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Svalbard's Record-Breaking Arctic Summer 2024: Anomalies Beyond Climatological Warming Trends

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Key Points:

- 2024 mean summer and August temperatures on Svalbard reached unprecedented levels, breaking previous records by record margins
- The August mean temperature falls outside of historically observed climatological variability, even after accounting for warming trends
- Persistent atmospheric patterns and coupling with anomalously warm sea surfaces drove the unprecedented warmth in the Svalbard Archipelago

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract

The Svalbard archipelago region is one of the fastest warming regions in the world. The majority of warming has occurred in wintertime, although the summer season has also been warming approximately linearly since 1980. Nevertheless, in recent years, many monthly and seasonal temperature records have been set in summer, with 2024 breaking its mean summer and August temperature records by the largest margins in the measurement history. In this study, we examine 2024s temperature extremes. The mean August temperature stands out as falling outside of the climatological distribution even after accounting for the warming trend. Our findings suggest that 2024s records are a result of an unprecedented combination of persistent atmospheric patterns and interaction with the warming seas. Given the exceptional nature of these temperature extremes, we recommend further research to the potential increase in the persistence of weather and the consequences of associated temperature extremes.

Plain Language Summary

Svalbard, an archipelago in the high Arctic, is one of the fastest warming places in the world. The most notable warming has occurred in wintertime. However, recent summers have consistently been breaking temperature records. Summer temperatures are an important variable as they strongly impact glacier melt, permafrost and wildlife in the area. The summer of 2024 stood out, and broke the mean summer and August temperature records by margins far larger than observed during any time in Svalbard's measurement history. Our study shows that in 2024, August's mean temperature shattered its previous record by such a margin that it falls outside of previously observed temperature variability even after accounting for the observed climate warming trends. Our results suggest that these temperature spikes are part of an unusual combination of persistent weather with frequent winds from the south and interactions with the warmer seas around Svalbard. Further understanding is necessary to assess if this kind of persistent weather will become more common in a warmer climate. The impacts of such temperature extremes on glaciers and wildlife also require additional study.

1. Introduction

The Arctic has warmed rapidly in recent decades due to a phenomenon known as Arctic amplification. Recent studies estimate that the warming rate in the Arctic has been around 2 to 4 times faster than the global average (Andersen et al., 2020; Rantanen et al., 2022). However, within the Arctic, warming rates show strong spatial and seasonal variability. One of the fastest warming regions in the Arctic (and the world) is the Barents Sea area, including the Svalbard Archipelago region (Isaksen et al., 2022). The rapid warming in this region is associated with several positive feedbacks (e.g., cloud, water vapor, and lapse rate feedbacks) (Adakudlu et al., 2019), many of which are triggered by an increase in heat and moisture fluxes from the ocean to atmosphere due to the strong influx of Atlantic water—known as "Atlantification"—and the consequent reduction in sea ice (Lind et al., 2018) and increase of sea surface temperatures (SSTs) (Isaksen et al., 2022). Due to seasonal variations in the boundary conditions for atmospheric warming (e.g., sea ice) the air temperatures in recent decades have increased least in summer and most in winter (Isaksen et al., 2022).

However, during recent summers, seasonal and monthly mean temperatures have been broken consistently on Svalbard, often by large margins. The summer of 2024, the 3rd consecutive record warm summer on the archipelago (Grinde et al., 2024a), stood out in particular. Not only did Svalbard Airport in Longyearbyen measure the warmest summer and August on record, it also broke its respective seasonal and monthly mean temperature records by record-large margins.

In this study, we investigate the Svalbard Airport temperature time series to put this record-shattering event in climatological context. Additionally, we utilize atmospheric and ocean reanalysis data to examine the underlying causes of these extreme temperatures.

2. Data and Methods

Our study is based on timeseries of in situ weather station observations and reanalysis data. In addition, the North Atlantic Oscillation (NAO) index was analyzed and air parcel trajectories were computed.

2.1. Weather Station Time Series

Monthly temperatures were obtained through the Norwegian Center for Climate Services (https://seklima.met.no/). The temperature analyses were based on Svalbard Airport's homogenized temperature data set (Nordli et al., 2014). All years since 1980 were detrended by subtracting the product of the trend's slope and the number of years since 1980, such that:

$$T_{\text{detrend}} = \begin{cases} T, & t < 1980 \\ T - \alpha\,(t - 1980), & t \geq 1980 \end{cases}$$

Where T is the monthly or seasonal temperature, α is the trend's slope and t the year number. The trend was computed by applying an ordinary least squares regression on the temperatures over the period 1980–2023.

Anomalies were computed by subtracting the resulting detrended baseline period (1900–2023):

$$T' = T_{\text{detrend}} - \overline{T_{\text{detrend}}}$$

where T' is the temperature anomaly.

The number of standard deviations of an anomaly was obtained by computing by the "Z-score":

$$Z = \frac{T'}{\sigma}$$

where σ is the detrended temperatures' standard deviation over the baseline period.

2.2. Reanalysis Data

ERA5 reanalysis data (Hersbach et al., 2020) was utilized for analysis of the large-scale weather patterns, SSTs, and atmospheric mass transport in the Svalbard region. ORAS5 reanalysis data (Copernicus Climate Change Service, Climate Data Store, 2021) was used for analysis of ocean currents. Anomalies were computed relative to the 1980–2023 baseline.

2.3. NAO Index

The NAO index was downloaded from the Royal Netherlands Meteorological Institute (KNMI) Climate Explorer and is calculated as the principal component of the first empirical orthogonal function of the NCEP-NCAR reanalysis (Kalnay et al., 1996) sea level pressure over 0–90°N, 90°W-30°E.

2.4. Lagranto Trajectories

LAGRANTO (Sprenger & Wernli, 2015) air mass trajectories were computed based on operational analysis from the European Centre for Medium-Range Weather Forecasts and initialized twice a day (00 and 12 UTC) for each day of summer at the coordinates of Longyearbyen and a location just south of Svalbard's main island (see Note SN1 in Supporting Information S1 for details).

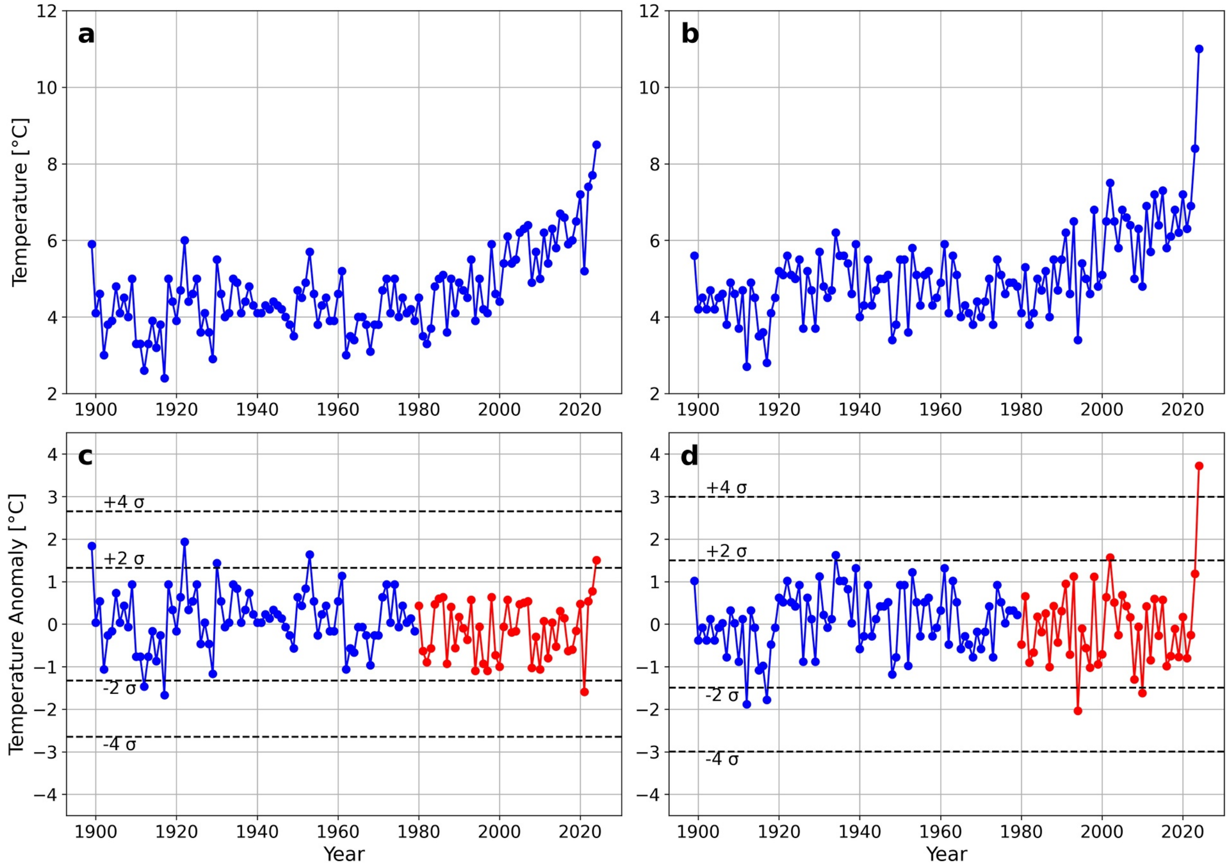

Figure 1. Time series of (a) seasonal mean temperature for summer (June–August) and (b) monthly mean temperature for August at Svalbard Airport. Plots (c)–(d) show temperature anomalies relative to the climatology of 1900–2023, where years 1980–2023 are detrended. The red color represents the detrended temperature anomalies. Black dashed lines indicate the scale of standard deviation relative to the 1900–2023 climate, with 1980–2023 detrended.

3. Results

3.1. Temperature Records With Record Margins

In 2024, Svalbard Airport in Longyearbyen measured an average summer (June, July, August) temperature of 8.5°C, 0.8°C above the previous record, marking the 3rd consecutive record warm summer (Figure 1a). Even more remarkably, the station recorded a mean August temperature of 11.0°C (Grinde et al., 2024a), which is 2.6°C above last year's record (Figure 1b). Not only are these temperatures seasonal and monthly records, but the margins at which the records are broken are themselves record breaking, indicating a major shift in temperature extremes (Table 1). Other weather stations in the vicinity of Svalbard Airport (within 11 km) reported similarly high temperatures (within 0.1°C), and weather stations in the Svalbard archipelago (within 450 km) showed temperature anomalies of almost similar magnitude for summer and August 2024 (Figures S1 and S2 in Supporting Information S1 respectively).

Table 1
Mean Summer (Left) and August (Right) Temperature Records at Svalbard Airport, Ranked By the Magnitude of the Margin By Which the Previous Record is Broken

Summer temperature records			August temperature records		
Rank	Year	Margin (°C)	Rank	Year	Margin (°C)
1	2024	0.8	1	2024	2.6
2	2020	0.5	2	2023	0.9
3	2015, 2023	0.3	3	2002	0.7
5	2022	0.2	4	1934	0.5
			5	1993, 1998	0.3

We note that June 2024 also was the warmest June on record at Svalbard Airport (0.1°C above the previous record set in 2022) (Grinde et al., 2024b), while July 2024 was the 6th warmest July on record. However, due the magnitude of the records, we focus on the month of August and the summer as a whole.

Relative to the climate of the 20th century at Svalbard Airport, 2024s record high summer and August temperatures exhibited anomalies of 6.3σ and 8.3σ for the respective season and month, indicating that these temperatures would have been virtually impossible in last century's climate. However, it is evident that Svalbard has been warming rapidly since around 1980 (Figures 1a and 1b) with the summer and August mean temperatures increasing approximately linearly from 1980 to 2023 at a rate of 0.67°C/decade and 0.61°C/decade, respectively. Therefore, we need to establish the likelihood that this year's extreme is a result of the superposition of natural variability on the decadal warming trend. To this aim, we consider the event relative to the 1900–2023 conditions while removing the influence of the 1980–2023 linear warming trend (Figures 1c and 1d). The resulting temperature populations do not deviate significantly from a normal distribution (Figure S3 in Supporting Information S1).

The detrended 2024 summer and August mean temperatures are 2.2σ and 5.0σ above their respective baselines (Figures 1c and 1d). While 2024s summer mean temperature still represents the largest positive anomaly in the 1980 to 2024 period, the Svalbard Airport time series contains even larger positive anomalies during the first half of the 20th century. Therefore, the record summer mean temperature remains within the range of observed variability superimposed on the linear warming trend. In contrast, August 2024s mean temperature spike is of such a magnitude that, even after accounting for the linear warming trend, it falls well outside historically observed climate variability. This indicates that August 2024 is an exceptional event, unprecedented in both the past century's climate and the warming climate of 1980–2023.

To allow for comparison with the ERA5 reanalysis data, we also computed the summer and August anomalies relative to the non-detrended 1980–2023 baseline, which yields results of 3.0σ and 4.7σ, respectively.

3.2. Atmospheric and Marine Conditions

The summer and August temperature records are a result of both the persistence and magnitude of the anomalously warm weather. Throughout summer, 88% of the days were warmer than the 1980–2023 climatology at Svalbard Airport (Figure S4 in Supporting Information S1). In August specifically, every day experienced mean daily temperatures above the long-term average. August 11th measured the highest daily mean temperature on record: a striking 18.0°C (Grinde et al., 2024a).

3.2.1. Atmospheric Circulation and Oceanic Interactions

Atmospheric circulation clearly favored summer warmth due to consistent southerly flow in the Svalbard archipelago region. ERA5 monthly mean sea level pressure shows a persistent low-pressure anomaly to the (south) west of Svalbard and a high-pressure area to its east throughout the whole summer. As a result, the pressure gradient (shown by contours in Figures 2a–2c) indicates an average south(east)erly flow component during all summer months, with the strongest southerly flow occurring in August (Figure 2c). Furthermore, the MSLP-based NAO index was record high in August and the 2nd highest on record in summer as a whole, underscoring the persistence and strength of the Icelandic low (Figure S5 in Supporting Information S1). In June the southerly air flow in the Svalbard region was also favored by the lowest Greenland Blocking index (Hanna et al., 2016) since 1964.

These persistent atmospheric conditions were associated with an anomalously strong zonal jet stream over Northeastern Canada and the North Atlantic (Figure S6 in Supporting Information S1). In the Atlantic sector, the jet stream was clearly shifted northward in June (Figures S6a and S6d in Supporting Information S1). In July and August the jet stream showed more meridional features in the Arctic (Figures S6b, S6c, S6e, and S6f in Supporting Information S1), eventually penetrating deep into the central Arctic in August and forming an almost enclosed, elongated vortex around the North Pole (Figures S6c and S6f in Supporting Information S1). In every month, the upper tropospheric wind patterns favored a low-pressure center around Iceland, explaining the observed positive NAO index (Figures S6a–S6c in Supporting Information S1). In July and August, subtle ridging can be identified on the basis of the jet stream patterns between Scandinavia and Nova Zemlaya, favoring the aforementioned high-pressure anomalies to Svalbard's southeast.

The resulting circulation patterns in the lower troposphere (Figures 2a–2c), as well as LAGRANTO-trajectory analysis (Sprenger & Wernli, 2015) (Figures 3a–3c; Figures S7a–S7c in Supporting Information S1), indicate that during summer 2024, and most notably in August, air masses were regularly transported from the Northern Eurasian continent and North Atlantic to the Svalbard Archipelago region, crossing either the Norwegian or Barents Sea. Noteworthily, many of these regions were also anomalously warm during summer. Specifically parts of Northern Europe—the origin of part of the airmasses–stand out, having experienced a record warm summer

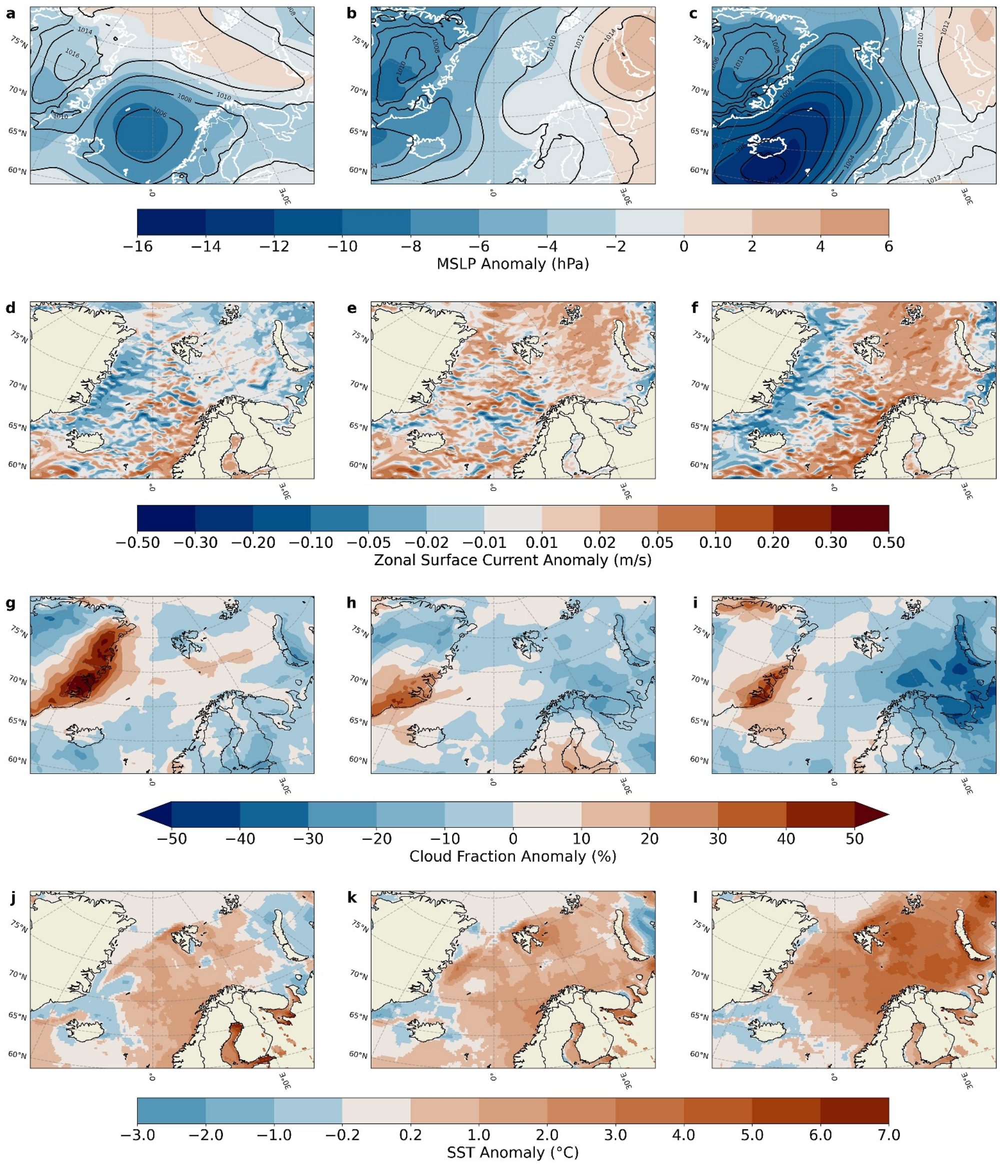

Figure 2. (a)–(c) ERA5 reanalysis mean sea level pressure (MSLP) anomaly (shading) and average MSLP given by the isobars (black contours) for June (a), July (b), and August (c). (d)–(f) Shading as (a)–(c), but for ORAS5 reanalysis zonal surface current anomaly (m/s). (g)–(i) As (a)–(c), but for anomalies of the ERA5 reanalysis average cloud fraction (%). (j)–(l) As (a)–(c), but for ERA5 reanalysis SST anomalies. The color-vision deficiency friendly color map used in this and the following figure, as well as some of the Figures in Supporting Information S1, is from Crameri et al. (2020).

(Copernicus Climate Change Service, 2024). It was likely a combination of already anomalously warm air masses, and the interaction with the underlying sea, that resulted in the amplified warming observed in Svalbard. We note that, specifically in June, air masses were also regularly advected from the north and (north) east, even when some of those air parcels were originally located at a latitude lower than that of the Svalbard Archipelago (Figure 3 and Figure S7a in Supporting Information S1). Air masses advected from the north and (north) east have undergone warming in summer as a consequence of sea ice loss and increased SSTs in the Northern Barents Sea (Isaksen et al., 2016, 2022). This is an additional explanation for warmth in June 2024 and underscores the role of interaction between the ocean surface and atmosphere. However, in August 2024 southerly winds strongly dominated and, accordingly, climatological changes in the ocean north(east) of Svalbard played a minor role for air temperatures in Longyearbyen.

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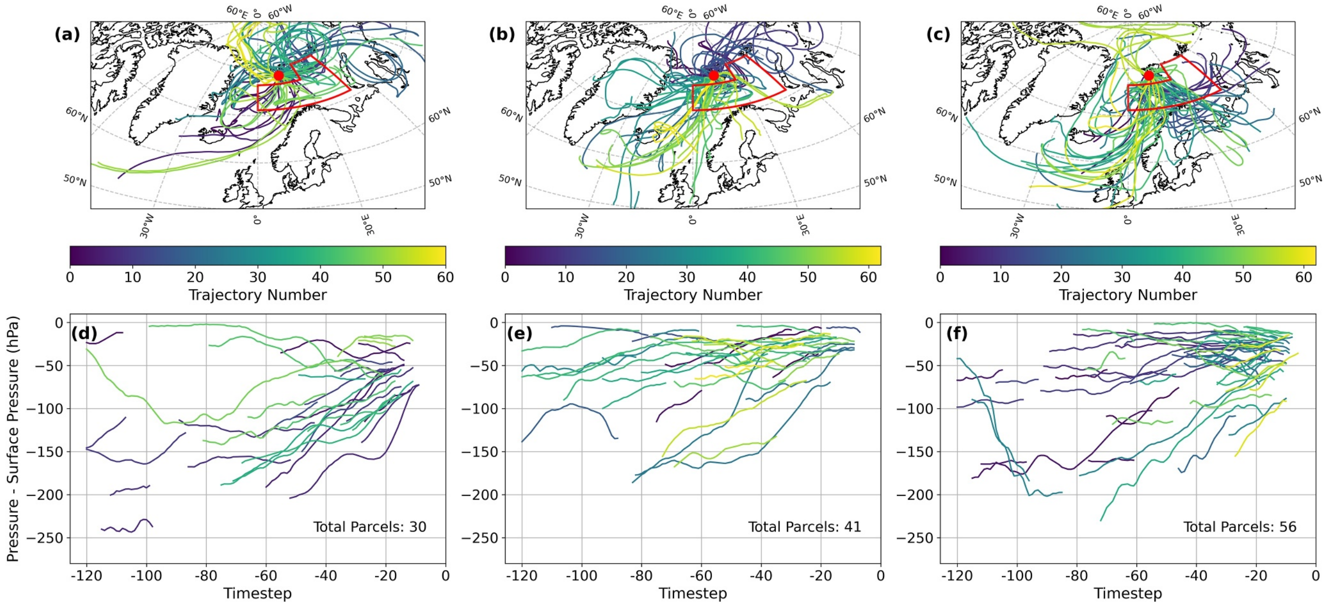

Figure 3. (a)–(c) operational European Centre for Medium-Range Weather Forecasts analysis backward LAGRANTO trajectories (−120hr) initialized at the Svalbard Airport (red dot) for June, July, and August, respectively. Trajectory number 0 indicates parcels initialized at 00 UTC on the first day of the month, with every following trajectory being initialized 12hr later. Details: Note 1 in Supporting Information S1. Panels (d)–(f) show the parts of the trajectories that reside in the red box in Figure (a)–(c) for at least 12hr. *Y*-axis indicates the pressure minus the surface pressure, representing the height of the air parcel. Especially in August, many parcels show prolonged amounts of time at low elevations above the sea surface towards the end of the trajectory. Annotated is the total number of parcels that resides in the defined area for at least 12hr.

The anomalously warm air masses heading north from the Eurasian continent and North Atlantic continuously lost heat to the underlying seas, resulting in increased SSTs. Higher SSTs, in turn, reduced the heat loss experienced by subsequent air masses as they headed towards the Svalbard Archipelago. We now identify two mechanisms which enhanced this coupling with the Barents Sea.

Firstly, the southerly winds forced an eastward oceanic current anomaly through Ekman transport (Ekman, 1905) (Figures 2d–2f), especially enhanced in August (Figure 2f), drawing warm Atlantic water crossing the Norwegian Sea to the Svalbard Archipelago and Barents Sea region, resulting in increased SSTs.

Secondly, the Barents Sea region was less cloudy than usual in July and August, as indicated by ERA5 cloud fraction anomalies (Figures 2h and 2i). This is probably due to the anticyclone located over the Novaya Zemlya area (Figures 2b and 2c). In August in particular, parts of the Barents Sea had 30%–50% less cloud cover than normal, allowing abundant solar radiation to warm the sea surface (Figure 2i). This warming may be enhanced by complicated feedbacks between SST, radiative and turbulent surface fluxes, atmospheric boundary layer stratification and clouds (Vihma et al., 2014).

As a result of the warming by the southerly air flow, eastward ocean current, and abundant sunshine, a strong marine heatwave developed in the Barents Sea and northeastern part of the Norwegian Sea during the course of the summer, according to the NOAA Marine Heatwave Watch classification (based on Hobday et al., 2018) (Figure S8 in Supporting Information S1). SST anomalies gradually increased from June to August, peaking in August at up to 4–5°C above normal over the seas between Fennoscandia and Svalbard (Figures 2j–2l). In August, practically the entire Barents Sea, Norwegian Sea and Greenland Sea were warmer than usual (Figure 2l).

By the arrival of August, the average pressure pattern (Figure 2c) and strongly positive SST anomalies south(east) of Svalbard (Figure 2l) produced the ideal combination for efficient atmospheric heat transport into the Svalbard archipelago region, resulting in the exceptional August temperatures.

3.2.2. Quantifying Circulation and SST Anomalies

To quantify the anomaly of the atmospheric circulation, and given that during the majority of summer the flow towards/over Svalbard was southerly, we calculated the ERA5 atmospheric vertically-integrated northward mass flux across 76°N in the sector 10–30°E. The time series of northward mass transport shows a maximum in 2024 both for the entire summer and August (Figures 4a and 4b). As in the case of air temperature in Svalbard Airport, the 2024 peak transport is more pronounced for August than for the entire summer. However, the August 2024 peak in the mass transport exceeds the reference period mean by 3.4σ, which is much less than the 4.7σ for the air temperature peak (based on the 1980–2023 non-detrended baseline). This confirms that the anomalously strong synoptic-scale transport from the south can in large part explain the extreme air temperatures in 2024, although the anomaly was not of the same magnitude as the temperature anomaly observed at Longyearbyen Airport.

The time series for SSTs south and east of Svalbard align with the observations made in Section 3.2.1, indicating that SSTs in the area were above the 1980–2023 average throughout summer 2024 (Figures 4c–4f). The time series also confirms that the anomalies grew as the summer progressed (ranging from +0.4σ in early June to +4.4σ in late August), with the most noteworthy result being that the SSTs were already at the highest levels on record at the onset of August (+2.5σ, Figure 4e). This suggests that the extremely high SSTs in August were not merely a result of warmth during that month, but also played a crucial role in sustaining and amplifying atmospheric heat transport by preconditioning the sea surface for continued warming in the following weeks.

Overall, quantifying the circulation and SST anomalies confirms that the flow pattern and SSTs were exceptionally anomalous, both in the summer as a whole but specifically in August. The above also supports the overall conclusion that followed from the analysis of the atmospheric overview in Section 3.2.1, indicating that the interactions between the atmospheric heat transport and the high SSTs are the main drivers behind the extreme temperatures observed on the Svalbard Archipelago.

Still, it is likely that other factors also contributed to the extreme temperatures in Svalbard, with the negative cloud anomaly directly over Svalbard (specifically in June, Figure 2g) and around the Archipelago (mainly in July and August, Figures 2h and 2i) being one example. Adiabatic warming also contributed to the high temperatures for some of the air masses arriving in Svalbard (Figures S9 and S10 in Supporting Information S1). However, most air masses transported over the seas resided in the lowermost 50-hPa layer for at least some time before reaching Svalbard, especially in July and August (Figures 3d–3f and Figures S7d–S7f in Supporting Information S1), which reinforces the importance of the anomalously warm surface.

4. Discussion and Conclusions

In the summer of 2024, Svalbard measured its warmest summer and August on record, with the mean August temperature falling far beyond previously observed climatological variability, even after accounting for linear climate change trends. Based on our analysis, we conclude that the temperature extremes are the result of an unprecedented combination of persistent weather patterns and interaction with the anomalously warm seas.

While SSTs in the Norwegian and Barents Sea are very likely to further increase in upcoming decades (e.g., Alexander et al., 2018; Noh et al., 2024), it remains an open question whether persistent weather regimes, specifically those characterized by prolonged southerly winds, will become more common in a warmer climate. Arctic amplification does generally result in more persistent weather in summer, at least over the northern mid-latitudes (Coumou et al., 2018; Pfleiderer et al., 2019), as a weaker meridional temperature gradient favors shifts in the jet stream, amplified quasi-stationary waves, and weakened storm tracks. Contrastingly, during the last decades, the baroclinicity in the Arctic has increased (Zhang et al., 2023). In summer, the increased baroclinicity, quantified in terms of Eady Growth Rate (Eady, 1949), is due to reduced stratification in the lower troposphere and regionally increased temperature gradients over coastal areas of Siberia and North America, where the land surface has warmed much faster than the offshore regions north of the coastline (Crawford & Serreze, 2016). Accordingly, increasing persistence of summer weather is not expected everywhere in the Arctic but may be favored over the Barents Sea region, where the SSTs have strongly increased and are expected to keep increasing in a warming climate.

The magnitude of the 2024 summer warming in Svalbard is of such significance that it no longer fits the climatological definition of a "polar climate", where the maximum monthly mean temperature remains below 10°C (Beck et al., 2018; Köppen, 1936). Given the unprecedented nature of these temperature extremes, we recommend further research on the mid-latitude forcing of Arctic weather and climate, and the impacts of the amplified Arctic warming on large-scale atmospheric circulation. Particular focus is warranted on the potential increase in the persistence of weather patterns, the associated extreme events, and the non-linear feedbacks which

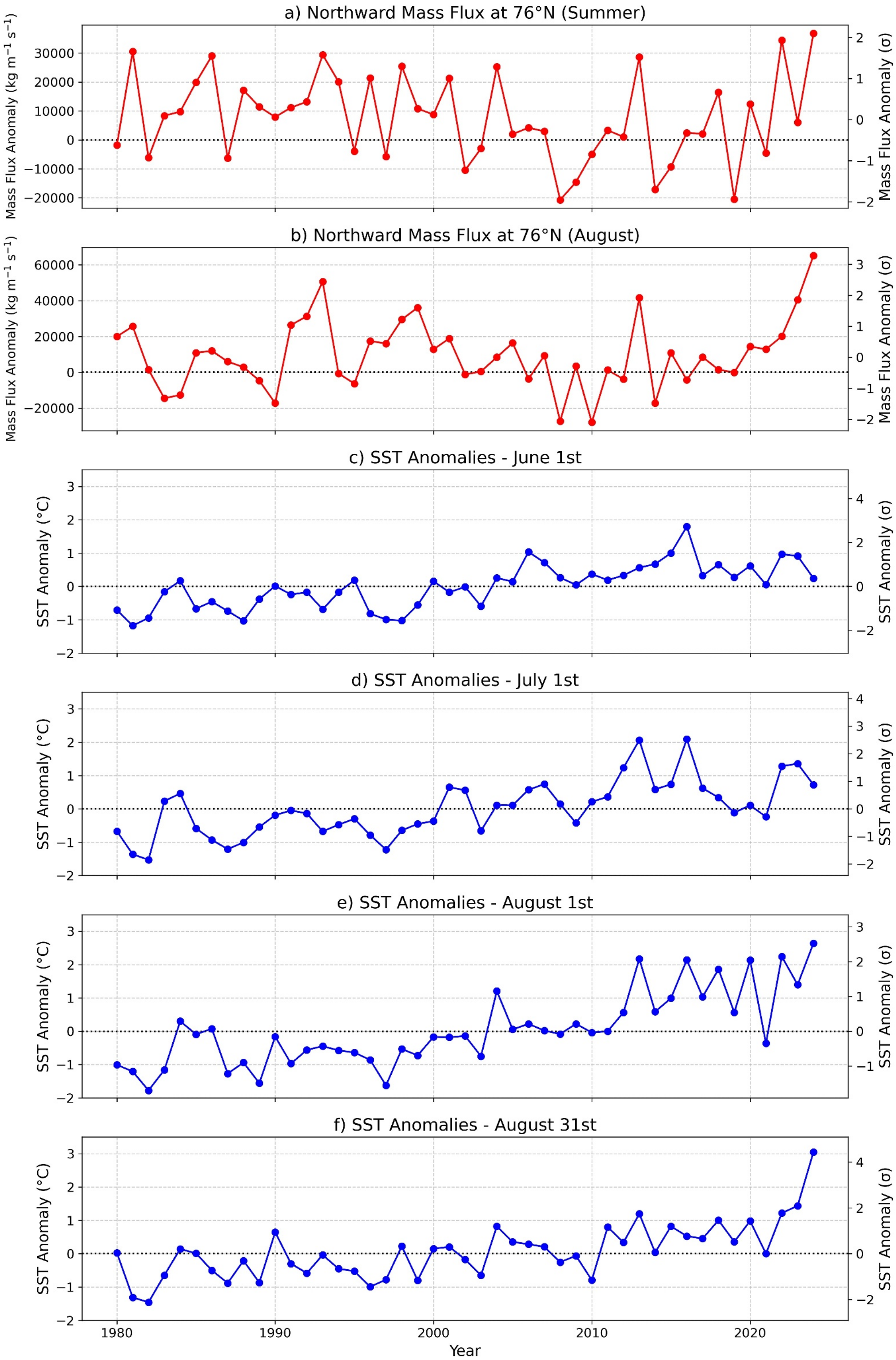

Figure 4. (a), (b) Northward atmospheric mass flux anomaly relative to 1980–2023 average (kg m^{-1}s^{-1}, left *y*-axis; standard deviations, right *y*-axis) at 76°N in the sector 10–30°E in summer and August respectively. (c)–(f) SST anomalies (°C, left *y*-axis; standard deviations, right *y*-axis) south and east of Svalbard (red box in Figure 3), for four selected dates: June 1st, July 1st, August 1st, and August 31st, relative to their 1980–2023 baseline.

may amplify these extremes. The consequences of such warm summers require additional studies due to the far-reaching impacts on glacier mass balance (Geyman et al., 2022), the regional biosphere (Descamps et al., 2017), permafrost (Humlum et al., 2003), as well as human well-being (Timlin et al., 2022) and activity in the area.

Data Availability Statement

Weather station data from stations in Norway (including Svalbard) can be retrieved from https://seklima.met.no. ERA5 data (Copernicus Climate Change Service, Climate Data Store, 2023) is available at DOI: 10.24381/cds.f17050d7, while monthly ORAS5 (Copernicus Climate Change Service, Climate Data Store, 2021) data is accessible from DOI: 10.24381/cds.67e8eeb7. KNMI Climate Explorer NAO index data can be downloaded at: https://climexp.knmi.nl/data/inao_ncepncar.dat. Marine heatwave data from the NOAA Marine Heatwave Watch is available through: https://coralreefwatch.noaa.gov/product/marine_heatwave/.

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