Variability of the North Atlantic response to sudden stratospheric warming events in a simplified atmospheric model

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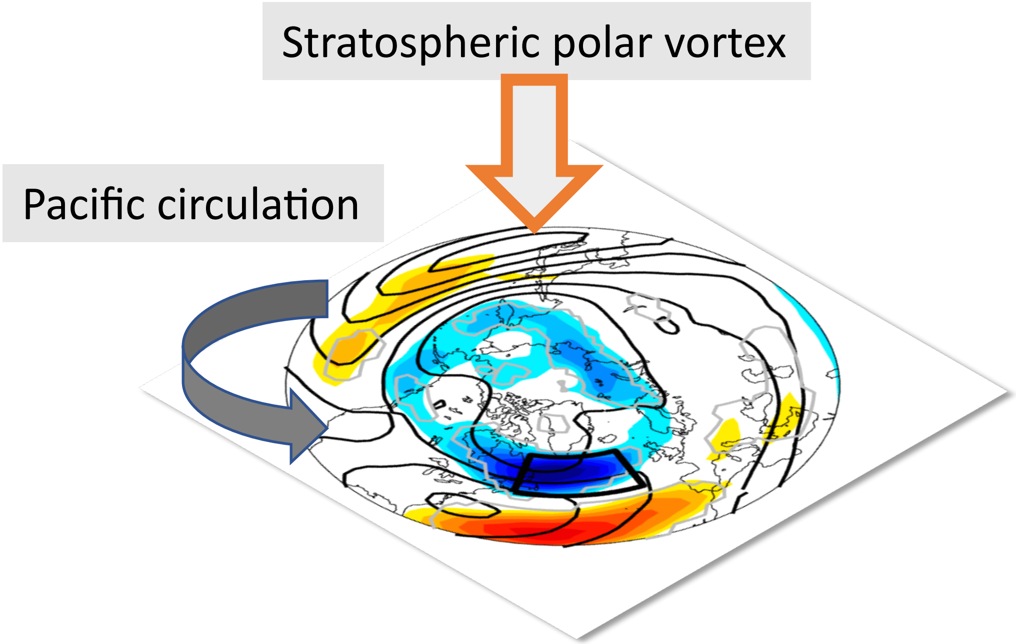
Summary: Recent studies have shown that only two thirds of sudden stratospheric warming (SSW) events are followed by the canonical, negative phase of the North Atlantic Oscillation (NAO). In this study, we examine the role of potential candidates in determining the downward impact of SSW events. We use **ERA-Interim reanalysis (1979-2019)** and **a simplified atmospheric model (ISCA)** forced with seasonally varying sea surface temperatures to examine the influence of the pre-existing circulation in the troposphere on the North Atlantic response to stratospheric forcing.

Main findings:

- In the simplified model, we find that 60% of SSW events are followed by a downward impact (i.e., negative NAO response). **This ratio is similar to reanalysis.**
- A weaker lower stratospheric anomaly after SSW events contributes to a weaker downward impact in the Atlantic.
- Anomalous geopotential height anomalies in the eastern Pacific are found to be consistent with North Atlantic anomalies after SSW events. The Pacific is here suggested to contribute to the sign of the North Atlantic response.



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BLUE ACTION

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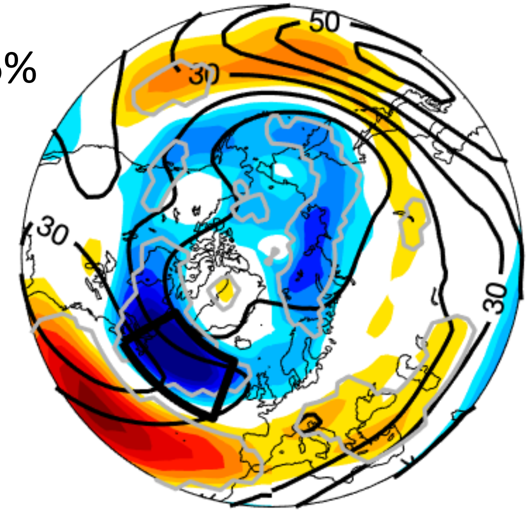
Motivation

Tropospheric response following SSW events between 1979-2019

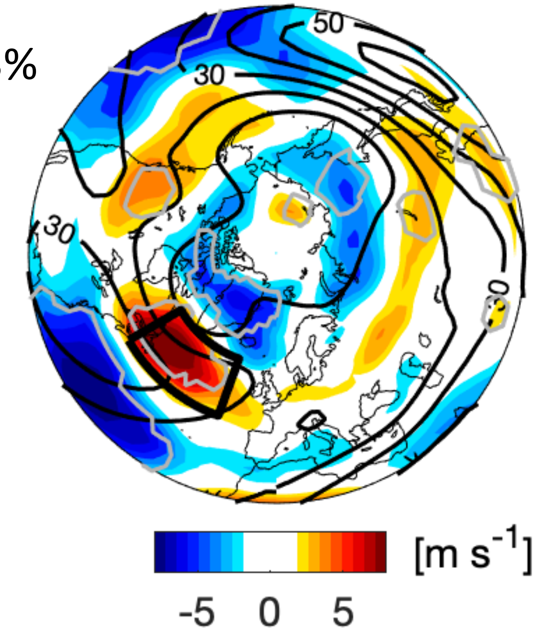
Equatorward Atlantic jet shift

66%



Poleward Atlantic jet shift

33%



300-hPa zonal wind anomaly from daily climatology (color contours)
DJF climatology (black contours), anomalies at 95% significance (gray)

ERA-Interim reanalysis (Dee et al., 2011).

Source: *Afargan-Gerstman and Domeisen, 2020, GRL*

- **Two thirds of SSWs are associated with an equatorward jet shift** (the canonical negative NAO response, e.g., *Baldwin and Dunkerton, 2001*).
- **In one third of SSWs**, the response Is characterize by a poleward jet shift**.**

What factors determine the downward impact of SSW events?

Methodology and datasets

Reanalysis data

We use daily ERA-Interim reanalysis (Dee et al., 2011) for the years 1979-2019.

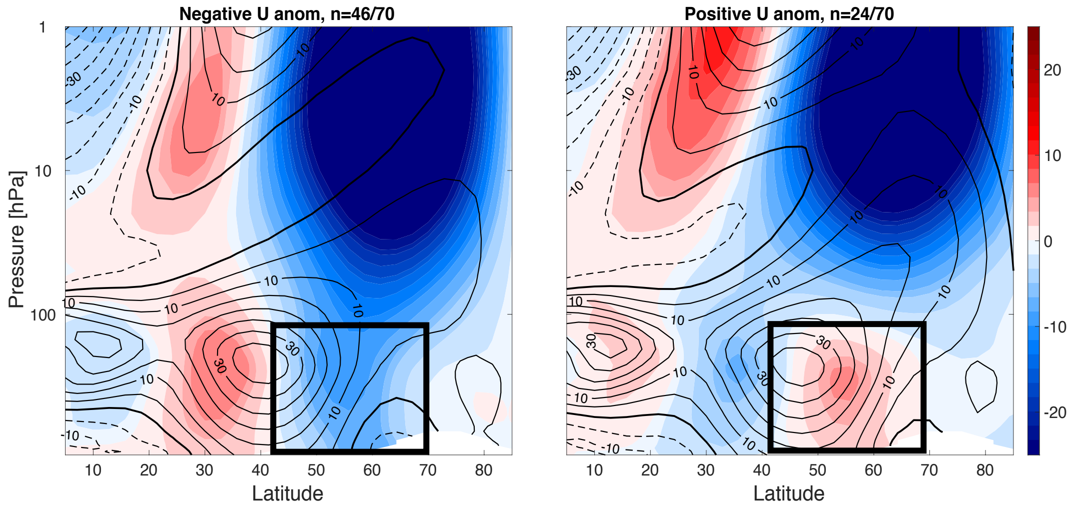
Major SSW events for the period 1979-2014 are chosen according to Butler et al., 2017 for ERA-Interim. Between 1979 to 2014, 24 SSW events are detected. Two additional SSW events (in 2018 and in 2019) are included in the analysis.

Simplified general circulation model (ISCA)

- We use the ISCA modelling framework (Vallis et al. 2018).
- The model is based on Geophysical Fluid Dynamics Laboratory (GFDL) dynamical core coupled with simplified physical parametrizations.
- We use the multi-band radiation scheme (RRTM) implemented in the MiMA model (Jucker and Gerber, 2017)
- Resolution: T42, with 50 vertical levels up to 0.02 hPa.

We use a simplified model (ISCA), forced by climatological sea surface temperatures (SSTs) to analyze the variability of the downward impact of SSW events.

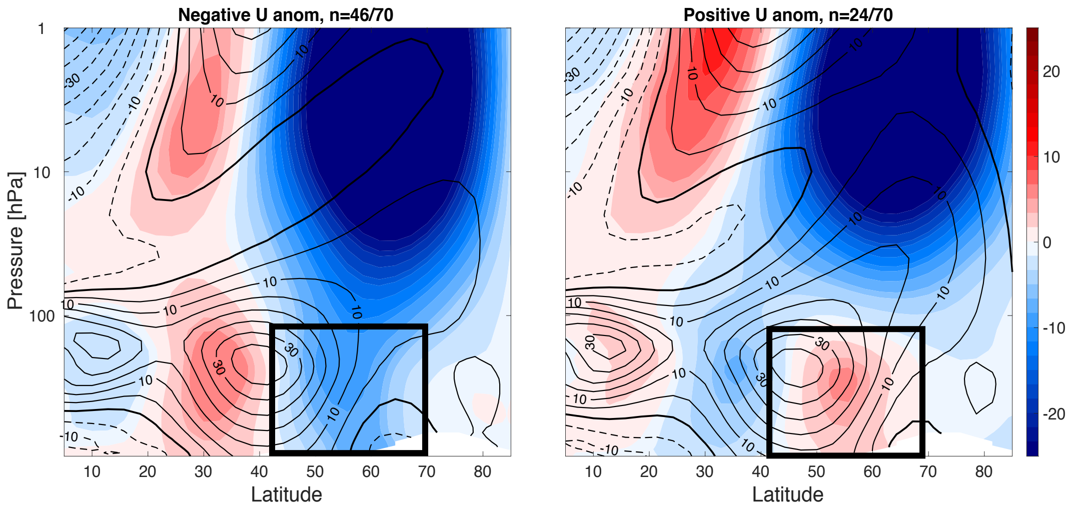
We apply a criterion for equatorward/poleward Atlantic jet shift (U@300 hPa) on simulated SSW events in the model (in total: 94 SSWs).



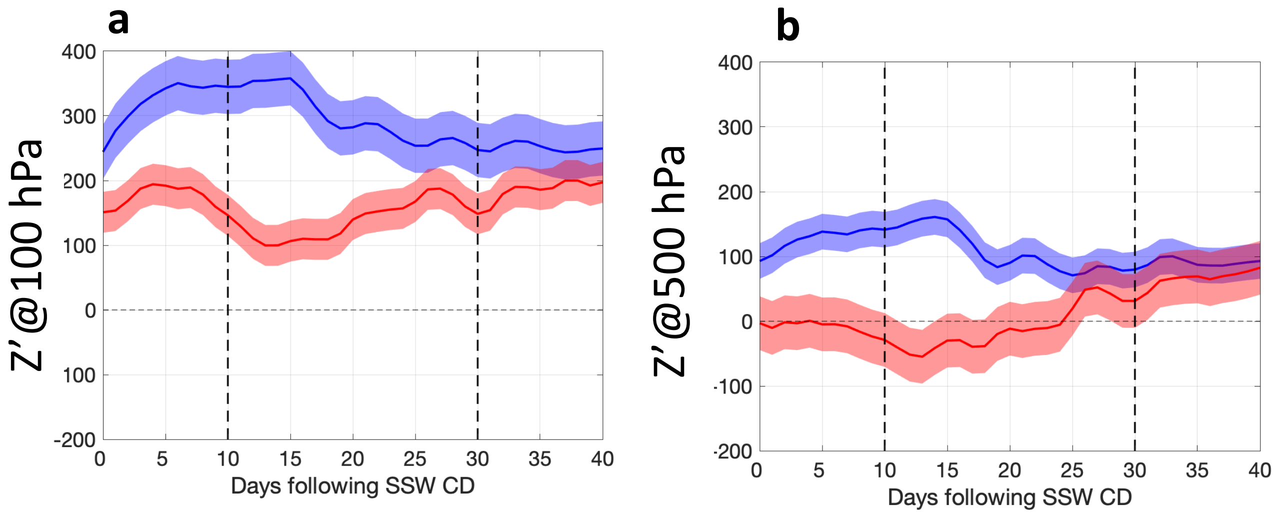
Zonal wind anomalies for (a) SSW events with an equatorward, and (b) poleward Atlantic jet shift in model simulations under climatological SST forcing.

Persistence in the lower stratosphere

In the model, the negative phase of the NAO is found to be the most common response to SSWs, occurring after ~66% of the SSWs (under climatological SST forcing). For the remaining ~33% of the SSW events, the response is associated with a positive phase of the NAO.



Zonal wind anomalies for (a) SSW events with a negative NAO response, and (b) positive NAO (define according to the U@300 hPa) in idealized model simulations under climatological SST forcing.



Geopotential height anomaly averaged over the polar cap and over the Atlantic sector at pressure levels of (a) 100 hPa, and (b) 500 hPa following SSW events with negative (blue) and positive (red) tropospheric zonal wind anomalies. Shading indicates one standard deviation.

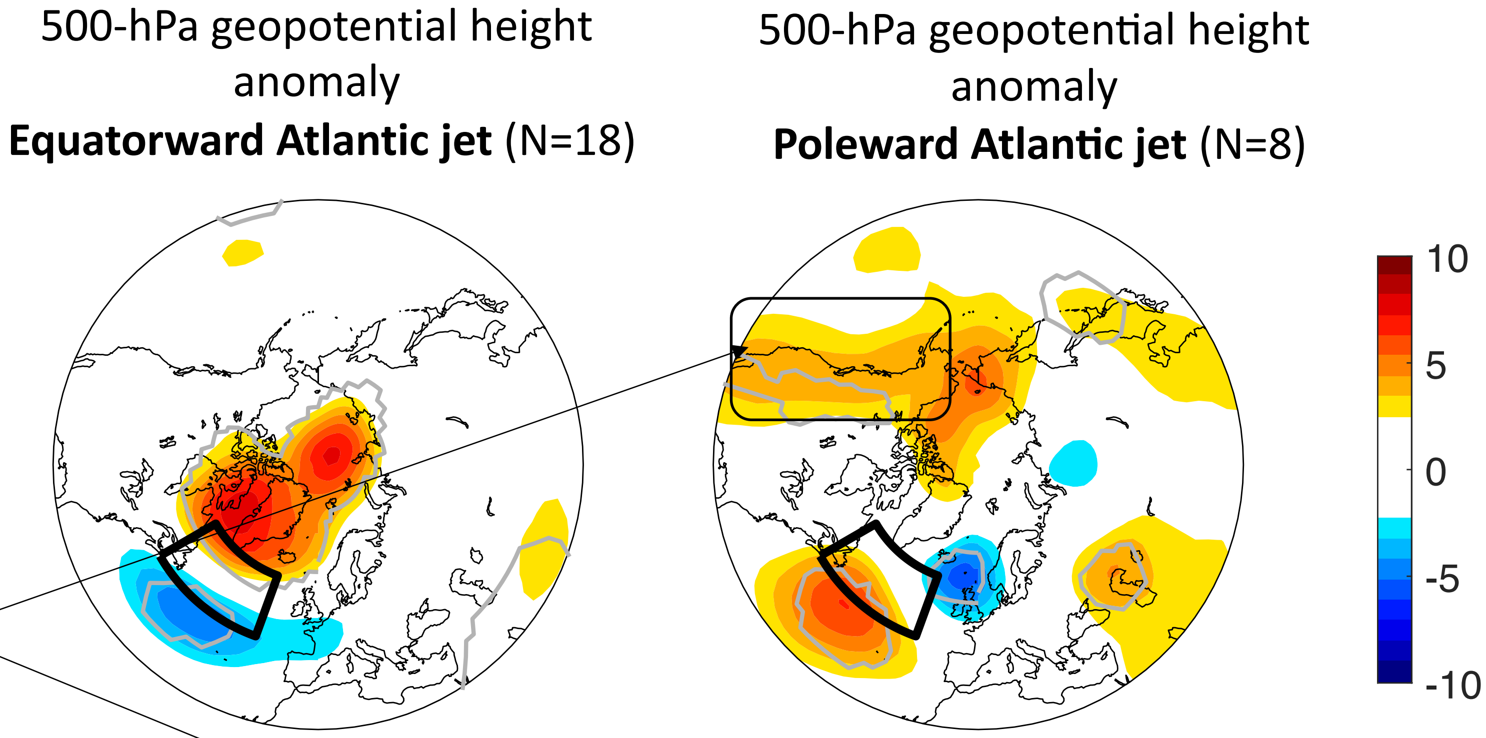
Geopotential height anomalies @100 hPa are stronger after SSW events with a negative NAO response than after SSWs without a negative NAO impact, suggesting that a **weaker magnitude of the lower stratospheric anomaly** after SSW events is associated with the lack of downward response.

These results are consistent with *Karpechko et al. 2017*.

Potential tropospheric pathway between the Pacific and the Atlantic

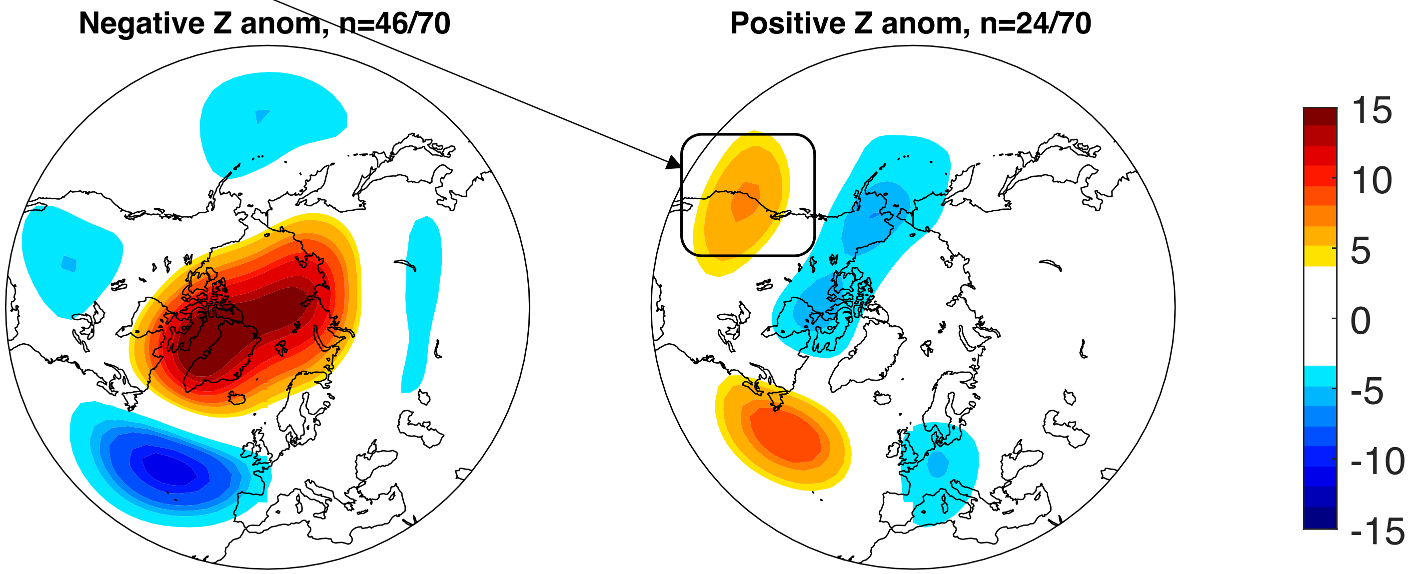
in **ERA-Interim:**

What is the role of North America – Eastern Pacific ridge anomaly?

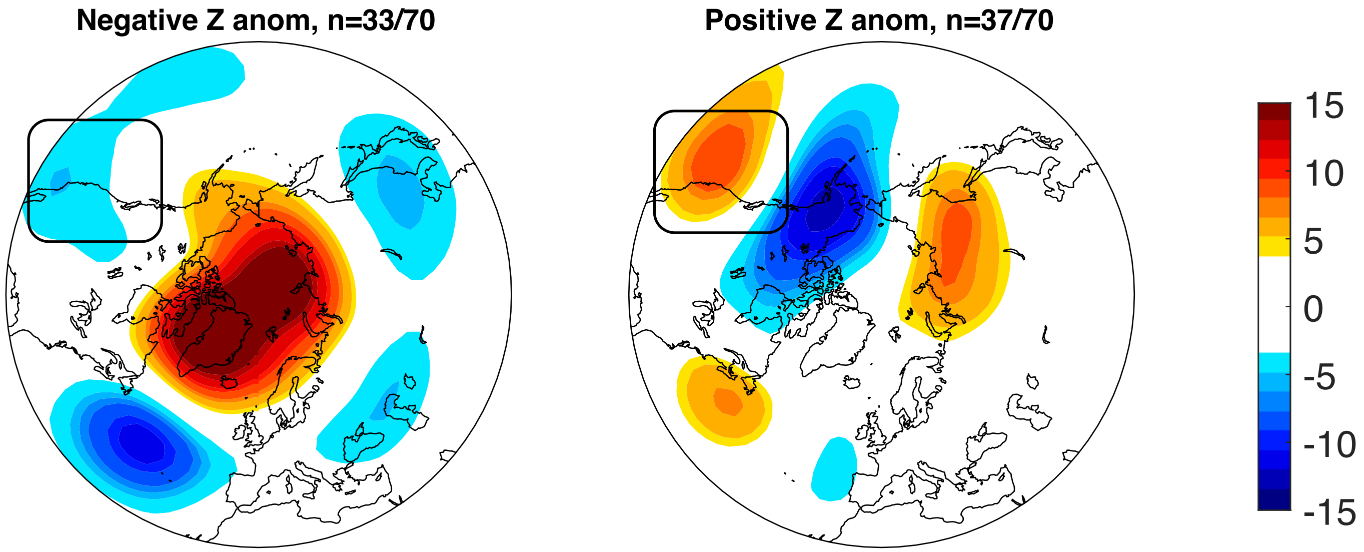


in **the simplified model:**

Consistent with reanalysis, high-pressure anomaly in the eastern Pacific accompanies SSW events which lack the negative NAO response.



Connection to trough/ridge anomaly in the eastern Pacific



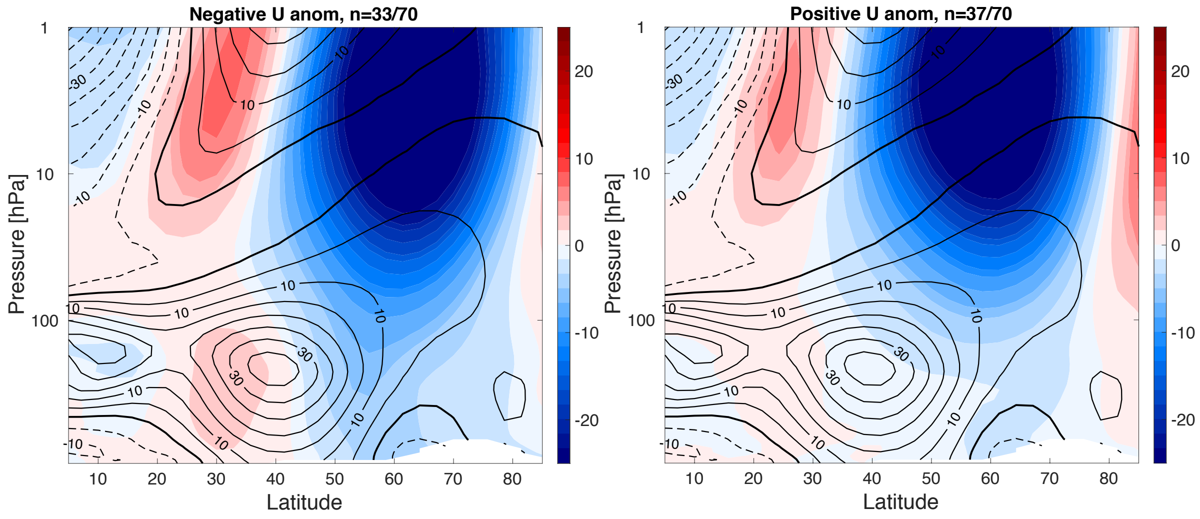
Composites of 500-hPa geopotential height anomalies separated for states of (a) eastern Pacific trough, and (b) ridge anomaly. Anomalies are averaged over 10 days after the onset of SSW events in the idealized model.

When the Pacific circulation anomaly after SSWs is used as a criterion, we find that ~50% of SSW events are associated with an eastern Pacific trough anomaly, and the other half of SSWs are associated with a ridge anomaly.

A trough anomaly is correlated with a strong negative NAO response, whereas a ridge anomaly is linked with a weaker Atlantic response.

East Pacific trough

East Pacific ridge

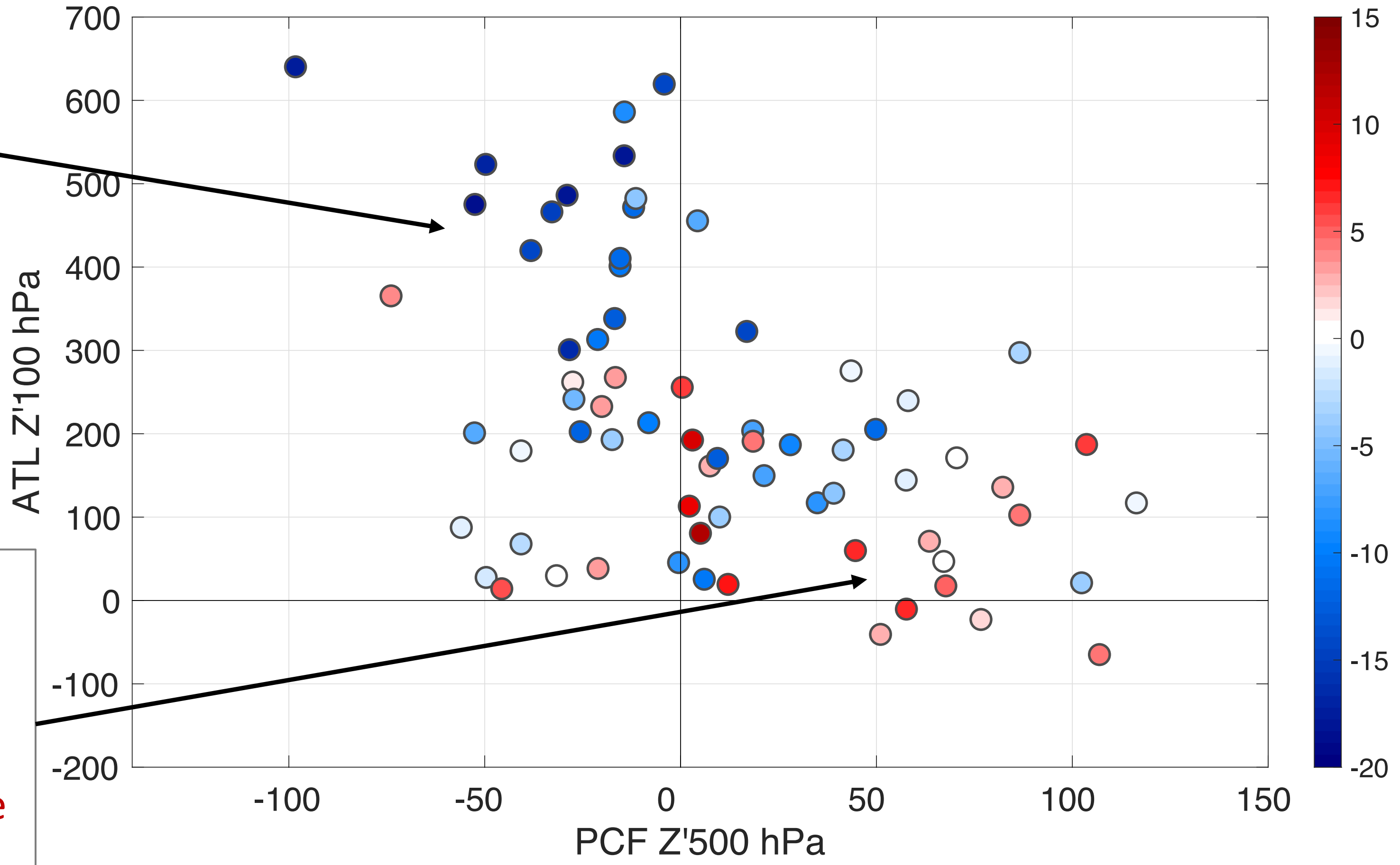


Composites of zonal wind anomaly (m s^{-1}) in idealized model simulations for (a) trough and (b) ridge anomaly in the east Pacific. Anomalies are averaged over 30 days after the onset of SSW events.

Diversity of the North Atlantic response to SSW events

The relation between lower-stratospheric geopotential height (Z) anomaly over the Atlantic sector [0-60°W, 60°N-90°N] and tropospheric geopotential height anomaly over the eastern Pacific [200°E-250°E, 20°N-40°N]. Anomalies are averaged between day 1-10 after the SSW.

Strong anomalies in the lower stratosphere and **negative Z' anomaly in the Pacific** are associated with a negative downward impact.



Positive zonal wind anomaly after SSW

The color shading indicates the zonal wind anomaly over the midlatitude Atlantic [45°-60°N], averaged over a 30-day period after SSWs.

Negative zonal wind anomaly after SSW

Weak anomalies in the lower stratosphere and **positive Z' anomaly in the Pacific** are associated with positive downward impact.

References:

Afargan-Gerstman, H., & Domeisen, D. I. (2020). Pacific modulation of the North Atlantic storm track response to sudden stratospheric warming events. Geophysical Research Letters, e2019GL085007.

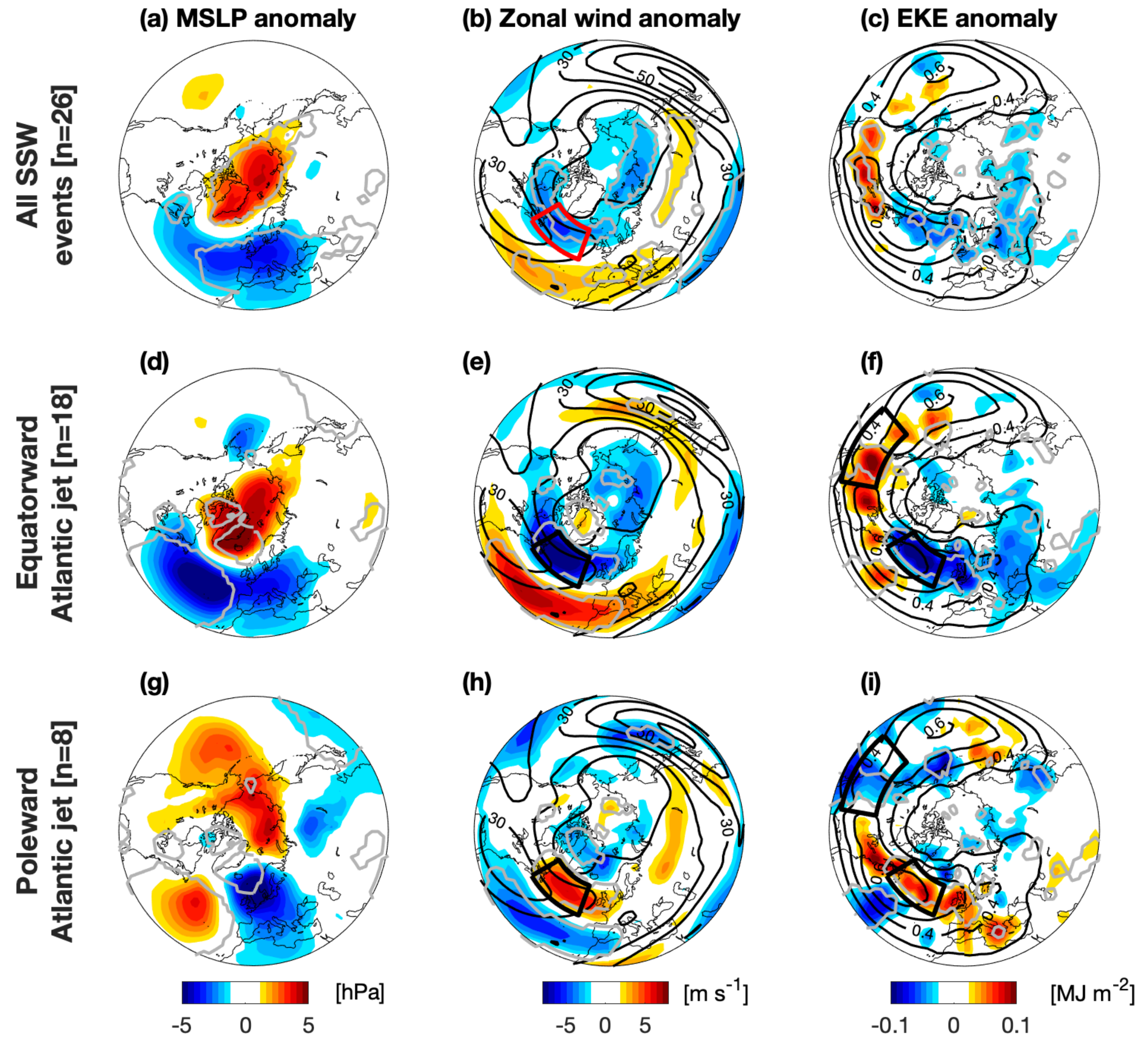
Baldwin, M. P., & Dunkerton, T. J. (2001). Stratospheric harbingers of anomalous weather regimes. Science, 294(5542), 581-584.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., ... & Bechtold, P. (2011). The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Quarterly Journal of the royal meteorological society, 137(656), 553-597.

Karpechko, A. Y., Hitchcock, P., Peters, D. H., & Schneidereit, A. (2017). Predictability of downward propagation of major sudden stratospheric warmings. Quarterly Journal of the Royal Meteorological Society, 143(704), 1459-1470.

Vallis, G. K., Colyer, G., Geen, R., Gerber, E., Jucker, M., Maher, P., Paterson, A., Pietschnig, M., Penn, J., & Thomson, S. I. (2018). Isca, v1. 0: A framework for the global modelling of the atmospheres of Earth and other planets at varying levels of complexity.

Appendix



Composites of the tropospheric circulation averaged over the 30 days following (top row) all 26 historical SSW events, and SSW events associated with (middle) equatorward and (bottom) poleward Atlantic jet shifts (18 and 8 events, respectively) in the ERA-Interim reanalysis (1979-2019). Shading represents the (a,d,g) MSLP anomalies (hPa), (b,e,h) zonal wind anomalies ($m\ s^{-1}$) at 300 hPa, and (c,f,i) storm track intensity, expressed using EKE ($MJ\ m^{-2}$), vertically integrated from 1000 to 200 hPa.

Source: *Afargan-Gerstman and Domeisen, 2020, GRL*