Spotlight: the January 2021 sudden stratospheric warming

Article

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Spotlight: The January 2021 Sudden Stratospheric Warming

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Abstract

On 5 January 2021, the Arctic stratospheric polar vortex dramatically weakened, and the temperature of the Arctic stratosphere rapidly increased in an event known as a major sudden stratospheric warming (SSW). It is likely that this SSW influenced surface weather conditions for over a month afterward.

Main text

Significant disruptions to the stratospheric polar vortex (SPV), known as major sudden stratospheric warmings (SSWs), occur on average 6 times per decade (Butler et al. 2017). These phenomena involve a reversal of the westerly polar night jet stream to easterlies, defined using the daily-averaged zonal-mean zonal winds at 10hPa (~30km) and 60°N. The deceleration of the jet occurs due to the breaking of vertically propagating planetary waves (long wavelength Rossby waves) in the stratosphere. According to ERA5 reanalysis, a major SSW began on 5 January 2021 (Figure 1a). This was the first major SSW since 2 January 2019 (Lee and Butler 2020), and the third in the past four winters. During the onset of the SSW, the average temperature of the Arctic stratosphere at 10hPa rose by close to 30degC in under a week. Although the SPV became significantly elongated and some splitting was observed in the lower stratosphere, the SSW was primarily a displacement-type event driven by one of the largest amplitude wavenumber-1 disturbances (i.e., a single ridge-trough wave pattern) in the past four decades[1].

There were 16 days of daily-mean zonal-mean easterly winds associated with the January 2021 SSW. These were not consecutive but occurred in 3 separate periods: 5 days from 5-9 January, 9 days from 12-20 January, and 2 days from 1-2 February. Although these were separate reversals of the zonal winds, they are considered to be a single major SSW – typically, there is a requirement of at least 20 consecutive days of westerly winds between SSWs (e.g., Charlton and Polvani 2007) allowing for the vortex to recover from the initial disruption. The occurrence of multiple wind reversals in a single event has occurred several times before; for example, there were 3 separate reversals following the SSW of 22 February 2008.

The strongest daily-mean easterlies occurred during the second reversal (zonal wind -9.3ms^{-1}). Whilst the magnitude of the easterlies was not particularly remarkable for a major SSW, the duration ranks 10th out of all 27 major SSWs since 1979 (c.f. Table 1 in Lee and Butler 2020)

[1] The interested reader is directed to the following NASA webpage showing a variety of stratospheric indices: https://acd-ext.gsfc.nasa.gov/Data_services/met/ann_data.html

albeit shorter than the 3 prior SSWs (in 2013, 2018 and 2019). By the middle of February, the warming subsided and the SPV recovered toward average, and later above-average, strength.

Major SSWs are typically associated with the negative phase of the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) at the surface in subsequent weeks, with a resultant increased risk of cold-air outbreaks across the Northern Hemisphere. During January and early February 2021, both the AO and NAO were strongly negative. According to the indices produced by the NOAA Climate Prediction Center, the January AO and NAO were both at their lowest since 2010[2]. The relationship between this extreme surface weather pattern and the SSW is evident in Figure 1b, which shows the anomalously high geopotential heights over the Arctic (indicative of the negative AO phase) throughout the atmospheric column. The maximum positive height anomalies during late-January and early-to-mid February coincided with significant cold-air outbreaks and snow for northwest Europe including Britain (Kendon, 2021), as well as the extreme cold-wave over North America (BBC News, 2021). The duration of these surface impacts for over a month after the onset of the SSW highlights the importance of these phenomena on the subseasonal timescale.

It is also notable that the tropospheric AO was negative *before* the major SSW, and thus causality cannot be fully established from this qualitative analysis. It is possible that other subseasonal phenomena, such as the Madden-Julian Oscillation, may have contributed to or enhanced these surface weather patterns.

Acknowledgments

ERA5 reanalysis is available from the Copernicus Climate Data Store (https://cds.climate.copernicus.eu/#!/home).

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[2] https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/teleconnections.shtml

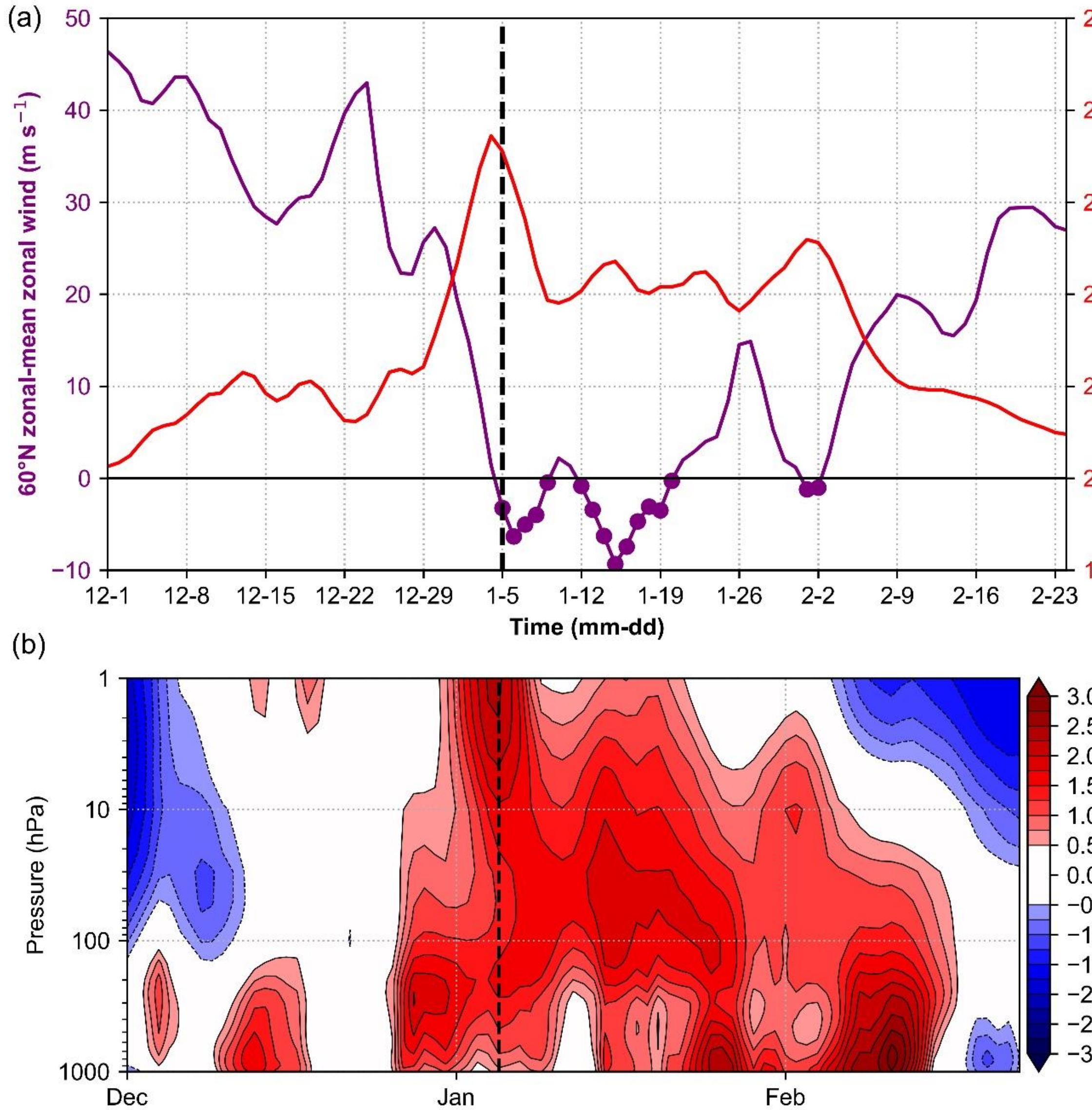

Figure 1 (a) Evolution of the 10 hPa 60°N zonal-mean zonal winds (left-hand ordinate, in purple) and 60-90°N temperature (right-hand ordinate, in red) from 1 December 2020 to 24 February 2021. Data are daily-averaged values from ERA5 reanalysis. Circles indicate days with easterly winds. **(b)** Vertical (log-pressure) cross-section of 60-90°N average geopotential height anomalies over the same period, standardised with respect to the daily mean and standard deviation over the full ERA5 dataset since 1979. In both panels, the vertical black dashed line indicates the onset of the major SSW on 5 January.