

Are SSW impacts on surface temperature extremes changing due to increasing CO₂ concentrations?



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1 – Motivation

Sudden stratospheric warmings (SSWs) are extreme disruptions of the wintertime polar circulation (polar vortex) that can **alter the tropospheric weather for over two months**¹ and potentially influence the occurrence of **surface extreme events**².

Climate models show great **uncertainty** in how the stratospheric polar vortex is going to change in the future due to the CO₂ increase³, with **opposite response of the SSWs frequency to CO₂**⁴.

Is the SSWs-troposphere connection going to change in the future? Are these changes model dependent?

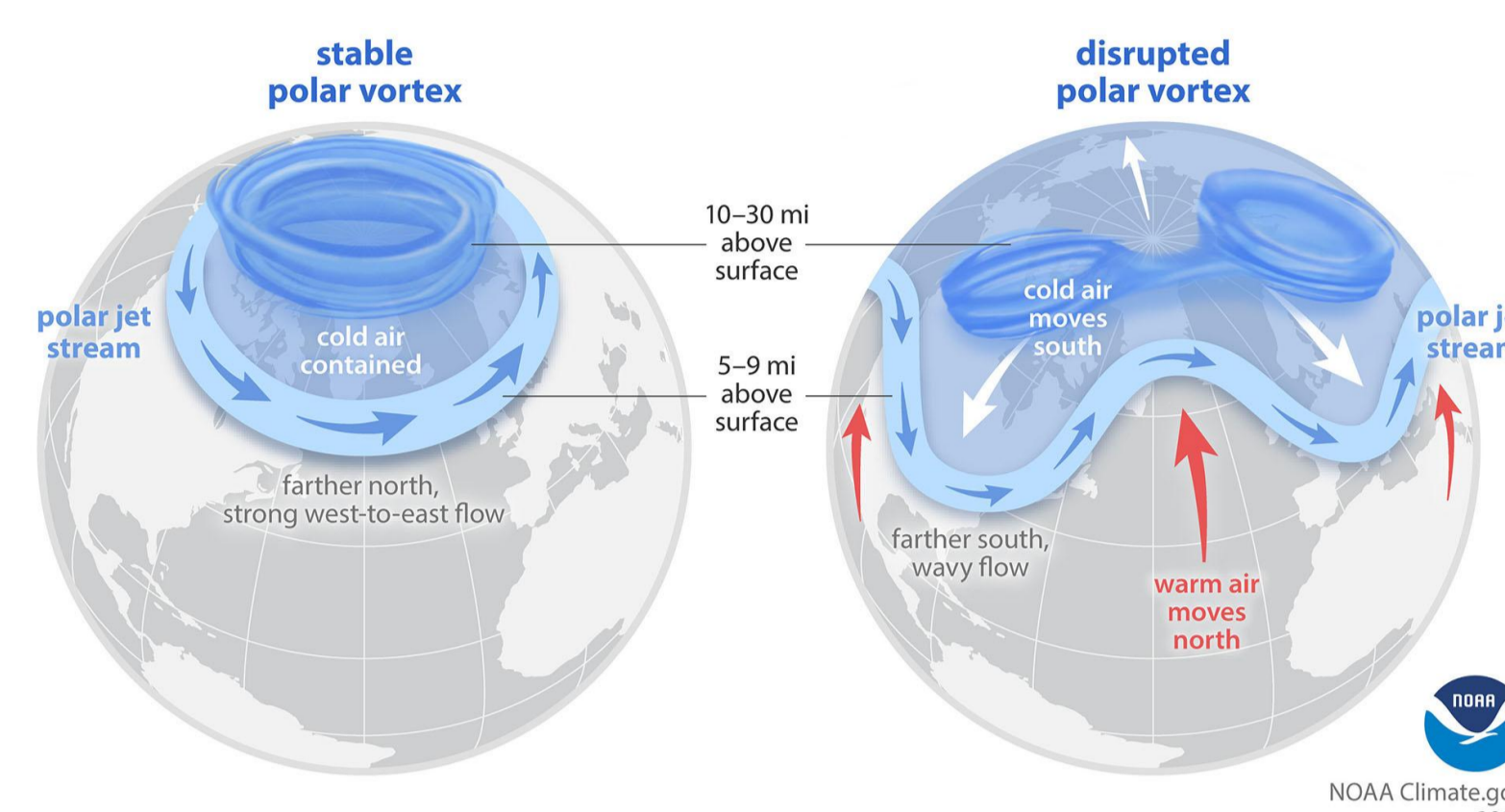


Figure 1: Illustration of the stratospheric polar vortex a) stable polar vortex b) disrupted polar vortex when a Sudden Stratospheric Warming happen. Figure from NOAA <https://www.noaa.gov/>.

2 – Data & Methods

- **12 CMIP6 climate models:**
 - High top models
 - Simulations used: pre-industrial conditions (**piControl**) vs quadrupling CO₂ concentrations (**abrupt4xCO₂**)

- **Climate models classification:** Based on the sign of the change in SSWs frequency

Models with a negative change in SSWs (NEG)

Models with a positive change in SSWs (POS)

3 – Stratosphere-troposphere connection during SSWs

3.1 Downward propagation of the stratospheric signal:

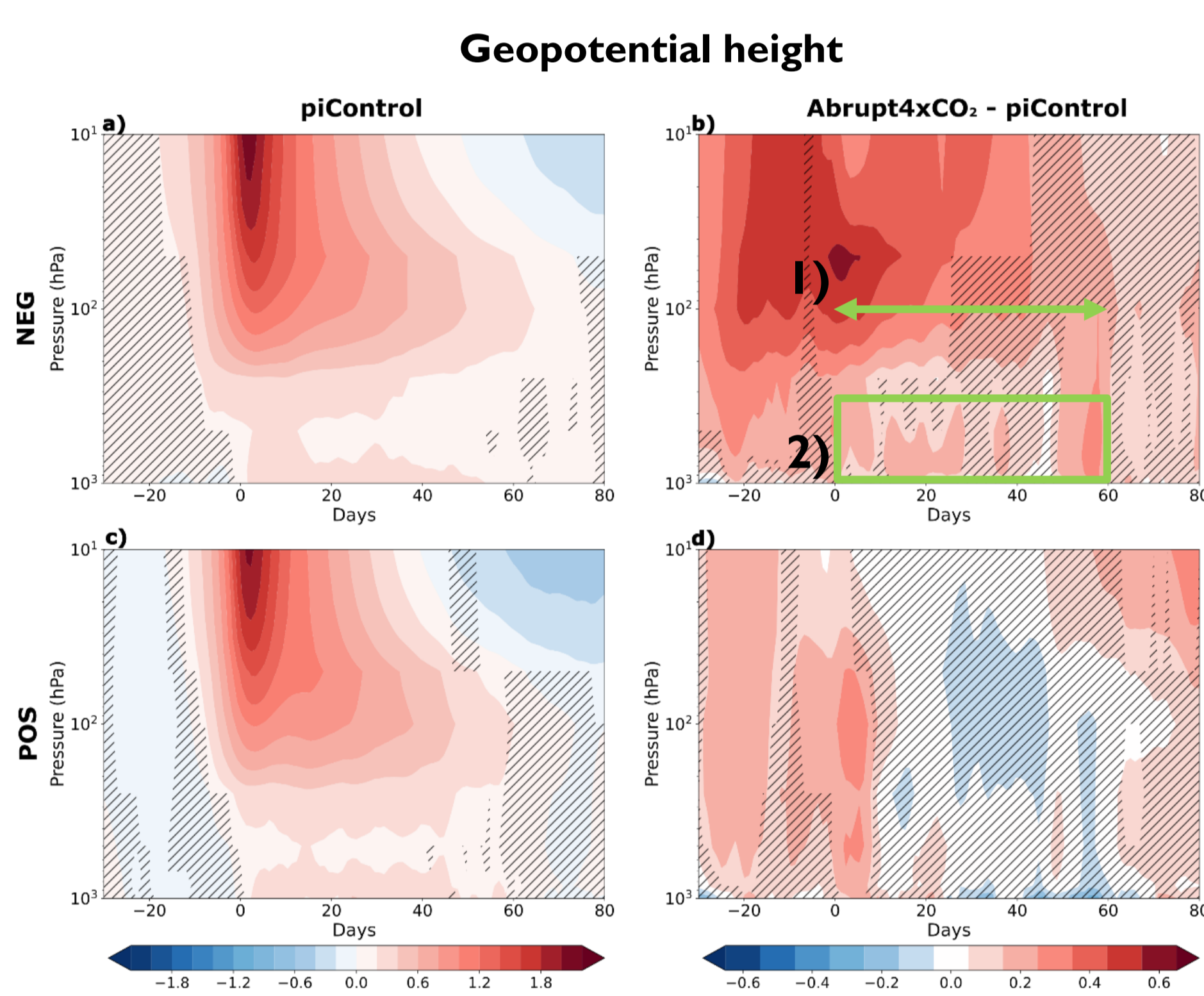


Figure 2: Standardized geopotential height anomalies for the polar cap (65°-90°) for SSWs composites from (-30-80) days relative to the onset: (a,c) piControl simulation for multimodel mean NEG and POS models respectively, (b,d) abrupt4xCO₂ - piControl simulation for multimodel mean NEG and POS models. Stripes represent non-statistically significant values.

The **lower stratosphere (100 hPa)** is highly relevant for the stratosphere-troposphere coupling and the amplitude of SSW surface impacts.

The SSW signal is similar in the piControl simulation for both **NEG** and **POS** models. We found an **opposite response** to the CO₂ increase between the two model groups.

There is **stronger** downward propagation in **NEG** models in the abrupt4xCO₂ (Figure 2):

- 1) More persistence at 100hPa
- 2) Stronger signal reaching surface

3.2 SSWs Surface impacts:

Sea level pressure: Near-surface circulation anomalies intensify due to increased CO₂ in the North Atlantic region particularly in **NEG** models.

Surface temperature: SSW impacts on do not change except for Barents—Kara Sea where sea ice loss could be heavily affected.

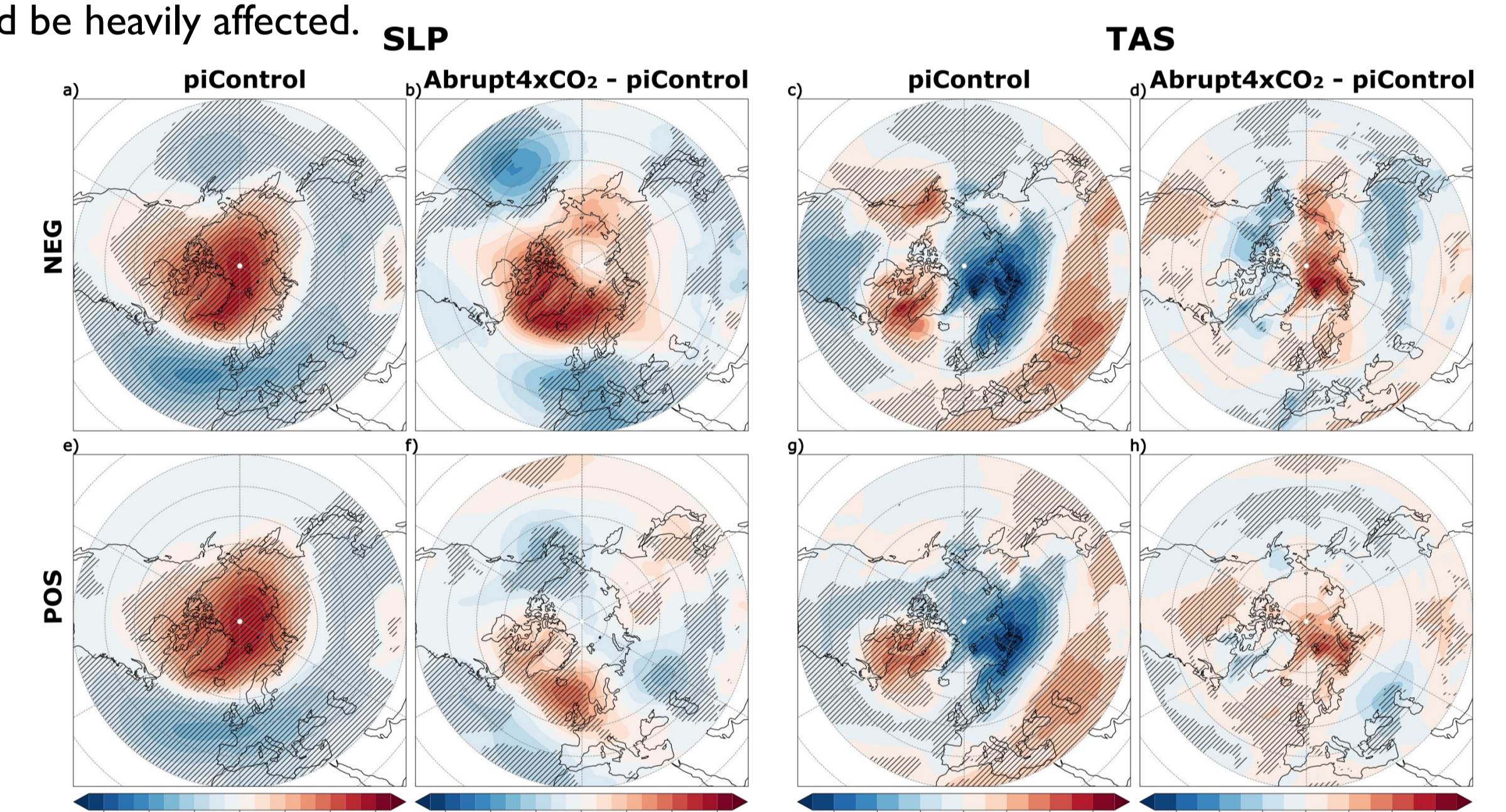


Figure 3: Composites of averaged SLP anomalies (shading, hPa) over days (0,60) relative to the SSWs onset for the multimodel mean for piControl simulation for (Top row) NEG models and (Bottom row) POS models and Differences abrupt4xCO₂ minus piControl

Larger differences in SLP and TAS in **NEG** models that show **stronger SSWs surface impacts** as a response to the CO₂ increase (Figure 3):

4 – SSW and Surface temperature extreme events

Scandinavian cold spells:

Scandinavia is where the Canonical response of SSWs is located as the SLP pattern resembles the SSWs response (Figure 4).

It is the region most affected by the SSWs impacts and **~1/3 of cold spells** are preceded by an SSW.

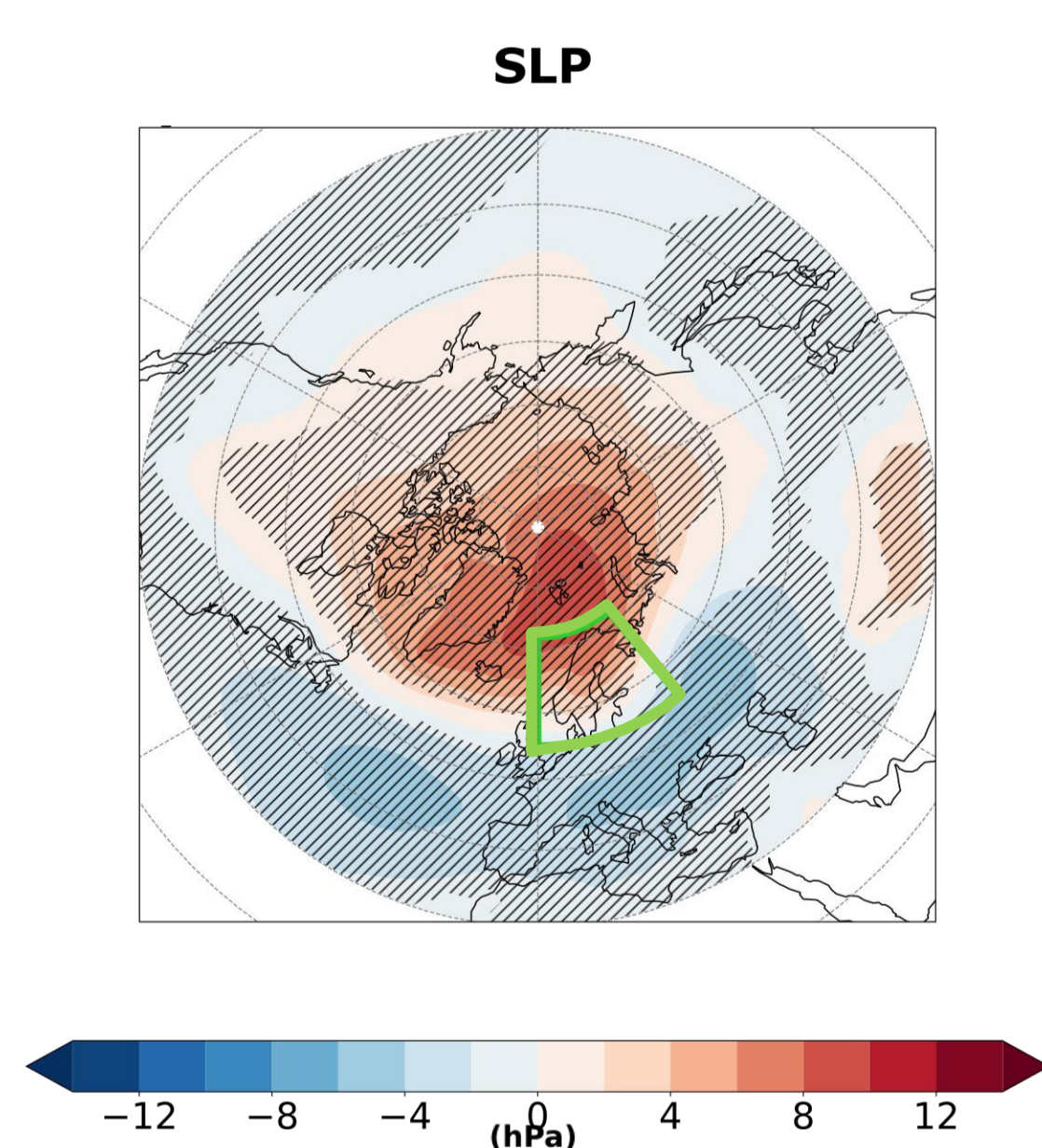


Figure 4: Composites of SLP anomalies for SSWs-related cold spells duration in Scandinavia in the piControl simulation for c) NEG models and f) POS models. Stripes represent significant values at a 95% confidence level.

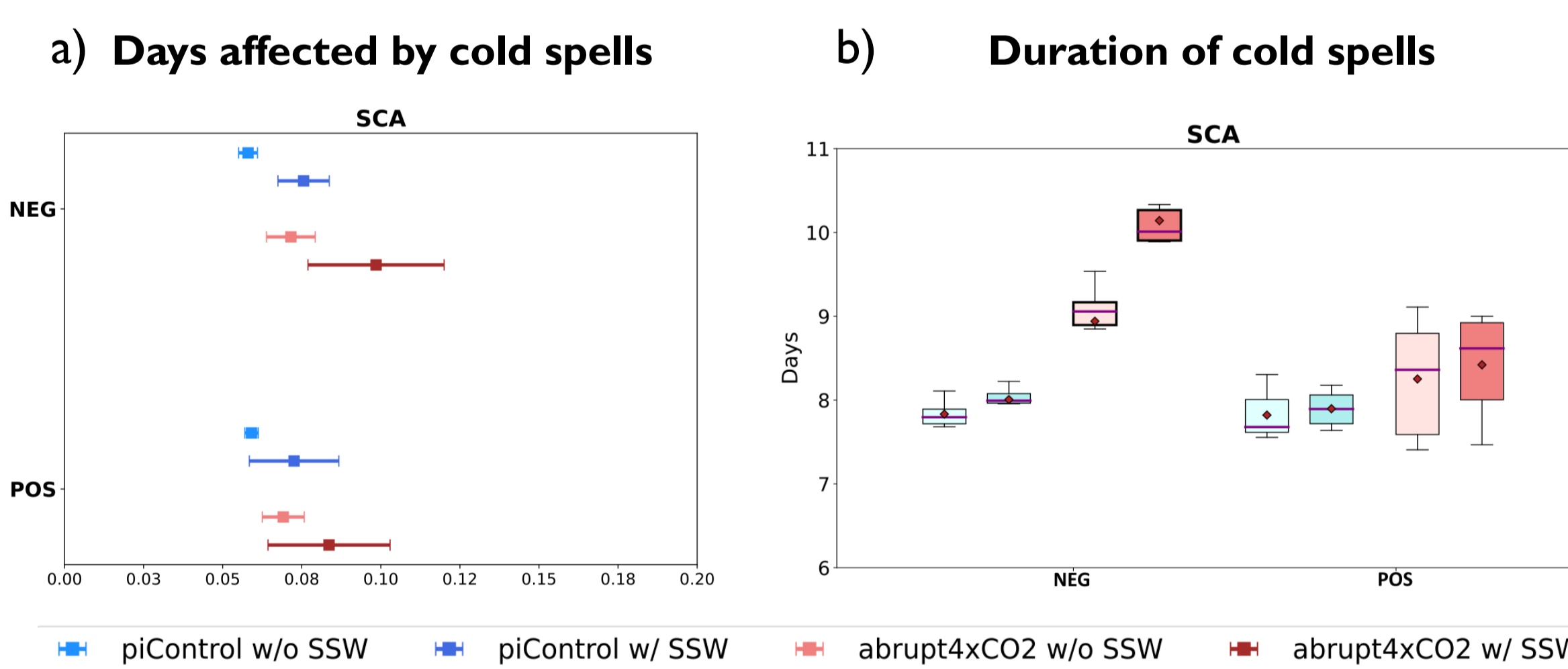


Figure 5: a) Probability of days affected by a surface extreme event in Scandinavia. Bars represent ±1 standard deviation. b) Boxplots of the multimodel distribution of surface extreme event duration

Pre-Industrial:

- There is an **increased risk (~25%)** in the probability of occurrence of cold spells after an SSW
- Cold spells with SSWs **tend to be more persistent** but the difference is not statistically significant

Response to 4xCO₂:

- The probability of cold spells increases even more in **NEG** models
- Cold spells are more persistent after an SSW specially in **NEG** models where the duration is up to **10 days**

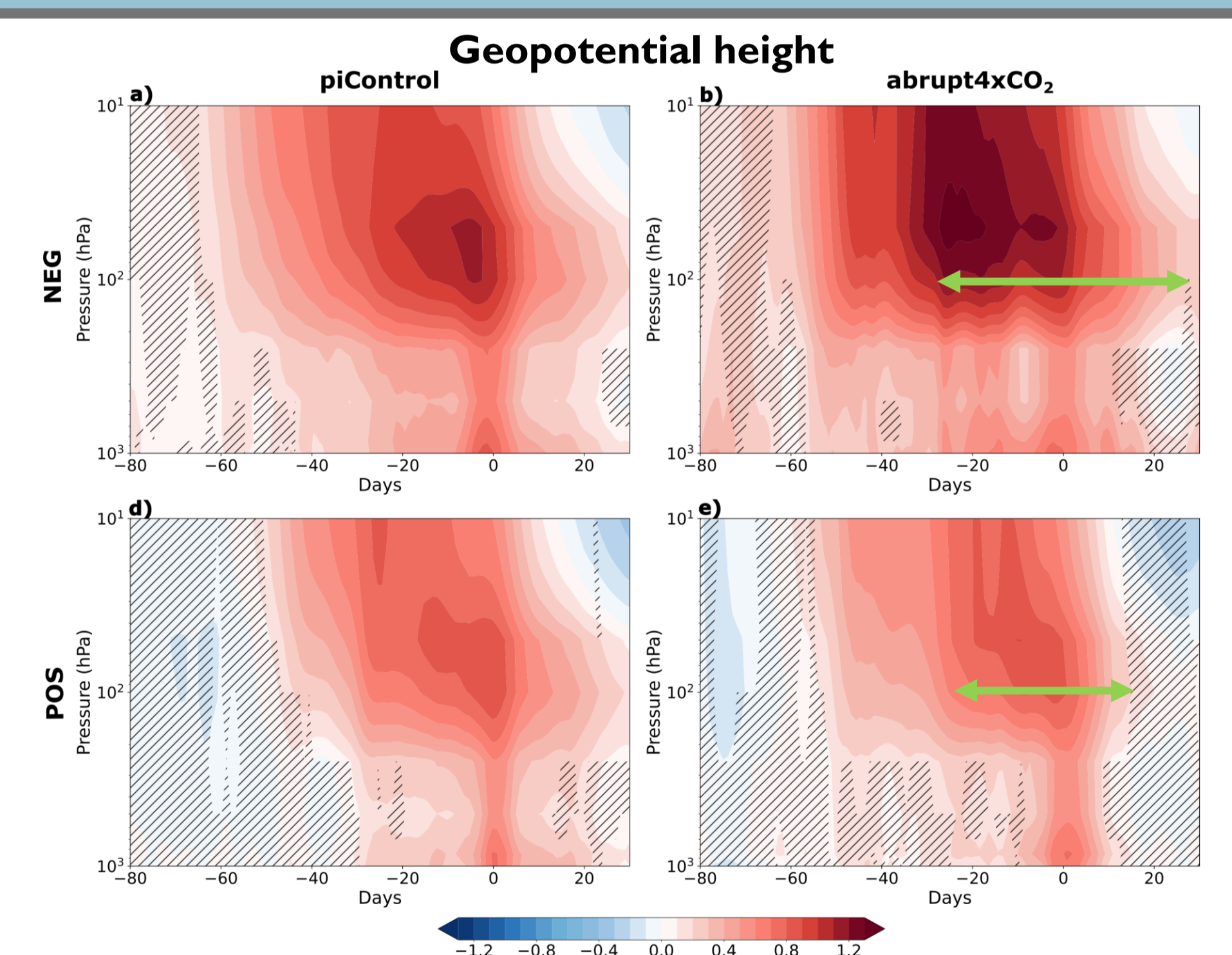


Figure 6: Composite maps of standardized geopotential height anomalies for the polar cap (65°-90°N) for SSWs-related cold spells in Scandinavia from (-80, 30) days relative to the onset of the extremes. Panels (a, d) show results from the piControl simulation and (b, e) for abrupt4xCO₂ simulation for the multimodel mean of NEG and POS models, respectively. Stripes represent non-significant values at a 95% confidence level.

The favorable conditions for cold spells following SSWs are intensified due to CO₂ increase, especially in **NEG** models where the downward propagation is stronger (Figure 6)

5 – Conclusions

- The sign of the change in the SSW frequency also affects the downward propagation of their signal under increased CO₂ concentrations. **NEG** models simulate a larger persistence of the SSW anomalies in the lower stratosphere in the abrupt4xCO₂ run compared to the piControl, leading to a stronger signal reaching the surface.
- SSWs favor the occurrence of days affected by cold spells over the Scandinavian region. They also tend to prolong the duration of these extremes. These impacts are larger for **NEG** models in the abrupt4xCO₂ simulation where there is a stronger downward propagation of the SSW signal caused by the larger persistence in the lower stratosphere.

6 – References

- ¹ Baldwin, M. P., Ayarzagüena, B., Birner, T., Butchart, N., Butler, A. H., Charlton-Perez, A. J., et al. (2021). 809 Sudden Stratospheric Warmings. *Reviews of Geophysics*, 59(1).
- ² Domeisen, D. I. V., & Butler, A. H. (2020). Stratospheric drivers of extreme events at the Earth's surface. 841 *Communications Earth and Environment*. Nature Publishing Group.
- ³ Karpechko, A. Y., Afargan-Gerstman, H., Butler, A. H., Domeisen, D. I. V., Kretschmer, M., Lawrence, Z., et al. 911 al. (2022). Northern Hemisphere Stratosphere-Troposphere Circulation Change in CMIP6 Models: 1. Inter-912 Model Spread and Scenario Sensitivity. *Journal of Geophysical Research: Atmospheres*, 127(18).
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