Characteristics and Surface Impacts of Southern Hemisphere Minor Stratospheric Warmings under Different Global Warming Levels

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Motivation

Sudden stratospheric warmings (SSWs) are extreme events in the winter/spring polar stratosphere. During winter, when the polar middle atmosphere gets very cold, a strong westerly jet develops around the pole forming the polar vortex. A strong weakening of this jet, which can even lead to the breakdown of the polar vortex, i.e. to an SSW, can feed back onto the tropospheric circulation. These extreme stratospheric events **are followed by anomalies in the tropospheric annular modes** on both hemispheres (NAM and SAM) lasting for a few weeks. The persistence of this signal can enhance the predictability of surface conditions.

On the NH these events occur every other year, while **on the SH there were only two events observed**: in 2002 and in 2019. In 2019 the SH polar vortex did not break down but the weakening of the vortex was strong enough for a significant surface impact. Lim et al. (2019) showed that **weak vortex years are connected to extreme heat events in Australia** which increase the risk of wild fires. It is therefore of great importance to assess how likely such stratospheric extreme events are in the near and far future.

Here, we investigate the occurrence and surface impacts of such extreme stratospheric events for different global warming thresholds.

Model Experiments and Methods

We performed AMIP-like experiments with ECHAM6 T63/L95 (lid at 0.01 hPa) using daily SST and SIC forcing based on ERA5 data for different scenarios: **Historical**, **2018** (present state), **1.5 K**, **2 K**, **3 K** and **4 K global warming (GW)** levels with respect to pre-industrial temperatures.

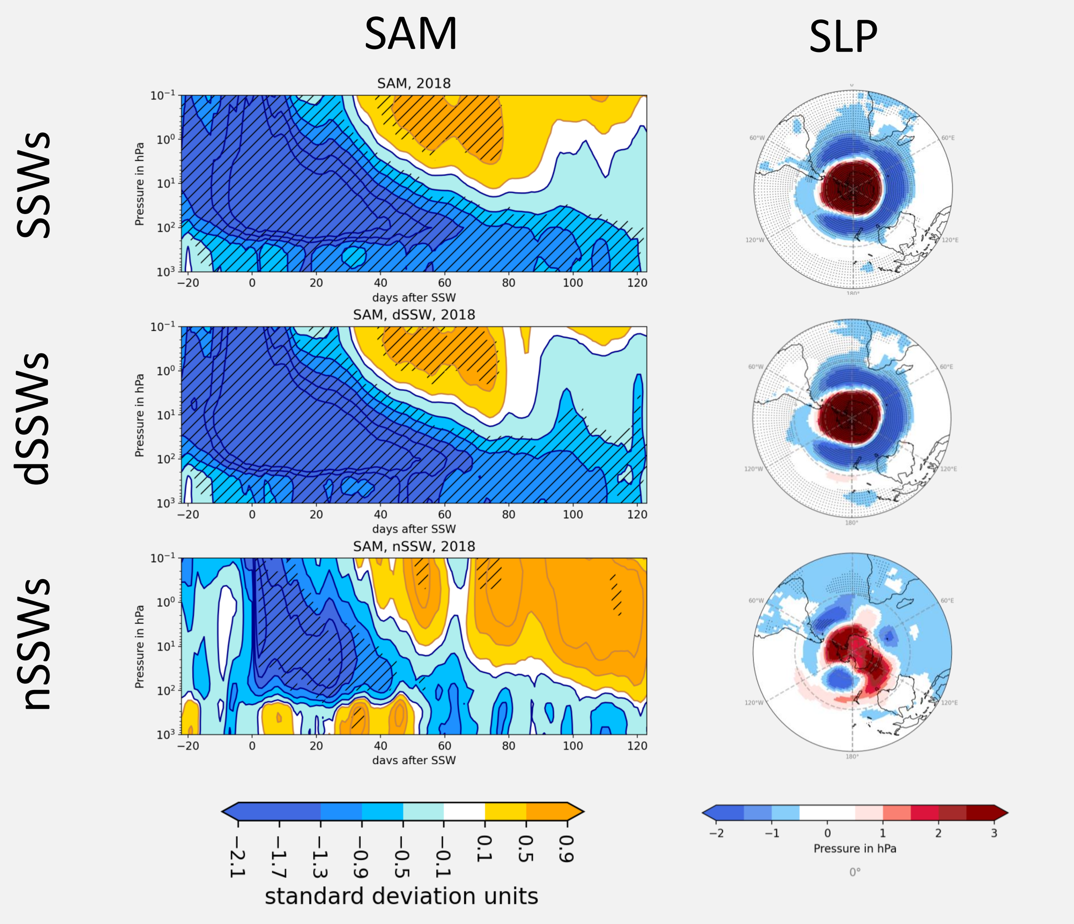
Historical experiment	Transient 1980 to 2019 forcing conditions in the atmosphere and the surface, historical forcing until 2014 and after that following the SSP8-5.8 CMIP6 scenario; 5 ensemble members.
2018 experiment	Perpetual 2018 conditions in the atmosphere and the at the surface; 292 model years.
GW experiments	Perpetual atmospheric and surface conditions that apply to the given warming levels under SSP5-8.5 conditions. To design the SST and SIC forcing, warming levels were calculated from a coupled FOCI simulation (Matthes et al. 2020) following the SSP8-5.8 scenario. SST trends from 2018 until the individual warming levels (+/- 15 years) were added to the daily 2018 SST field based on ERA5 data up to 60° latitude. Poleward of that the forcing converges to the model SIC and SSTs. We ran about 200 model years per warming threshold.

Extreme events in the stratosphere are defined to occur when the zonal mean zonal wind at 60°S and 10 hPa decreases to 20 m/s at least (Rao et al. 2020). For simplicity we call these events **SSWs**. To separate SSWs from the final warmings (the return to the summer circulation), the zonal mean zonal wind has to return to values larger than 20 m/s for at least 10 consecutive days before the final breakdown of the polar vortex.

SSW characteristics and surface impact

Following the method of Karpechko et al. (2017) for the NH, we defined downward propagating (dSSWs) and non-downward propagating (nSSWs) events based on the Southern Annular Mode (SAM) at 1000 and 150 hPa. We show that this method is also applicable to the weaker SSW definition that we applied for the SH warming events. The surface anomalies in SSW years is shown for all experiments and dSSWs in more detail.

SSW downward propagation – 2018 conditions



Long-lasting SAM anomaly within the stratosphere with an effect on the surface SAM up to 120 days after the start of the events.

Significant surface impacts of the SSWs mainly result from the dSSWs.

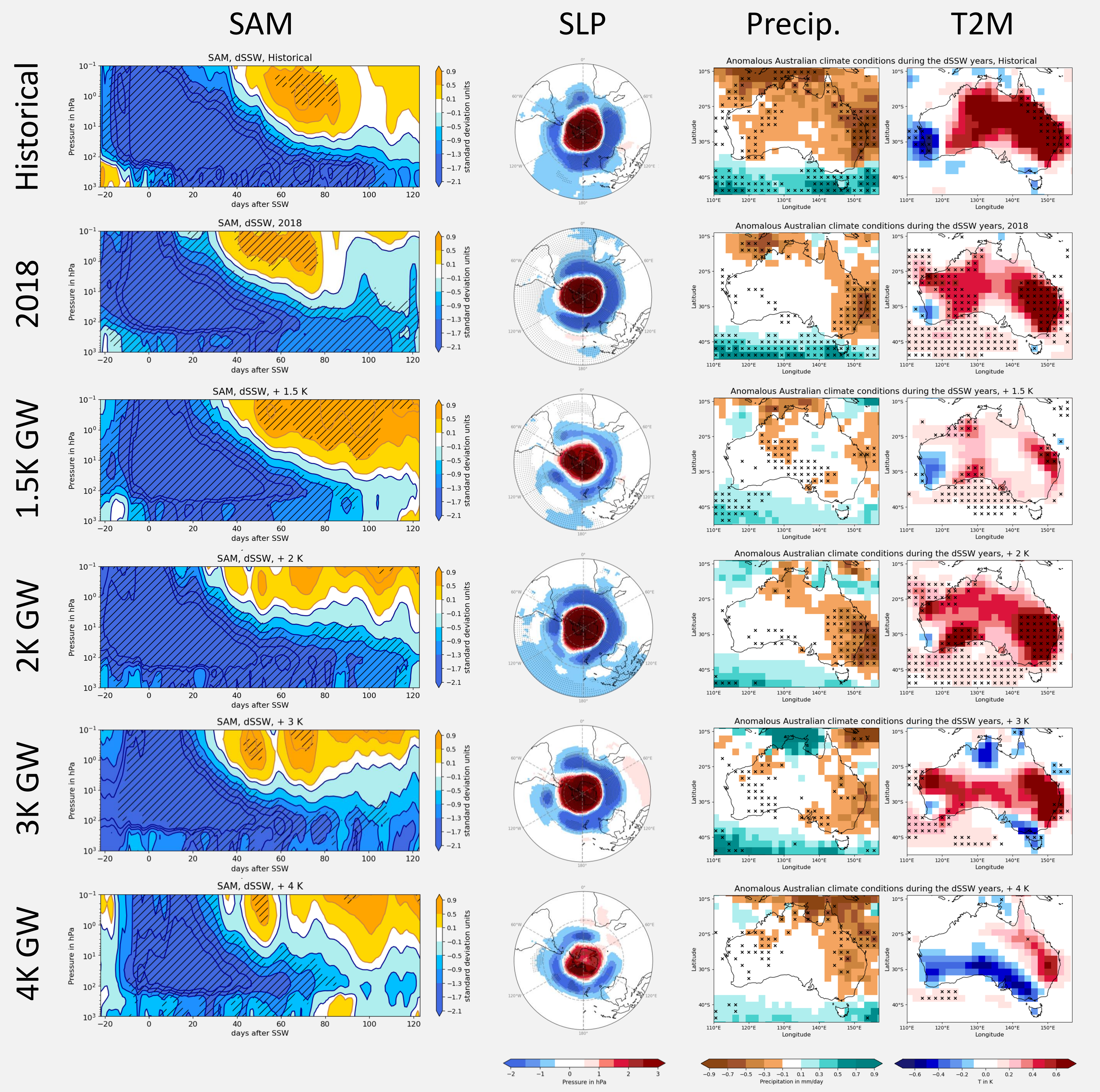
The SAM and sea level pressure (SLP) anomalies after SSWs are shown for the 2018 experiments. We use the 2018 experiment as an example here since it has the best statistics. However, the difference between dSSWs and nSSWs are similar for the other experiments as well.

SSW frequencies

Experiment	Model Years	SSWs/decade	dSSWs/decade	nSSWs/decade	dSSWs/nSSWs	mSSWs/decade
Historical	200	0.85	0.65	0.20	3.25	0.35
2018	302	1.03	0.86	0.17	5.20	0.23
1.5 K global warming	203	0.89	0.74	0.15	5.00	0.34
2 K global warming	204	0.93	0.49	0.44	1.11	0.20
3 K global warming	203	0.59	0.44	0.15	3.00	0.10
4 K global warming	201	0.70	0.45	0.25	1.80	0.05

The number of SSWs per decade peaks for the 2018 setting and roughly decreases with global warming levels afterwards. This feature is even more pronounced for dSSWs. A cut seems to occur at 2K warming, where the number of nSSWs closely reaches that of dSSWs. The ratio of dSSWs/nSSWs roughly decreases with the global warming level. Major Warmings (mSSWs) are also shown. mSSW number also decreases for higher GW levels.

dSSW surface impact under different global warming levels



Surface response in SSW years well represented in our model runs under historical and present day climate conditions

Decrease in significance for 1.5 K GW

Slight changes in the surface response pattern for 2K and 3K warming. Significance reduces under 3K warming.

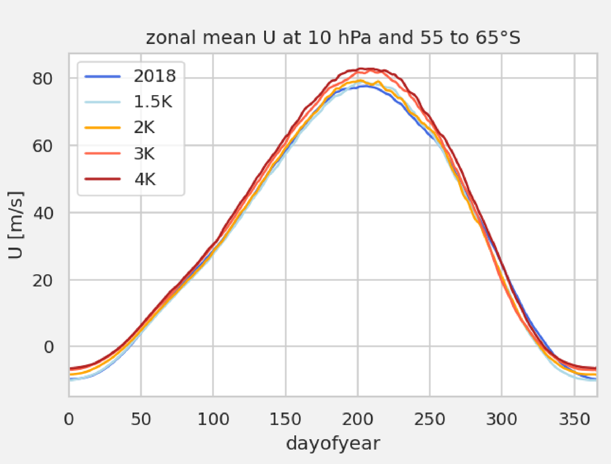
Surface response under 4K warming changes.

The SAM, SLP, precipitation (Precip.), and 2m air temperature (T2M) anomalies after the onset of the dSSWs (SAM) and for the October to December season in dSSW years vs. all years (for all other variables) in the different experiments. GW = global warming.

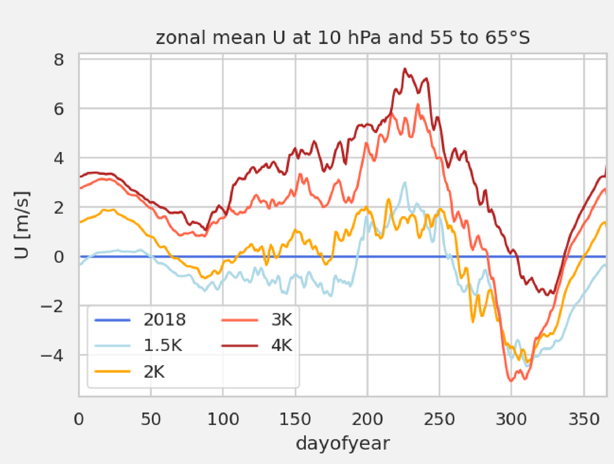
What is causing the difference in SSW occurrence under global warming?

The occurrence of SSWs is directly linked to the strength of the stratospheric polar vortex, which is effected by both: GHG increase and Ozone recovery. The figure below shows that the strength of the stratospheric jet between 55 and 65°S at 10 hPa generally increases for the different GW levels, especially during June, July and August. However, the trend is less clear for September and October.

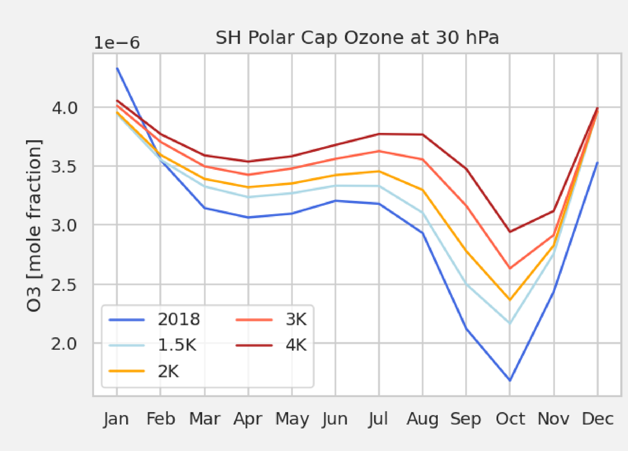
Strengthening of the polar vortex



Jet strength relative to 2018



Ozone recovery



Outlook/Discussion

Occurrence of SSWs and surface response suggest that there is a change in the SH STC with a warming of about 2K. This threshold is influenced by the interplay between GHG increase and ozone recovery and is probably model dependent. The effect on upward wave propagation still has to be investigated.

The effect of interactive chemistry on the GHG – Ozone interplay would be an interesting subject for future studies. Also with respect to the fact that ozone recovery might be underestimated in the CMIP6 forcing for the SSP5-8.5 scenario (Revell et al. 2022).

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