The 2020 Siberian heat wave

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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

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-38°C2%B0c-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
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 $>6.0^\circ$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 65–90°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.
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
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.

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).
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CONFICT OF INTEREST
The authors declare no competing interests.

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REFERENCES
Blackmon, M.L., Wallace, J.M., Lau, N. and Mullen, S.L. (1977) An observational study of the northern hemisphere wintertime circulation. Journal of the Atmospheric Sciences, 34, 1040–11053. https://doi.org/10.1175/1520-0469(1977)034<1040:AOSOTN>2.0.CO;2.

Blackport, R. and Screen, J.A. (2020) Insignificant effect of Arctic amplification on the amplitude of mid-latitude atmospheric waves. Science Advances, 6, eaay2880. https://doi.org/10.1126/sciadv.aay2880.

Cohen, J., Pfeiffer, K. and Francis, J.A. (2018) Warm Arctic episodes linked with increased frequency of extreme winter weather in the United States. Nature Communications, 9, 869. https://doi.org/10.1038/s41467-018-02992-9.

Cohen, J., Zhang, X., Francis, J., Jung, T., Kwok, R., Overland, J., et al. (2020) Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. Nature Climate Change, 10, 20–29. https://doi.org/10.1038/s41558-019-0662-y.

Dai, A., Luo, D., Song, M. and Liu, J. (2019) Arctic amplification is caused by sea-ice loss under increasing CO₂. Nature Communications, 10, 121. https://doi.org/10.1038/s41467-018-07954-9.

Deser, C., Tomas, R.A. and Peng, S. (2007) The transient atmospheric circulation response to North Atlantic SST and sea ice anomalies. Journal of Climate, 20, 4751–4767. https://doi.org/10.1175/JCLI4278.1.

Francis, J.A., Skific, N. and Vavrus, S.J. (2018) North American weather regimes are becoming more persistent: is Arctic amplification a factor? Geophysical Research Letters, 45, 11414–11422. https://doi.org/10.1029/2018GL080252.

Garfinkel, C.I., Waugh, D.W. and Gerber, E.P. (2013) The effect of tropospheric jet latitude on coupling between the stratospheric polar vortex and the troposphere. Journal of Climate, 26, 2077–2095. https://doi.org/10.1175/JCLI-D-12-00301.1.

Gong, H., Wang, L. and Chen, W. (2019) Multidecadal changes in the influence of the Arctic oscillation on the east Asian surface air temperature in boreal winter. Atmosphere, 10, 757.

Hoskins, B.J., McIntyre, M.E. and Robertson, A.W. (1985) On the use and significance of isentropic potential vorticity maps. Quarterly Journal of the Royal Meteorological Society, 111, 877–946. https://doi.org/10.1002/qj.49711147002.

Overland, J., Wang, M. and Box, J.E. (2019b) An integrated index of recent pan-Arctic climate change. Environmental Research Letters, 14, 035006.

Overland, J.E., Dunlea, E., Box, J.E., et al. (2019a) The urgency of Arctic change. Polar Science, 21, 6–13.

Screen, J.A. and Simmonds, I. (2014) Amplified mid-latitude planetary waves favour particular regional weather extremes. Nature Climate Change, 4, 704–709. https://doi.org/10.1038/NCLIMATE2271.

Thompson, D.W.J., Baldwin, M.P. and Wallace, J.M. (2002) Stratospheric connection to northern hemisphere wintertime weather: implications for prediction. Journal of Climate, 15, 1421–1428.

Woollings, T., Barnes, E., Hoskins, B., Kwon, Y.-O., Lee, R.W., Li, C., et al. (2018) Daily to decadal modulation of jet variability. Journal of Climate, 31(4), 1297–1314. https://doi.org/10.1175/JCLI-D-17-0286.1.

Wu, R. and Chen, S. (2020) What leads to persisting surface air temperature anomalies from winter to following spring over mid- to high-latitude Eurasia? Journal of Climate, 33, 5861–5883.

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