ETH zürich

Pacific modulation of the North Atlantic storm track response to sudden stratospheric warming events

Hilla Afargan-Gerstman and Daniela I.V. Domeisen
Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland.

Contact:
Hilla.Gerstman@env.ethz.ch

1 SUMMARY

Sudden stratospheric warming (SSW) events have been suggested to be followed by a surface impact, though this response varies between events. Using reanalysis data, we identify two types of tropospheric responses to SSWs: Two thirds of the SSW events are dominated by an equatorward shift of the jet in the Atlantic, consistent with the canonical SSW response in the form of a negative signature of the North Atlantic Oscillation (NAO). For the remaining third of SSW events the response is associated with a poleward shift of the jet in the North Atlantic. Anomalous transient eddy kinetic energy in the eastern North Pacific is found to be consistent with North Atlantic anomalies. The Pacific is here suggested to contribute to the sign of the North Atlantic response, as synoptic wave propagation from the Eastern Pacific links the Pacific and Atlantic storm tracks, increasing the persistent downward impact of SSWs in the Atlantic for both the equatorward and poleward jet response.

2 METHODS

We use daily ERA-Interim reanalysis (Dee et al., 2011) for the years 1979-2014. The midlatitude storm track is diagnosed from the vertically-integrated transient eddy kinetic energy (EKE) computed by bandpass filtering daily horizontal winds using a Butterworth filter with a cutoff period of 3-10 days, integrated between 1000 and 200 hPa.

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. We use the zonal wind at 300 hPa to define the type of the SSW downward impact on the troposphere. SSWs followed by an equatorward shift of the North Atlantic jet (the *canonical* negative NAO response, e.g., Baldwin and Dunkerton, 2001) are defined if zonal wind anomalies, computed with respect to the daily climatology, averaged over a period of 30 days after the SSW central date and over the midlatitude Atlantic region (45°N to 60°N, 300°E to 340°E, red box in **Fig.1b**) are negative. If a SSW is followed by mean positive zonal wind anomalies in this region it is defined as being followed by a poleward Atlantic jet shift response.

This yields a criterion for the two composites, representing the variability of the tropospheric response: either an equatorward Atlantic jet shift or a poleward shift. **We identify 16 out of 24 SSWs (66.6%) as equatorward Atlantic jet shift (EQ) and 8 (33.3%) as poleward Atlantic jet shift (PL) events.**

3 RESULTS

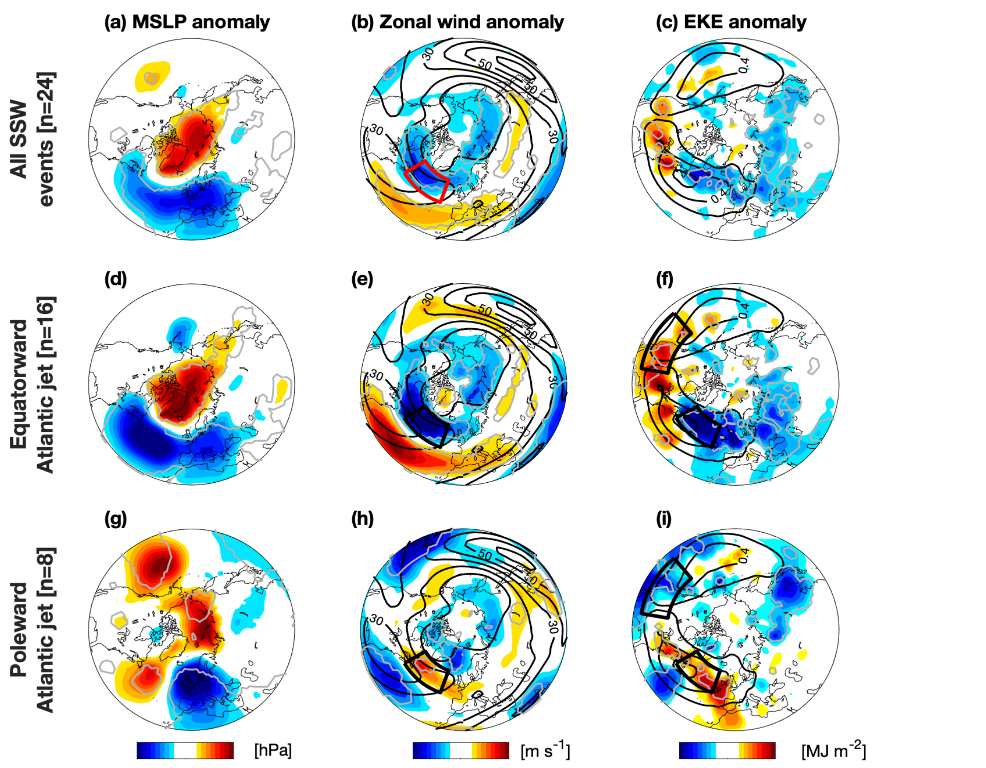

Fig. 1. Composites of the tropospheric circulation averaged over the 30 days following (top row) all 24 historical SSW events, and SSW events associated with (middle) equatorward and (bottom) poleward Atlantic jet shifts (16 and 8 events, respectively) in the ERA-Interim reanalysis (1979-2014). Shading 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.

We separate the SSW events based on the characteristics of their tropospheric jet shift response in the North Atlantic (**Fig.1**). In two thirds of the SSWs, the SSW is followed by a persistent negative NAO response, consistent with previous classifications (e.g., Karpechko et al. 2017, Charlton-Perez et al. 2018, Domeisen 2019). A zonally symmetric MSLP anomaly, associated with a dipole pattern, is found in both the Atlantic and the Pacific sectors (**Fig. 1d**). In contrast, in the second composite a zonally asymmetric response of MSLP emerges, with a negative MSLP anomaly in the eastern Atlantic and Eurasia, and a positive anomaly in the eastern Pacific (**Fig. 1g**). In the North Atlantic, EKE is strongly reduced in midlatitudes for SSW events with an equatorward jet shift, while increasing in the subtropics. During SSW events with a poleward shift of the Atlantic jet, however, the opposite response is observed (**Fig. 1i**). Over both sectors, transient EKE can exhibit either a positive or a negative response to SSW events (**Fig.2**). In contrast to the North Atlantic, in the East Pacific - North America sector (black box in **Fig. 1f**) positive EKE anomalies tend to be associated with an equatorward Atlantic jet shift, while negative anomalies are often found for a poleward Atlantic jet shift (**Fig.2a**), as also demonstrated in EKE time evolution shown in **Fig.3**.

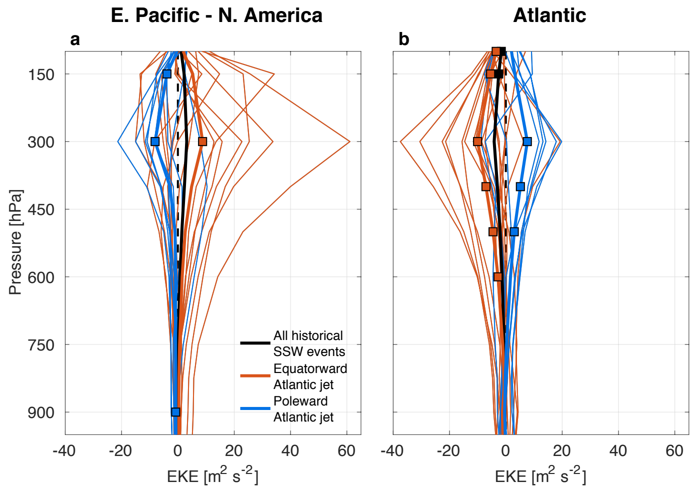

Fig. 2. Time mean anomalies (averaged over 30 days following the SSW central date) of EKE for all historical SSW events between 1979-2014, area-averaged over (a) East Pacific - North America and (b) Atlantic sectors. SSW events associated with an equatorward or poleward jet shift in the Atlantic are highlighted in red and blue, respectively. Bold curves represent the average of each composite. For each vertical level, anomalies with 95% significance (using a Student's t-test) are denoted by squares.

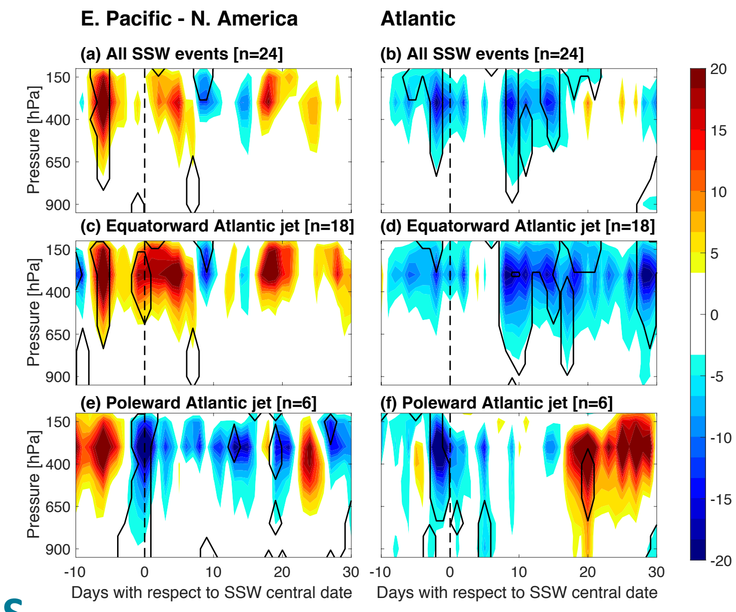

Fig. 3. Temporal evolution of EKE anomalies (shading, $m^2\ s^{-2}$) with respect to the SSW central date, area-averaged over the East Pacific - North America (left column) and the Atlantic (right column) sectors for: (a,b) all 24 historical SSW events, (c,d) SSW events with equatorward Atlantic jet shift, and (e,f) SSW events with poleward Atlantic jet shift. Box dimensions for each region are described in the text and shown in Fig.1f. Anomalies with 95% significance (using Student's t-test) are enclosed by black contours.

4 CONCLUSIONS

- After SSW events North Atlantic storm track activity is reduced, while the North Pacific exhibits a weaker and opposite response.
- We identify two distinct tropospheric responses, one symmetric and the other asymmetric with respect to the Atlantic and Pacific.
- The type of downward response tends to be linked to anomalies in the eastern North Pacific. In particular, different states of transient eddy activity can be observed in the North Pacific between SSW composites followed by an equatorward or poleward jet shift in the Atlantic, hinting at a North Pacific forcing.
- By shaping synoptic wave propagation into the Atlantic sector, the Pacific is suggested to modulate the North Atlantic response to SSWs, and increase the persistence of the tropospheric response to stratospheric forcing in the Atlantic.

5 REFERENCES

Baldwin, M. P., & Dunkerton, T. J. (2001). Stratospheric harbingers of anomalous weather regimes. Science, 294(5542), 581-584.
Butler, A. H., Sjoberg, J. P., Seidel, D. J., & Rosenlof, K. H. (2017). A sudden stratospheric warming compendium. Earth System Science Data, 9(1).
Charlton-Perez, A. J., Ferranti, L., & Lee, R. W. (2018). The influence of the stratospheric state on North Atlantic weather regimes. Quarterly Journal of the Royal Meteorological Society, 144(713), 1140-1151.
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.
Domeisen, D. I. (2019). Estimating the Frequency of Sudden Stratospheric Warming Events From Surface Observations of the North Atlantic Oscillation. Journal of Geophysical Research: Atmospheres, 124(6), 3180-3194.
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.

BLUE ACTION

The Blue-Action project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727852.