The mutual impact of weather regimes and the stratospheric circulation on European surface weather

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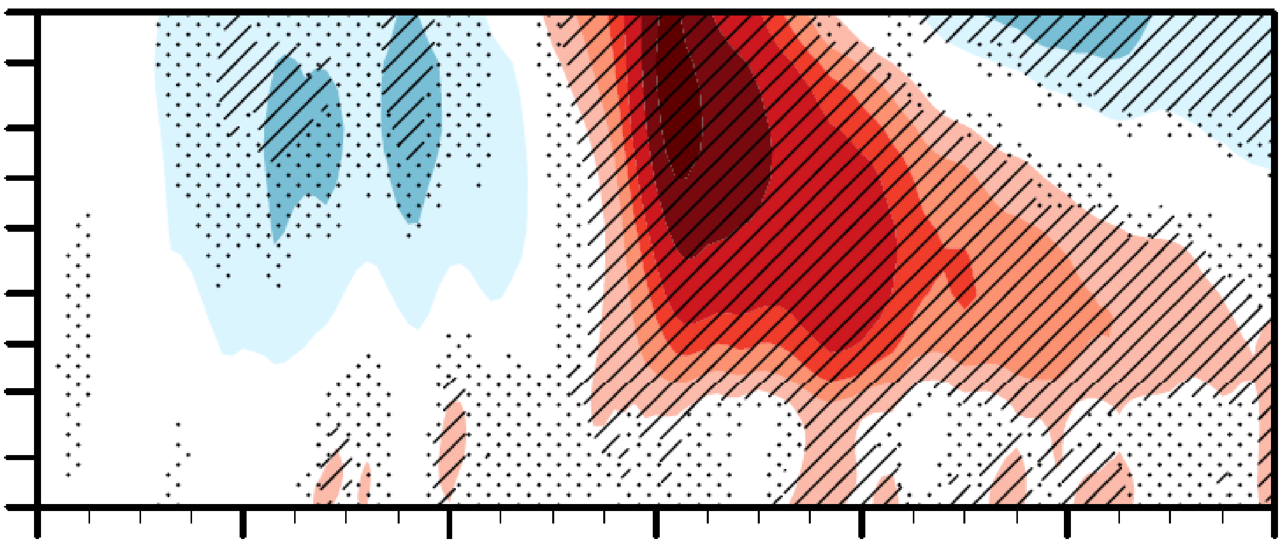

Overview and Summary

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- winter stratosphere modulates not only the NAO but also the occurrence of North-Atlantic weather regimes → **slides 3-5**
- Some regimes occur irrespective of the stratospheric conditions and provide pathways to unexpected weather (e.g. mild and windy during weak stratospheric polar vortex states) → **slides 5-6**
- Regime at onset of a sudden stratospheric warming (SSW) event can be an indicator of a subsequent mild and windy (Atlantic Trough) or cold and calm (Greenland Blocking) response → **slides 7-9**
- S2S reforecasts tend to have higher skill for surface weather during strong stratospheric polar vortex conditions → **slides 10-11**
- References → **slide 13**

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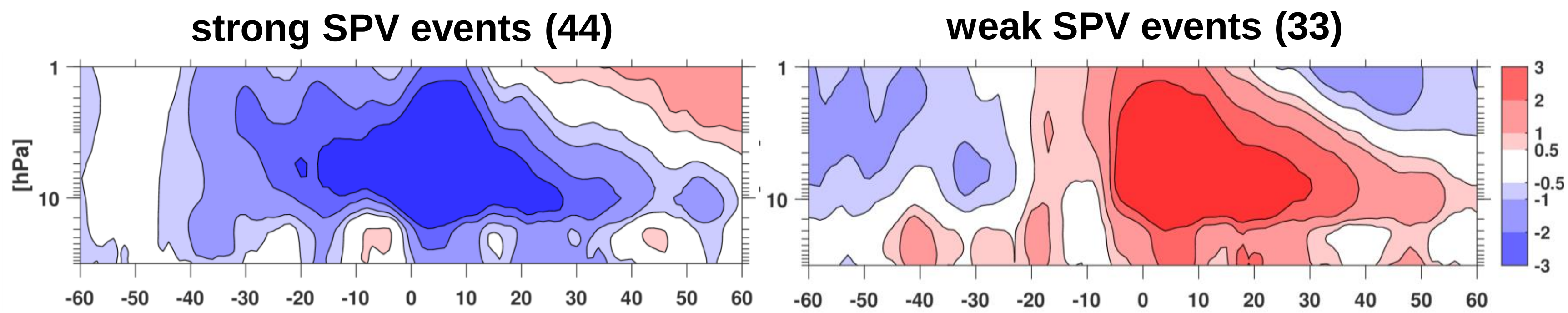
Troposphere-stratosphere coupling during extreme states of the stratosphere



Top: Figures 11a & 12a from Beerli and Grams (2019): Composite of standardised mean polar-cap averaged (north of 60°N) geopotential height anomalies shown as a time–pressure height diagram for SPV events (following Limpasuvan et al. 2004, 2005).
The geopotential height anomalies are divided on each level by the 95% significance threshold based on the Student's t-test. Anomalies greater (smaller) than 1 (−1) are thus statistically significant. The x-axis shows the time lag with respect to the start of the polar vortex event.

Right: Figure 2c from Beerli and Grams (2019): Distribution of daily North Atlantic Oscillation (NAO) indexes for the 40 days following a strong or weak vortex event. Black/red line indicates the mean / median.

- winter arctic stratospheric polar vortex (SPV) is a potential source of subseasonal predictability
- extreme arctic SPV states tend to have a tropospheric impact in the northern hemisphere up to 6 weeks following an extreme SPV event.
- strong SPV events (strong westerly night jet, extreme cold conditions in stratosphere) favor negative geopotential height anomalies in the troposphere and shift of the NAO towards positive values (strong North Atlantic storm track)
- weak SPV events (collapsed westerly night jet, warm conditions in stratosphere) favor positive geopotential height anomalies in the troposphere and shift of the NAO towards negative values (blocking over Greenland)

Weather regimes in the Atlantic-European region

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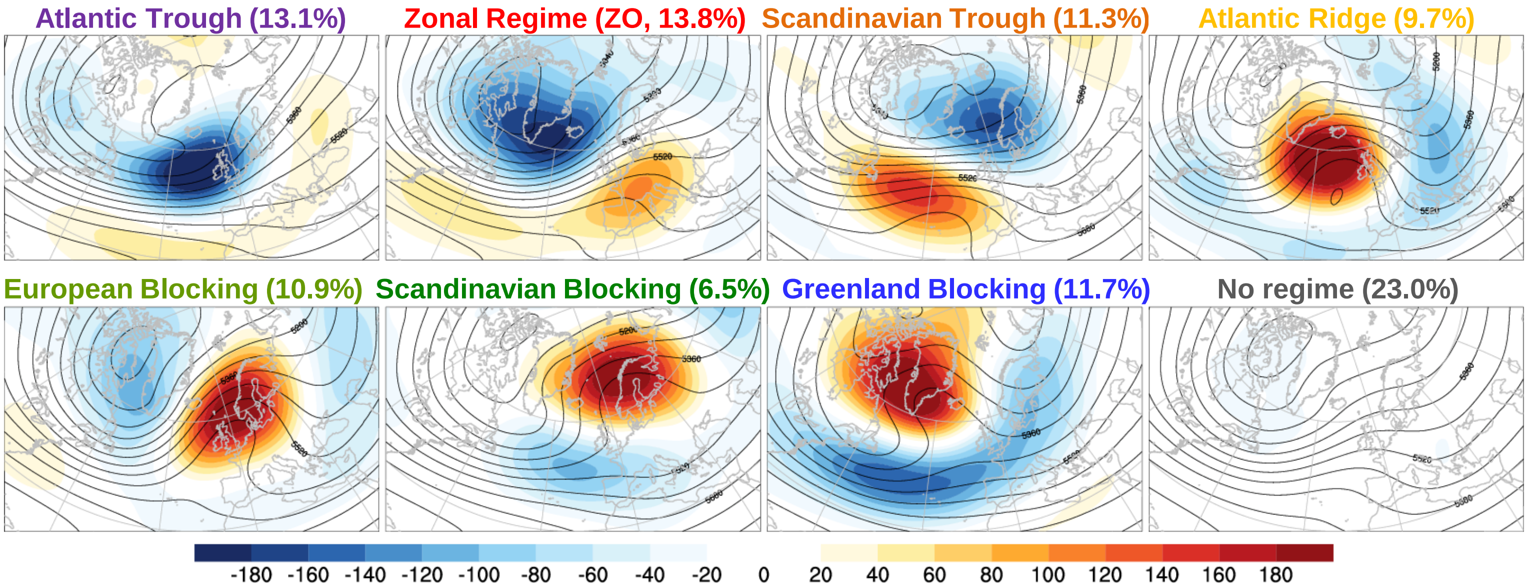


Top: 500hPa geopotential height anomalies (shaded in gpm) and abosolute values (black every 80 gpm) here shown for winter (DJF). Regime names and DJF (1979-2015) frequencies in subcaptions.

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

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

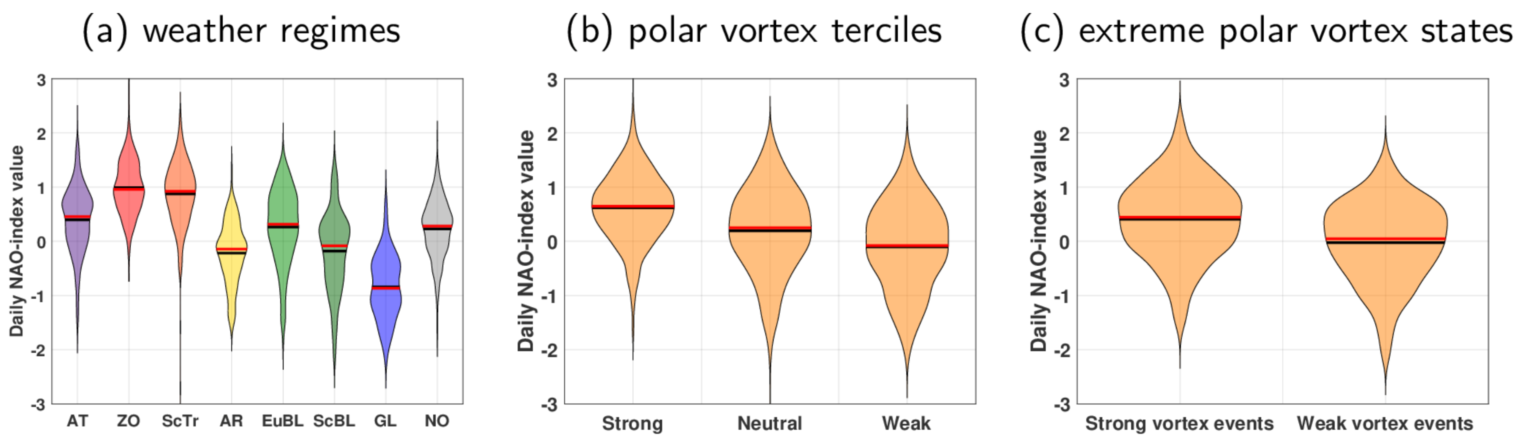
Cyclonic regimes:

- **Atlantic trough (AT)**
- **Zonal Regime (ZO)**
- **Scandinavian trough (ScTr)**

Blocked regimes:

- **Atlantic ridge (AR)**
- **European blocking (EuBL)**
- **Scandinavian blocking (ScBL)**
- **Greenland blocking (GL)**

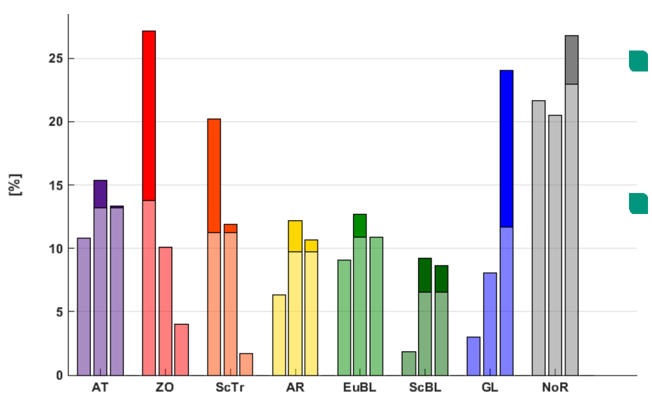
Stratospheric modulation of regime occurrence



Top: Figure 2 from Beerli and Grams (2019): Distribution of daily North Atlantic Oscillation (NAO) indexes for (a) all winter days (DJF) attributed to one of the seven weather regimes or no regime, (b) all winter days (DJF) attributed to the strong, neutral or weak stratospheric polar vortex conditions (defined as upper, middle, lower tercile of polar-cap 50hPa geopotential height anomaly), and (c) the 40 days following a strong or weak vortex events.

- weather regimes occur in broad range of NAO conditions
- only **ZO** & **ScTr** regime clearly project into **NAO+**
- only **GL** regime clearly projects into **NAO-**

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



- **ZO**, **ScTr**, and **GL** with strong projection into NAO modulated by SPV conditions
- **AT** and **EuBL** occur irrespective of SPV conditions

Beerli and Grams (2019) doi:10.1002/qj.3653
Papritz and Grams (2018) doi:10.1002/2017GL076921

Large-scale weather events during regimes

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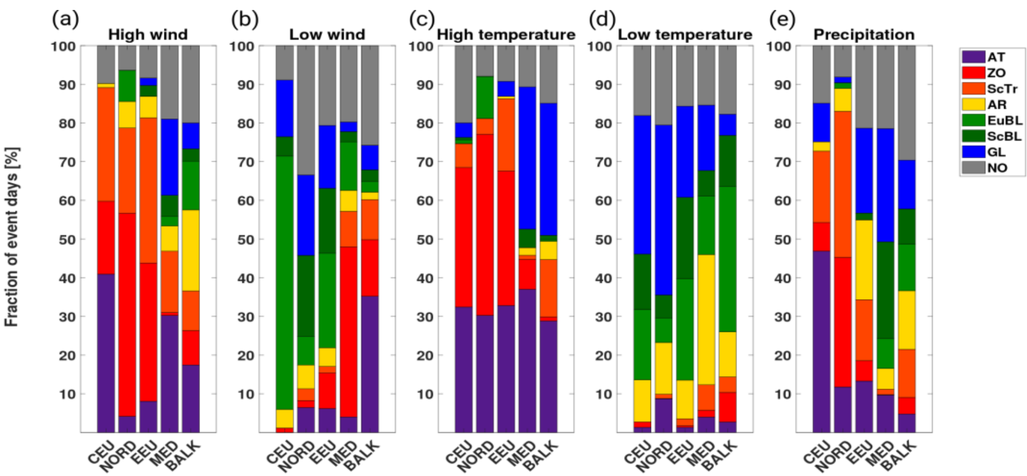


Figure 5 from Beerli and Grams (2019): Frequency of weather regimes for different large-scale weather events (a-e) and regions (individual bars).

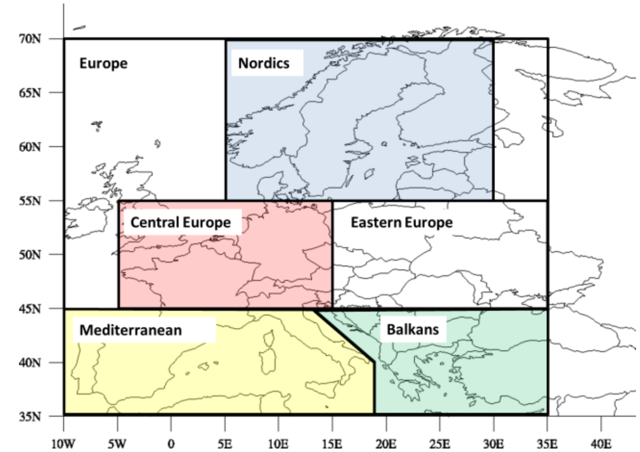
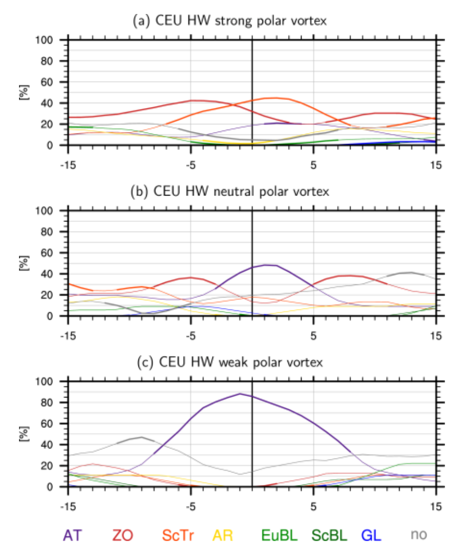


Figure 3 from Beerli and Grams (2019): Regions used to define large-scale weather events.

- large-scale weather events defined as 3-day extremes of regional averaged 2m temperature, 100m wind speed, or precipitation
- weather regimes provide multiple pathways to weather events, e.g. Central Europe high wind events occur during **AT**, **ZO**, and **ScTr**.
- weather events can occur irrespective of the **SPV** state: e.g. during weak SPV state **AT** unaffected by the SPV, provides a pathway to Central Europe high wind and high temperature events



Right: Figure 9 from Beerli and Grams (2019): Lagged (days, x-axis) weather regime frequency during Central European high wind events in different SPV states.

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

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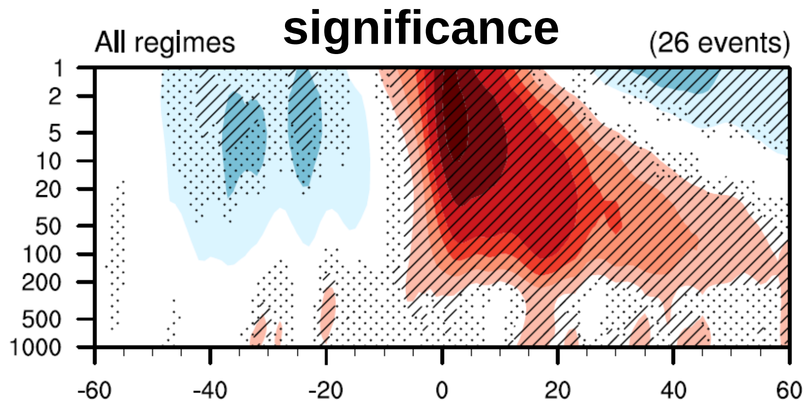
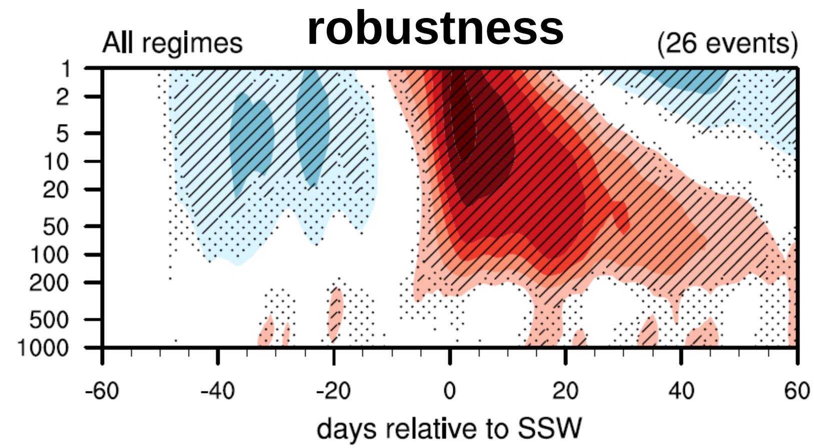
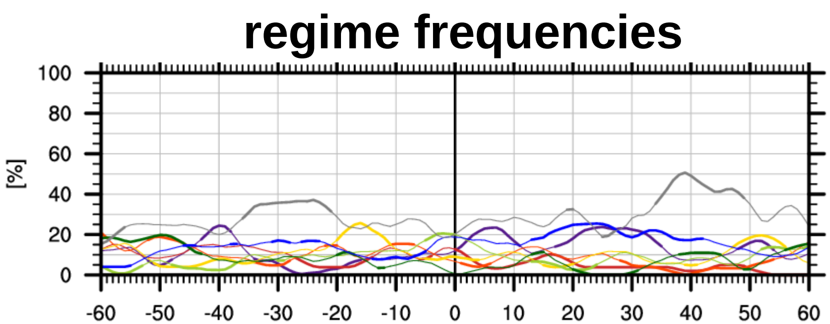
Downward impact of SSWs







Top: Figures 3a & A4a from Domeisen et al. (2020): Standardized geopotential height anomalie in the sector -80°E to 40°E / 60°N to 90°N for all SSW events 1979-2019. Hatching (stippling) indicates significance on the 25% (10%) level (left) wrt. to a random distribution, and robustness, i.e. the magnitude of the anomaly exceeds the interquartile range (10^{th} – 90^{th} percentile range) of a resampling.

Bottom: Figure A2a from Domeisen et al. (2020): weather regime frequency centred around SSW onset. Bold lines indicate statistical significance at the 10% level wrt. to a random distribution.

- composite mean downward impact of sudden stratospheric warming (SSW) events in the satellite era (1979-2019) is weak and hardly statistical significant or robust in the troposphere
- rigorous statistical testing required
- **GL** and **AT** most likely regimes following an SSW, but have contrasting weather impact in Europe (**GL**, cold & calm; **AT**, mild & windy)

Domeisen, Grams, and Papritz (2020) [doi_10.5194/wcd-2019-16](https://doi.org/10.5194/wcd-2019-16), *in revision*

Impact of SSWs and regime response

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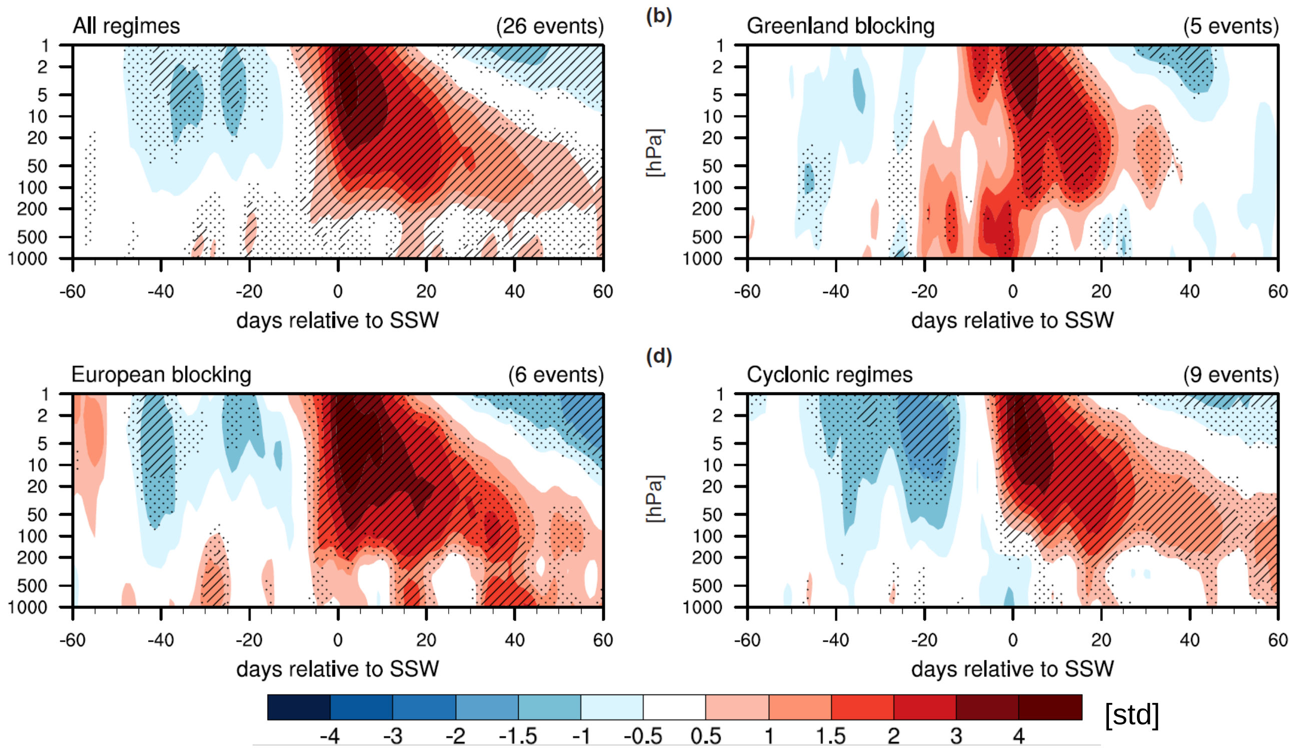
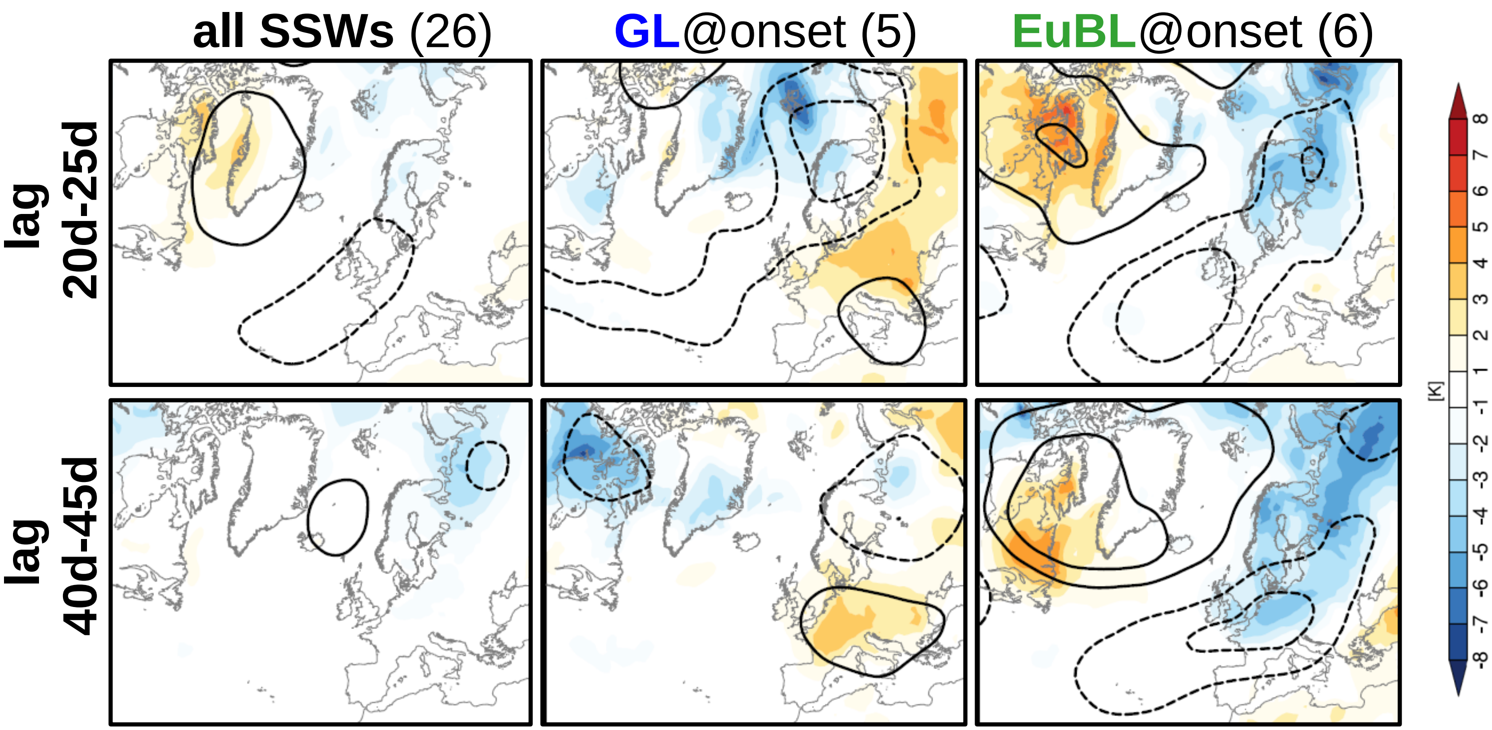


Figure 3 from Domeisen et al. (2020): Standardized geopotential height anomalie in the sector -80°E to 40°E / 60°N to 90°N for all SSW events 1979-2019 (a) and only those with GL (b), EuBL (c), and cyclonic regimes (AT, ZO, ScTR, d) at the time of the onset. Hatching (stippling) indicates significance on the 25% (10%) level (left) wrt. to a random distribution.

- strongly significant (and robust, not shown) positive geopotential height anomalies following SSWs with **EuBL** at onset. Weakly significant (but highly robust, not shown) negative anomaly following SSWs with **GL** at onset. No clear signals for SSWs with other regimes at onset or too small sample.
- strongly significant and robust (not shown) signals emerge despite low sample size.
- **GL** at SSW onset might be an indicator of the **AT** response (confirmed by regime freq., not shown)
- **EuBL** at SSW onset might be an indicator of the **GL** response (regime freq. not shown)

Domeisen, Grams, and Papritz (2020) doi_10.5194/wcd-2019-16, *in revision*

Surface impact of SSWs

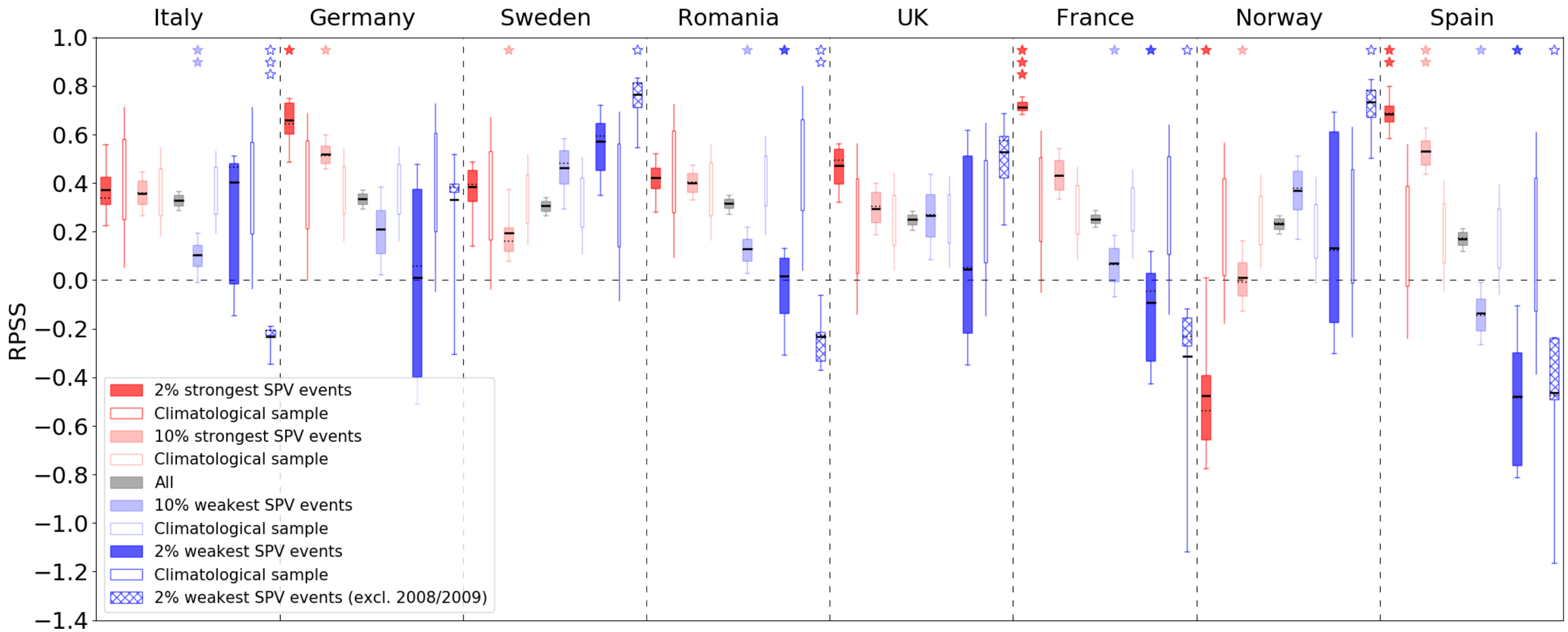


Adapted from Figures 4 & A5 in Domeisen et al. (2020): 2m temperature anomalies (shading every 1K, note the coarse 1K contour interval compared to other literature) and geopotential height anomalies (black contours every 50 gpm, negative values dashed) in 5d lags following SSW onset.

- composite mean temperature anomalies following **all SSWs** are weak (-1K to -2K in Europe, in agreement with literature)
- **GL** at SSW onset is an indicator of the mild and windy **AT** response (+3K to +4K in Central and Eastern Europe)
- **EuBL** at SSW onset is an indicator of the cold and calm **GL** response (-2K to -6K in Northern, Central, and eastern Europe)

Domeisen, Grams, and Papritz (2020) doi_10.5194/wcd-2019-16, *in revision*

Stratosphere dependent forecast skill



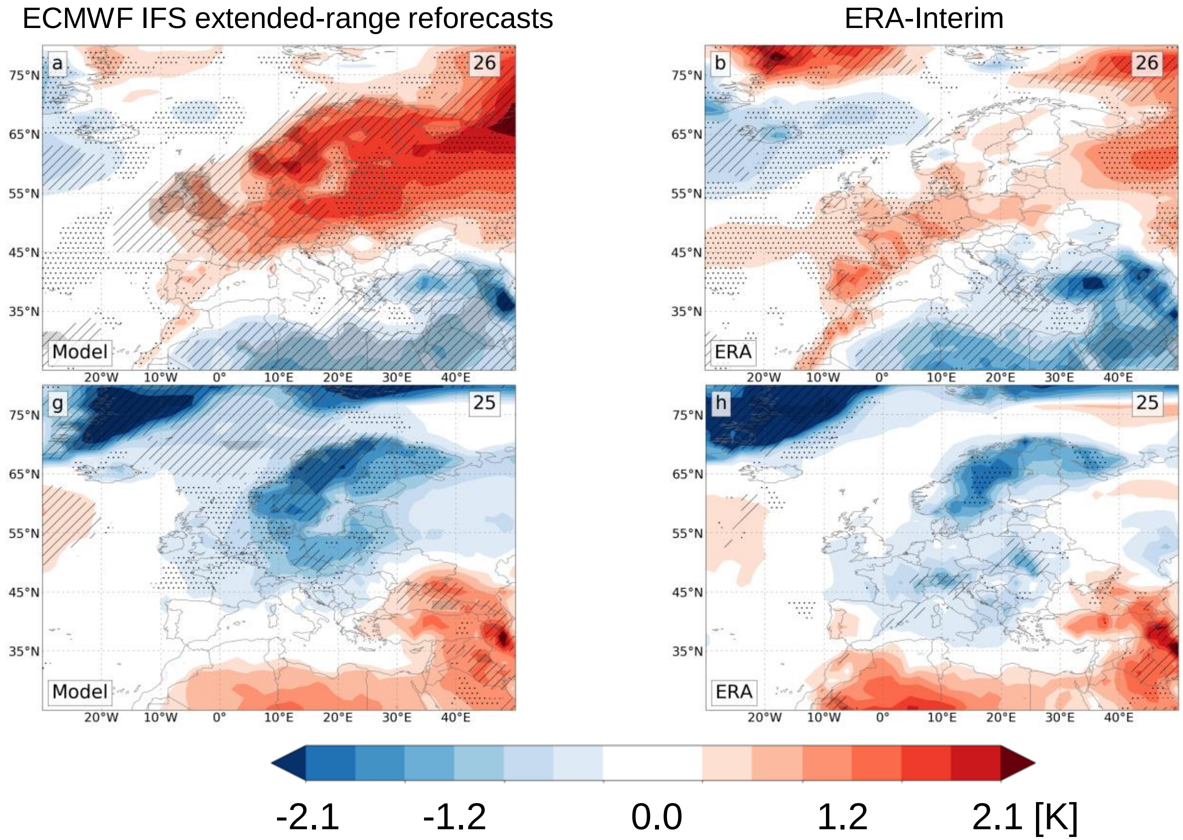
Adapted from Figure 4 in Büeler et al. (2020): RPSS distributions for month ahead, country-aggregated 2mT forecasts (categorical in upper, middle, lower terciles) initialized in different SPV states. Box-and-Whisker Plots show the 10, 25, 50 ,75 90% percentiles, dashed line the mean of the RPSS distribution. 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.

- skill in ECMWF IFS reforecasts (1997-2017) for month-ahead (0-30d) country-aggregated 2m temperature (and 10m wind & precipitation; not shown) highly variable depending on the SPV state
- Enhanced T2M skill over large parts of Europe, except Scandinavia, following strong SPV states
- Unchanged or reduced skill over Central to Southern Europe following weak SPV states, but enhanced skill over Scandinavia
- Skill modification significant for certain countries, such as France, Spain, or Norway

Büeler et al. (2020) *QJRMS, in revision*

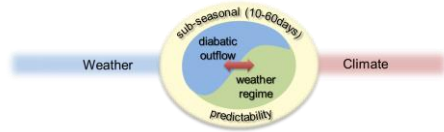
Systematic biases in S2S response

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



- Enhanced T2M skill following strong SPV states likely due to relatively well predicted warm conditions over Europe but overconfidence with respect to warm anomaly over Scandinavia
- Unchanged or reduced skill following weak SPV states except Scandinavia, likely due to well predicted cold anomaly over Scandinavia but model struggling to capture correct extent of cold anomaly into Central to Southern Europe.

Büeler et al. (2020) *QJRMS, in revision*



Summary

- winter stratosphere modulates not only the NAO but also the occurrence of North-Atlantic weather regimes
- Some regimes occur irrespective of the stratospheric conditions and provide pathways to unexpected weather (e.g. mild and windy during weak stratospheric polar vortex states)
- Greenland Blocking or European Blocking at onset of a SSW event can be an indicator of a subsequent mild and windy (Atlantic Trough) or cold and calm (Greenland Blocking) response
- S2S reforecasts tend to have higher skill for European surface weather during strong SPV conditions compared to weak conditions

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