Surface Air Temperature

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Highlights

- This past year (October 2020-September 2021) was the seventh warmest on record over Arctic lands (beginning in 1900 with surface air temperature anomalies 1.1°C above the 1981-2010 mean).
- The *warmest* Pan-Arctic and Asian Arctic autumn (October-December) terrestrial air temperatures were observed in 2020.
- For the second consecutive year, much higher-than-normal air temperatures were observed over northern Eurasia, and especially the Laptev Sea, during autumn of 2020 and spring of 2021.
- Temperature extremes yielded some unprecedented impacts on the Arctic environment, including the *first* rainfall observed at Summit at the top of Greenland.

Introduction

Surface air temperatures (SAT), typically measured at a height of 1.5 to 2 meters above land, ocean, or ice cover, are one of the most telling observational indicators and drivers of Arctic climate change (Box et al. 2019). Averaged SAT across Arctic lands (north of 60 °N), which have a higher density of weather observations relative to the Arctic Ocean and glaciated environments, have shown a pronounced, positive warming trend of nearly 3°C since the mid-1960s (Fig. 1). These increased air temperatures have been associated with changes in the frequency, intensity, and duration of Arctic atmospheric and hydrological extremes (Walsh et al. 2020) with impacts on permafrost thaw, glacier melt, and sea ice decline amongst other components of the Arctic and broader Earth system (Moon et al. 2019; see essays on the *Greenland Ice Sheet* and *Sea Ice*). In this essay, we recap the annual and seasonal Arctic SAT conditions of the last year (October 2020-September 2021) and place them in context compared to recent decades.

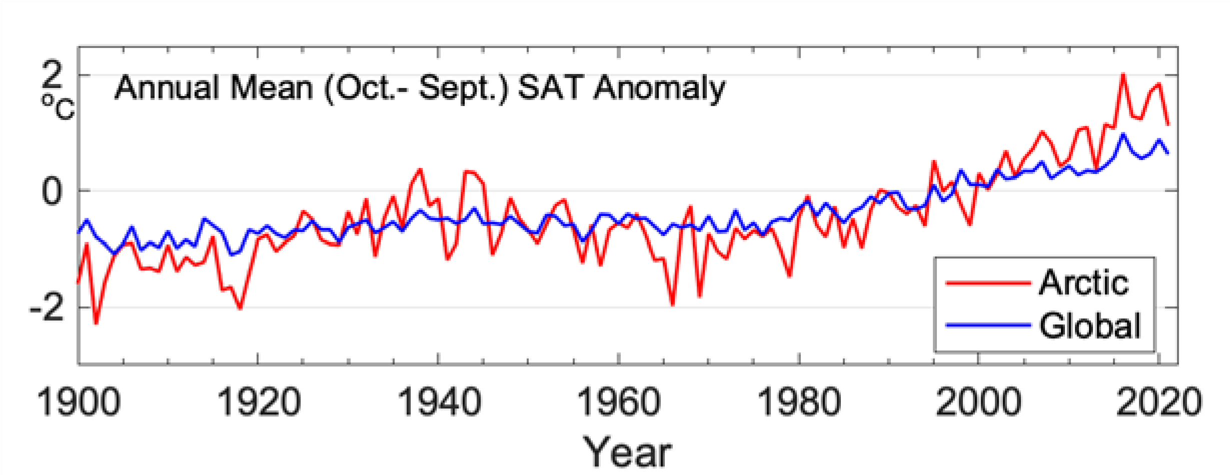

Fig. 1. Mean annual SAT anomalies (in °C) for weather stations located on Arctic lands, 60-90° N (red line), and globally (blue line) for the 1900-2021 period (n=122 years). Each temperature time series is shown with respect to their 1981-2010 mean. Source: CRUTEM5 SAT data are obtained from the Climate Research Unit (University of East Anglia) and Met Office.

Overview of the past year's terrestrial Arctic surface air temperatures

Averaged over the period from October 2020 to September 2021, the Arctic SAT anomaly for land areas north of 60° N was 1.1°C above the 1981-2010 mean (Fig. 1). This annual SAT anomaly marked the eighth consecutive year since 2014 that land temperature anomalies have reached at least 1°C. Considering the 1900 to 2021 historical period, 2021 was the seventh warmest year on record. The warmest autumn (October-December) and fourth warmest spring (April-June) in the Arctic strongly contributed to the annual temperature anomaly (Table 1). Autumn 2020 was also much warmer than average at the regional scale with record warming over the Asian Arctic, while the European Arctic saw its second highest SAT since 1900. The Greenland-Iceland region also had its third warmest summer (July-September) on record in 2021.

Table 1. Pan-Arctic and regional SAT rankings for different seasons during October 2020 through September 2021. The rankings are based on seasonal temperature data since 1900. Longitudinal bounds for each of the four regions are shown in parentheses, and the corresponding southern extent for all areas is 60° N. The warmest season since 1900 is shown in **bold**, while seasons of at least 90th percentile warming are shown in *italics*. Source: CRUTEM5 SAT data are obtained from the Climate Research Unit (University of East Anglia) and Met Office.

Season	Pan-Arctic	European Arctic (0-90° E)	Asian Arctic (90-180° E)	North American Arctic (180° E-60° W)	Greenland-Iceland Region (60° W-0° E)
OND 2020	**Warmest**	*2nd warmest*	**Warmest**	*7th warmest*	*6th warmest*
JFM 2021	53rd warmest	95th warmest	65th warmest	24th warmest	*5th warmest*
AMJ 2021	*4th warmest*	*5th warmest*	*7th warmest*	21st warmest	19th warmest
JAS 2021	*11th warmest*	*13th warmest*	*12th warmest*	28th warmest	*3rd warmest*

It is notable that since 2000, on average, annual Arctic SAT anomalies have exceeded their global mean SAT counterpart by more than a factor of two (Fig. 1). This enhanced boreal warming pattern, often termed "Arctic Amplification," results from a complex interplay of localized feedbacks and energy transport into the region (Previdi et al. 2021). These mechanisms vary in the Arctic across space and time, and their interactions can have compounding effects on Arctic change. For example, declines in the late spring and summer Arctic sea ice and Eurasian Arctic terrestrial snow cover decrease the albedo (solar reflectivity) of these respective areas, which enables more solar radiation absorption and accelerates surface warming (see essays on *Sea Ice*, *Sea Surface Temperature*, and *Snow Cover*). Meanwhile, oceanic and atmospheric heat transport can affect the Arctic cryosphere and interconnected ocean-ice-atmosphere interactions throughout the year (Cohen et al. 2020).

Seasonal recap of Arctic air temperatures

Arctic air temperature anomalies and extremes are further discussed by season: autumn 2020 (October-December [OND]), winter (January-March [JFM]), spring (April-June [AMJ]), and summer (July-September [JAS]) 2021 (Fig. 2). To emphasize large-scale air temperature patterns versus local variability, near-surface air temperatures at 925 hPa (~750 meters above the surface) are described. The seasons are defined to span the water year (October-September) and coincide with annual cycles of variables discussed in the Arctic Report Card. For example, melt of Arctic sea-ice tends to begin in spring and reach its seasonal minimum in late summer, i.e., September.

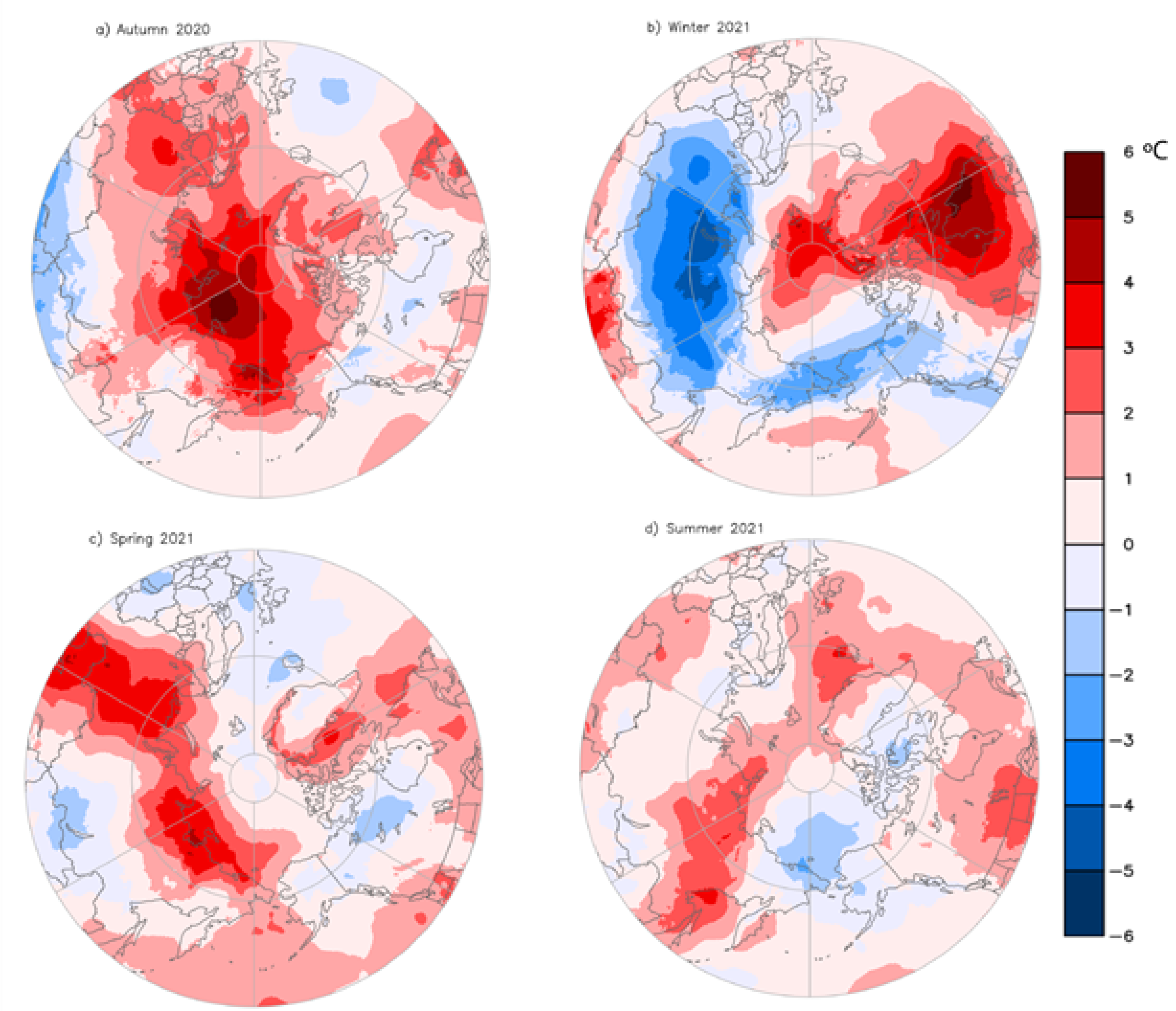

Fig. 2. Near-surface (925 hPa) seasonal air temperature anomalies (in °C) for (a) autumn 2020, (b) winter 2021, (c) spring 2021, and (d) summer 2021. Anomalies are shown relative to their 1981-2010 means. Source: ERA5 reanalysis air temperature data are obtained from the Copernicus Climate Change Service.

Autumn 2020. Widespread air temperature anomalies of at least 1-2°C above normal were observed across the Arctic Ocean and adjacent lands during autumn (Fig. 2a). Temperature anomalies were warmest atop the Laptev Sea (5-7°C) and over Chukotka extending into the Chukchi Sea (4-6°C). A trough in the jet stream over eastern Eurasia (Fig. 3a) supported relatively warm, southerly airflow across the Chukchi (see essay on *Sea Ice*). This wind pattern, coupled with heat exchange from the warm, upper ocean to the overlying atmosphere, likely contributed to the Chukchi region's positive air temperature anomaly. Terrestrial high-latitude temperatures were also above average within autumn. November was characterized by record warmth both in Norway (tying the record set in 2011 in a series starting in 1900; Grinde et al. 2020) and in Sweden (0.1°C above the previous record from 2000 in a series dating from 1860; SMHI 2020).

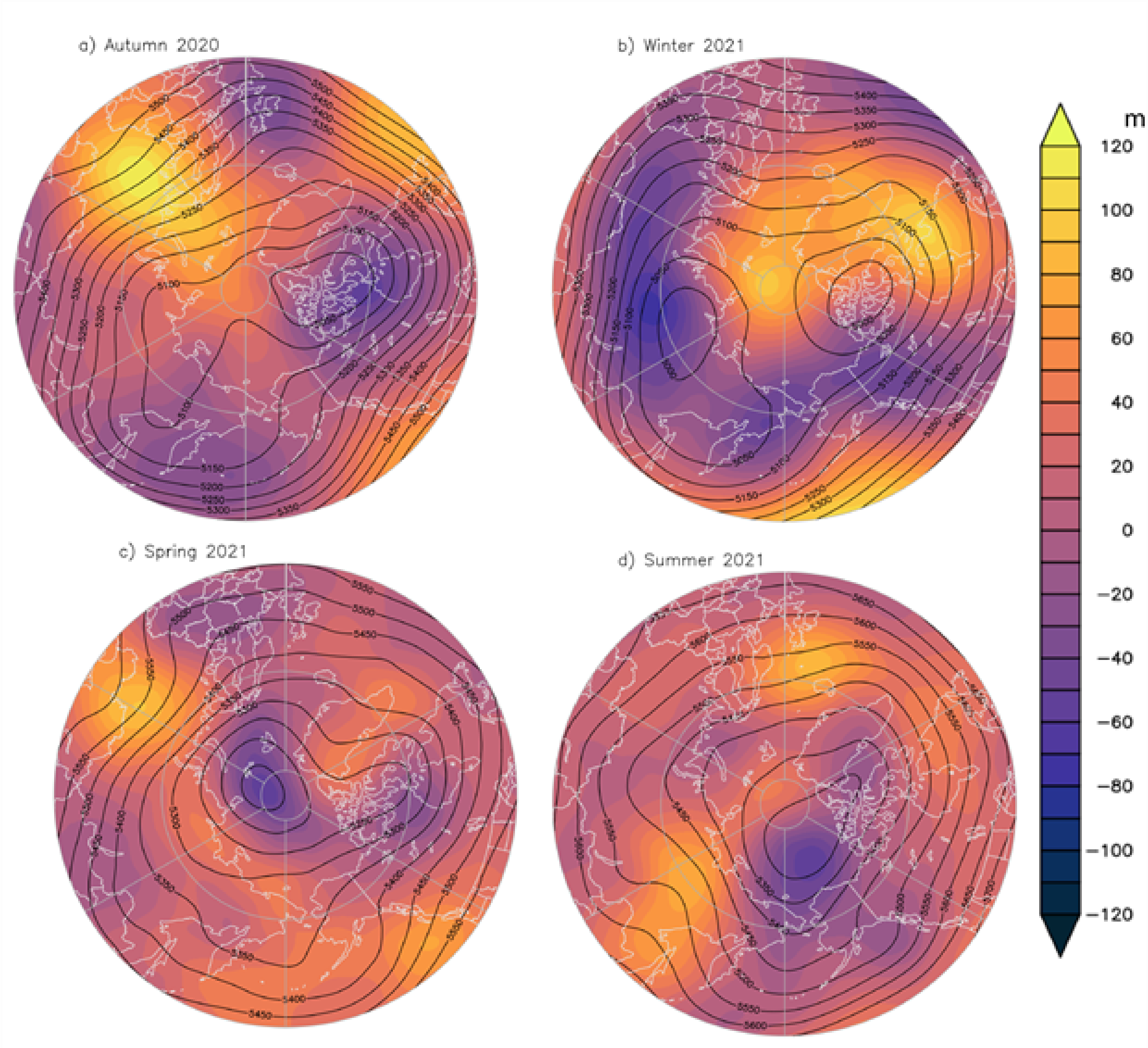

Fig. 3. Mid-tropospheric circulation patterns described by 500 hPa geopotential heights (contours) for (a) autumn 2020, (b) winter 2021, (c) spring 2021, and (d) summer 2021. The geopotential height values are listed in meters (m) from the surface. Anomaly values in the 500 hPa seasonal fields are overlaid for reference (shading). Corresponding winds tend to circulate clockwise around higher height values. Source: ERA5 reanalysis geopotential height data are obtained from the Copernicus Climate Change Service.

Winter 2021. During winter, a sharp temperature contrast between the Arctic Ocean and lands was present over much of the region. The central Arctic Ocean SAT remained 2-4°C warmer than normal, while cold anomalies predominantly extended from coastal zones southward into northern Eurasia and northwestern North America, including north-central Alaska and the Yukon and Northwest Territories (Fig. 2b). Much of western Greenland, Baffin Bay, Labrador Sea, and adjacent northeastern Canadian lands experienced near-surface air temperatures 3-5°C above average. Two lobes developed in the winter jet stream with one lobe steering polar air southward into north-central Eurasia and the other lobe transporting cold air into the North American lower latitudes (Fig. 3b).

Spring 2021. Springtime coincided with warmer-than-average conditions over the Arctic Ocean and adjacent lands (Fig. 2c). Air temperatures in northern Eurasia coastal areas and adjacent Arctic waters were 2-4°C warmer than the 1981-2010 average. Air temperatures over Baffin Bay and the Labrador Sea were also above normal. The swath of higher-than-normal Eurasian spring air temperatures was associated with low snow cover and anomalously early melt of the Laptev Sea's ice cover (see essays on *Terrestrial Snow Cover* and *Sea Ice*). Several air temperature records were set at Arctic weather stations, including 39.9°C (103.8°F) observed at Fort Smith, Northwest Territories, Canada, on 30 June 2021, which broke the provincial maximum surface temperature record (Henson and Masters 2021).

Summer 2021. The highest summer air temperature anomalies were found over northern Iceland and the Greenland Sea (2-3°C) and across the Sea of Okhotsk (3-4°C), extending into Eurasia (Fig. 2d). Another active wildfire season in eastern Siberia was associated with warmer-than-normal air temperatures (Dixon 2021). Air temperatures of 1-2°C below normal were found in the Pacific Arctic over portions of the Beaufort, Chukchi, and East Siberian Seas. Positive temperature anomalies were present over the North Atlantic Arctic during which anomalous air temperature events occurred in late July and mid-August, producing melt extremes on the Greenland Ice Sheet. Of note, the National Science Foundation's Summit Station, situated at the highest point on the ice sheet, experienced a rare melt event, and rain was reported for the first time since the station's inception in 1989 (see essay on *Greenland Ice Sheet*).

Data overview

CRUTEM5 SAT data (Osborn et al. 2021) are used to place pan-Arctic and regional land temperatures in an annual and seasonal context. ERA5 reanalysis (Hersbach et al. 2020) is implemented to show large-scale seasonal air temperature and geopotential height fields. Previous iterations of the ARC have used NCEP/NCAR reanalysis (Kalnay et al. 1996) to highlight similar climate variables, though in the 2021 essay we transition to the newer, higher spatiotemporal resolution ERA5 reanalysis that has generally been shown to perform well in Arctic terrestrial and marine environments (Graham et al. 2019; Avila-Diaz et al. 2021).

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