

RESEARCH ARTICLE

The 2020 Siberian heat wave

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Funding information

Climate Program Office; Cooperative Institute for Climate, Ocean, and Ecosystem Studies, Grant/Award Number: NA20OAR432027; Joint Institute for the Study of the Atmosphere and Ocean, Grant/Award Number: NA15OAR4320063

Abstract

Siberia saw a heat wave of extreme monthly temperatures of +6°C anomalies from January through May 2020, culminating with near daily temperature records at the Arctic station of Verhojansk in mid-June. This was a major Arctic event. The proximate cause for the warm extremes from January through April was the record strength of the stratospheric polar vortex (SPV) and tropospheric jet stream. The SPV and high geopotential heights to the south combined to provide strong zonal winds from the west that reduced the potential penetration of cold air from the north. An index of vortex strength is the Arctic Oscillation (AO); averaged over January–April, the AO set extreme positive records in 1989, 1990, and 2020 (baseline starting in 1950). The strength and stability of the SPV over the central Arctic contributed to the winter–spring persistence of the heat wave in Siberia. May–June temperatures were related to high tropospheric geopotential heights over Asia. An open question is whether these dynamic events are becoming more persistent. Such record events will not occur every year but one can expect that they will occasionally naturally reoccur over the next decades due to internal atmospheric variability in addition to a continued global warming background.

KEYWORDS

Arctic, arctic change, heat wave, jet stream, polar vortex, severe weather

1 | INTRODUCTION

There was much international media interest in late June 2020 that the northeastern Siberian Arctic town of Verhojansk (67.55°N and 133.38°E) may have set a record for the highest temperature documented in the Arctic Circle of 38°C measured on 20 June (<https://public.wmo.int/en/media/news/reported-new-record-temperature-of-38C-north-of-arctic-circle>). The event was associated with extensive wild fires, pest infestations, and melting permafrost. From a climate perspective, the large temperature anomalies and their causes that persisted across Siberia from January through April are also of

importance. Figure 1a–f (left column) shows the positive monthly temperature anomaly patterns that cover most of the Eurasian continents during January through June 2020. The location of maximum positive anomalies of +6°C did vary from month to month: January, March and June having two centres lying in west and east Siberia, and February, April and May have a core over central Siberia. A large, rapid multi-method attribution study, supported by observational and large ensemble model analyses, indicates with high confidence that extremely warm periods such as the 6 months of January–June 2020 over the Siberian region would have been at least 2°C cooler in a world without human

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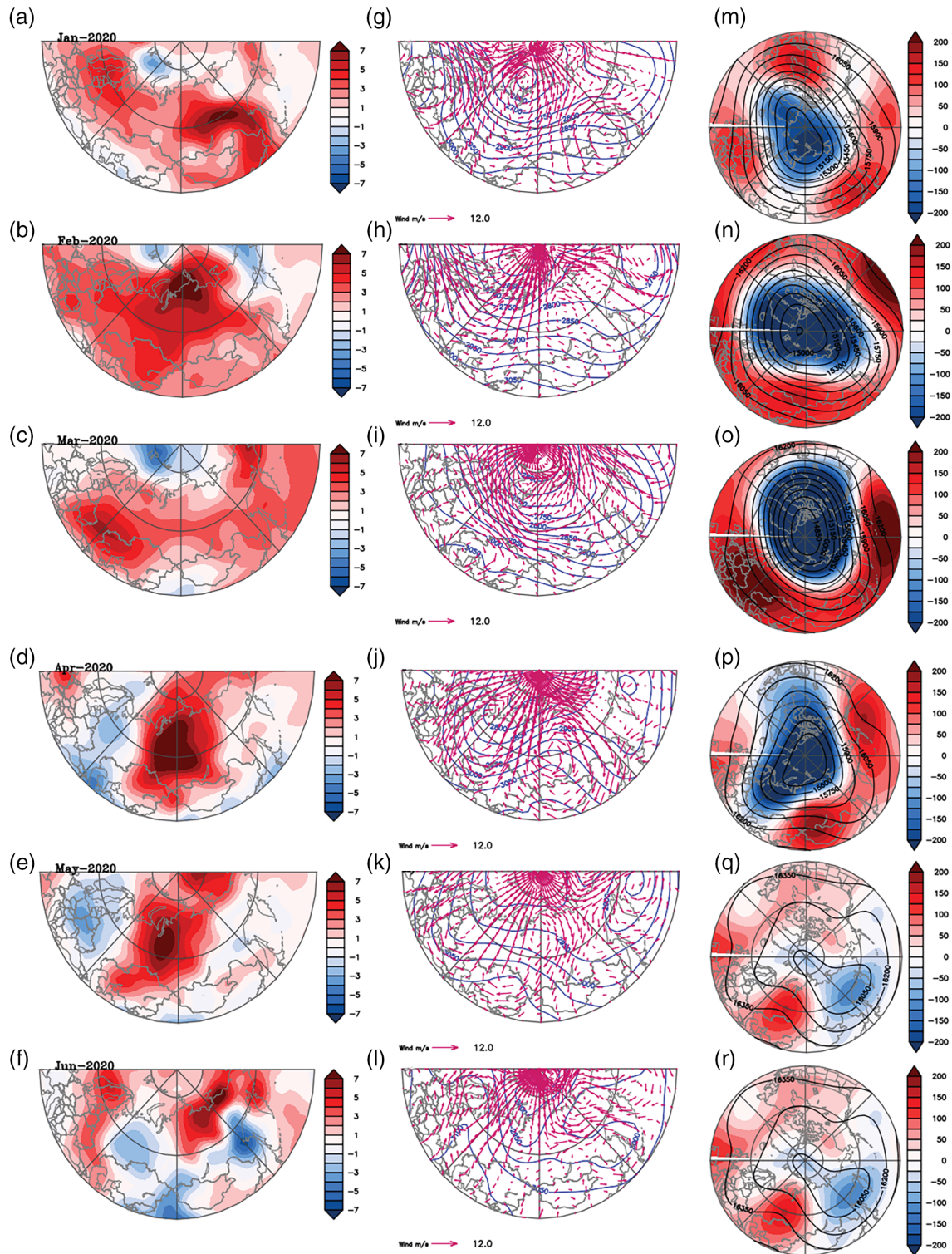


FIGURE 1 (a–f) Low level atmospheric air temperature anomalies ($^{\circ}\text{C}$) at 925 hPa during January through June 2020. (g–l) Geopotential height (contours) and winds anomaly vectors at 700 hPa, and (m–r) 100 hPa geopotential height (contours) and anomalies (colours). Anomalies are relative to a 1981–2010 baseline. Data source: NCEP-NCAR reanalysis (ftp://ftp.cdc.noaa.gov/Datasets/ncep_reanalysis.derived/)

influence (Ciavarella *et al.*, 2020) <https://www.worldweatherattribution.org/wp-content/uploads/WWA-Prolonged-heat-Siberia-2020.pdf>

Extreme weather events in the Arctic and subarctic continue based on their magnitudes. Both winter 2016 and 2018 had extensive Arctic areas with near surface air

temperature anomalies of $>6.0^{\circ}\text{C}$, almost twice as large as previous anomalies (1981–2010 climatology) (Overland *et al.*, 2019a). In 2018, unusual meteorological events caught the public's attention with reports of wintertime temperatures warming to near the freezing point at the North Pole. Sea ice reduction during summers 2007, 2012, 2016, 2019 and 2020 were the top five minima of September sea-ice cover. A feature of these events and the Siberian heat wave is that they do not occur every year, suggesting a random component related to chaotic atmospheric dynamics, rather than a steady change of Arctic Amplification (Dai *et al.*, 2019) due to thermodynamic processes. Here we investigate the unusual strength of the stratospheric polar vortex (SPV) and the associated tropospheric jet stream during early 2020 as the proximate cause for the persistent winter–spring 2020 Siberian heat wave.

2 | 2020 JET STREAM AND POLAR VORTEX PATTERNS

The monthly tropospheric jet stream pattern based on the 700 hPa geopotential height field for January–March (Figure 1g–i, contours) imply strong zonal winds across north central Siberia. The contribution to the strengthening of the jet stream over Siberia is due to the low geopotential height feature over the Arctic and ridging to the south over southern Siberia. There are month to month differences in the waviness of the 700 hPa geopotential height field as highlighted by the 700 hPa geopotential height contours (solid blue curves) and anomaly wind patterns shown by the arrows in Figure 1g–l. Southerly wind components are especially noted in February and April over central Siberia. January and March show southwesterly winds over Europe and southerly winds over eastern Asia. These monthly differences in winds,

showing different temperature advection regimes, correspond to the regional monthly differences in maximum temperature anomalies in Figure 1a–f.

The geopotential height and anomaly pattern for the stratospheric polar vortex (SPV) at 100 hPa is shown in Figure 1m–r (right column). The polar vortex is strong from January through April with dark blue shading of negative height anomalies centred over the North Pole with extensive areal coverage. Low Arctic geopotential heights from the lower stratosphere to the troposphere show a near vertically-consistent meridional circulation features/height anomalies that lead to the month to month variations in the 700 hPa winds and the near surface temperature anomaly fields. This vertical alignment is further shown by the daily time series of the standardized polar cap geopotential height anomaly for early 2020 calculated at each level, averaged over $65\text{--}90^{\circ}\text{N}$ (Figure 2). Such vertical alignment and adjustment has been noted in the atmospheric literature (Blackmon *et al.*, 1977; Hoskins *et al.*, 1985; Deser *et al.*, 2007; Garfinkel *et al.*, 2013).

3 | COMPARISONS WITH CLIMATOLOGY

January–April 2020 represents one of the strongest SPV, and can be represented by its tropospheric correlate, the Arctic Oscillation (AO; Thompson *et al.*, 2002). As noted by Thompson *et al.*, surface pressure of the AO index is a favourable index of the overlying air mass and the SPV, especially during the 2020 case where the SPV is centred on the Pole. The time series of the four-month average January–April AO is shown in Figure 3. The years 1989, 1990, and 2020 stand out as major years with the index twice as large as other positive AO years (values of 1.9, 2.3, 2.3). 2020 corresponds to the negative 100 hPa geopotential anomaly fields in Figure 1m–p.

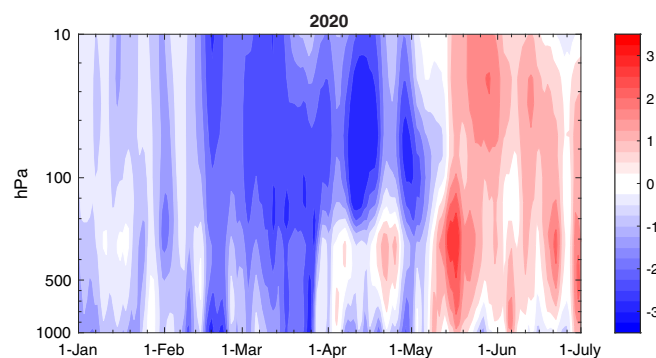


FIGURE 2 The January–June 2020 daily time series of the normalized geopotential height anomalies at different atmospheric levels averaged over $65\text{--}90^{\circ}\text{N}$. Anomalies are calculated by subtracting 1981–2010 daily climatology, averaged over the polar cap, and normalized by the 1981–2010 daily standard deviation. Data from the NCEP/NCAR reanalysis

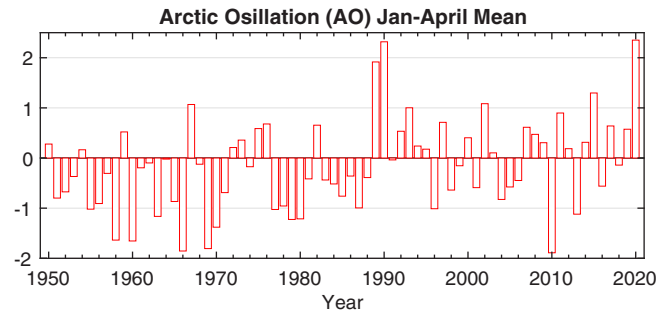


FIGURE 3 Historical Arctic oscillation (AO) index time series for January–April average. Index from NOAA Climate Prediction Center (CPC)

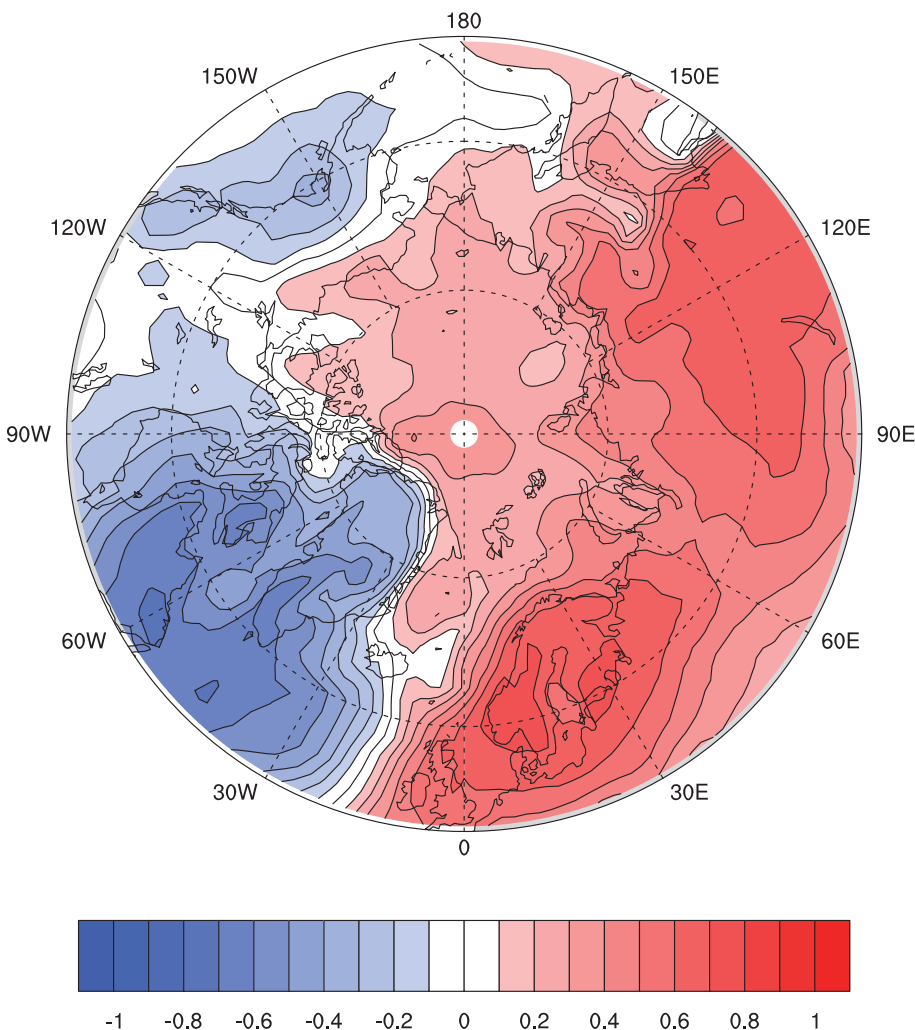


FIGURE 4 Regression of 925 hPa air temperatures on the January–April mean value of the AO. Air temperature based on NCAR/NCEP reanalysis and AO from Climate Prediction Center for 1950–2019. Image provided by the NOAA-ESRL Physical Sciences Laboratory, Boulder Colorado from their web site at <https://psl.noaa.gov/>. <https://www.psl.noaa.gov/cgi-bin/data/testdap/corr.pl>

The connection from SPV, through tropospheric temperature advection, to regional heat wave temperature anomalies has multiple contributions. Yet such an attribution can be shown by a regression of near surface temperatures (925 hPa) onto the AO index (Figure 4). The

multi-year regression shows the main features of winter–early spring 2020: an extensive positive relation from Europe through East Asia and a bimodal maxima distribution over Europe and East Asia. Eurasian surface air temperature anomalies have also been shown to be

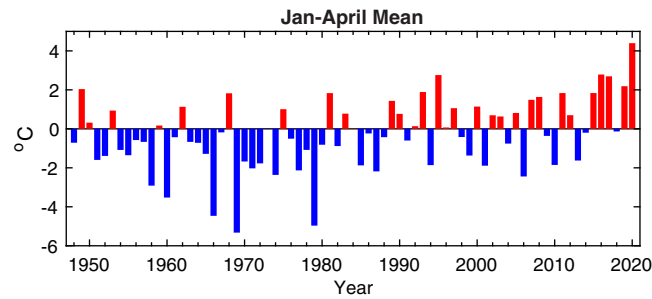


FIGURE 5 Historical regional surface air temperature anomalies at 2 m over Siberia (60–72.5°N, 60–140°E) for January–April. Data source: NCEP-NCAR reanalysis (<ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis.derived/>)

associated with the persistence of large-scale atmospheric circulation anomaly patterns over the North Atlantic and Eurasia, featuring a combination of the North Atlantic Oscillation (NAO)/AO and the Scandinavian pattern (SCA), from winter to spring (Gong *et al.*, 2019; Wu and Chen, 2020). NAO was greater than 1.0 for January–March 2020 and SCA was strongly negative (negative heights over Scandinavia and correlated with positive Siberian temperatures) for January–May 2020.

Figure 5 provides the historical regional surface air temperature (2 m) anomalies over Siberia (60–72.5°N, 60–140°E) for January–April. Although 1989 and 1990 (large AO years, Figure 3) have positive temperature anomalies, 2020 is the only year with a regional average temperature anomaly greater than 3.0°C; this maximum supports Ciavarella *et al.* (2020) that 2020 regional Siberian temperature maximum had an additional contribution from global warming beyond the dynamic contribution from SPV. Also note the multiple low temperatures before 1980.

4 | MAY–JUNE 2020

Although May–June 2020 show similar Siberian warm air temperature maxima as earlier in the year, there is a different mix of mechanisms responsible for the two types of anomalous warmth, with the SPV setting the proximate forcing for January–April temperatures and its weakening in for May–June (Figures 1 and 2). For May the centre of the jet stream cyclonic geopotential height minimum at 700 hPa remains over the Atlantic side of the Arctic (Figure 1k). Higher geopotential heights build in from the south (May) or northeast Asia (June) (Figure 1k,j). During June this orients warm air over the Siberian coastal Arctic with positive temperature advection from the southwest over the Sea of the Okhotsk.

5 | SUMMARY

The Verhojansk June temperature record is a continuation of the broader Siberian winter/spring heat wave that represents a major Arctic event. It is an example of random weather added to the ongoing Arctic temperature amplification and provides a new extreme observation (Ciavarella *et al.*, 2020). The vertically connected SPV and tropospheric jet stream in January–April 2020 provided the atmospheric dynamic feature that supported the eastward and localized northward warm air advection for the temperature anomalies. The high geopotential heights over Asia contributed to the set up for the record June Arctic Siberian temperature. The SPV and jet stream congruence was associated with a record AO during January–April that contributed to heat wave persistence (Deser *et al.*, 2007; Wu and Chen, 2020).

The Siberian heat wave is an example of meteorological events that depend on the sum of Arctic Amplification and temperature advection from the variability of jet stream/SPV driven wind patterns over the subarctic. Record events such as the 4 month persistent temperature anomaly will not occur every year or in all Arctic or midlatitude locations, but one can expect that they will occasionally reoccur over the next decades. A basic science issue is whether there will be a change in the frequency or duration of atmospheric circulation events due to Arctic change. The dynamics will mostly remain due to internal instabilities (Deser *et al.*, 2007; Woollings *et al.*, 2018). Based on the single 2020 spike in the positive AO in 2020, and the separation of historical circulation patterns from AA (Overland *et al.*, 2019b), current data suggests a negative answer to the change in the frequency question with no proven trend in circulation (Screen and Simmonds, 2014; Cohen *et al.*, 2018, 2020; Francis *et al.*, 2018; Blackport and Screen, 2020).

ACKNOWLEDGEMENTS

This paper has support of the Arctic Research Program of the NOAA Global Ocean Monitoring and Observing Office. This is PMEL Contribution 5119. This publication is funded in part by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) under NOAA Cooperative Agreement NA15OAR4320063 and by the Cooperative Institute for Climate, Ocean, and Ecosystem Studies under NOAA Cooperative Agreement NA20OAR432027. The JISAO contribution number is 2020-1079. We appreciate Nicholas Bond for suggesting Figure 4. Data were obtained from available sources as noted by references: Global Historical Climatology Network (GHCN) and NCEP-NCAR reanalysis.

CONFLICT OF INTEREST

The authors declare no competing interests.

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How to cite this article: Overland JE, Wang M. The 2020 Siberian heat wave. *Int J Climatol*. 2021; 41 (Suppl. 1):E2341–E2346. <https://doi.org/10.1002/joc.6850>