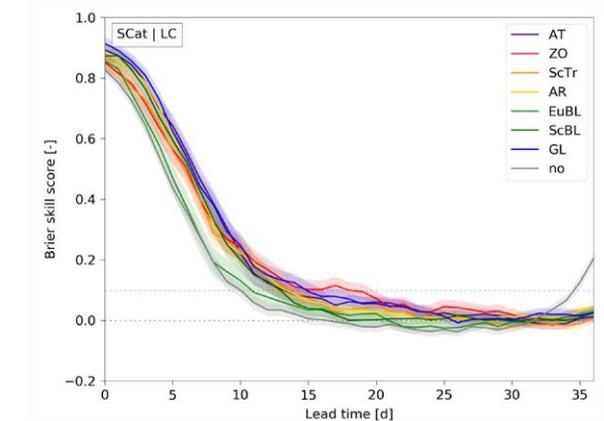
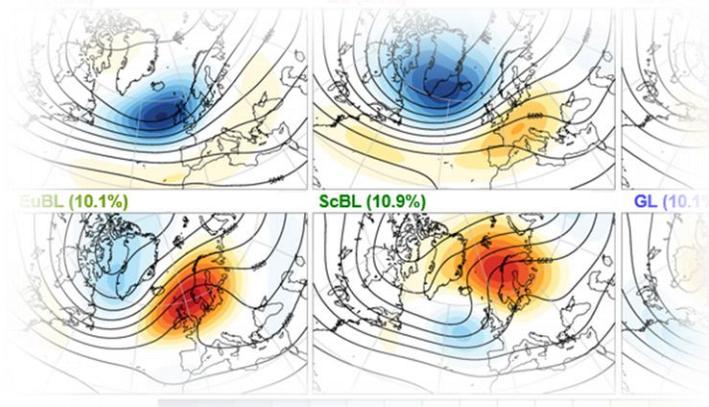


Sub-seasonal atmospheric predictability: understanding the role of diabatic outflow (SPREADOUT)

Christian M. Grams, Dominik Büeler, Moritz Pickl, Julian F. Quinting, and Jan Wandel

¹Institute of Meteorology and Climate Research (IMK-TRO), Karlsruhe Institute of Technology (KIT), Germany

²now at: Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland



Subseasonal prediction

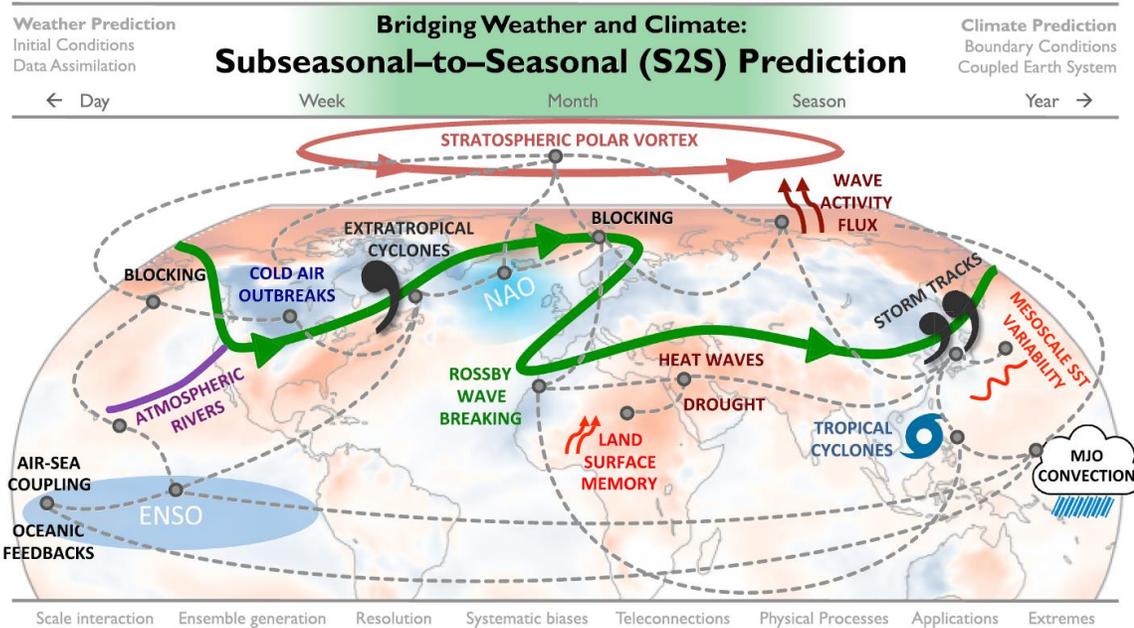
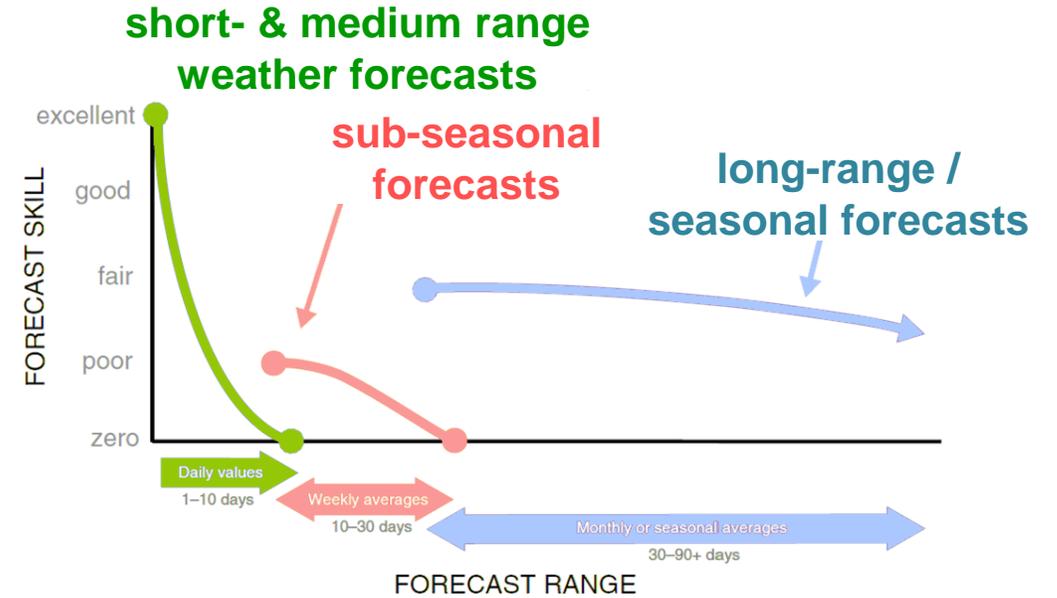
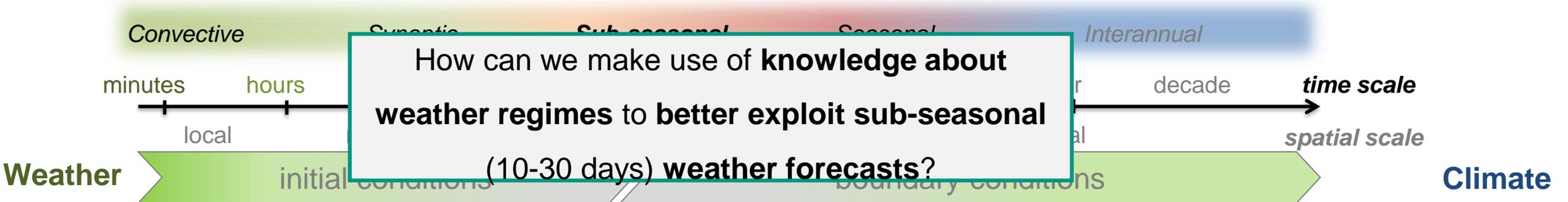


Fig. 1 Lang et al. 2020, JGR-A, [doi:10.1029/2019JD031833](https://doi.org/10.1029/2019JD031833)



adapted from White et al. 2017, Met.App., [doi:10.1002/met.1654](https://doi.org/10.1002/met.1654)

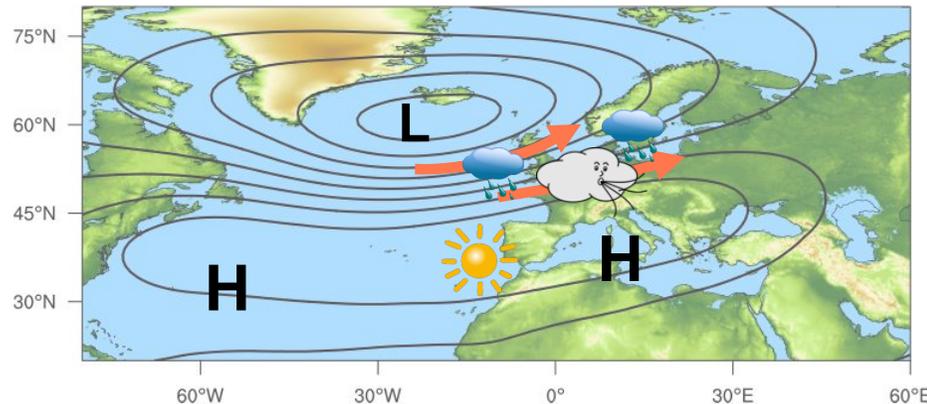


Weather regimes

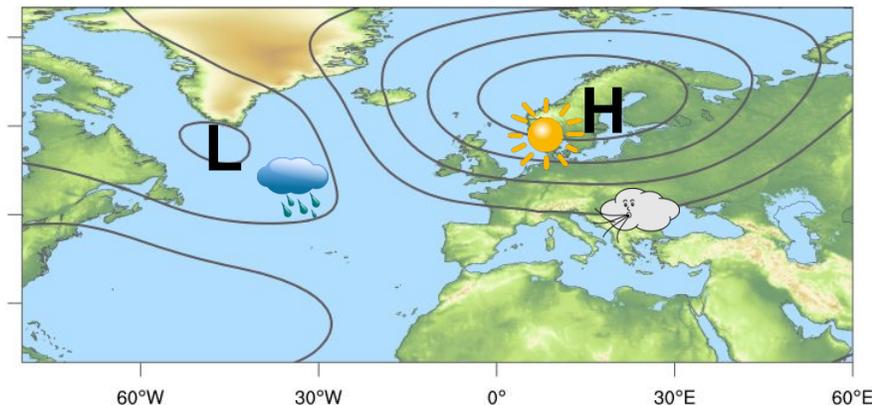
- WR are *quasi-stationary, persistent, and recurrent* states of the large-scale flow
- WR describe *multi-day variability of large-scale flow* over a specific region
(e.g. Michelangeli and Vautard 1995, Ferranti et al. 2015, Falkena et al. 2019, Dorrington et al. 2020)

→ classical definitions: NAO, 4 seasonal regimes

Cyclonic regimes



Blocked regimes



- WR affect **surface weather** (e.g. Yiou and Nogaj 2004, Cassou et al. 2005)
- WR modulated by **slower climate modes** (MJO, ENSO, stratosphere, ...) (e.g. Lin et al. 2009, [doi:10.1175/2008JCLI2515.1](https://doi.org/10.1175/2008JCLI2515.1); Cassou 2008 [doi:10.1038/nature07286](https://doi.org/10.1038/nature07286); Klaus 2017, [doi:10.3929/ethz-b-000238793](https://doi.org/10.3929/ethz-b-000238793); Charlton-Perez et al. 2018, [doi:10.1002/qj.3280](https://doi.org/10.1002/qj.3280); Beerli and Grams 2020 [doi:10.1002/qj.3653](https://doi.org/10.1002/qj.3653); Lee et al. 2019, [doi:10.1029/2019GL084683](https://doi.org/10.1029/2019GL084683); Domeisen, Grams, and Papritz 2020 [doi:10.5194/wcd-2019-16](https://doi.org/10.5194/wcd-2019-16))

Weather regimes

■ Here: *year-round definition* of 7 Atlantic-European regimes

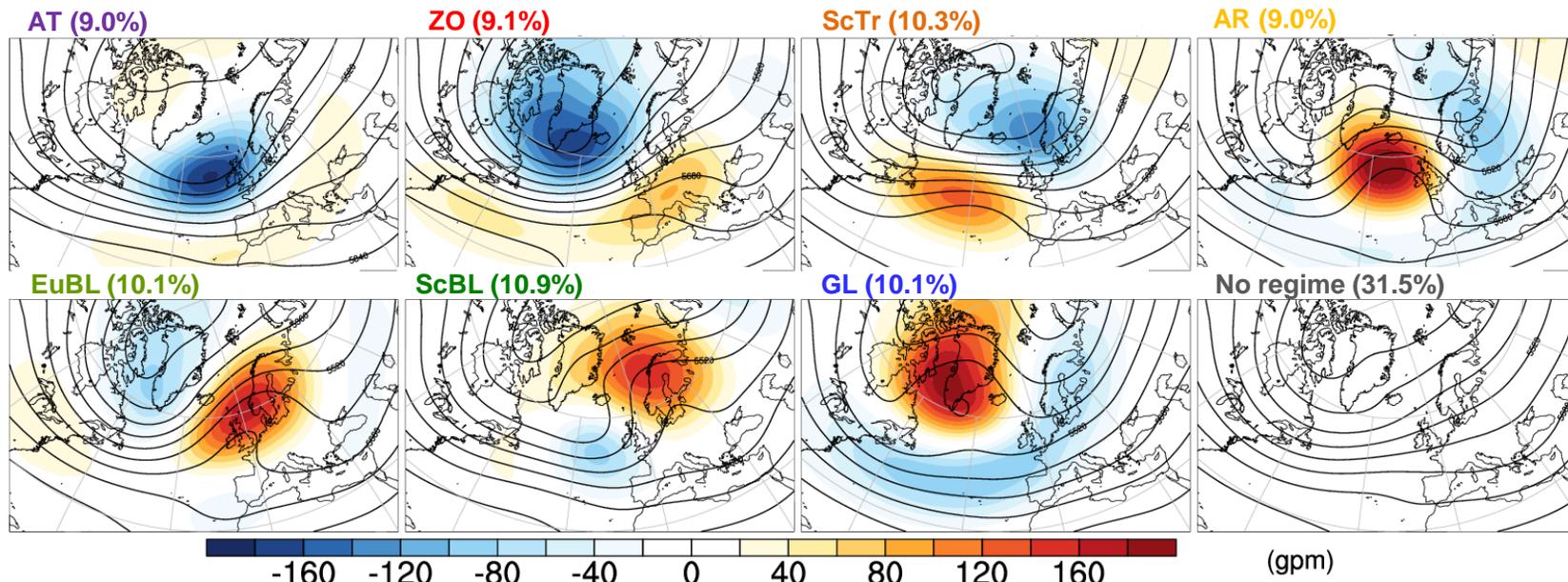
- 10d low-pass filtered normalized Z500 anomalies from ERA-Interim (1979-2016)
- EOF analysis & k-means clustering of 7 leading EOFs (76% of variability)
- objective definition of individual regime life cycles

Cyclonic regimes:

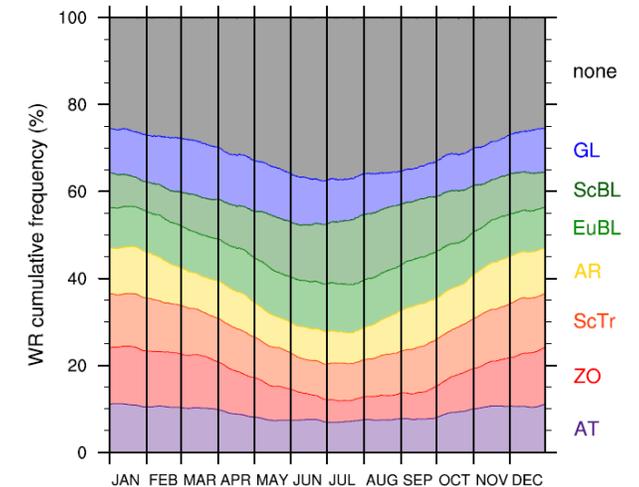
- Atlantic trough
- Zonal Regime
- Scandinavian trough

Blocked regimes:

- Atlantic ridge
- European blocking
- Scandinavian blocking
- Greenland blocking



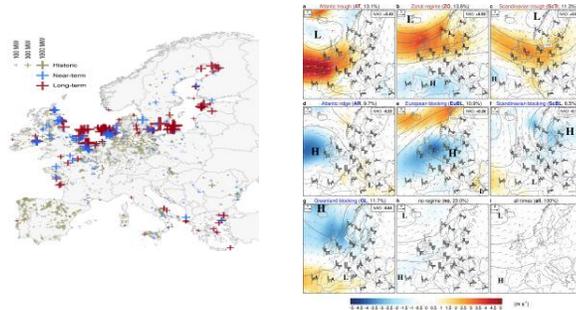
cluster mean Z500 anomaly ($\phi'(\varphi, \lambda)_{wr}$ shading) and absolute values (black contours)



regime frequency

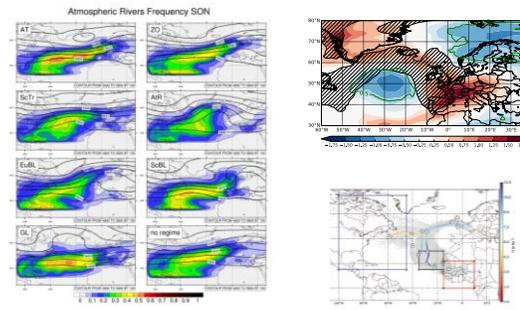
Relevance for sub-seasonal prediction

Wind power variability



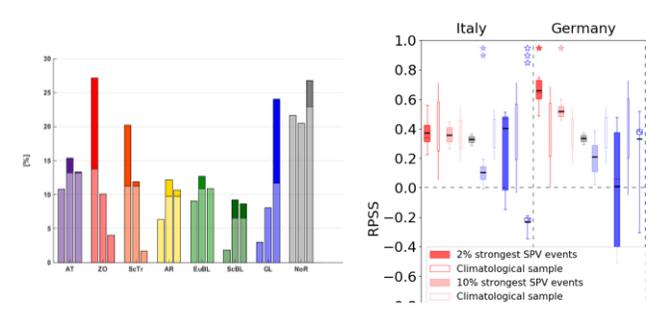
Beerli et al. (2017) [doi:10.1002/qj.3158](https://doi.org/10.1002/qj.3158)
 Grams et al. (2017) [doi:10.1038/nclimate3338](https://doi.org/10.1038/nclimate3338)
 Pickering et al. (2020) [doi:10.1088/1748-9326/ab70bd](https://doi.org/10.1088/1748-9326/ab70bd)

Modulation of extreme precipitation



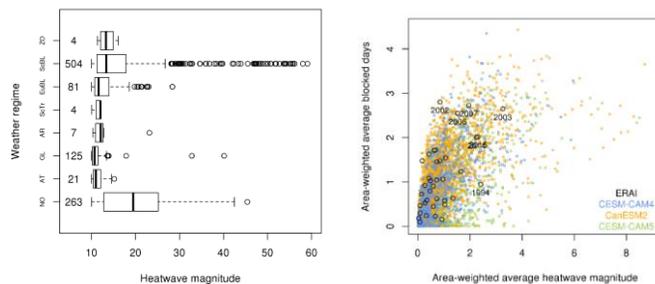
Grams et al. (2014) [doi:10.5194/nhess-14-1691-2014](https://doi.org/10.5194/nhess-14-1691-2014)
 Pasquier et al. (2019) [doi:10.1029/2018GL081194](https://doi.org/10.1029/2018GL081194)
 Mohr et al. (2020) [doi:10.5194/wcd-1-325-2020](https://doi.org/10.5194/wcd-1-325-2020)

Impact of the stratosphere



Beerli und Grams (2019) [doi: 10.1002/qj.3653](https://doi.org/10.1002/qj.3653)
 Domeisen et al. (2020) [doi:10.5194/wcd-1-373-2020](https://doi.org/10.5194/wcd-1-373-2020)
 Büeler et al. (2020) [doi:10.1002/qj.3866](https://doi.org/10.1002/qj.3866)

Heat waves



Schaller et al. (2018) [doi:10.1088/1748-9326/aaba55](https://doi.org/10.1088/1748-9326/aaba55)
 Spensberger et al. (2020) [doi:10.1002/qj.3822](https://doi.org/10.1002/qj.3822)

Cold air outbreaks & health

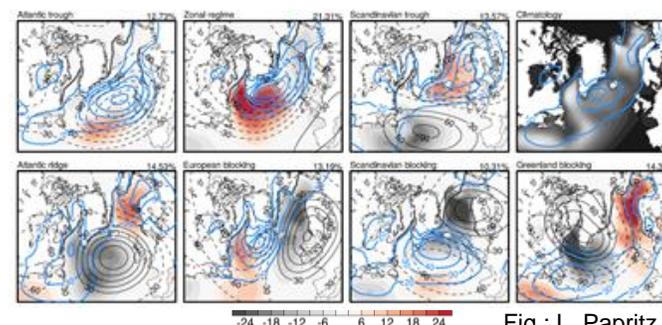
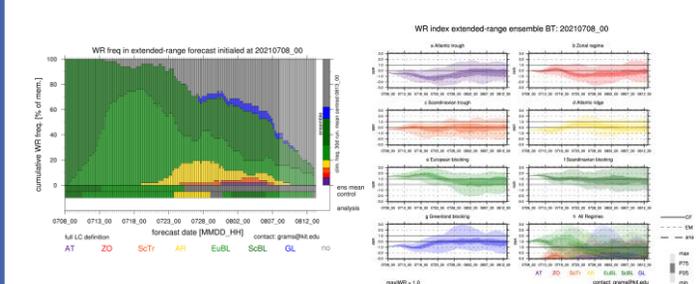


Fig.: L. Papritz,
 Papritz and Grams (2018) [doi:10.1002/2017GL076921](https://doi.org/10.1002/2017GL076921)
 Charlton-Perez et al. (2019) [doi:10.1016/j.wace.2019.100218](https://doi.org/10.1016/j.wace.2019.100218)
 White et al. (2022) [doi:10.1175/BAMS-D-20-0224.1](https://doi.org/10.1175/BAMS-D-20-0224.1)

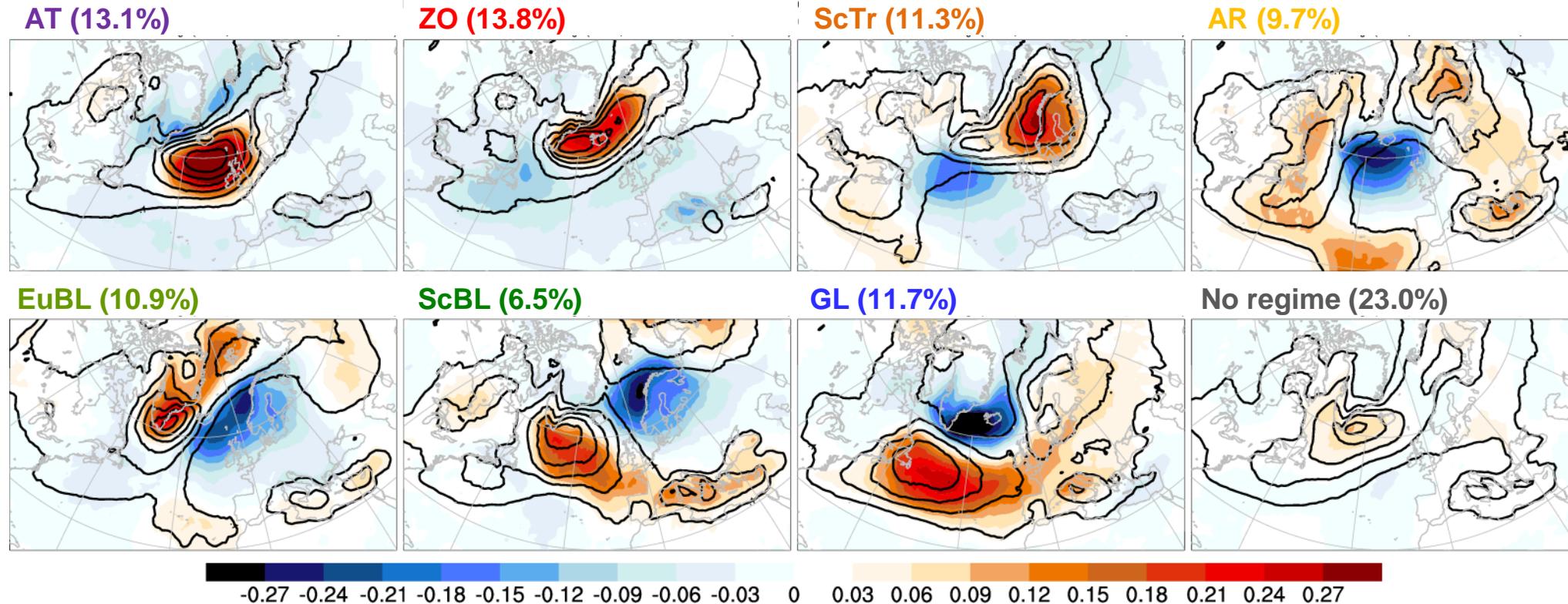
Regime forecast products



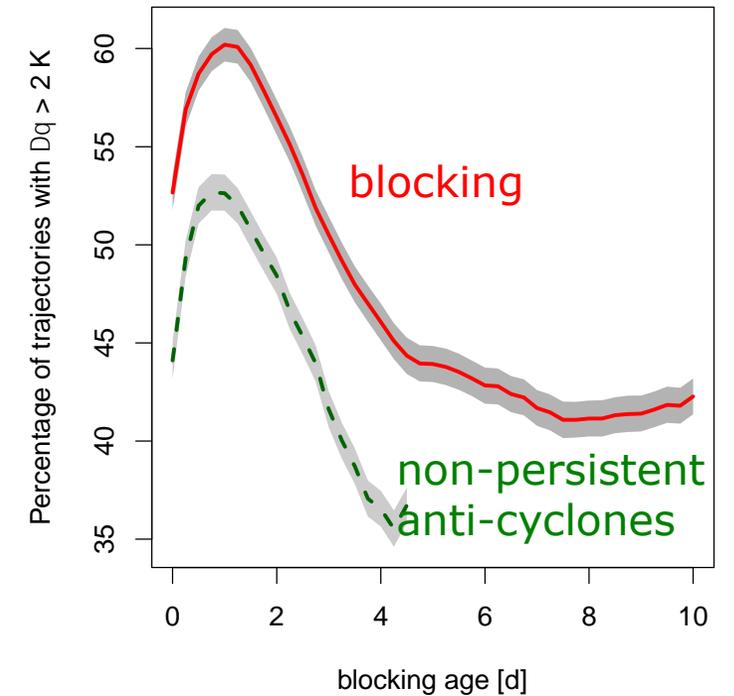
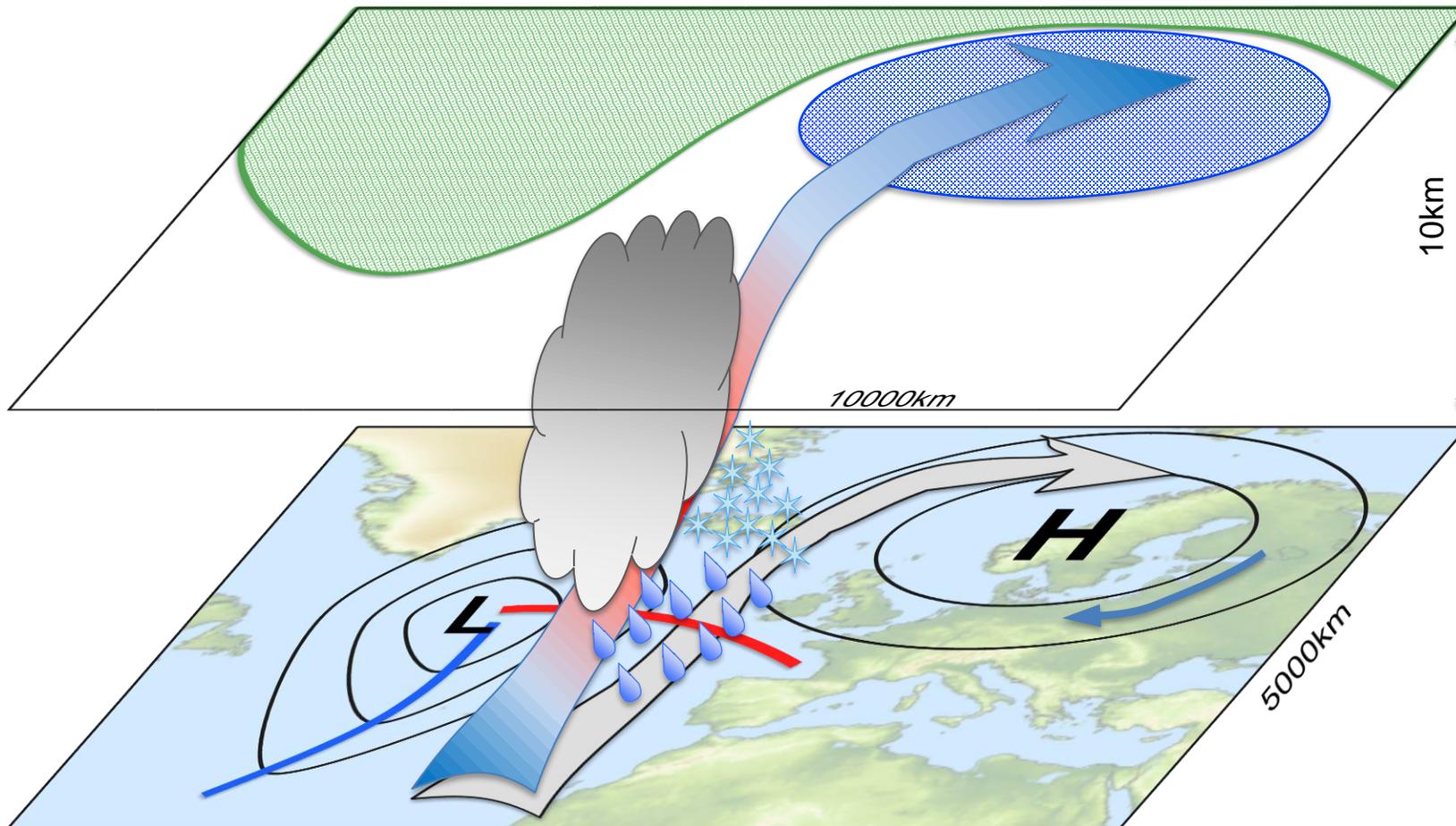
Grams et al. (2020) <https://www.ecmwf.int/en/newsletter/165/meteorology/how-make-use-weather-regimes-extended-range-predictions-europe>

Link to storm tracks and cyclone activity

cyclone frequency anomaly (shading in %) and absolute frequencies (black every 10 %) in DJF
 (1979-2015, ERA-Interim, *Wernli and Schwerz 2006*)

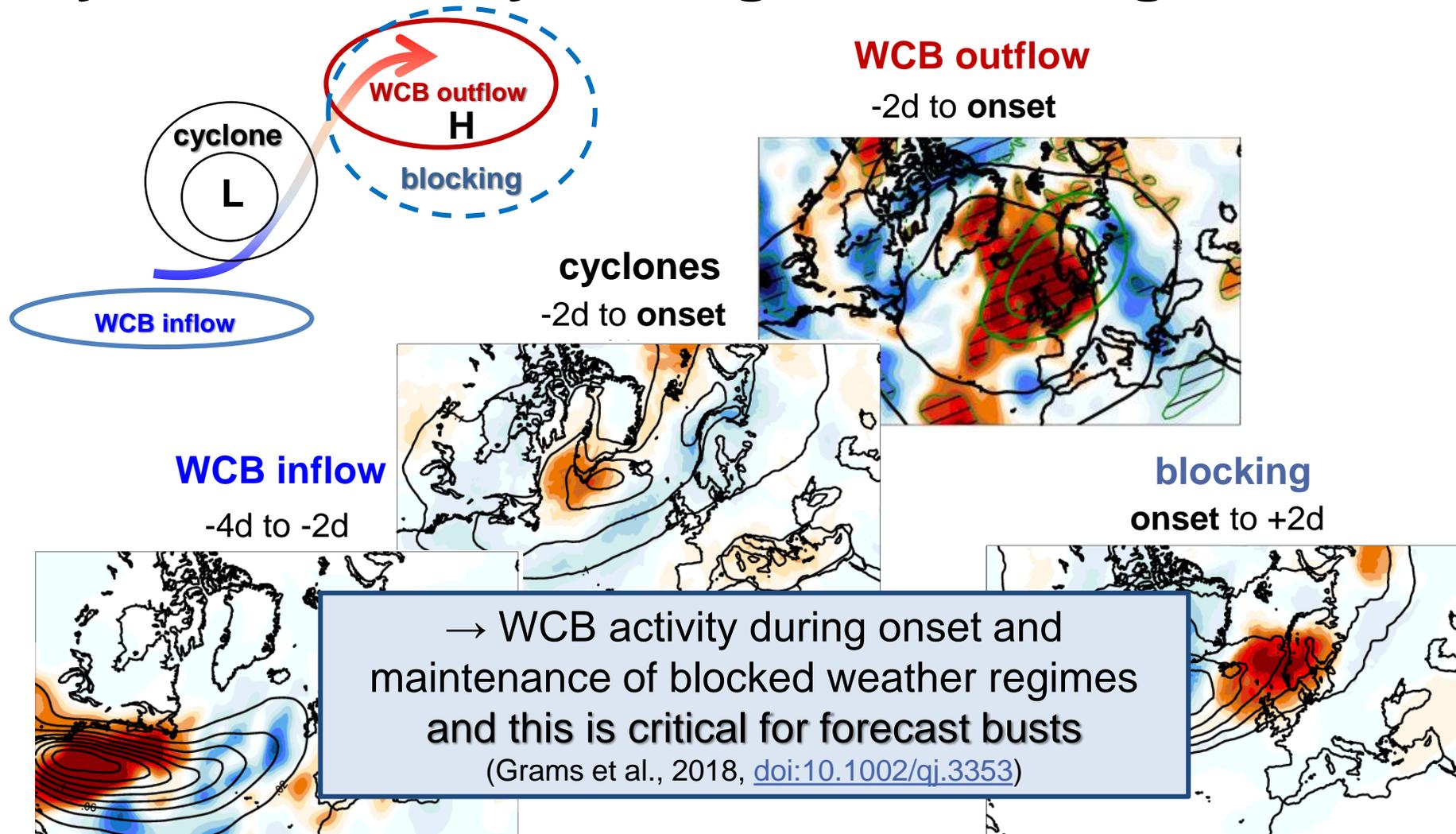


Blocked regimes and latent heat release



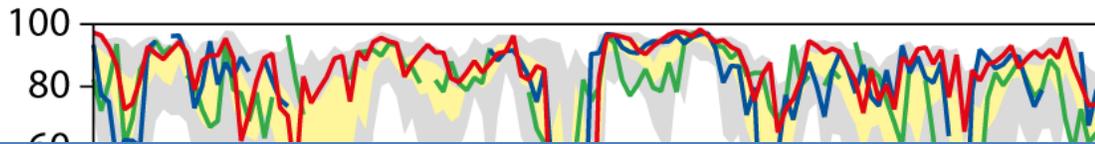
Pfahl, S. et al. (2015), *Nature Geosci.*, [doi:10.1038/ngeo2487](https://doi.org/10.1038/ngeo2487) , Grams and Archambault (2016), *Mon. Wea. Rev.*, [doi:10.1175/MWR-D-15-0419.1](https://doi.org/10.1175/MWR-D-15-0419.1)
 Steinfeld and Pfahl (2019), *Clim. Dyn.*, [doi:10.1007/s00382-019-04919-6](https://doi.org/10.1007/s00382-019-04919-6) , Steinfeld et al. (2020), *Weather Clim. Dynam.*, [doi:10.5194/wcd-1-405-2020](https://doi.org/10.5194/wcd-1-405-2020)

Summary WCB activity during blocked regimes



Forecast bust March 2016

+144h Z500 ACC - Europe



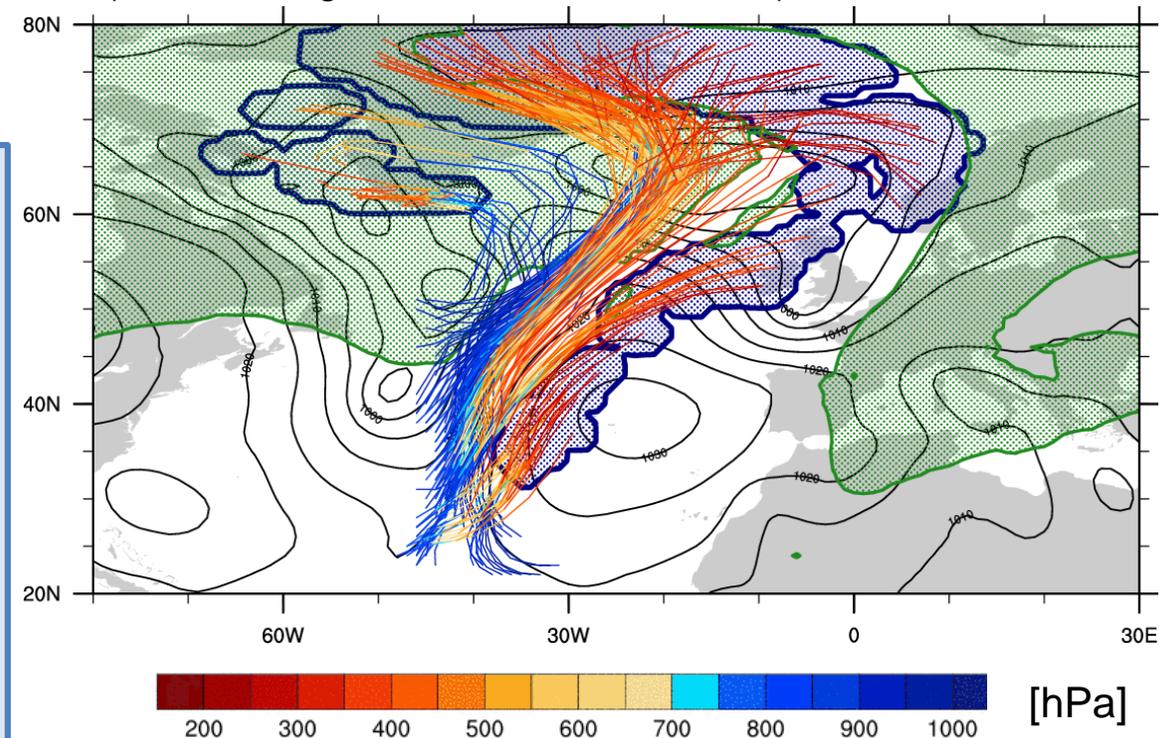
- March 2016 bust was related to onset of **European Blocking**
 - misrepresentation of ascending warm conveyor belt (WCB) airstream at **EuBL** onset
- WCB activity amplifies initial condition error and projects it on the large-scale extratropical circulation

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

tra starting & pmsl 20160309_00

tra ending & 2PVU@315K 20160311_00

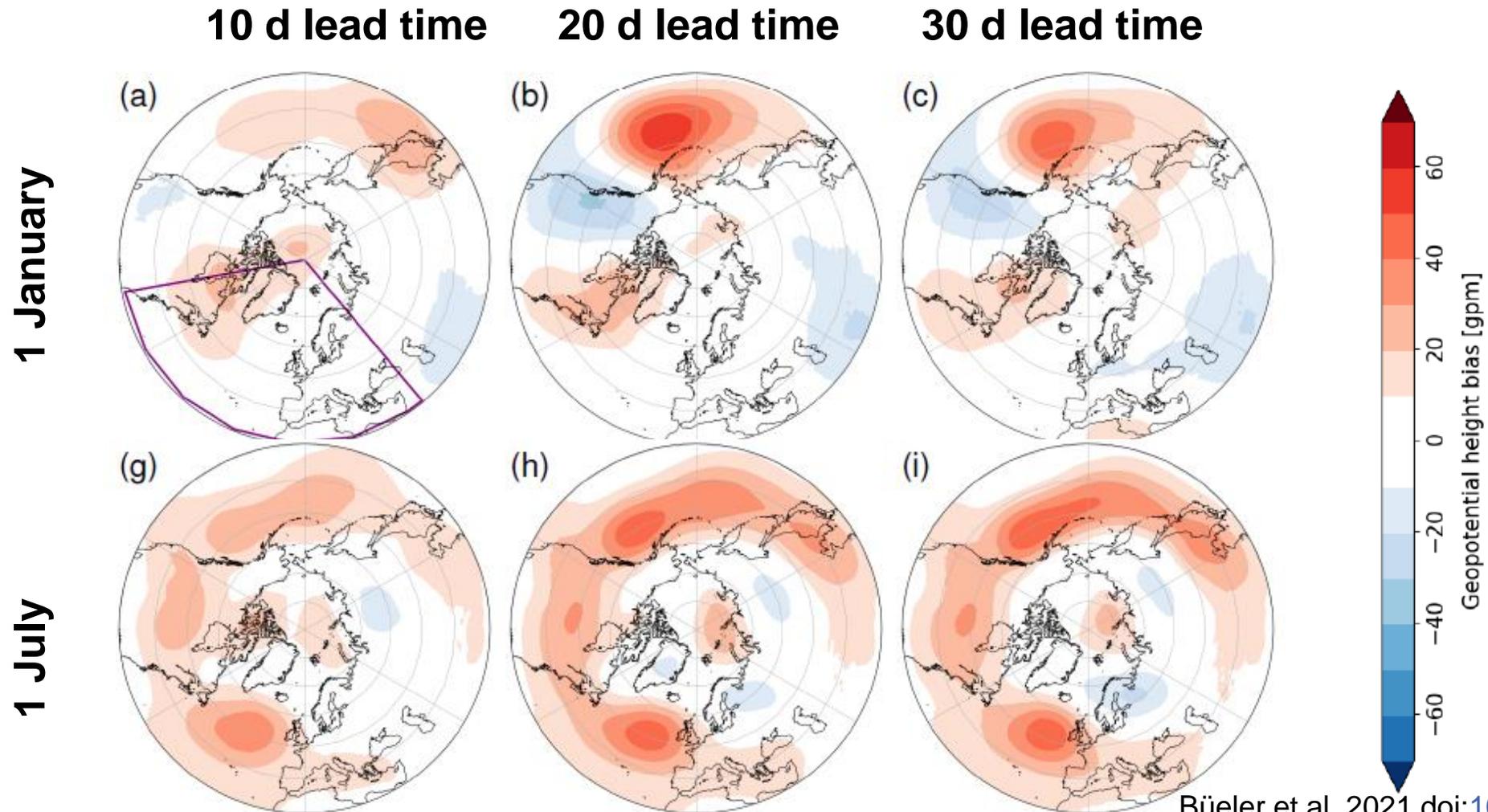
(blue hatching shows WCB outflow mask)



Outline

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500 hPa geopotential height biases in IFS S2S reforecast vs. ERA-Interim 1997-2017



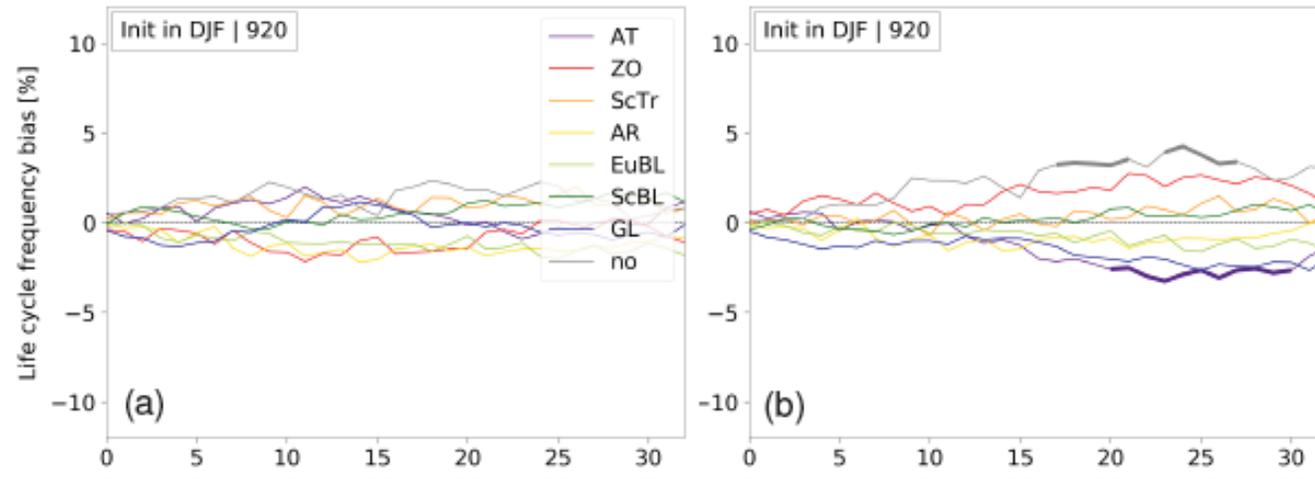
Büeler et al. 2021 doi:[10.1002/qj.4178](https://doi.org/10.1002/qj.4178).

Weather regime frequency biases

non-calibrated

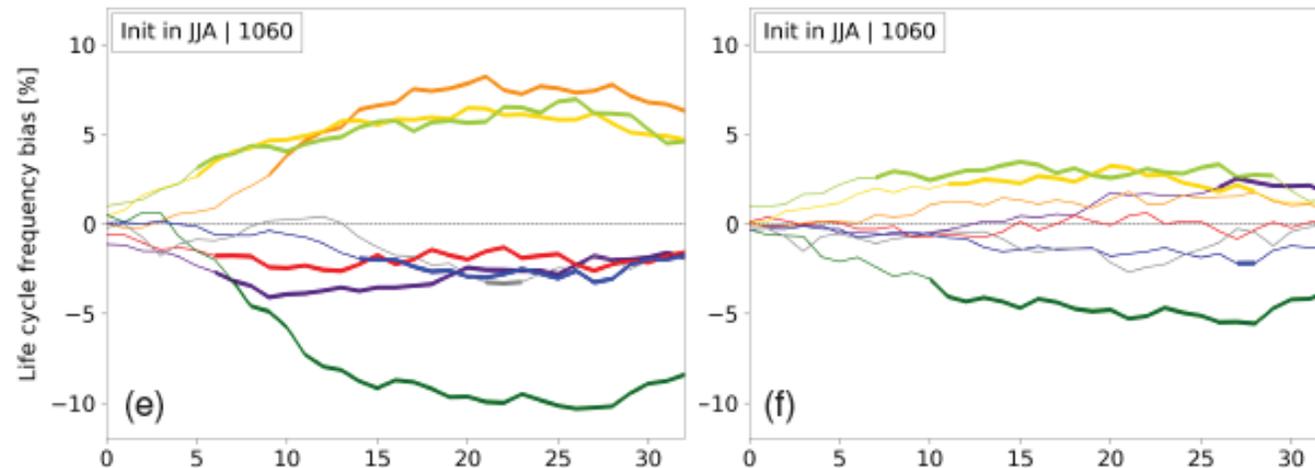
calibrated

DJF



- in uncalibrated forecasts large significant (bold lines) frequency biases in summer, but not in winter
- calibration (removal of Z500 bias) overall reduces WR frequency biases at all lead times
- calibration most effective in summer but important biases remain
- calibration hardly changes skill (not shown)

JJA



Büeler et al. 2021 doi:[10.1002/qj.4178](https://doi.org/10.1002/qj.4178).

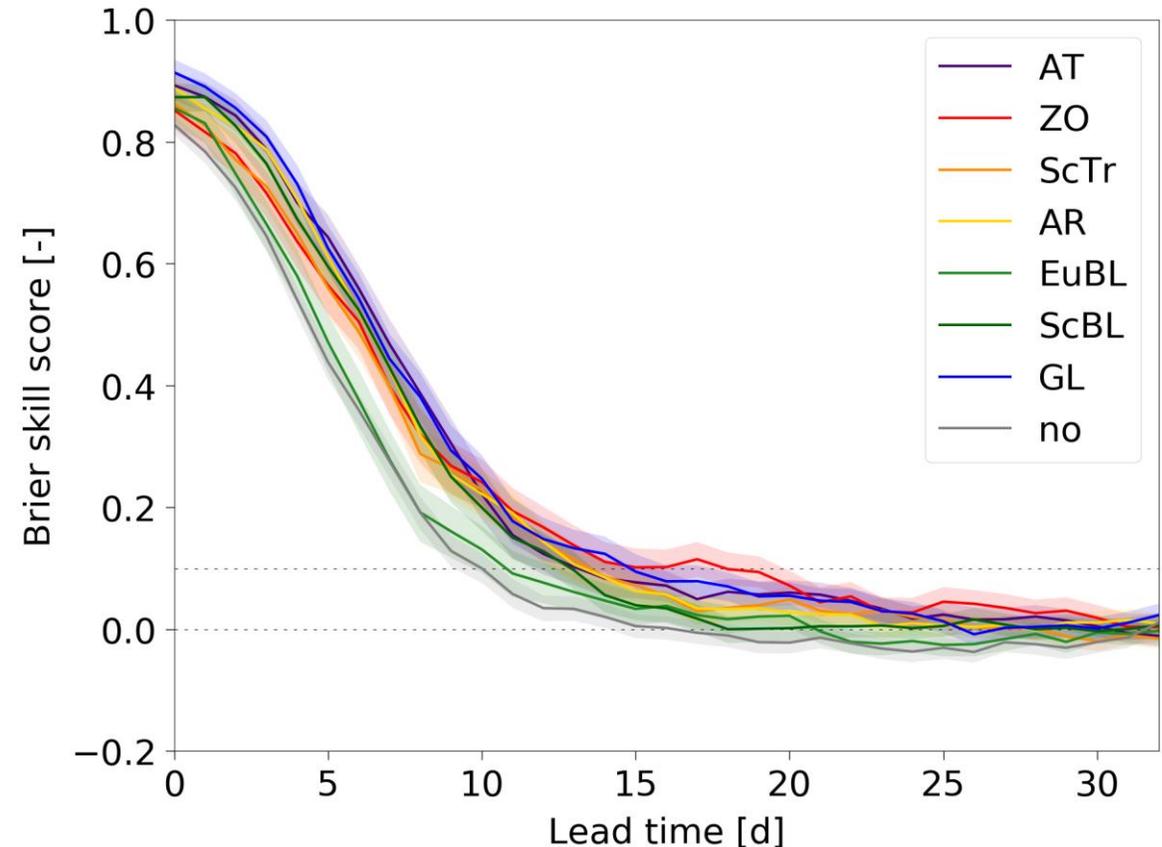
Weather regime forecast skill

- skill horizon in winter is about 5d longer than in summer
- skill horizon for EuBL is significantly shorter by 3-5d than for all others
- skill horizon longest for ZO, GL (representing the NAO phases) driven by winter and likely due to high persistence and stratospheric influences
- here skill for daily data. Skill increases with larger verification window

→ **EuBL** most problematic

Role of misrepresentation of WCB activity?

Year-round skill for individual WR life cycles

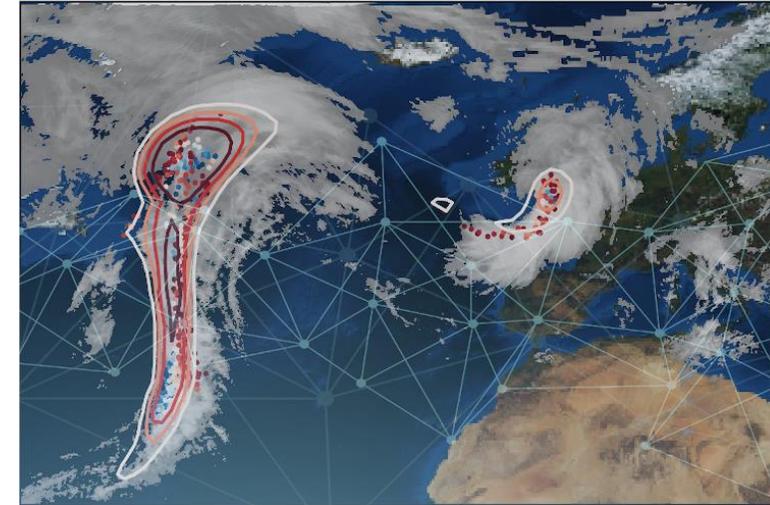
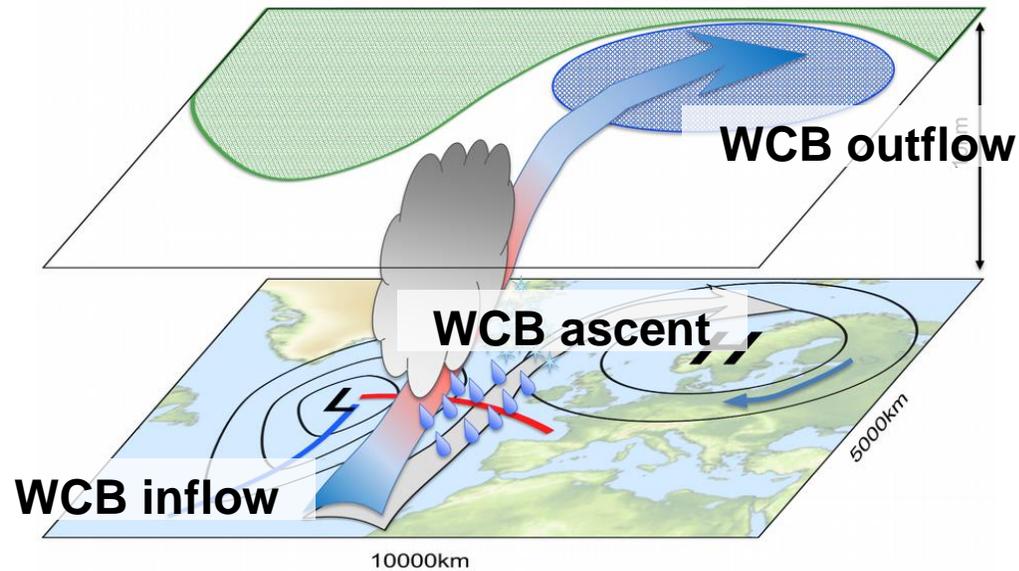


Büeler, D., L. Ferranti, L. Magnusson, J. F. Quinting, and C. M. Grams, 2021: Year-round sub-seasonal forecast skill for Atlantic–European weather regimes. *Q. J. R. Meteorol. Soc.* **147**, 4283–4309, doi:[10.1002/qj.4178](https://doi.org/10.1002/qj.4178).

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An Eulerian WCB Metric (ELIAS2.0)



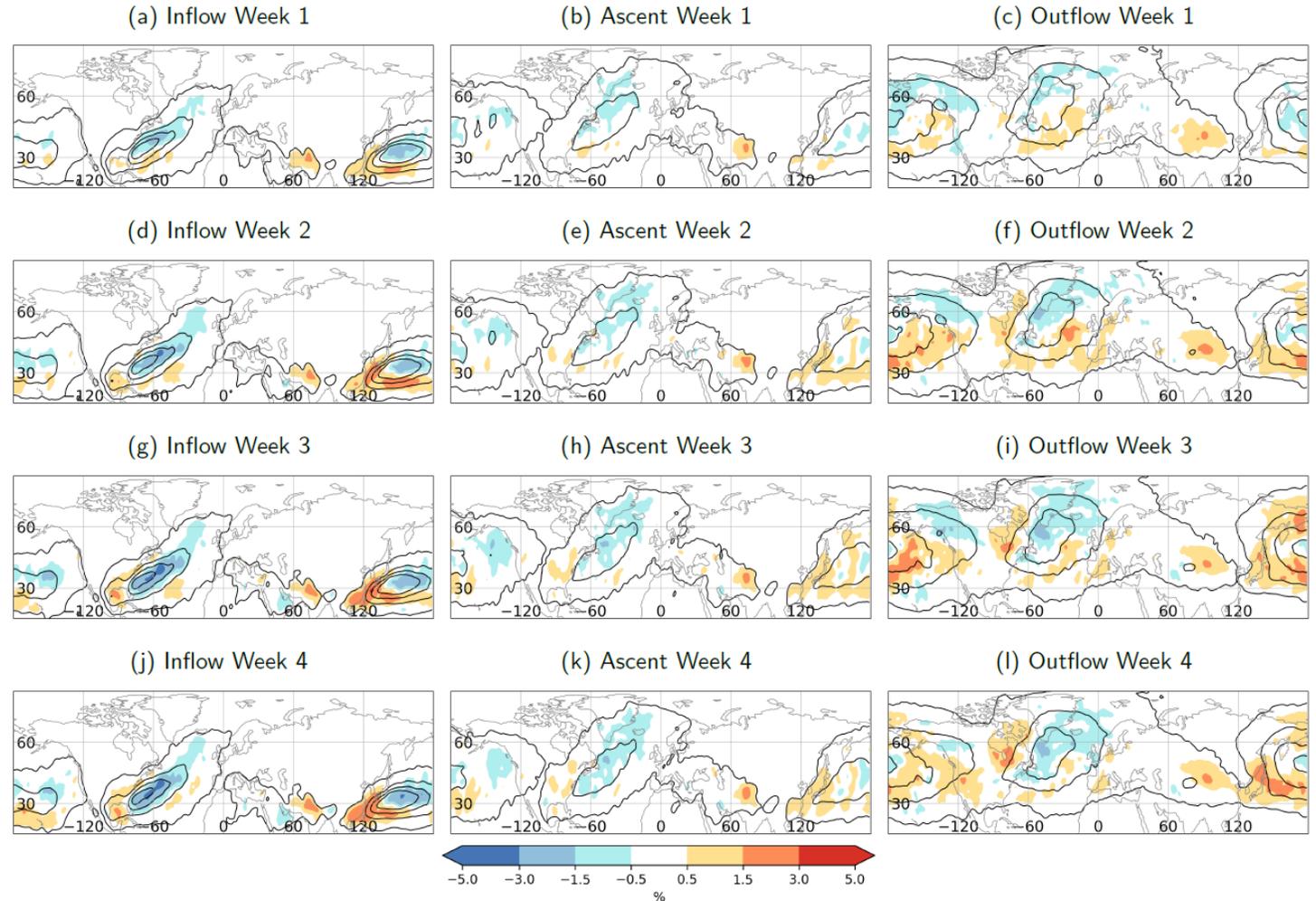
Example: dots Lagrangian air parcels in ascent phase. contours: conditional probability from Eulerian metric (plot: Julian Quinting)

- WCB identification requires trajectory calculation based on high spatio-temporal resolution
 - *feasible with reanalysis data and for case studies*
- lack of spatio-temporal resolution and huge data amount of S2S ensemble reforecasts requires different approach
- Eulerian metric for signature of WCB stages based on Unet-type convolutional neural network
 - **Quinting and Grams (2022)**, doi:[10.5194/gmd-15-715-2022](https://doi.org/10.5194/gmd-15-715-2022)
- Predictor selection and metric based on logistic regression
 - *Quinting and Grams (2021)*, [doi:10.1175/JAS-D-20-0139.1](https://doi.org/10.1175/JAS-D-20-0139.1)

WCB frequency biases in IFS reforecast model

WCB frequency biases for ECMWF IFS reforecasts 1997-2017 (DJF)

- systematic underestimation of WCB activity in northern North Atlantic
- saturates in week 2

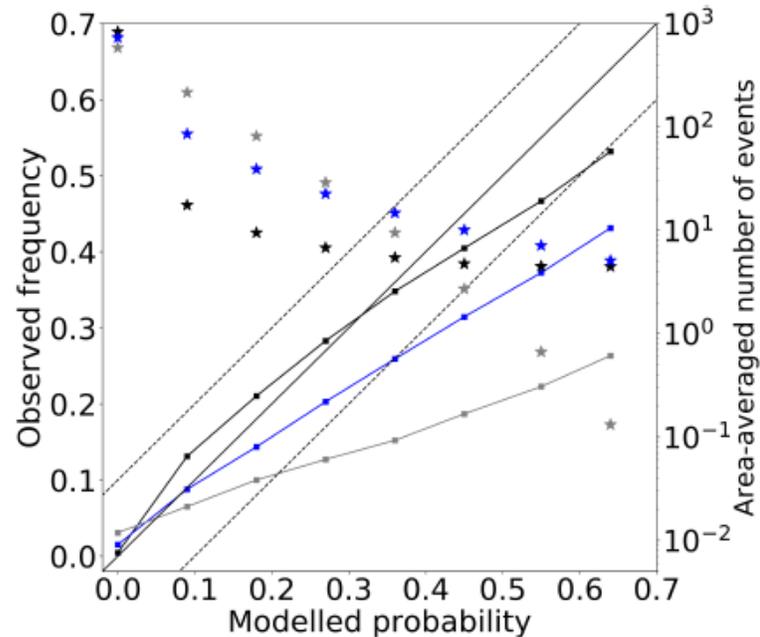


Wandel et al. 2021, JAS, doi: [10.1175/JAS-D-20-0385.1](https://doi.org/10.1175/JAS-D-20-0385.1) and Wandel et al. 2022 *in preparation*

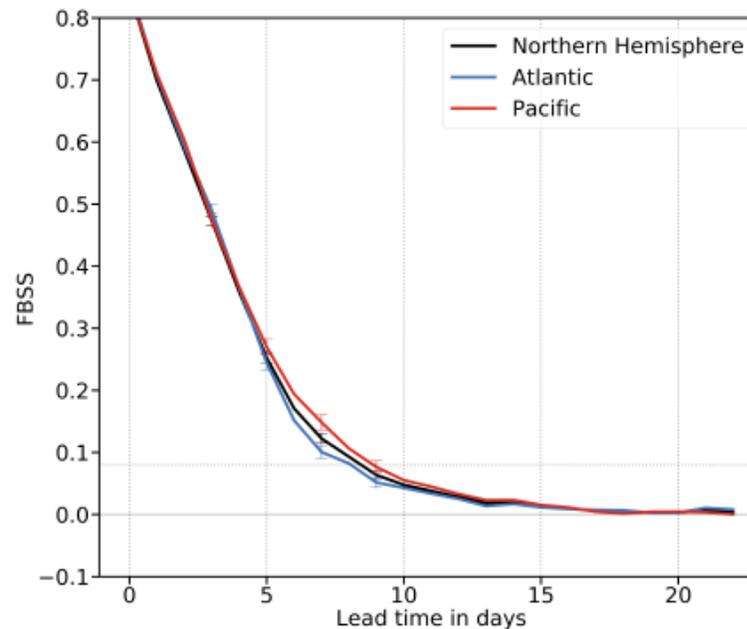
WCB outflow reliability and skill in S2S model

WCB outflow reliability

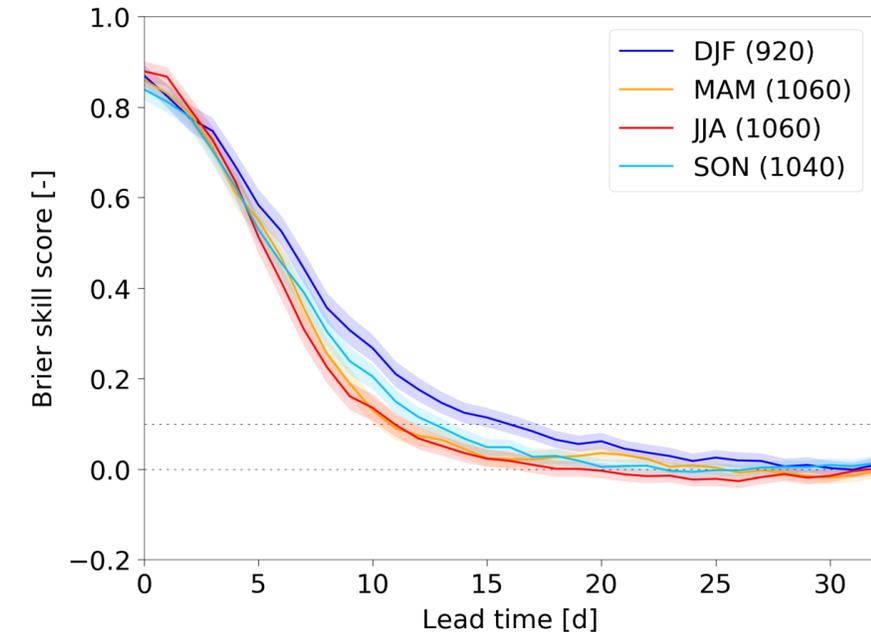
(day 3, day 7, day 15)



WCB outflow skill



cf. regime skill



Wandel, J., J. F. Quinting, and C. M. Grams, 2021: Toward a Systematic Evaluation of Warm Conveyor Belts in Numerical Weather Prediction and Climate Models. Part II: Verification of Operational Reforecasts. *Journal of the Atmospheric Sciences*, 78, 3965–3982, doi:[10.1175/JAS-D-20-0385.1](https://doi.org/10.1175/JAS-D-20-0385.1).

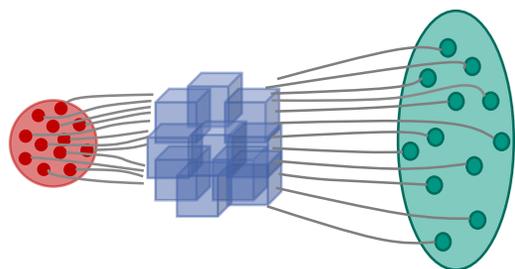
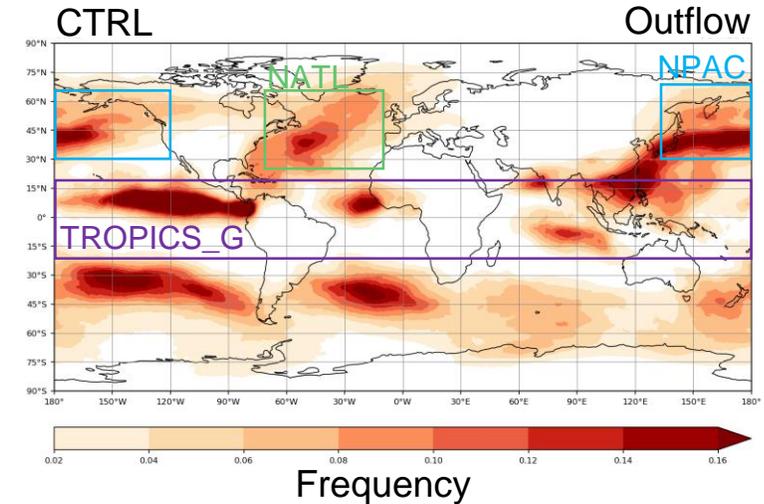
Wandel et al., 2022: The representation of warm conveyor belts in subseasonal reforecast models. *in preparation*.

Outline

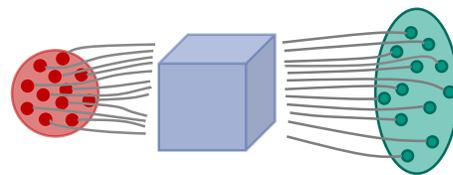
- 1) Introduction S2S, weather regimes, role of latent heat release
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Sensitivity of WCB representation on ensemble configuration

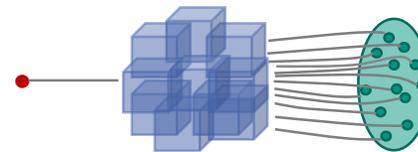
Model	ECMWF IFS CY46R1
Resolution	TCO399 (~ 36km) with 91 levels
Ensemble size	20 perturbed + 1 unperturbed control member
Simulated period	Aug. 15th - Oct. 15th 2016 ; restarted every other day (32 forecasts)
Lead time	288h (12 days)



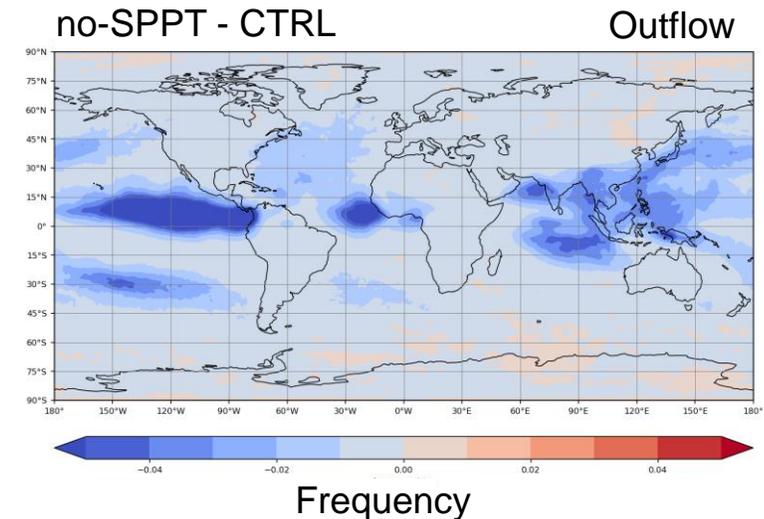
REF



no-SPPT

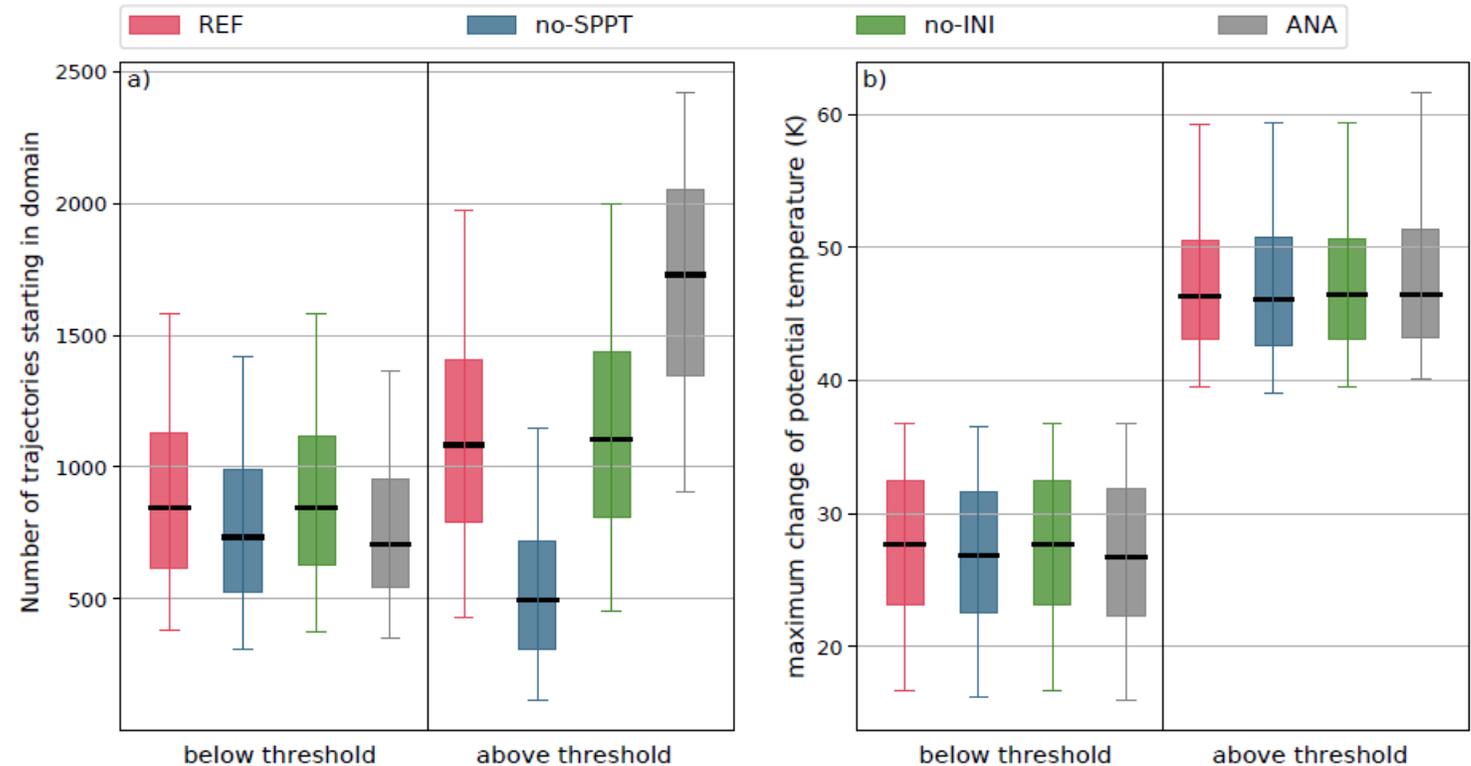


no-INI



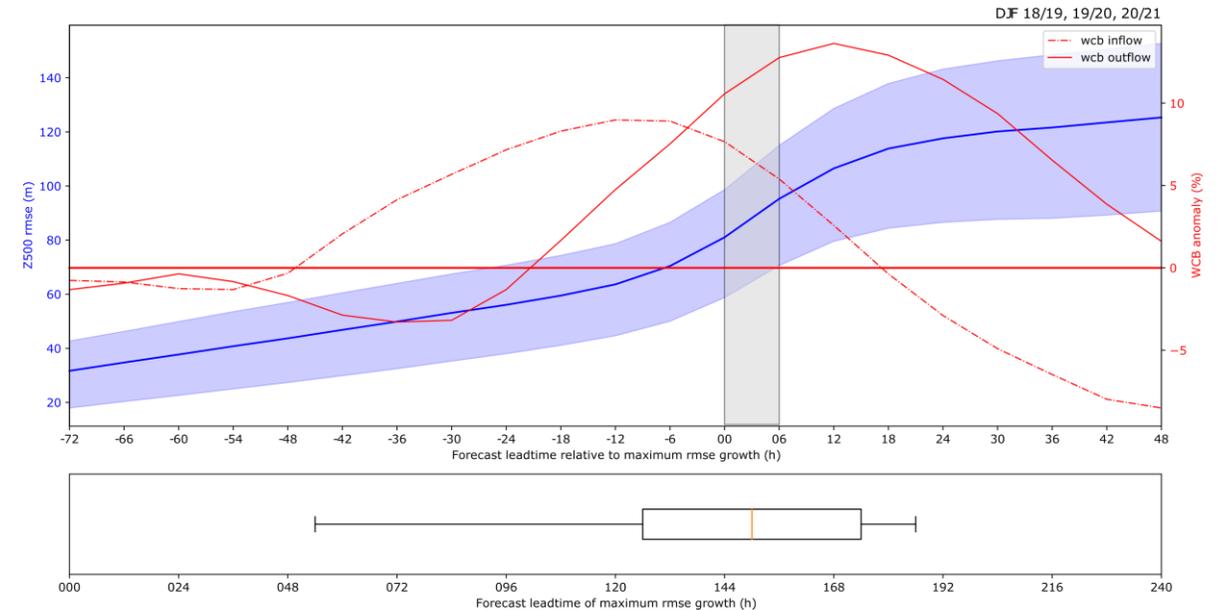
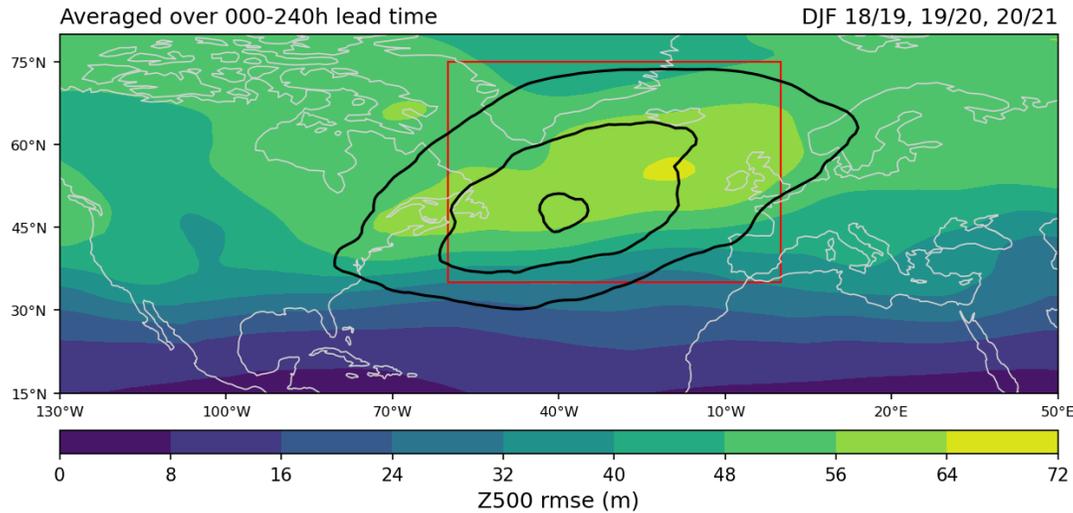
Sensitivity of WCB representation on ensemble configuration

- SPPT systematically increases the number of rapidly ascending air parcels (one-sided effect)
- strongest effect at high heating rates
- no changes of physical properties
- effect of IC fade quickly
- holds in operational forecasts across seasons (control forecast like a no-SPPT experiment)



Pickl, M., S. T. K. Lang, M. Leutbecher, and C. M. Grams, 2022 The effect of stochastically perturbed parametrisation tendencies (SPPT) on rapidly ascending air streams. *Q. J. R. Meteorol. Soc.*, 148, 1242-1261, doi:[10.1002/qj.4257](https://doi.org/10.1002/qj.4257).

Role of WCB in forecast error growth



RMSE and WCB activity around the time of maximum error growth

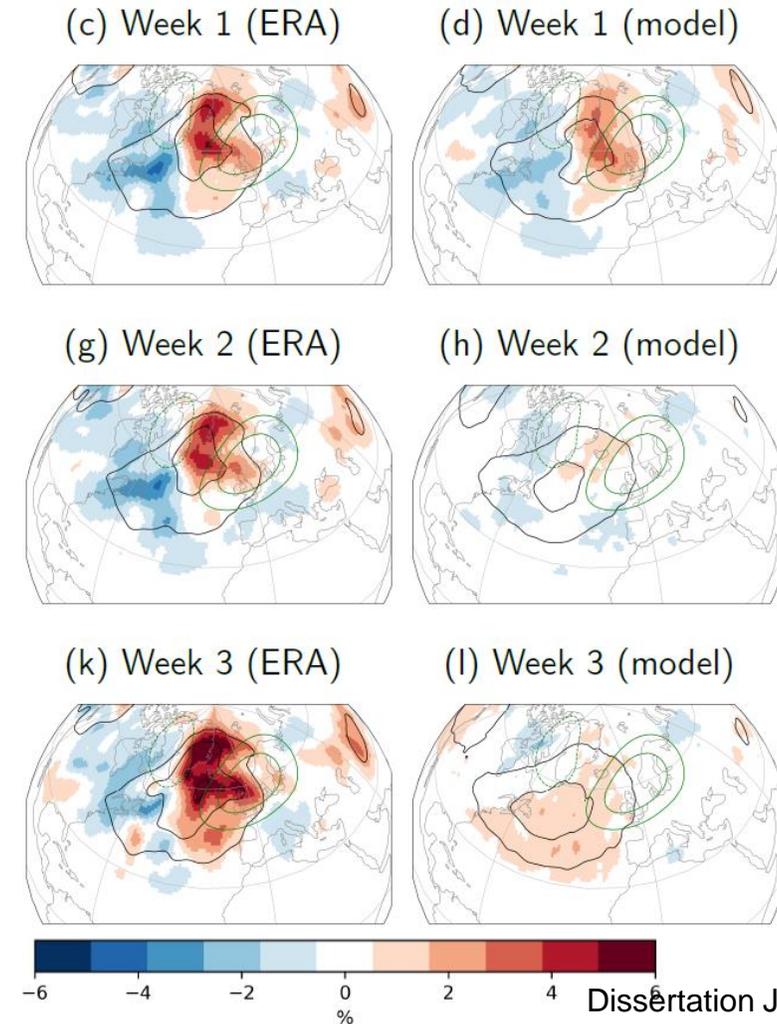
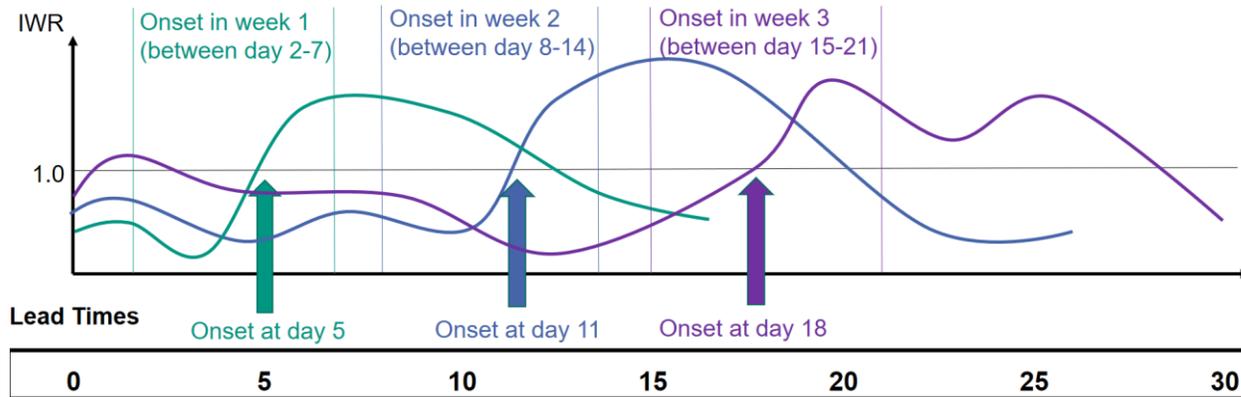
Pickl, M., et al., 2022: The role of warm conveyor belts for forecast error growth. *in preparation.*

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WCB outflow at regime **EuBL** onset

- EuBL onset in in ERA-Interim
- WCB outflow frequencies based on ELIAS2.0 for ERA and model for these times (not necessarily an **EuBL** onset in model)

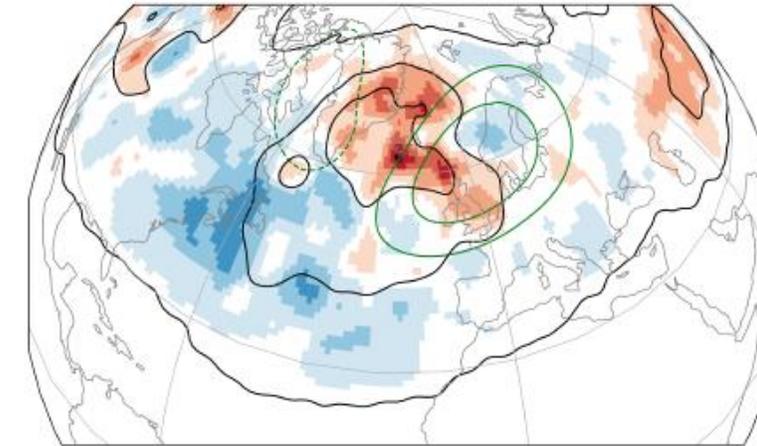
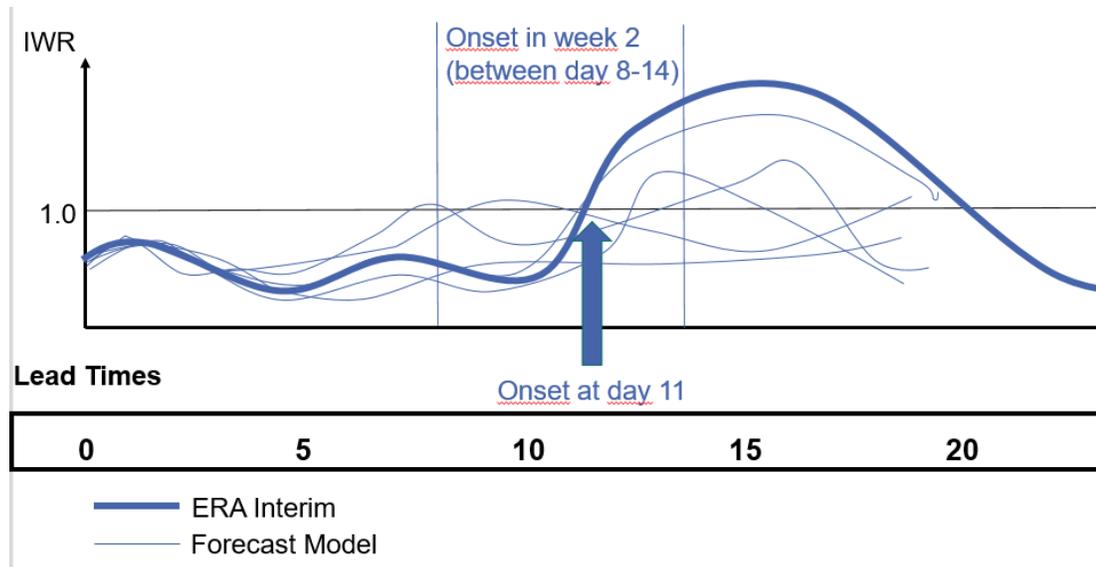


Dissertation Jan Wandel 2022 and Wandel et al. 2022 *in preparation*

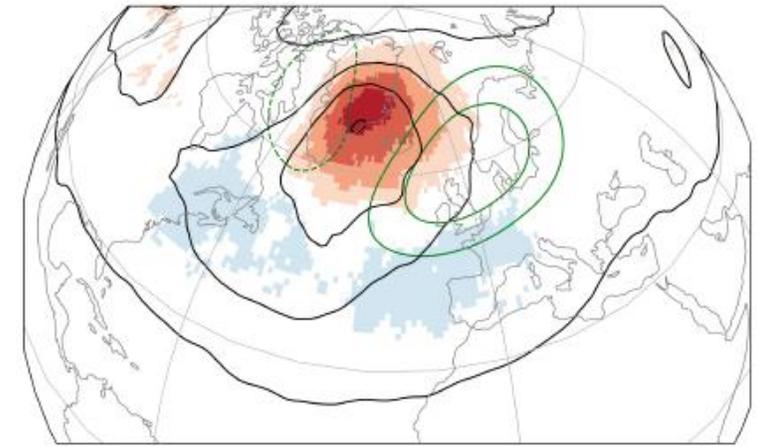
WCB outflow -2 to 0d prior to **EuBL** onset

- EuBL onset in week 2 in ERA-Interim and in model (not necessarily verifying)
- model overestimates WCB outflow towards Greenland

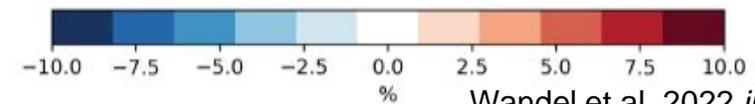
→ different pathway into **EuBL**?



ERA



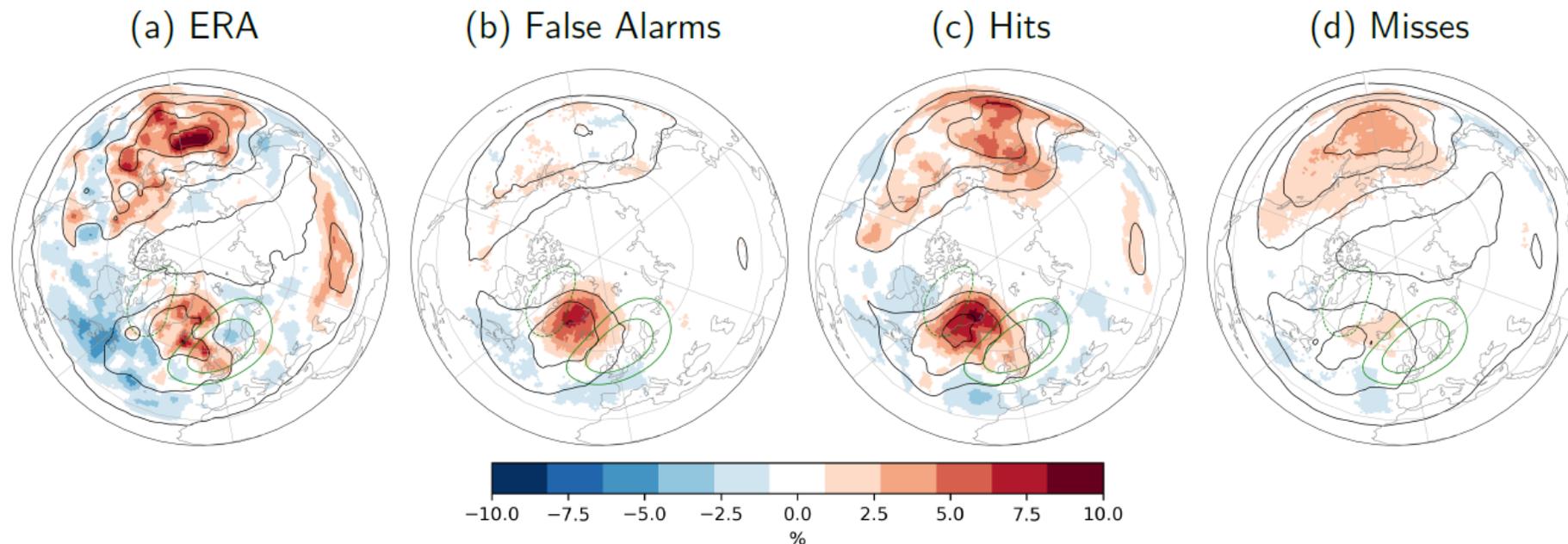
model



Wandel et al. 2022 *in preparation*

WCB outflow -2 to 0d prior to **EuBL** onset

- WCB outflow -2 to 0d prior to **EuBL** onset in week 2 stratified according to verifying forecasts (hits), false alarms, forecasts missing the onset (misses)



Wandel, J., Quinting, J. F., Büeler, D., Knippertz, P., and Grams, C. M., 2022: Why moist dynamic processes matter for the prediction of atmospheric blocking over Europe. *in preparation*.

Outline

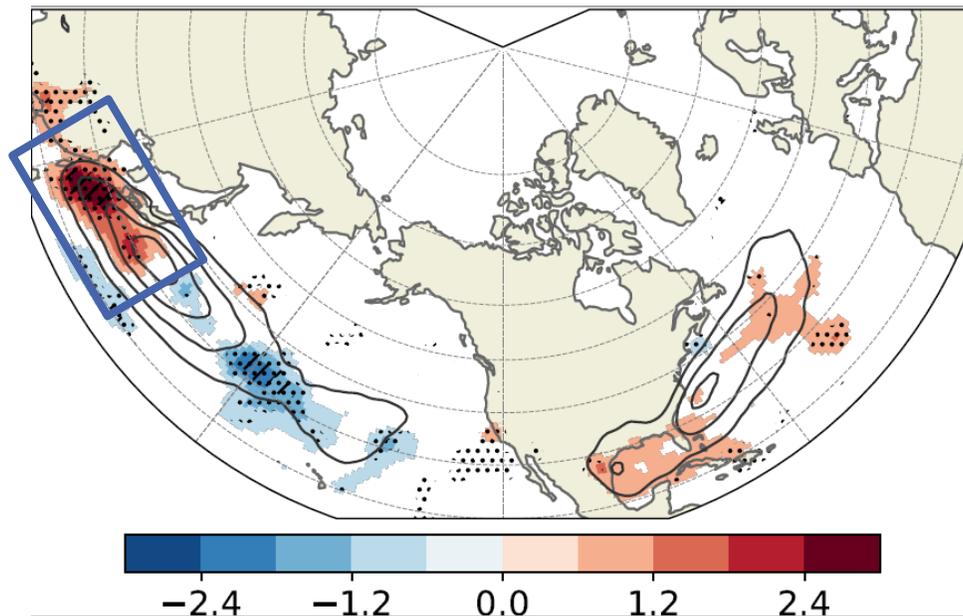
- 1) Introduction S2S, weather regimes, role of latent heat release
- 2) Predictability of regimes
- 3) Representation of WCBs in S2S models
- 4) Sensitivity of WCB to ensemble configuration
- 5) Role of WCB in predictability of regimes
- 6) Potential modulation of MJO teleconnection by WCB activity**

A potential modulation of the MJO teleconnection by WCB activity

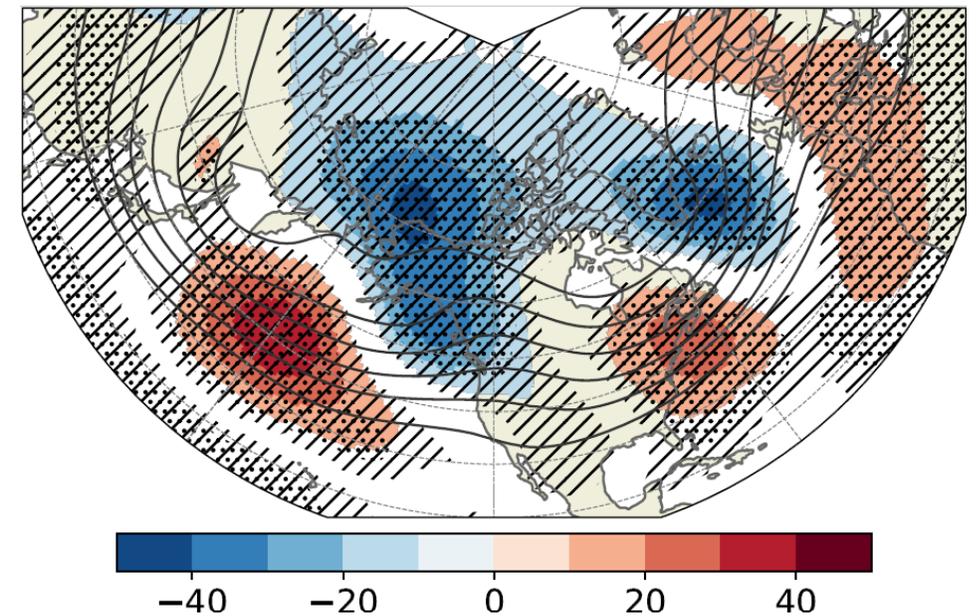
- after MJO phase 2 WCB activity is systematically enhanced in western NPAC
- stratification according to low (lower 25%) and high (upper 25%) of WCB activity in WNPAC

- canonically a NAO+/ZO response is expected (e.g. Cassou 2008, Lin et al. 2009, Fromang and Riviere 2020)

WCB inflow [%] 0-4d after ph 2



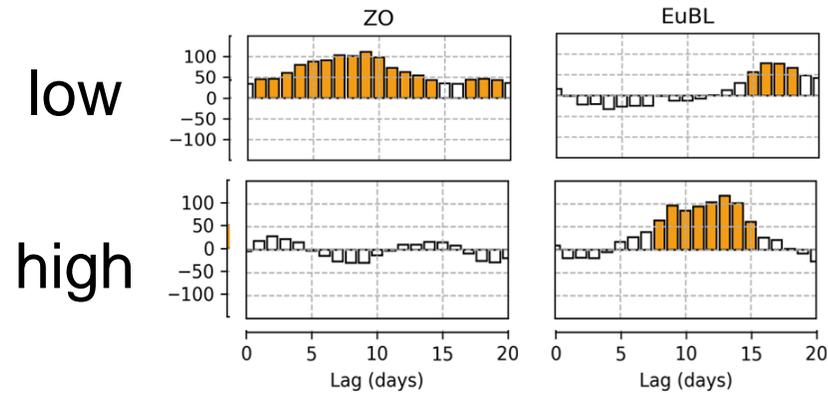
Z500 [gpm] 10-14d after ph 2



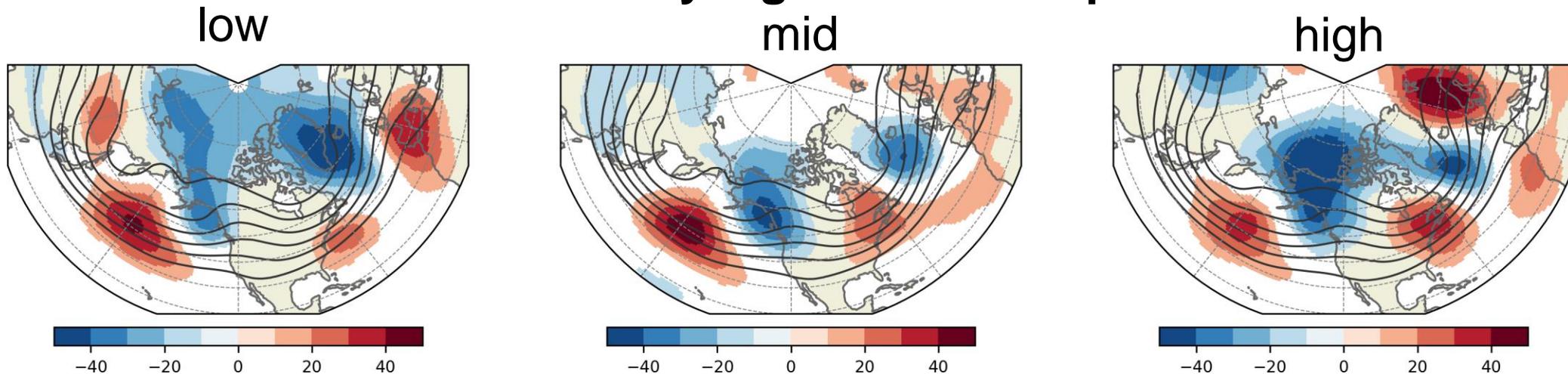
Quinting et al., 2022. *in preparation.*

A potential modulation of the MJO teleconnection by WCB activity

- stratification according to low (lower 25%) and high (upper 25%) of WCB activity in WNPAC
- low WCB activity → ZO response?
- high WCB activity → EuBL response?

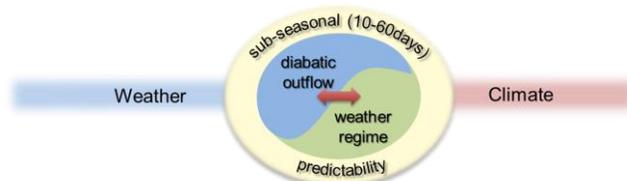


WCB activity lag 10-14d after phase 2



Quinting et al., 2022.. *in preparation.*

Summary



- NWP models struggle predicting regimes beyond week 2; lowest skill for blocking in the European region (**EuBL**)
Büeler et al. 2021 doi:[10.1002/qj.4178](https://doi.org/10.1002/qj.4178).
- WCBs frequencies underestimated in model. Skill lost in week 2
Wandel et al. 2021 doi:[10.1175/JAS-D-20-0385.1](https://doi.org/10.1175/JAS-D-20-0385.1) and 2022 in preparation
- SPPT improves WCB representation
Pickl et al. 2022 doi:[10.1002/qj.4257](https://doi.org/10.1002/qj.4257).
- WCB activity enhances error growth, thereby diluting skill for some regimes in particular **EuBL**
Grams et al. 2018 doi:[10.1002/qj.3353](https://doi.org/10.1002/qj.3353). and Wandel et al. 2022 in preparation
- WCBs important in establishing the MJO teleconnection towards Europe
Quinting et al. 2022 in preparation

<https://www.imk-tro.kit.edu/english/7425.php>



[@cgrams_lsdp](https://twitter.com/cgrams_lsdp)

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Impact on surface weather and society

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