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Using Weather Regimes in the Context of Energy Meteorology

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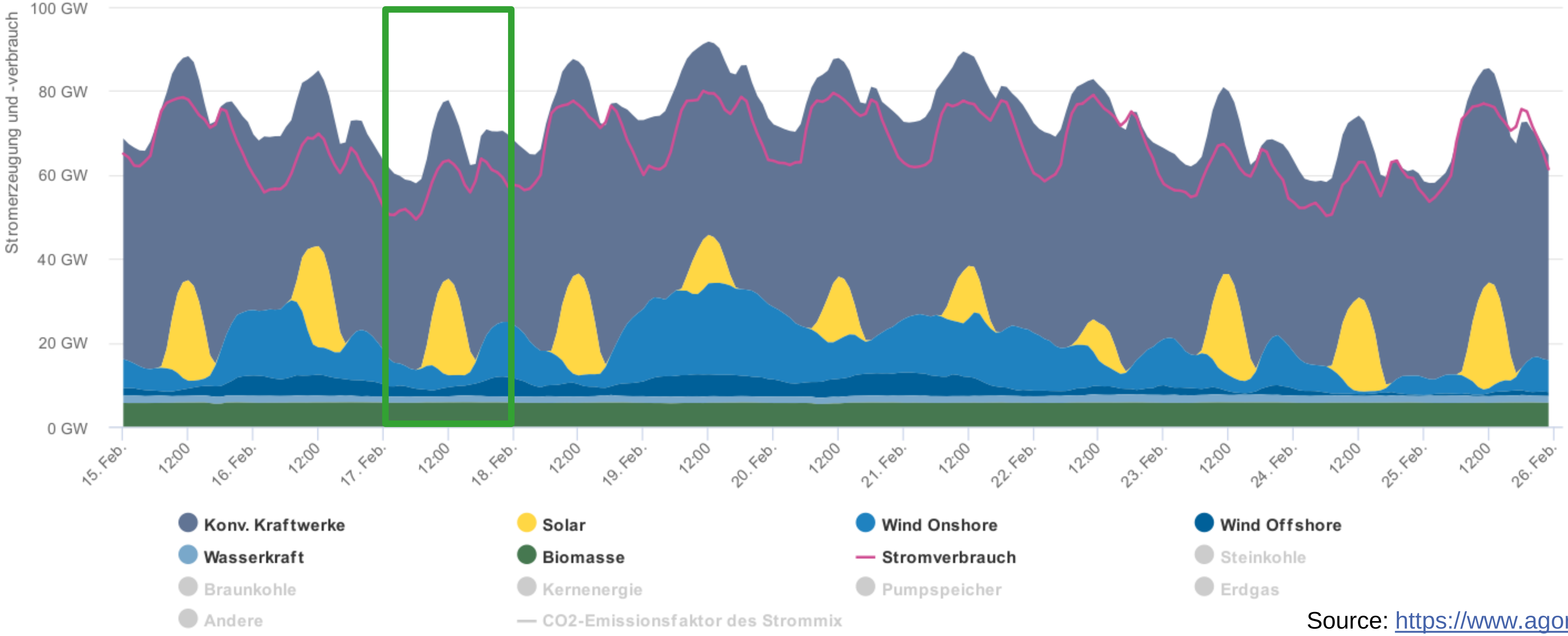
photo: Bernhard Mühr, www.wolkenatlas.de

Variability in the electricity mix

short-range variability (hours – days)

- Generation mix for Germany 15 - 25 February 2019

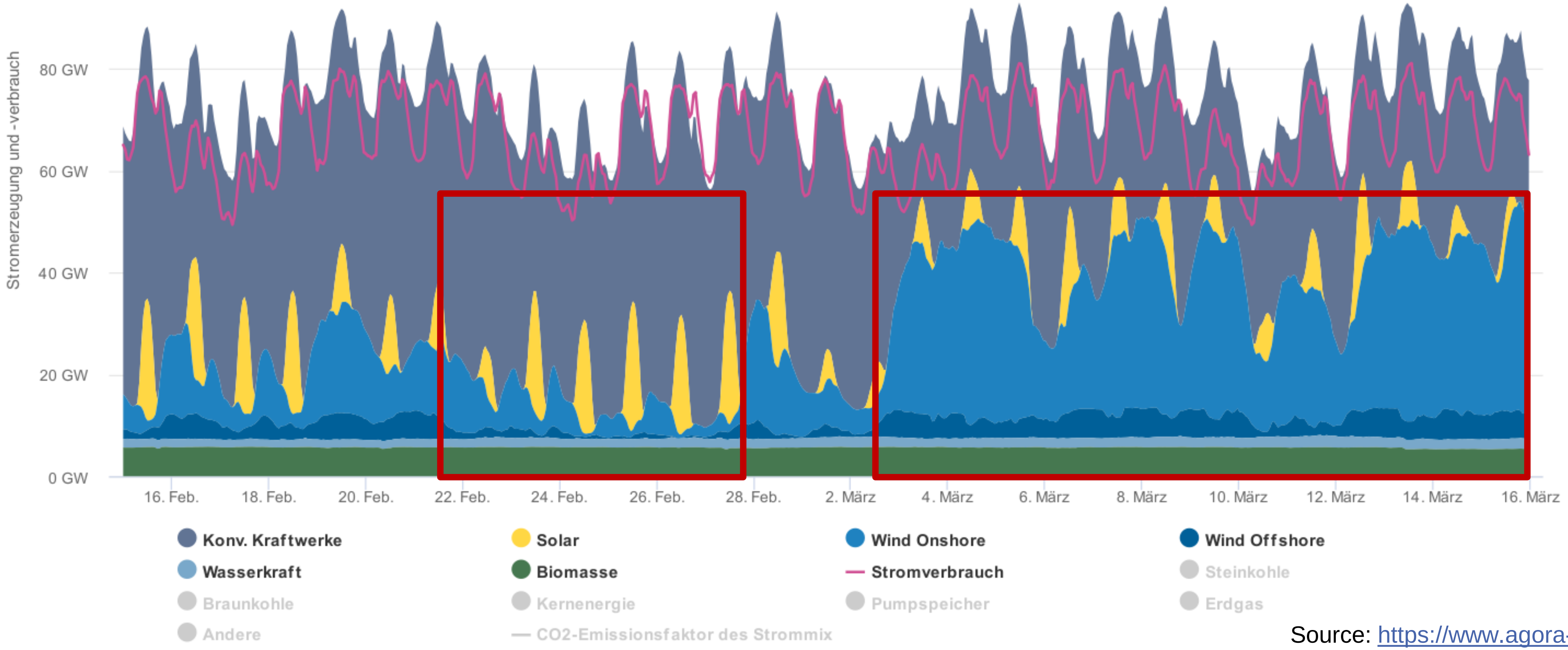


Source: https://www.agora-energiewende.de

Variability in the electricity mix

multi-day variability (days – weeks)

- Generation mix for Germany 15 February - 15 March 2019

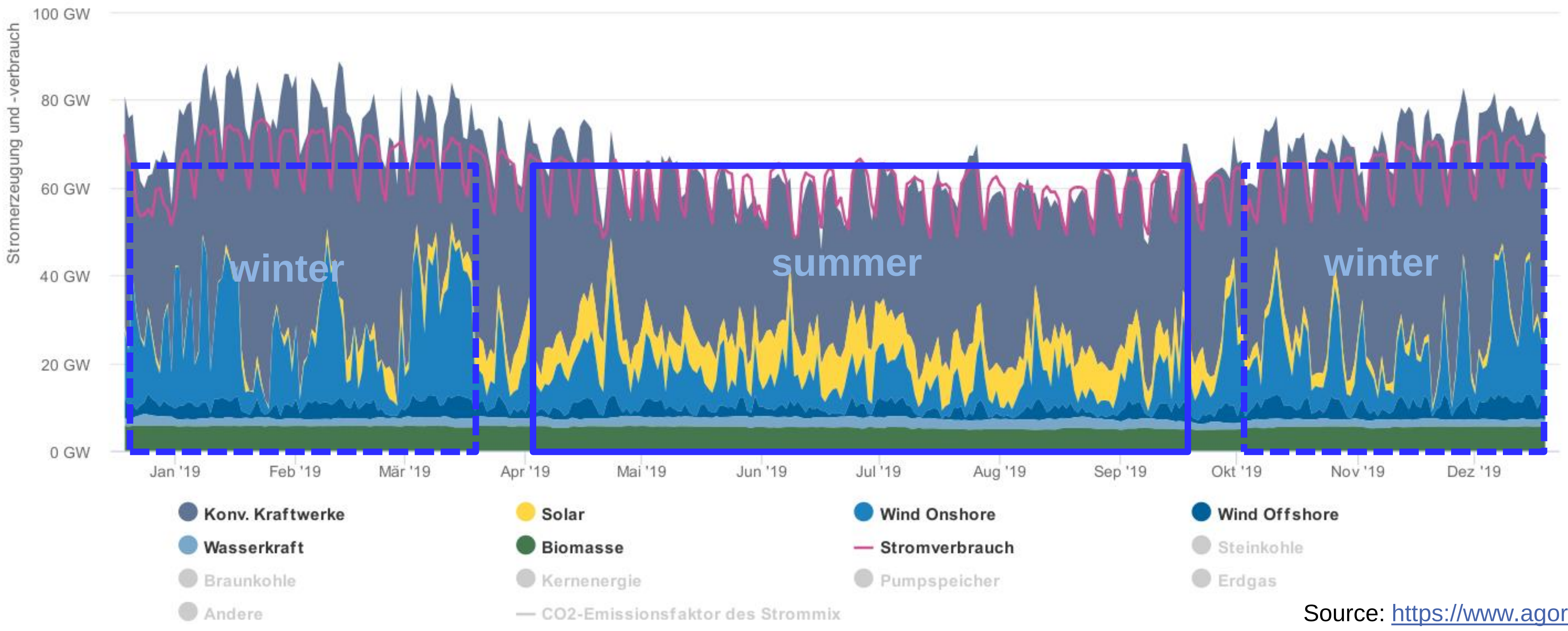


Source: https://www.agora-energiewende.de

Variability in the electricity mix

seasonal variability (months)

- Generation mix for Germany 1 January - 16 December 2019



Source: https://www.agora-energiewende.de

Weather variability affects renewables

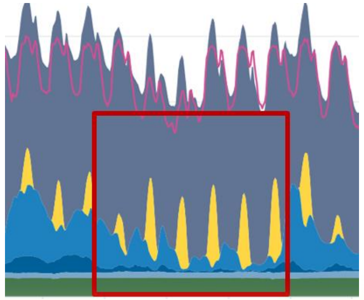
short-range variability (hours – days)

- ΔP=0-30 GW
- often matches p... demand

www.raonline.ch

Storage and flexible demand

multi-day variability (days – weeks)



Balancing through knowledge about weather regimes?

?

Large-scale storage not available!

seasonal variability (months)

- ΔP=10-50 GW
- ...egular seasonal ...ticorrelation of ...nd and solar

https://pxhere.com/de/photo/638728

Co-deployment of wind and solar PV

1) Variability across scales

2) Weather regimes

3) Modulation of wind power

4) Forecasting regimes

5) Modulation on subseasonal time scales

Weather regimes

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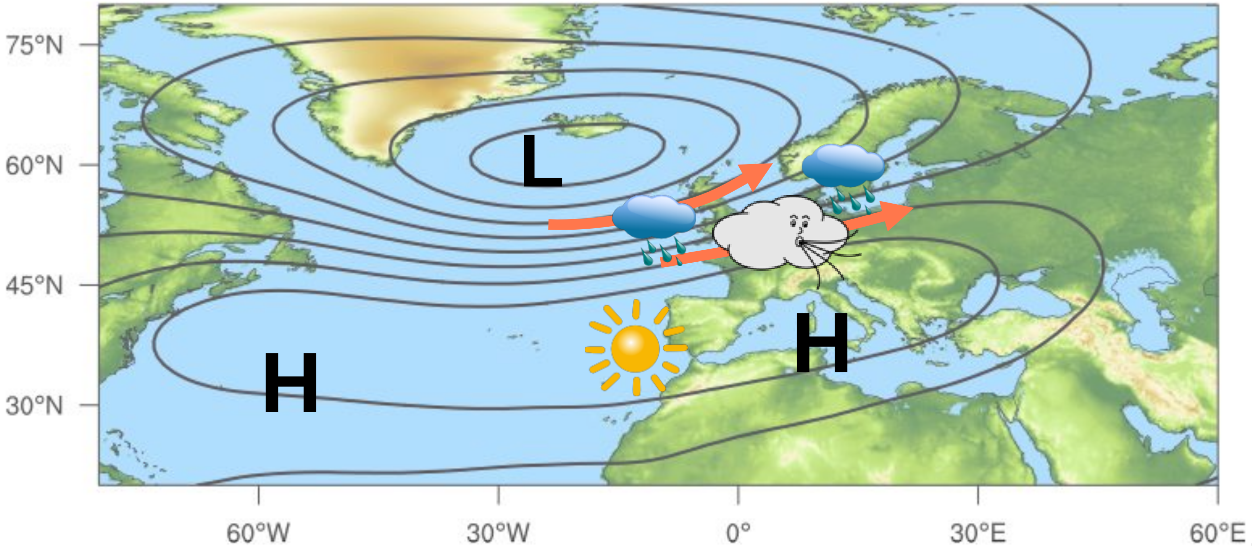
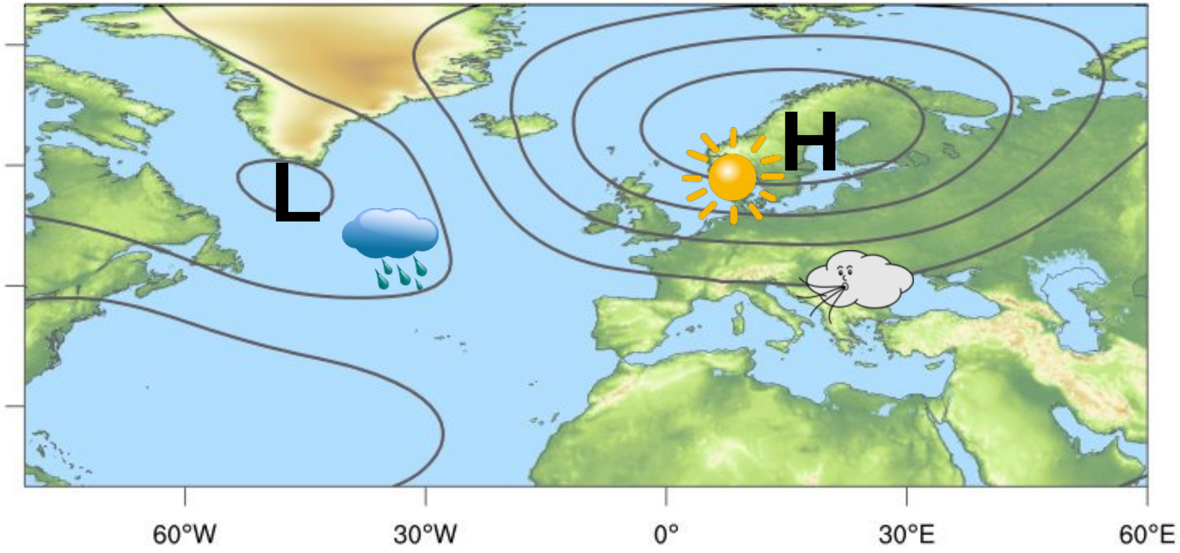
- are quasi-stationary, persistent, and recurrent flow patterns of the large-scale extratropical atmospheric circulation
  (e.g. Vautard 1990, Michelangeli et al. 1995, Hannachi et al. 2017)
- explain character of weather on multi-day to multi-week time scales

cyclonic regimes



blocked regimes



Weather regimes – Definitions

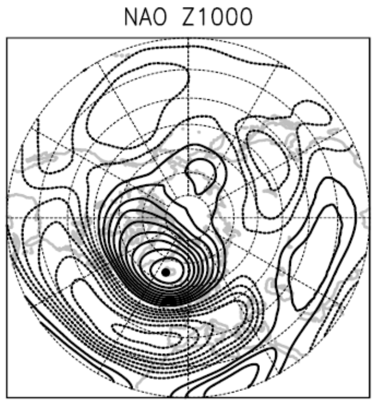


Fig. 1 from review by Hannachi et al. 2017

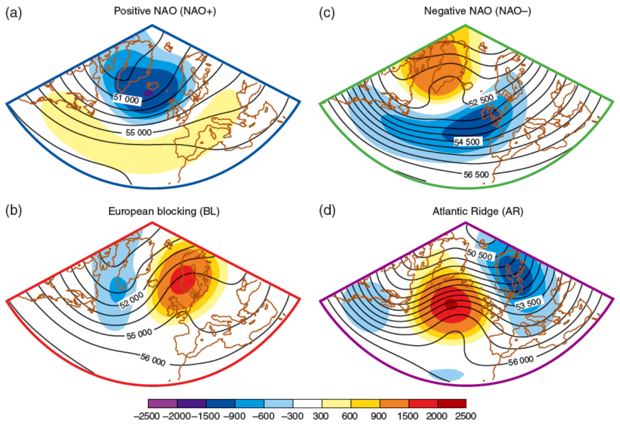


Figure 1. (a–d) Geographical patterns of the four Euro-Atlantic climatological regimes (both anomalies and full fields) for the October to April cold season. The geopotential anomalies (colour shading) and geopotential (contours) at 500 hPa are shown.

Fig. 1 from Ferranti et al. 2015

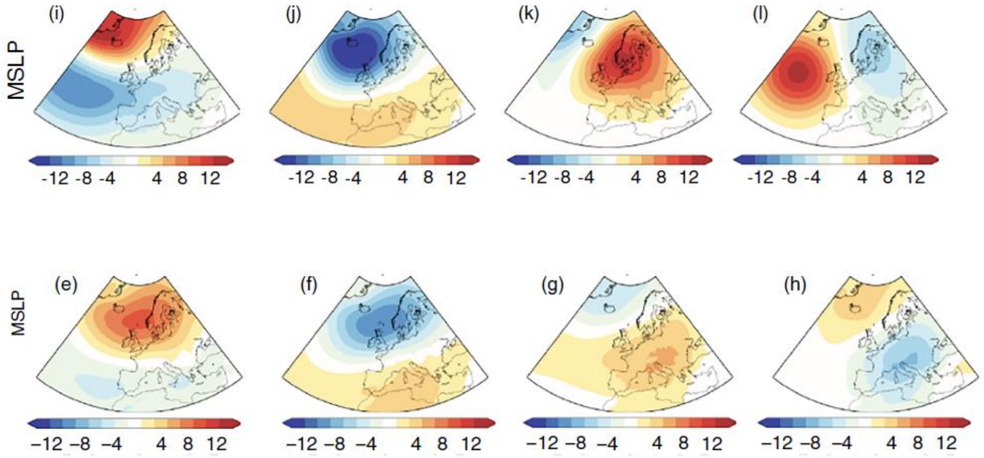


Fig. 2i-l and 3e-h from Bloomfield et al. 2020

- EOF analysis – clustering – persistence
- classification vs. physical grounding vs. targetted circulation types
- optimal number of regimes, seasonality (e.g. Falkena et al. 2020)
- regional extent: weather regimes vs. weather typing (e.g. Neal et al. 2016)

Weather regimes in other world regions

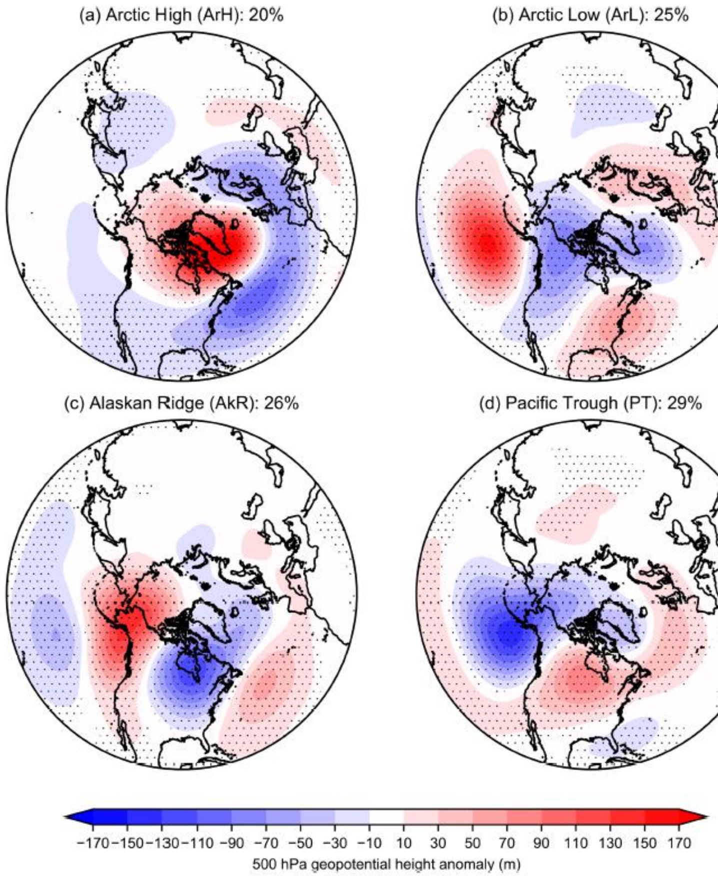


Fig. 1 from Simon Lee et al. 2019 , see also Vigaud et al. 2018

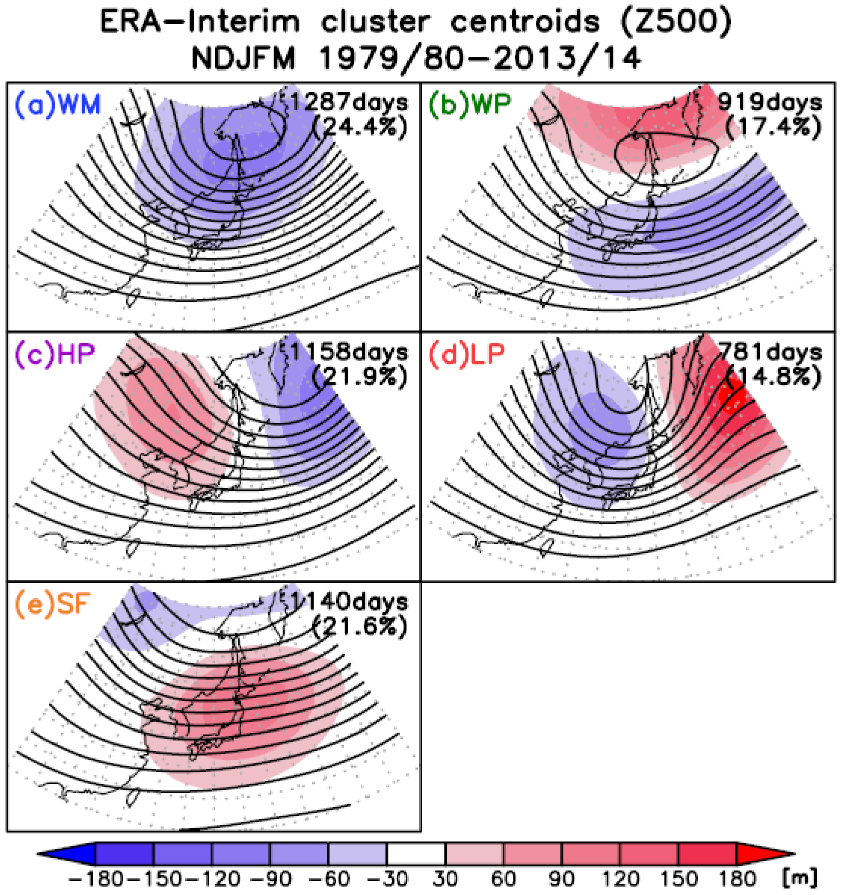


Fig. 1 from Matsueda and Kyouda 2016

1) Variability across scales

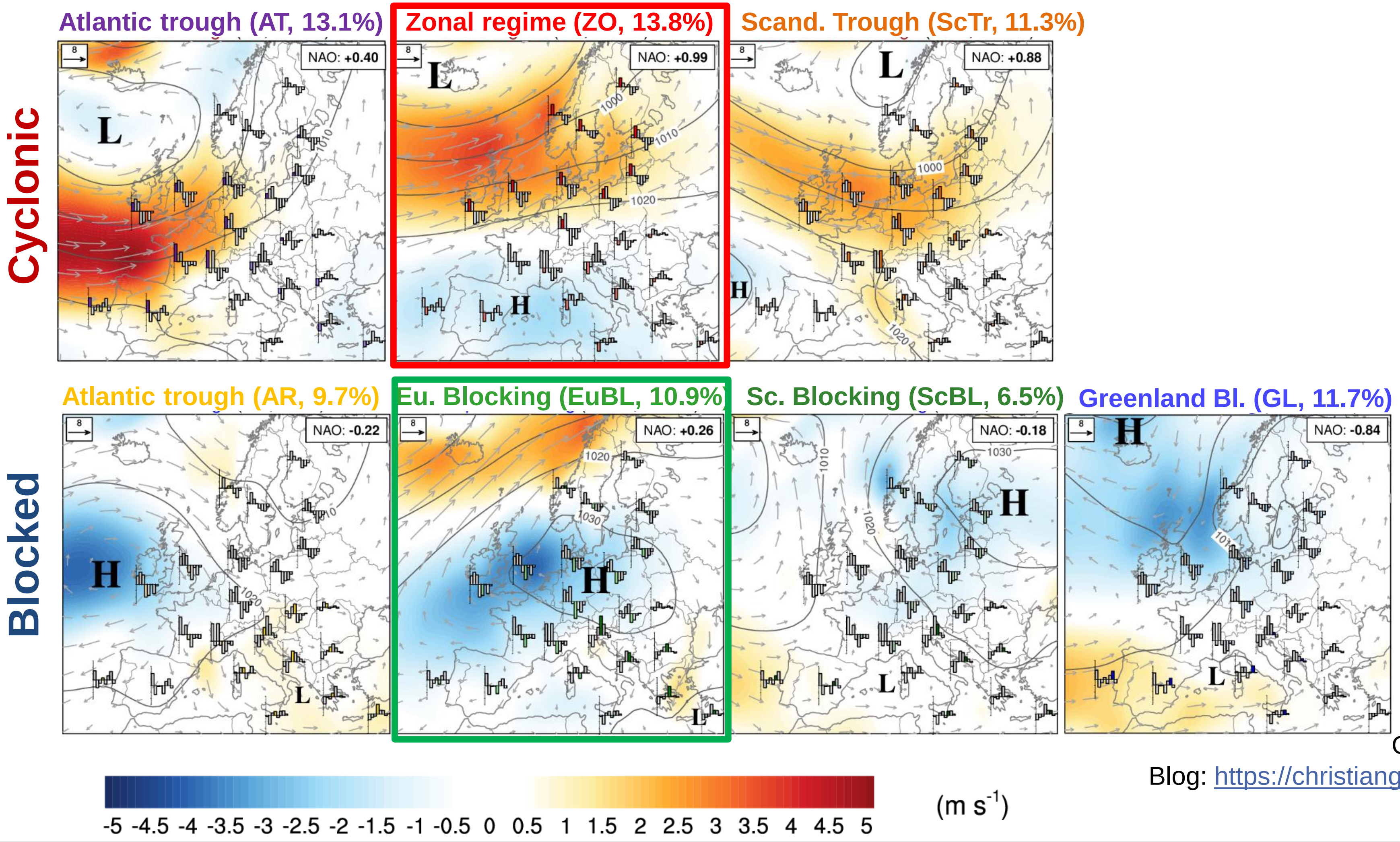
2) Weather regimes

3) Modulation of wind power

4) Forecasting regimes

5) Modulation on subseasonal time scales

Weather regimes – 100m wind variability (winter)

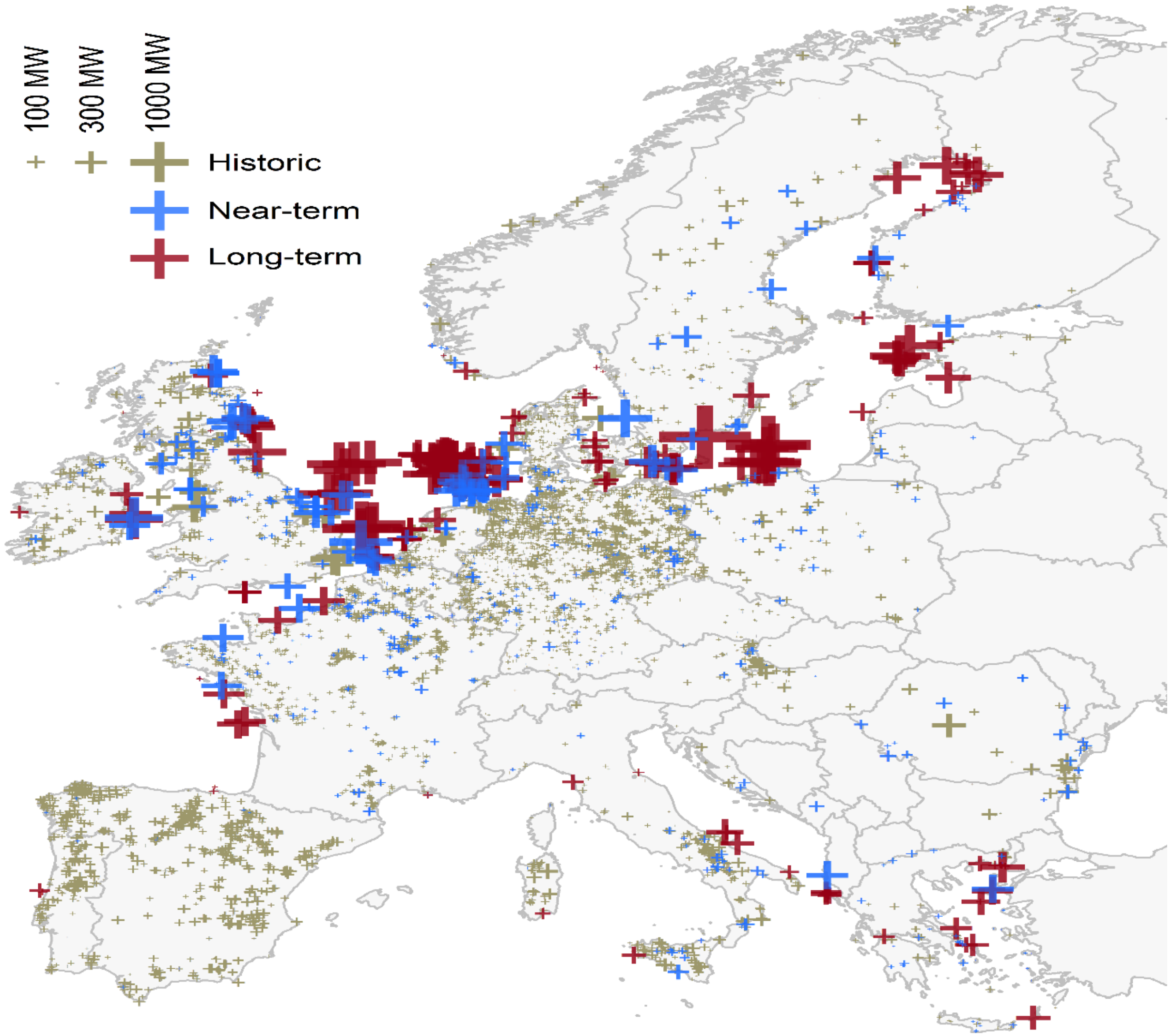


Cyclonic regimes go along with **above average wind** speed in most countries adjacent to the **North Sea**

Blocked regimes go along with **below average wind** speed in most countries adjacent to the **North Sea**

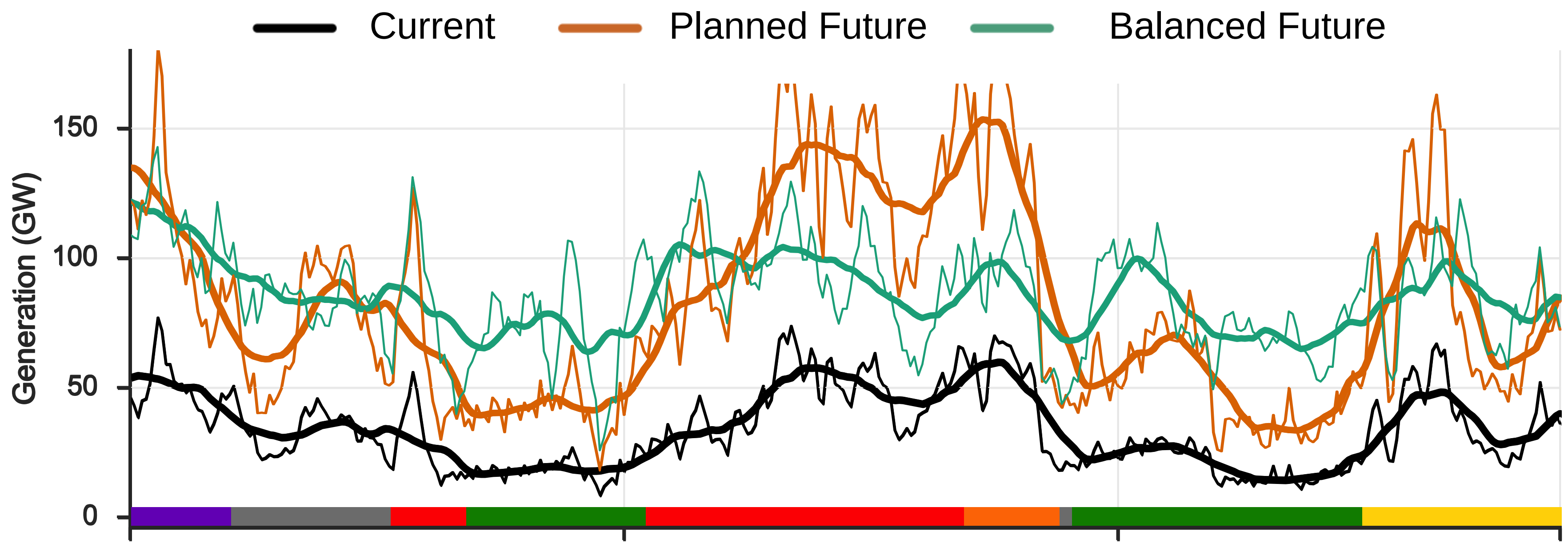
Grams, C.M., et al. (2017), doi:10.1038/nclimate3338.
Blog: https://christiangrams.wordpress.com/balancing-europes-wind-power/
see also Zubiate et al. (2017) doi:10.1002/qj.2943

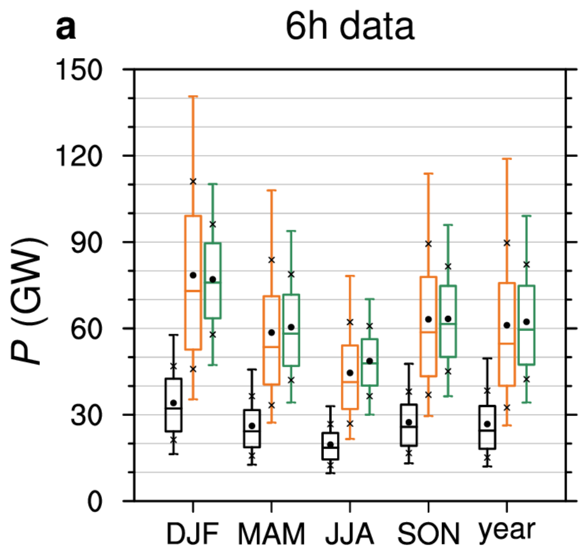
Current and Future wind deployment



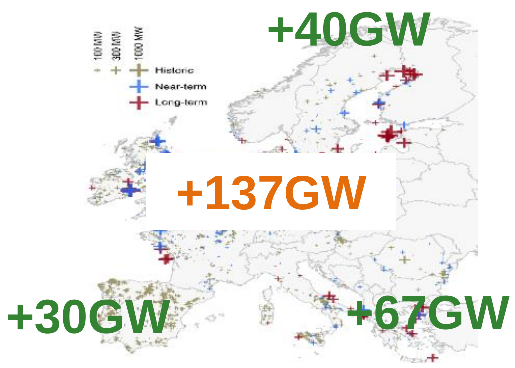
- Predominant offshore deployment in North Sea and Baltic Sea
- Hardly new deployment in Spain
- Little new deployment in Balkans

Example – winter 1992/93





→ Multi-day variability in European wind power could be balanced through spatial deployment informed by weather regimes



1) Variability across scales

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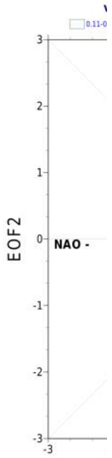
Weather regimes – forecast product examples

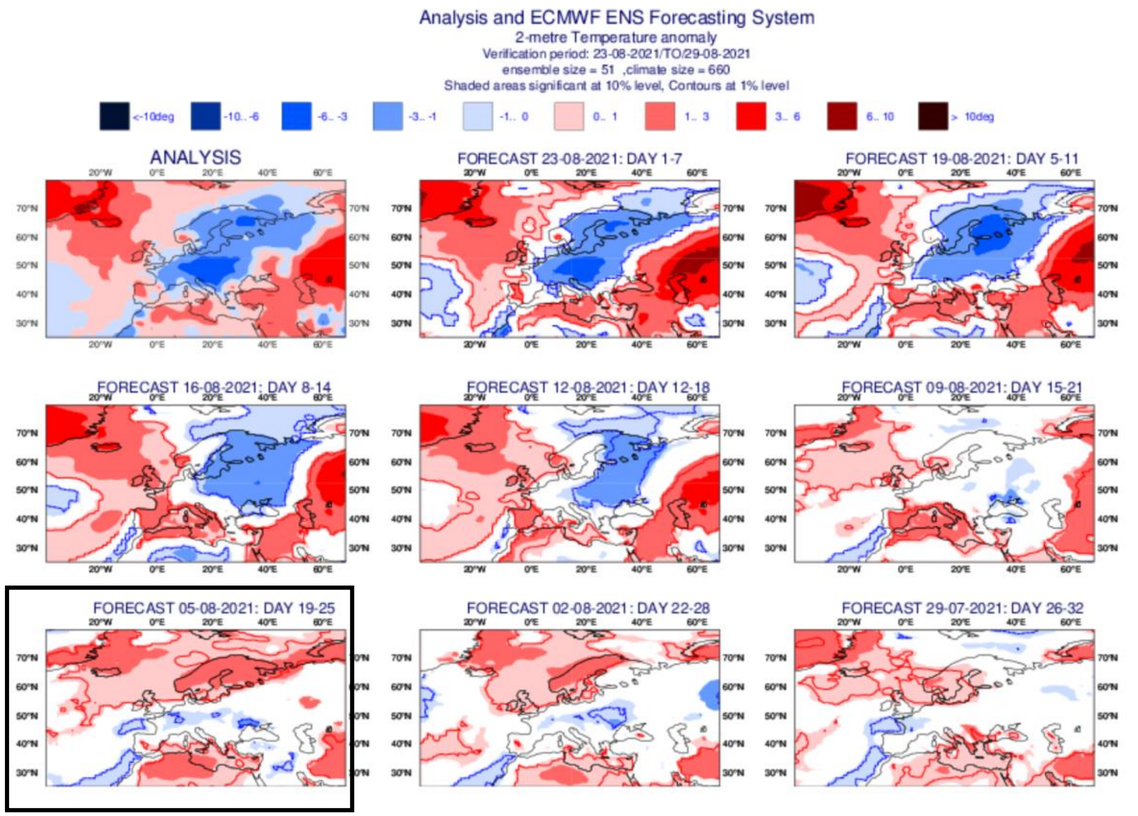
EC

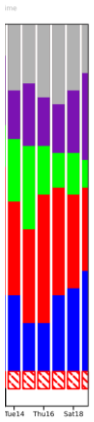
Global and regional anomaly

7WR lifecycles

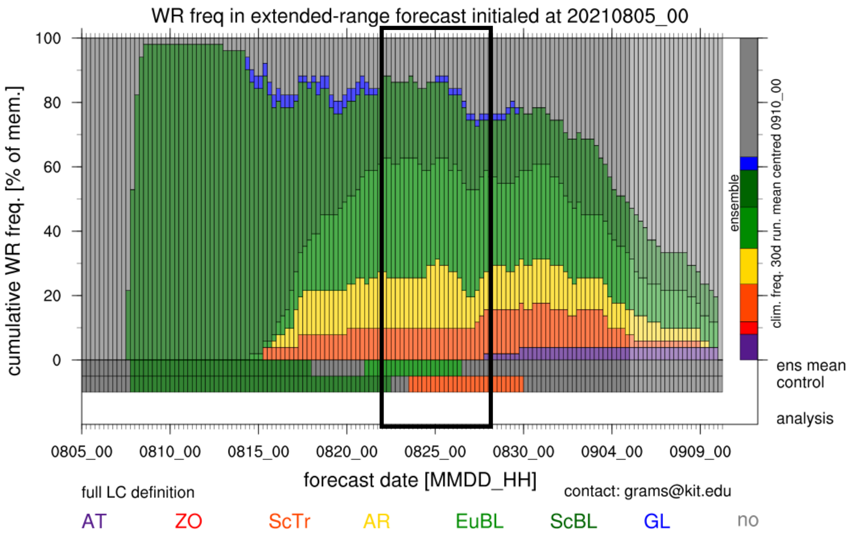
Exte







ECMWF



ECMWF

see disc

Weather regimes – (flow-dependent) forecast skill

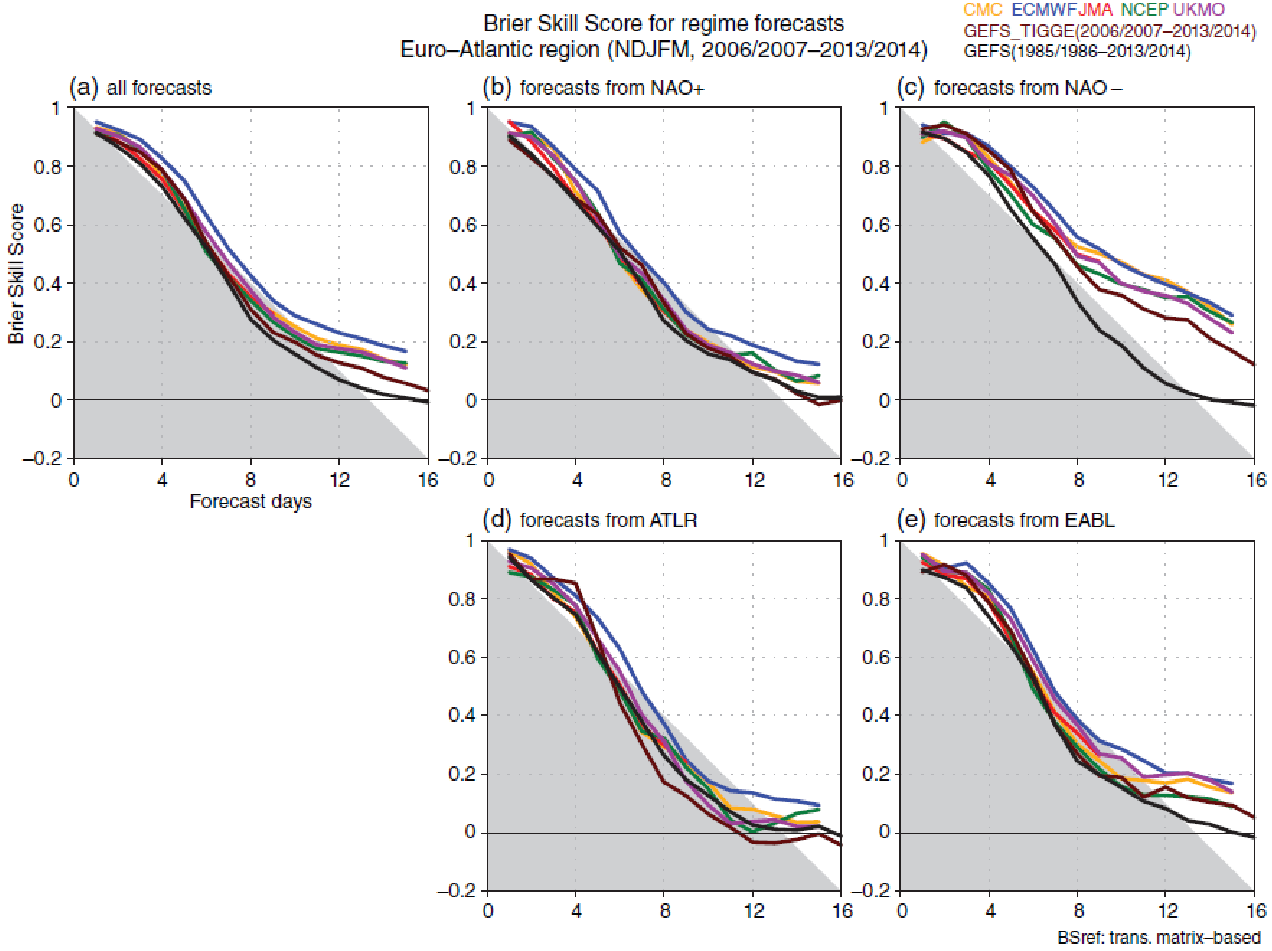


Fig. 6 from Matsueda and Palmer 2018, see also Ferranti et al. 2015

year-round BSS for individual regimes in ECMWF reforecasts

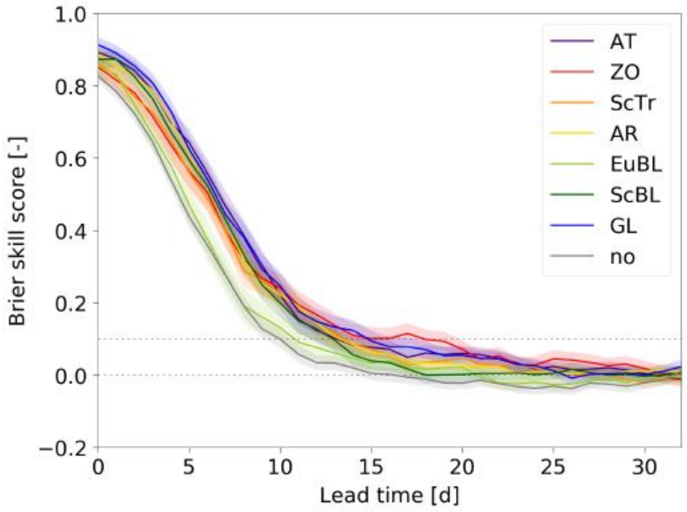


Fig. 6 from Büeler et al. 2021, *in revision*

1) Variability across scales

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Weather regimes – sources of S2S predictability

- Stratosphere

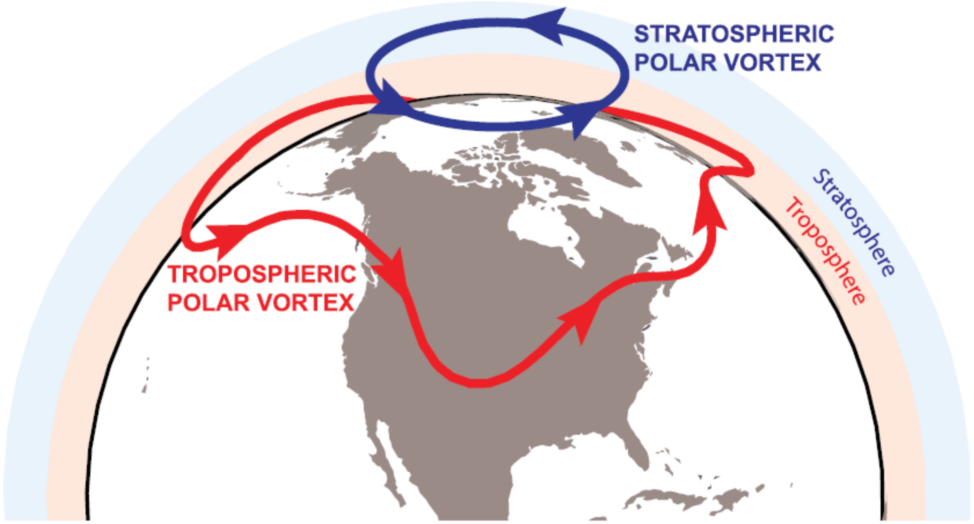


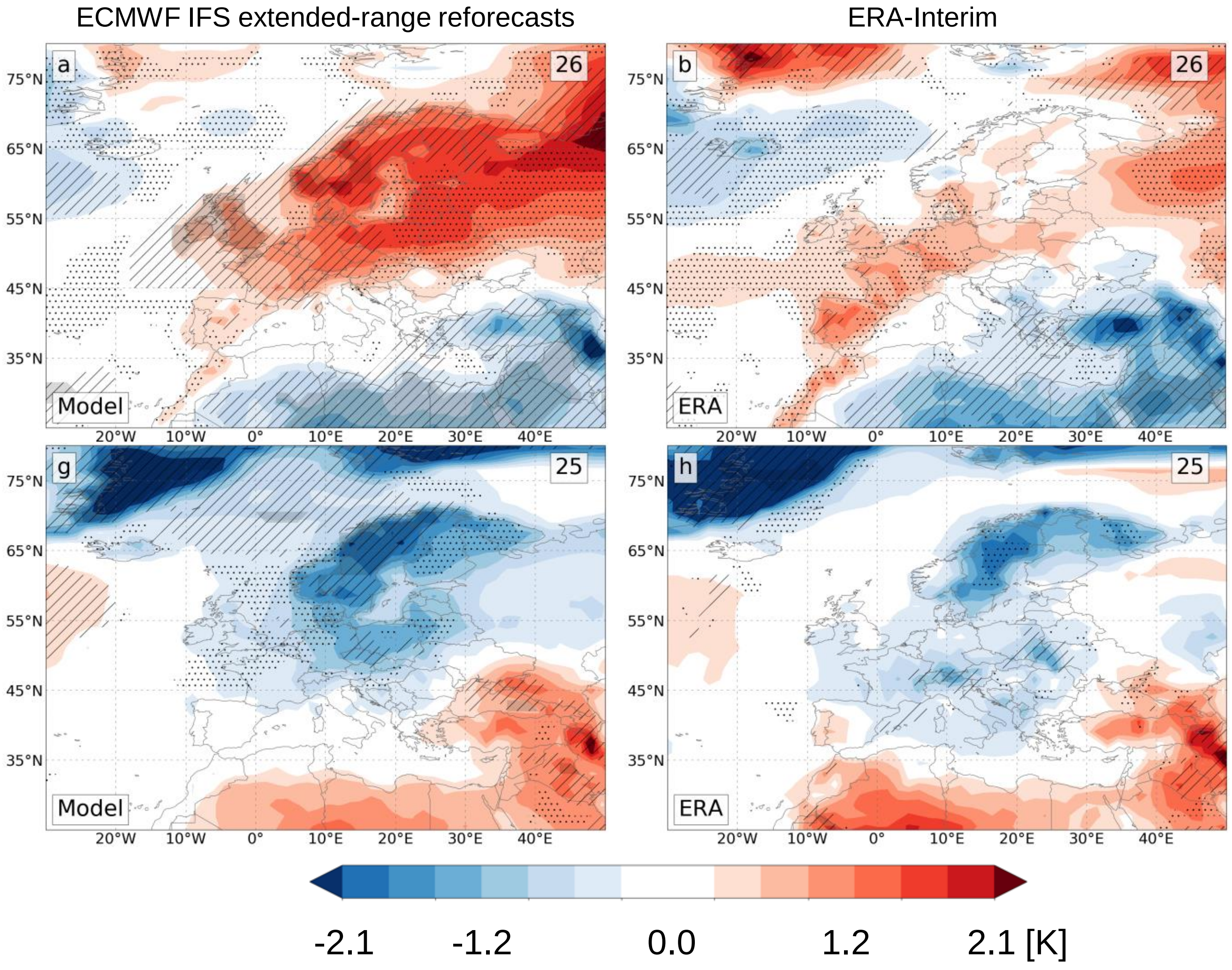
FIG. 1. Schematic of stratospheric and tropospheric polar vortices.

Fig. 1. from Waugh et al. 2016

- symmetric **SPV**
- westerly polar night jet in 10-50 km height

- **tropospheric westerly jet** meanders around globe
- 5-10km height

Systematic biases in S2S model response

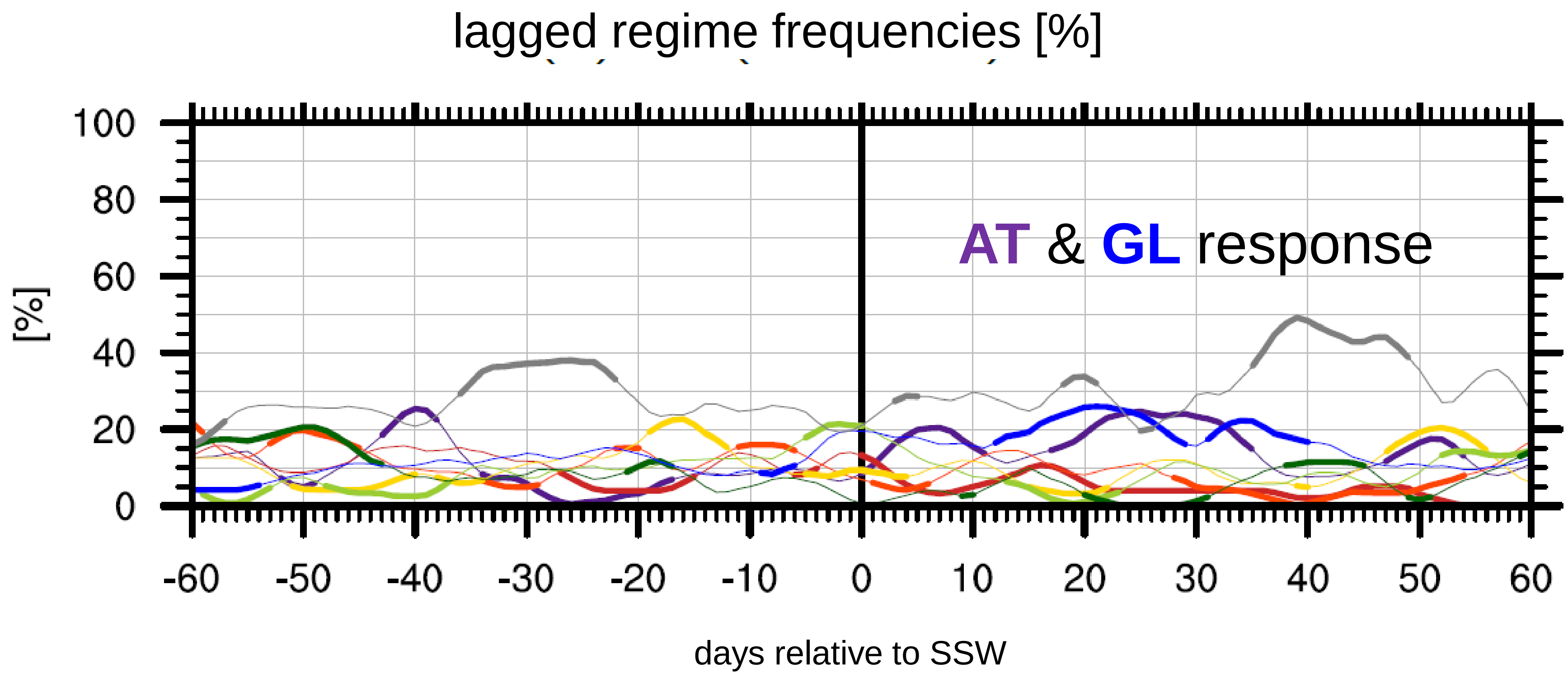


2m temperature anomaly 0-30d after 2% strongest/weakest SPV

- Left: ECMWF reforecasts tend to unambiguous warm/cold response
- Right: reality shows weaker anomalies

Büeler et al. (2020) *QJRMS*, doi:10.1002/qj.3866

Regime response to extremely weak SPV (SSW)



taken from Domeisen, Grams, and Papritz 2020, see also Beerli and Grams 2019, Beerli et al. 2017, Büeler et al. 2020, Charlton-Perez et al. 2018, Papritz and Grams 2018

Surface impact of SSWs – 2m temperature

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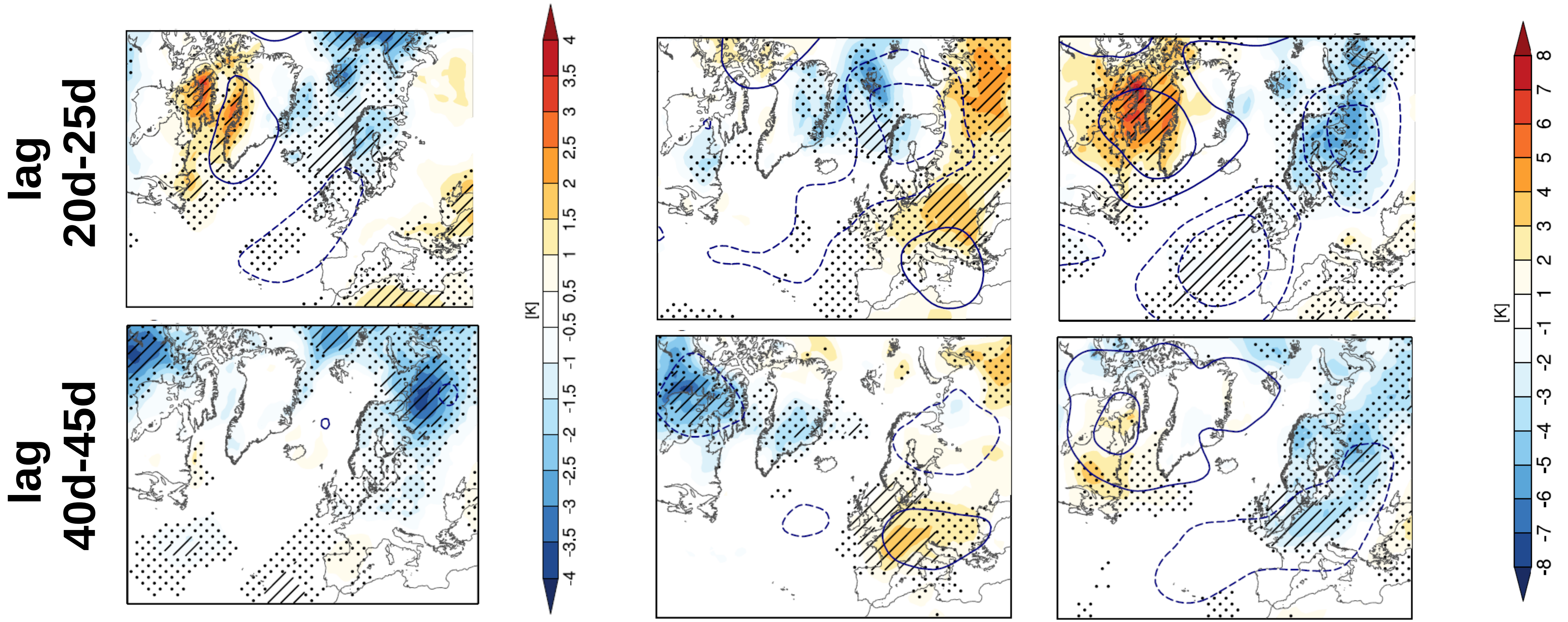
all SSWs (25) **GL**@onset (5) **EuBL**@onset (7)



taken from [Domeisen, Grams, and Papritz 2020]

Weather regimes – sources of S2S predictability

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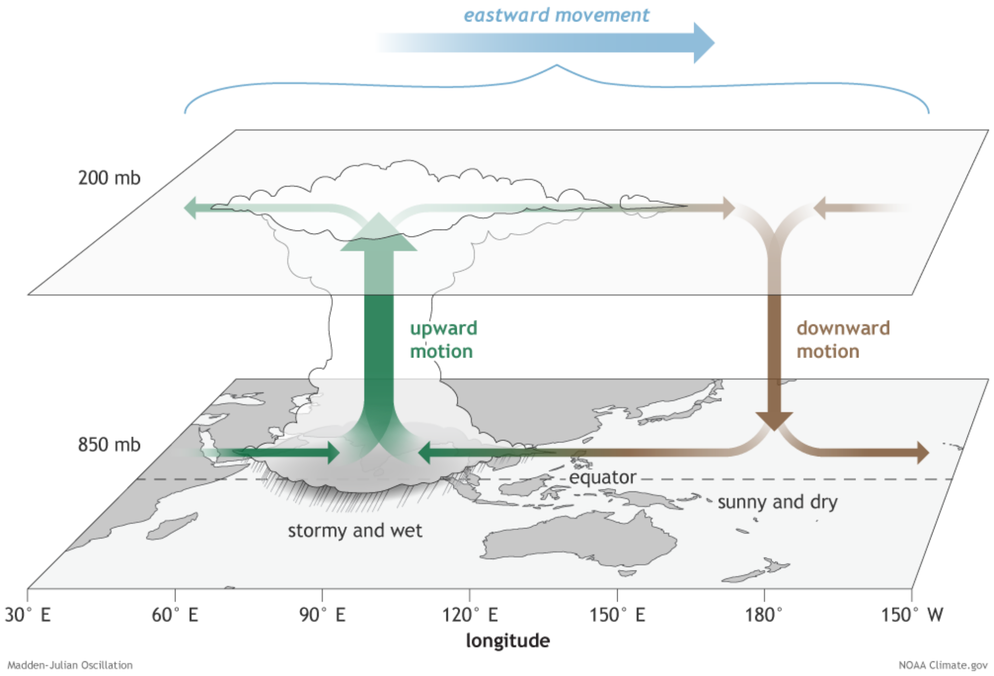
- Madden-Julian-Oscillation



Climate.gov drawing by Fiona Martin

Z500 anomalies after MJO Phase 3

5-10d 10-15d

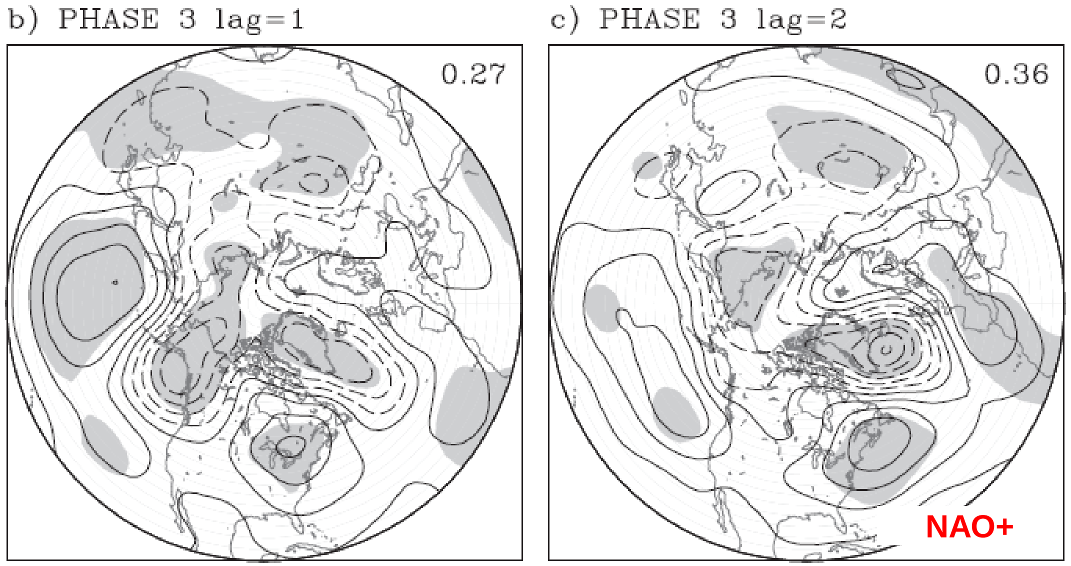


Fig 3 from Lin et al. 2009, see also Cassou et al. 2008, Robert Lee et al. 2019

Weather regimes – sources of S2S predictability

- Joint forcing by MJO – ENSO – stratosphere

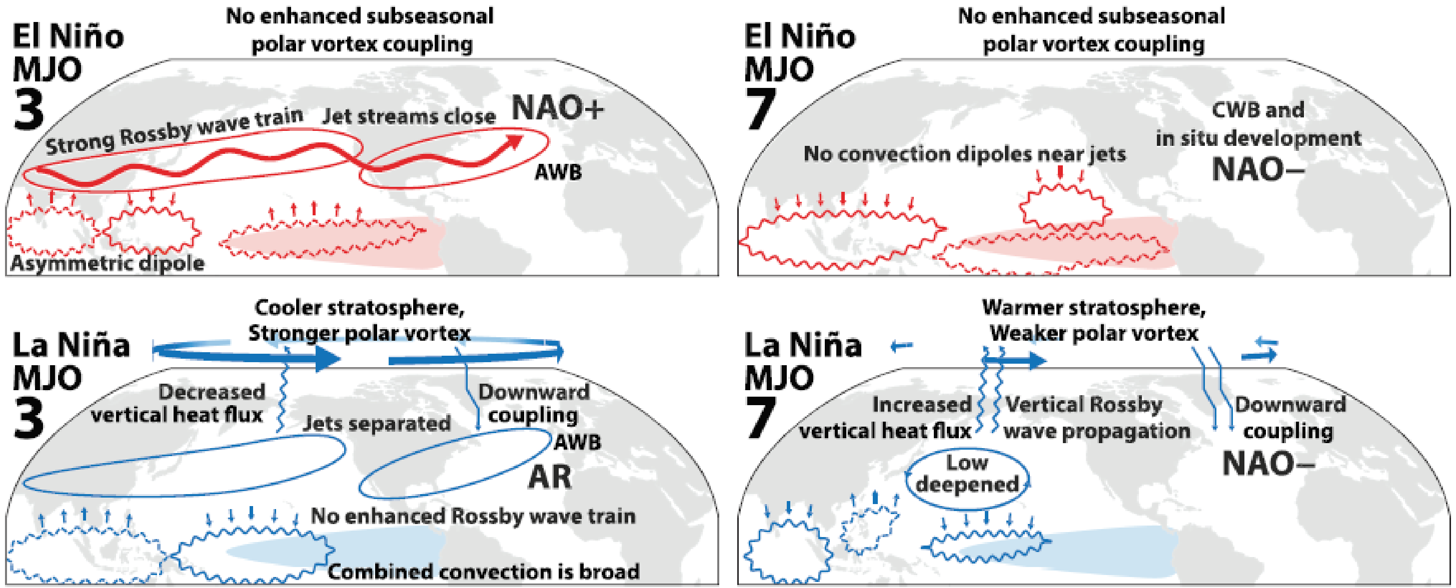


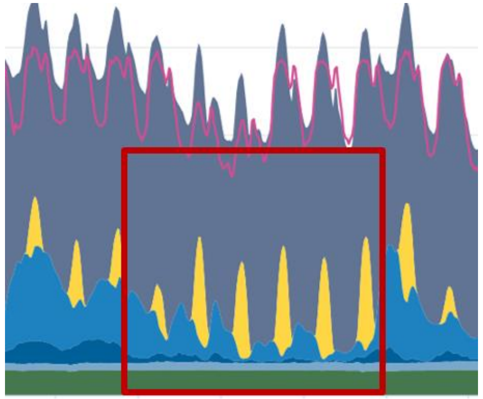
Figure 4. Schematic of ENSO modulation of subseasonal teleconnections from the MJO to the NAE region (narrative: Text S7). El Niño (upper panels; red) and La Niña (lower panels; blue) states are illustrated following MJO phases 3 (left panels) and 7 (right panels). AWB and CWB refer to anticyclonic wave breaking, and cyclonic wave breaking, respectively. The anomalous convection signals (solid: enhanced; dashed: suppressed) comprise the MJO, in the given phases, as modified by the large-scale ENSO circulation.

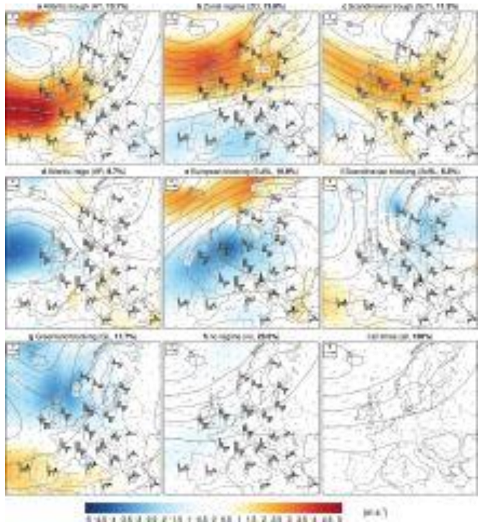
Fig. 4 from Robert Lee et al. 2019

Summary

- a note on regimes and climate change

- weather regimes are **quasi-stationary, persistent,** and **recurrent** flow patterns in the extratropics
- weather regimes govern **variability of weather on sub-seasonal time scales (10-30 days)**
- interesting for **country-aggregated or continent-scale forecast** in the energy sector
- **windows of forecast opportunity beyond 2 weeks** due to slower climate modes (MJO, stratosphere)





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Modulation of regime occurrence and predictability on S2S time scales (often in context of energy meteorology)

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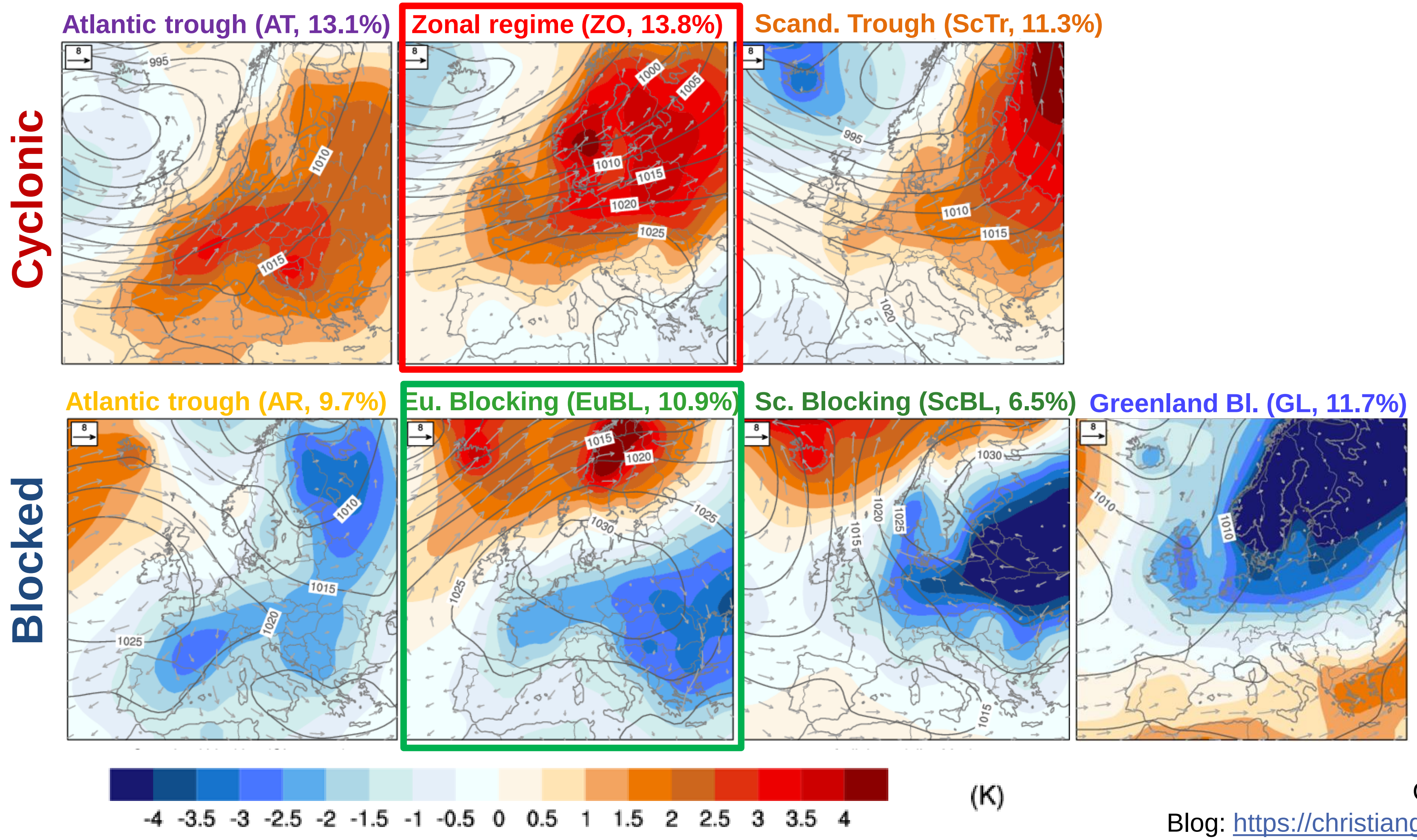
Weather regimes – 2m temperature variability (winter)

Karlsruhe Institute of Technology

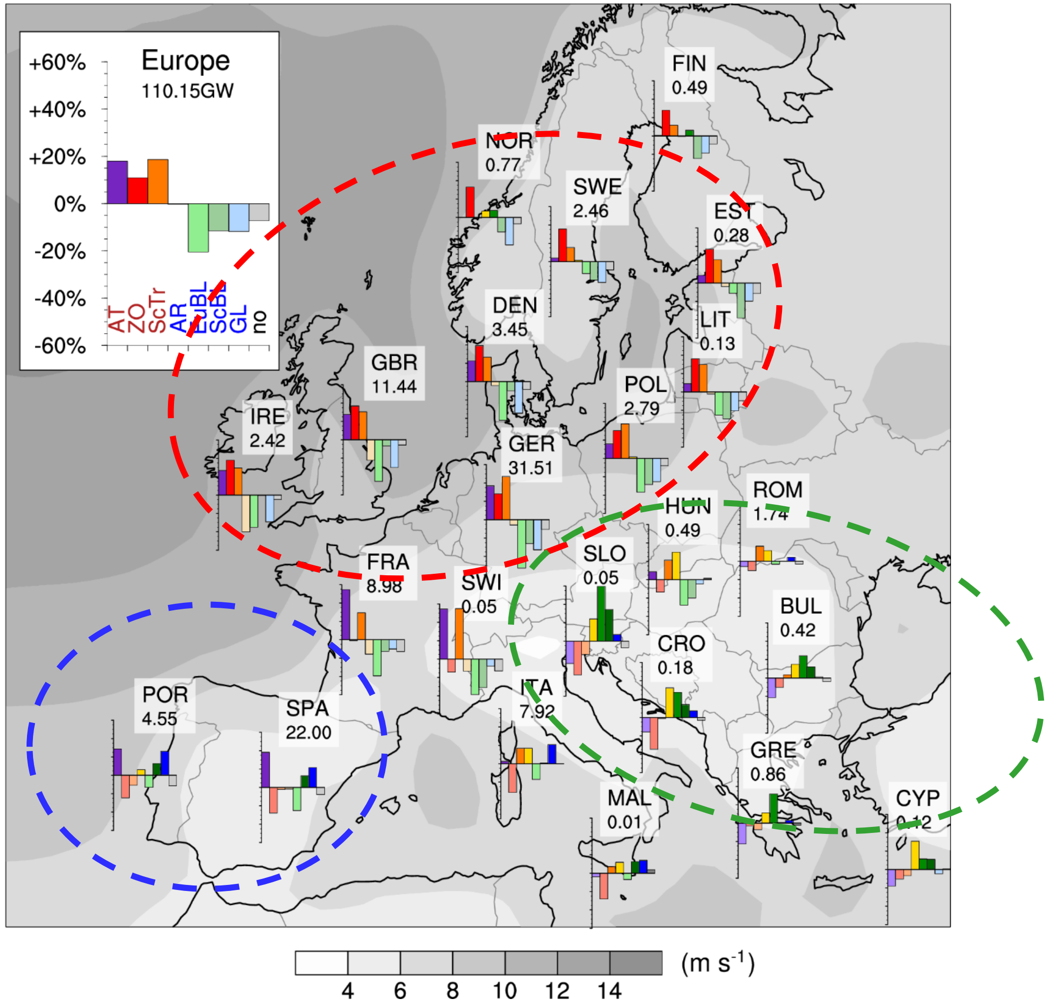


Cyclonic regimes go along with **mild conditions** in most parts of **Europe**

Blocked regimes go along with **cold conditions** in many parts of **Europe**

Grams, C.M., et al. (2017), doi:10.1038/nclimate3338.
Blog: https://christiangrams.wordpress.com/balancing-europes-wind-power/

Modulation of wind power potential



Bars for each country of

ΔCF : wind power output change wrt. winter mean

numbers: country's *IC* in GW
gray shading: DJF mean 100m wind

Grams, C.M., et al. (2017), doi:10.1038/nclimate3338.
Blog: https://christiangrams.wordpress.com/balancing-europes-wind-power/

Weather regimes – sources of S2S predictability

- Stratosphere

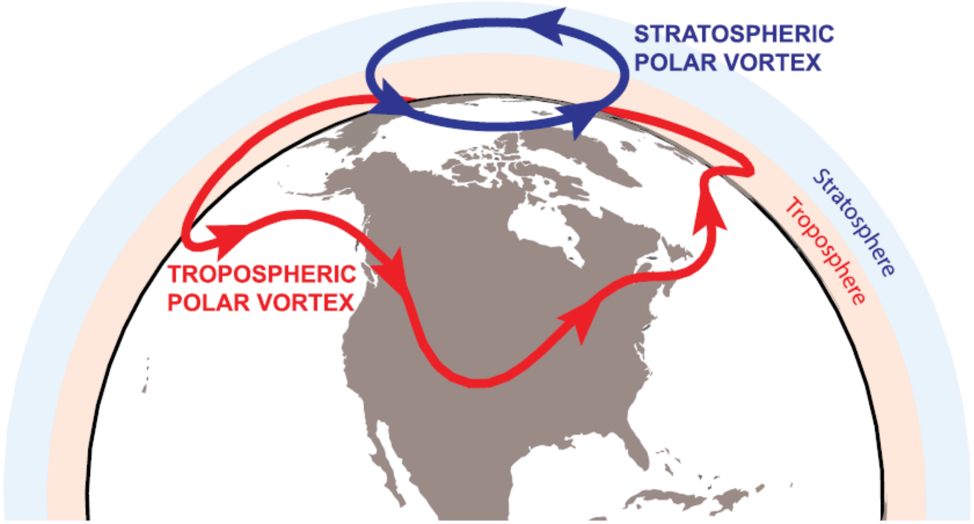


Fig. 1. Schematic of stratospheric and tropospheric polar vortices.

Fig. 1. from Waugh et al. 2016

regime frequency in **strong / neutral / weak** SPV states. Pale below winter (DJF) mean.

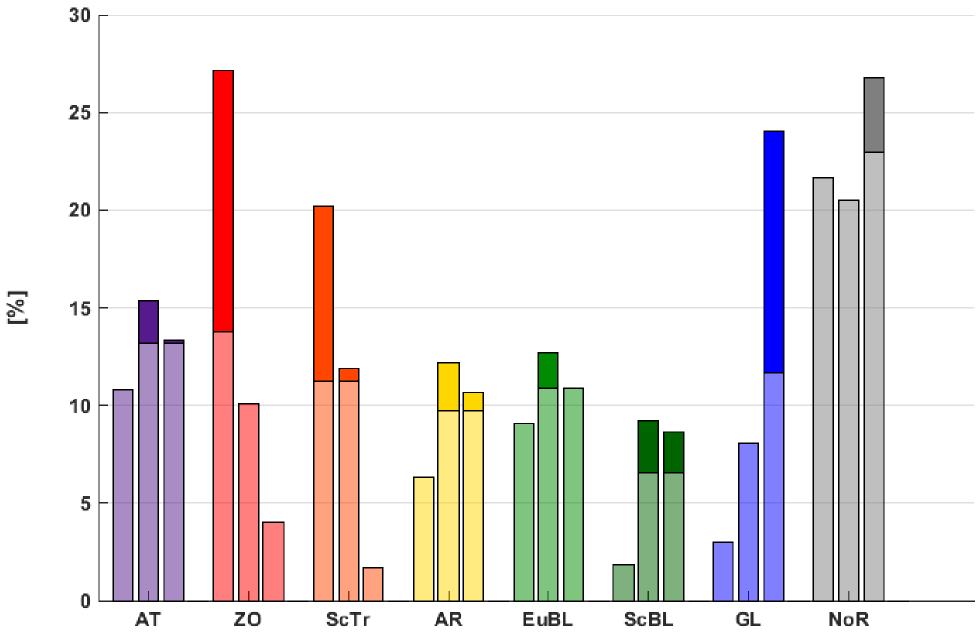
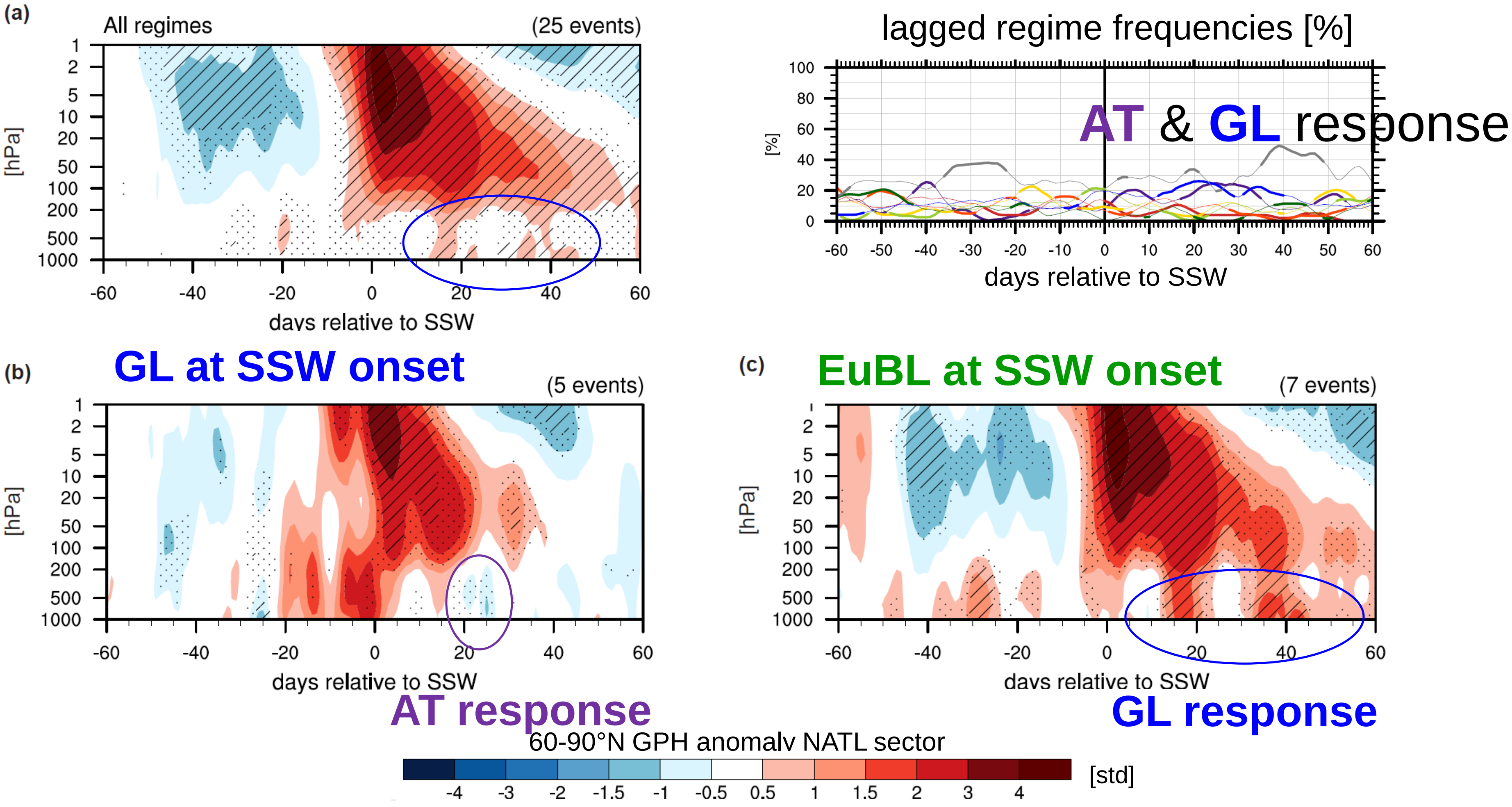


Fig. 6 from Beerli and Grams 2019, see also Beerli et al. 2017, Büeler et al. 2020, Charlton-Perez et al. 2018, Domeisen, Grams, and Papritz 2020, Papritz and Grams 2018

Downward impact of extremely weak SPV (SSW)



taken from Domeisen, Grams, and Papritz 2020

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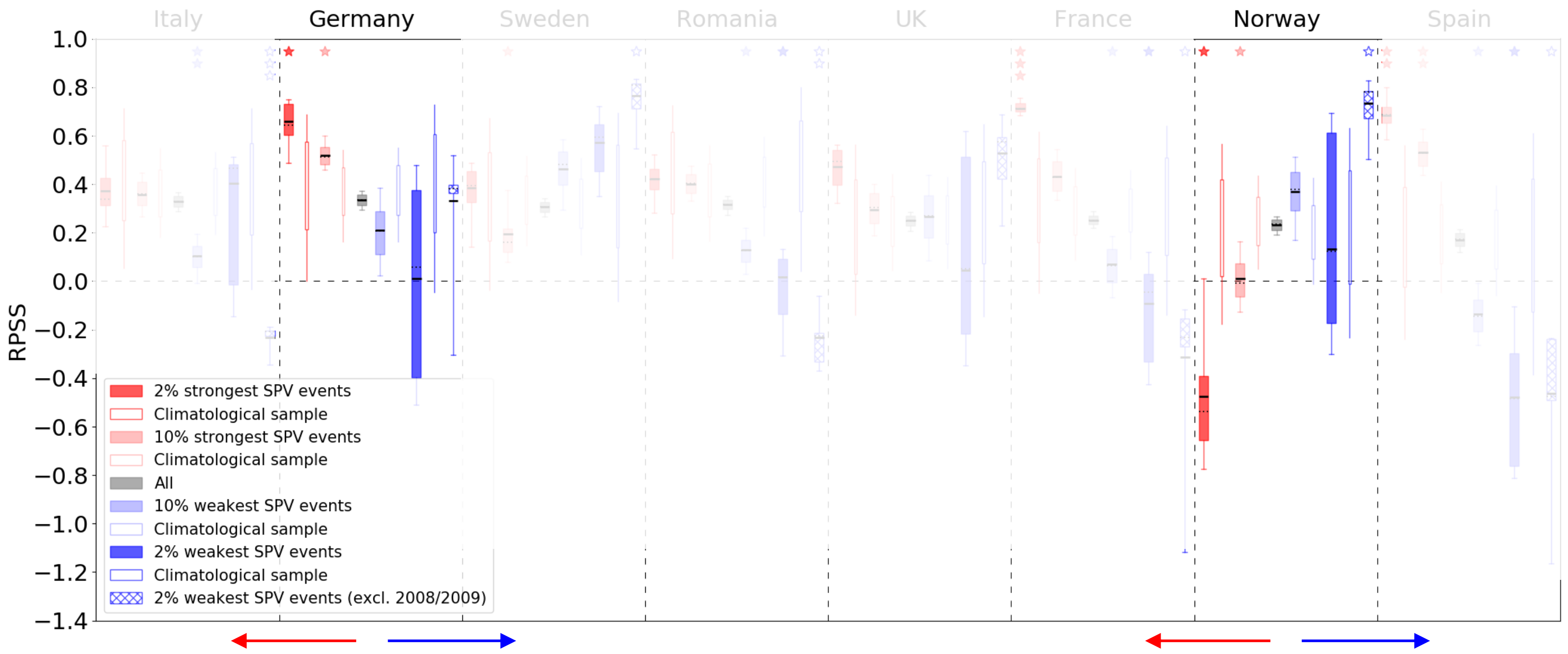
Institute of Meteorology and Climate Research (IMK-TRO)

Stratosphere-dependent forecast skill

RPSS distributions for month ahead, country-aggregated 2mT forecasts



Adapted from Figure 4 in Büeler et al. (2020): **RPSS distributions for month ahead, country-aggregated 2mT forecasts** (categorical in upper, middle, lower terciles) initialized in different SPV states. Box-and-Whisker Plots show the 10, 25, 50 ,75; 90% percentiles, dashed line the mean of the RPSS distribution. Thin box-and-whiskers show 10, 25, 75; 90% percentiles of distributions from random forecasts with similar sample size. One (two/three) stars denote overlap of less than 25% (10% / 5%) with the random distribution.

Büeler et al. (2020) *QJRMS,* doi:10.5194/wcd-2019-16