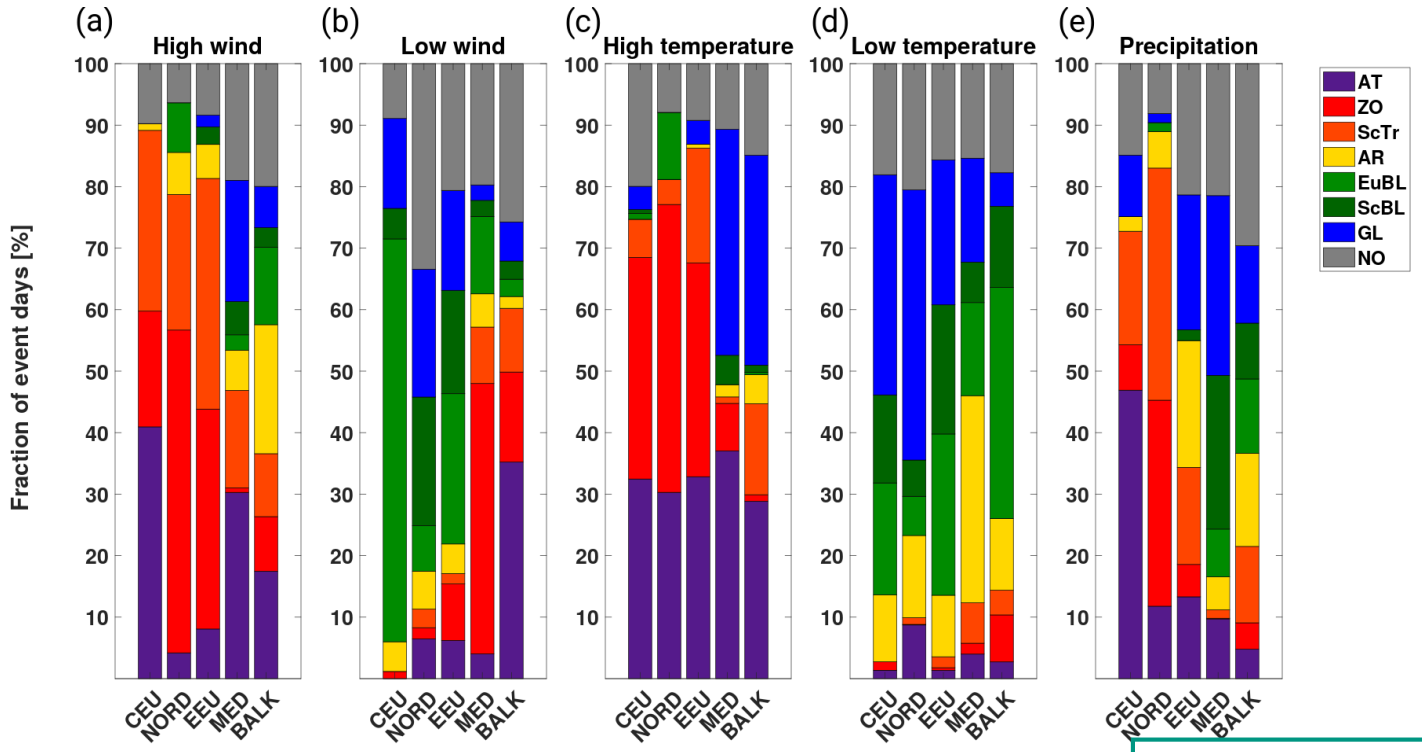


- **Rossby waves** propagate **too far eastward**
- strong lack of blocking during **RWP decay**

Slide by **J. F. Quinting**
Quinting and Vitart (2019), *GRL*, doi:10.1029/2018GL081381

Forecast opportunity: WR & large-scale extremes

- multiple pathways to regional extreme events via preferred weather regimes

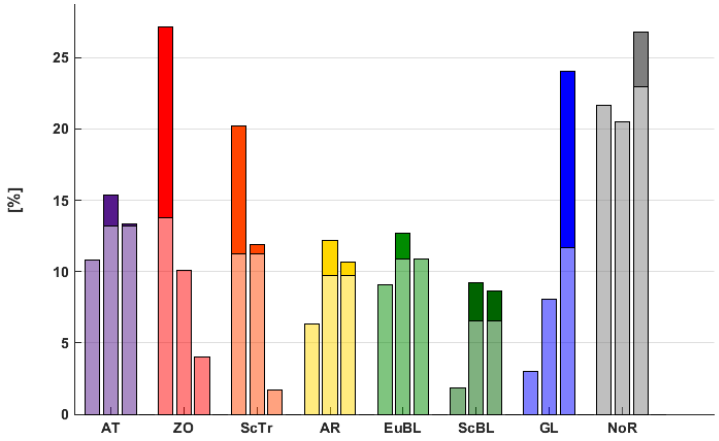


Beerli and Grams (2019), *QJRMS*, doi:10.1002/qj.3653

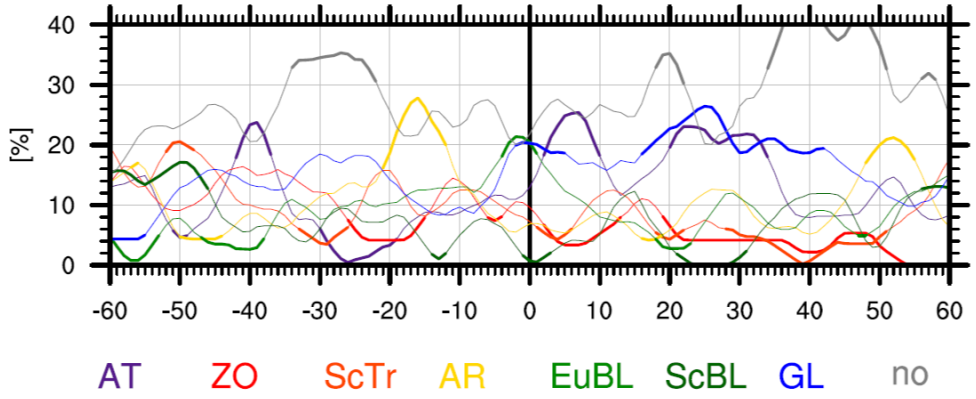
A cooperation with:

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

Beerli and Grams (2019) doi:10.1002/qj.3653

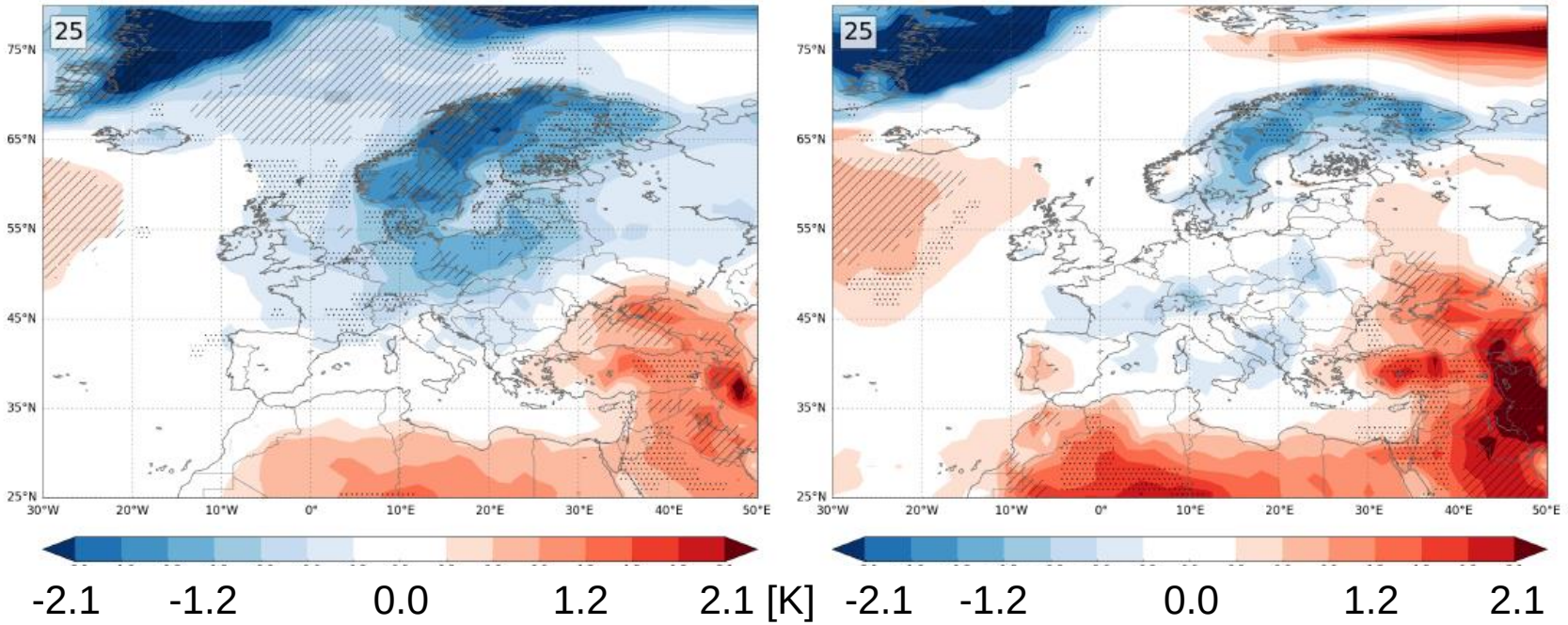
Papritz and Grams (2018) 10.1002/2017GL076921, Domeisen, Grams, Papritz (2019), *in preparation*

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