Recent Extreme Arctic Temperatures are due to a Split Polar Vortex

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ABSTRACT

There were extensive regions of Arctic temperature extremes in January and February 2016 that continued into April. For January, the Arctic-wide averaged temperature anomaly was 2.0°C above the previous record of 3.0°C based on four reanalysis products. Midlatitude atmospheric circulation played a major role in producing such extreme temperatures. Extensive low geopotential heights at 700 hPa extended over the southeastern United States, across the Atlantic, and well into the Arctic. Low geopotential heights along the Aleutian Islands and a ridge along northwestern North America contributed southerly wind flow. These two regions of low geopotential height were seen as a major split in the tropospheric polar vortex over the Arctic. Warm air advection north of central Eurasia reinforced the ridge that split the flow near the North Pole. Winter 2015 and 2016 geopotential height fields represented an eastward shift in the longwave atmospheric circulation pattern compared to earlier in the decade (2010–13). Certainly Arctic amplification will continue, and 2016 shows that there can be major Arctic contributions from midlatitudes. Whether Arctic amplification feedbacks are accelerated by the combination of recent thinner, more mobile Arctic sea ice and occasional extreme atmospheric circulation events from midlatitudes is an interesting conjecture.

1. Introduction

Many scientists are aware of Arctic amplification, that is, temperatures in the Arctic are increasing at more than twice the rate of the Northern Hemisphere (Serreze et al. 2009; Cohen et al. 2014).

In the last decade the Arctic has also been prone to surprises that are large, mostly unexpected changes. Probably the most famous ones are the record minimum September sea ice extents reached in 2007 and 2012. Relative to the trend line for 1979–2014, September 2007 ice extent was a negative anomaly of -1.2 million km^2, with a value of 4.3 million km^2 (Serreze and Stroeve 2015). In 2007 it was uncertain whether this extensive sea ice loss would precipitate a tipping point of continued loss. Other surprises were the extensive loss of snow cover on Greenland in 2012 (Nghiem et al. 2012) and on a decadal scale the transition of the central Arctic to mostly first-year sea ice (Lindsay and Schweiger 2015). In terms of atmospheric circulation the last decade has seen multiple record positive and negative values for the Arctic Oscillation (AO) index (Overland and Wang 2015) and an increased magnitude of the Arctic dipole (AD) pattern (Overland and Wang 2010; Wang et al. 2009).

A major surprise is the record Arctic-wide temperatures of January and February 2016. The January area-averaged 2-m air temperature anomaly north of 66°N is estimated as 4.0°–5.8°C based on four reanalyses products (Fig. 1a). Composite values are 2.0°C above previous records. February also represents monthly records but of smaller magnitude (Fig. 1b). Time series from three Arctic observational stations also show positive anomalies in the Pacific Arctic (e.g., Dikson Island, Russia, and

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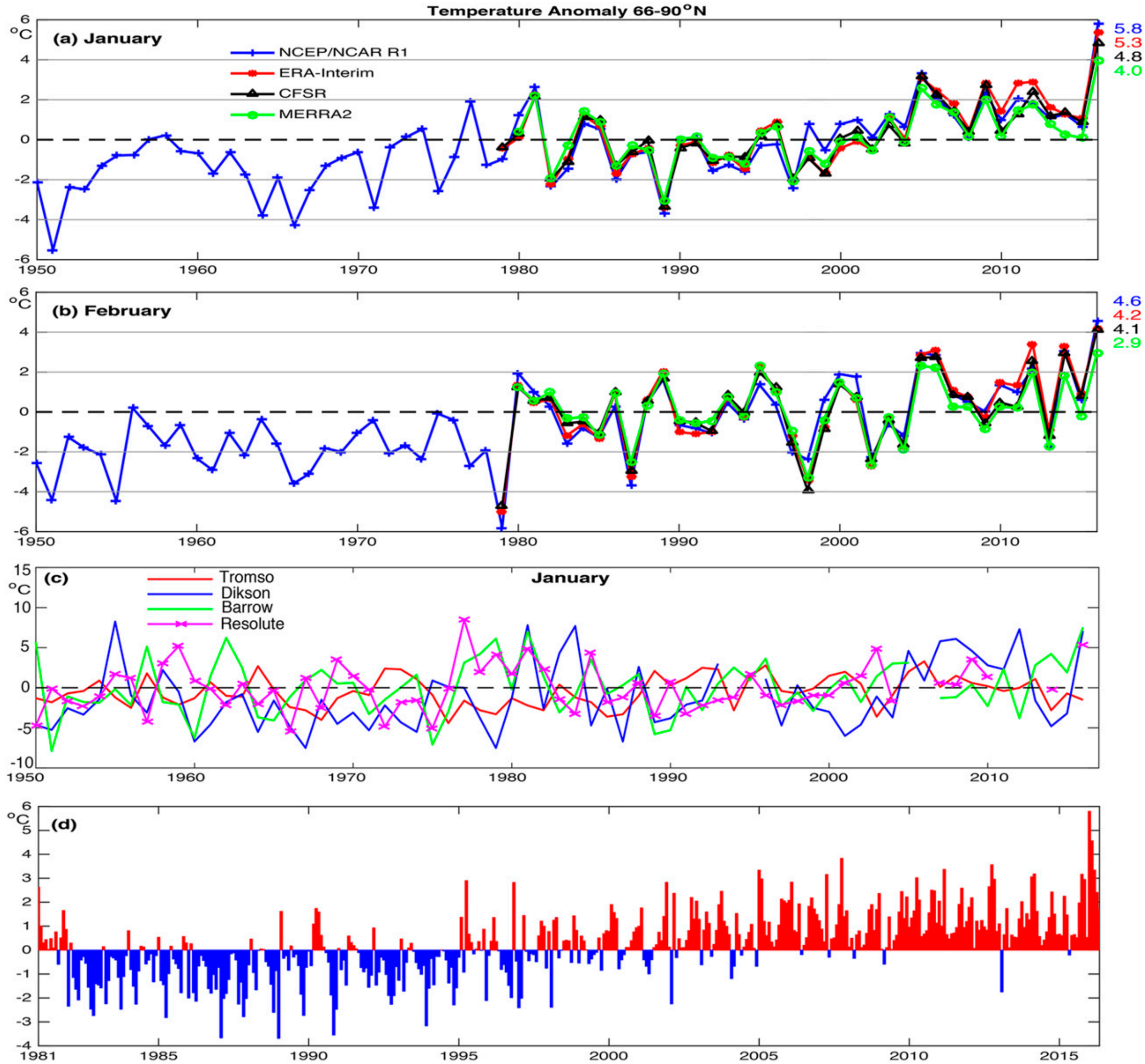

FIG. 1. (a),(b) January and February surface air temperature anomaly averaged over 66°–90°N based on four reanalysis products. Units are in °C. (c) Temperature anomalies based on four Arctic stations: Tromso, Norway (red); Dikson Island (blue), Russia; Barrow, Alaska (green); and Resolute (in Canada; magenta). (d) Monthly values of Arctic-wide 2-m air temperature anomalies through May 2016 based on NCEP–NCAR reanalysis.

Barrow, Alaska), and at Resolute (in Canada; Fig. 1c). In both January and February, the global mean surface air temperature also set new records, with anomaly values of 0.7° and 0.8°C according to NCEP–NCAR reanalysis. Arctic-wide positive temperature anomalies continued through May (Fig. 1d).

2. The January–February 2016 event

The spatial patterns of January and February surface temperature anomaly fields are similar among the four reanalyses (Fig. 2). All have two large anomaly centers of >6°C: one located in the Canada basin and the other located to the north of Franz Josef Land between the Kara and Laptev Seas, extending to the northern Barents Sea and east of Svalbard. Nearly the entire North American continent had positive temperature anomalies, with January of Alaska surpassing other regions. Northwestern Greenland also had a local maximum. Scandinavia in January had cold anomalies as noted at Tromso (Fig. 1c).

Record temperatures can be related to the January–February wind pattern (similar for both months) as

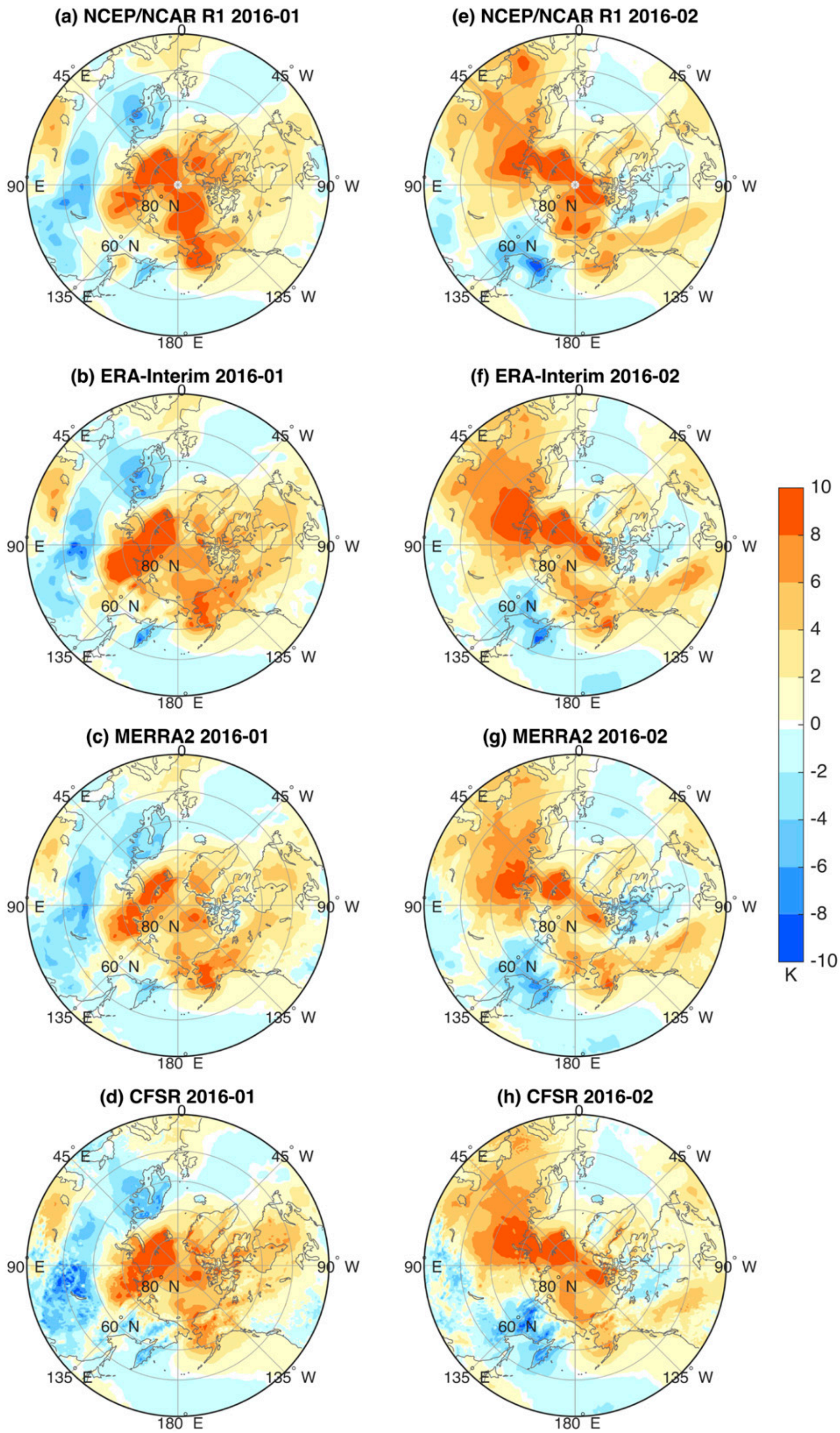

FIG. 2. Surface air temperature anomalies for (left) January and (right) February 2016 from four reanalysis products. The climatological mean period is defined as 1981–2010.

shown in the geopotential height and geopotential height anomaly fields at 700 hPa, and the meridional wind field at 850 hPa (Figs. 3a–c). What is striking about height pattern is the major split separation of the two centers of low geopotential height and their southward extensions into the North Pacific and North Atlantic. Although the phrase *polar vortex* is traditionally used for the stratosphere, it is useful to discuss geopotential height patterns such as Fig. 3a in terms of its shape, such as a split flow, circular, or wavy pattern, as a tropospheric polar vortex. The tropospheric polar vortex of strong winds follows the blue/green color transition band in Fig. 3a circling the Northern Hemisphere. Northward-trending contours along 90°E and over western North America are ridges in the height field. To the west of the ridge these winds bring warmer air from the south, resulting in the positive extremes of temperature anomalies north of the Barents Sea, the central Arctic basin, and Alaska (Fig. 2). Negative anomalies are to the east of the two ridges near Kamchatka and northwest of Hudson Bay, which is more obvious in February 2016 (right panels of Fig. 2).

That the January–February 2016 split vortex was unusual is confirmed from the 700-hPa height anomaly pattern (Fig. 3b) with a maximum extending from Eurasia, past the North Pole, into northwestern Greenland, and north of central Canada. The 850-hPa meridional wind component (Fig. 3c) shows southerly winds flowing across Alaska and the eastern Barents Sea. Positive low-level temperature anomalies are maintained by regional air temperature advection that can increase the local geopotential thickness and thus contribute to increased geopotential heights throughout the troposphere (Porter et al. 2012; Francis and Vavrus 2012; Overland and Wang 2015). This is the case in the central Arctic and it contributes to maintaining the split vortex (Fig. 3b). Also note the northerly flow into central Asia.

3. A 2015 transition in the tropospheric polar vortex

The 2016 spatial patterns of temperature anomalies, and the trough over the greater Atlantic sector of the Arctic, were also seen in January–February 2015 (Figs. 4a and 4b). The ridge over western North America is evident and the large region of low height values is extensive, covering from Hudson Bay across the Atlantic Ocean and to the central Arctic and beyond.

Early winter (December–January) atmospheric circulation of the previous decade (2006–13) was well represented by values of the AO with positive values corresponding to a more circular vortex with zonal flow over North America and negative values giving a wavy vortex pattern (Overland and Wang 2015). It should be

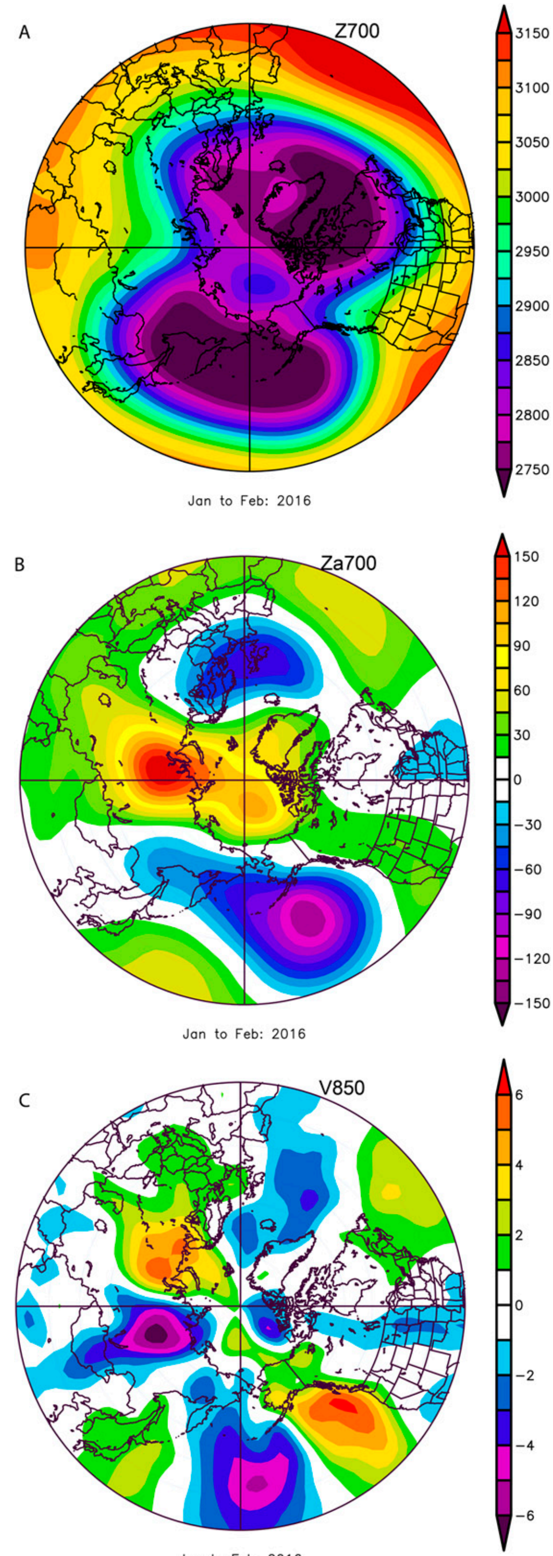

FIG. 3. Mean January and February 2016 spatial patterns of (a) 700-hPa geopotential height, (b) 700-hPa geopotential height anomaly, and (c) 850-hPa meridional wind anomaly.

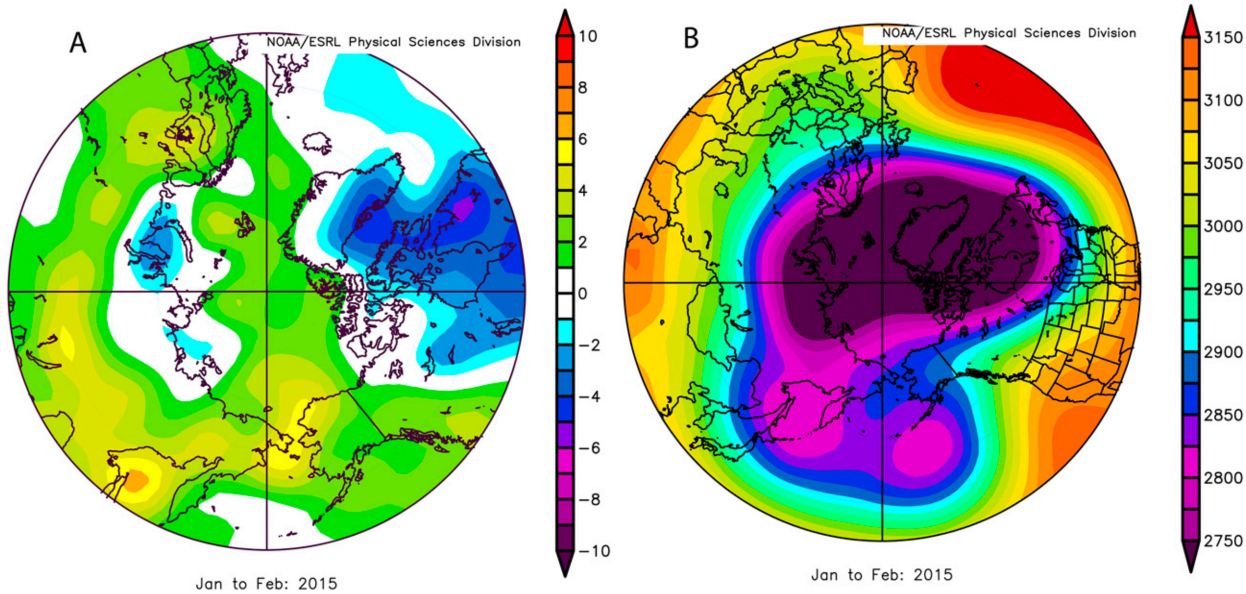

FIG. 4. Mean January and February 2015 spatial patterns of (a) surface air temperature anomalies and (b) geopotential height at 700 hPa.

clear that the single valued AO index is not a good representation for the more recent (2015–16) split flow patterns with higher heights in the central Arctic and lower heights in the Atlantic sector. An alternate metric is the Greenland blocking index (GBI; Hanna et al. 2016) that calculates the normalized monthly anomalies for the 500-hPa geopotential height area-averaged 60°–80°N, 80°–20°W from the daily average NCEP–NCAR reanalysis (Table 1). Positive GBI equal or greater than 1.0 are scattered in earlier years in Table 1. Strong positive years include months from 2006, 2010, 2011, and 2013 that implied a blocking regime with a wavy jet stream pattern where cold northwesterly winds penetrated into the central and southeastern United States. The year 2014 appears as transitional with small GBI, although all years show month-to-month variability. In contrast, winter 2015 had negative values for all December–March, and winter 2016 starts with a negative value (December 2015), consistent with southern Greenland being near the center of low heights in the 2015 and 2016 fields (Figs. 3a and 4b). The fall of heights over southern Greenland is part of much larger decline from Hudson Bay across the Atlantic and into the Arctic. The positive GBI value for January 2016 appears to be a counterfactual, but inspection of the spatial geopotential height field for January/February 2016 (Fig. 3a) shows that northern Greenland is influenced by the ridge over the North Pole extending across the Arctic as part of the split vortex in the central Arctic. This is clear in the height anomaly field (Fig. 3b) and emphasizes the strength of the split vortex in 2016.

4. A Pacific connection?

The eastward shift in the longwave pattern from the 2010 to 2013 winters to the 2015 and 2016 winters (Fig. 5) was a contributor to the positive temperature anomalies formed in the central Arctic. The decrease in geopotential height over the central North Pacific and the increase over western North America shows a strengthening ridge over the west coast of North America. This eastward shift of the Pacific ridge shifted the accompanying trough over the eastern United States, moving its central location to the Atlantic and destroying the Greenland high-latitude block seen in the earlier part of the present decade.

The potential for downstream impacts of North Pacific sea surface temperatures on the longitudinal

TABLE 1. The Greenland blocking index (GBI) for recent winter months. Bold numbers are positive values greater or equal to +1.0. December values are listed with the following year. [From Hanna et al. (2016).]

	Dec (previous year)	Jan	Feb	Mar
2006	0.4	−0.5	**1.2**	**1.9**
2007	−0.5	−0.1	**1.3**	−0.6
2008	−0.8	−0.3	−0.7	0.2
2009	−0.5	0	**1.0**	0.3
2010	**2.4**	**1.6**	**2.4**	**1.0**
2011	**3.2**	**1.3**	−1.0	−0.5
2012	−1.5	−0.3	0	−0.2
2013	**1.4**	0	0.8	**2.4**
2014	−1.1	0.2	−0.2	−0.8
2015	−0.4	−1.1	−1.1	−1.1
2016	−0.8	0.7	0.1	0.1

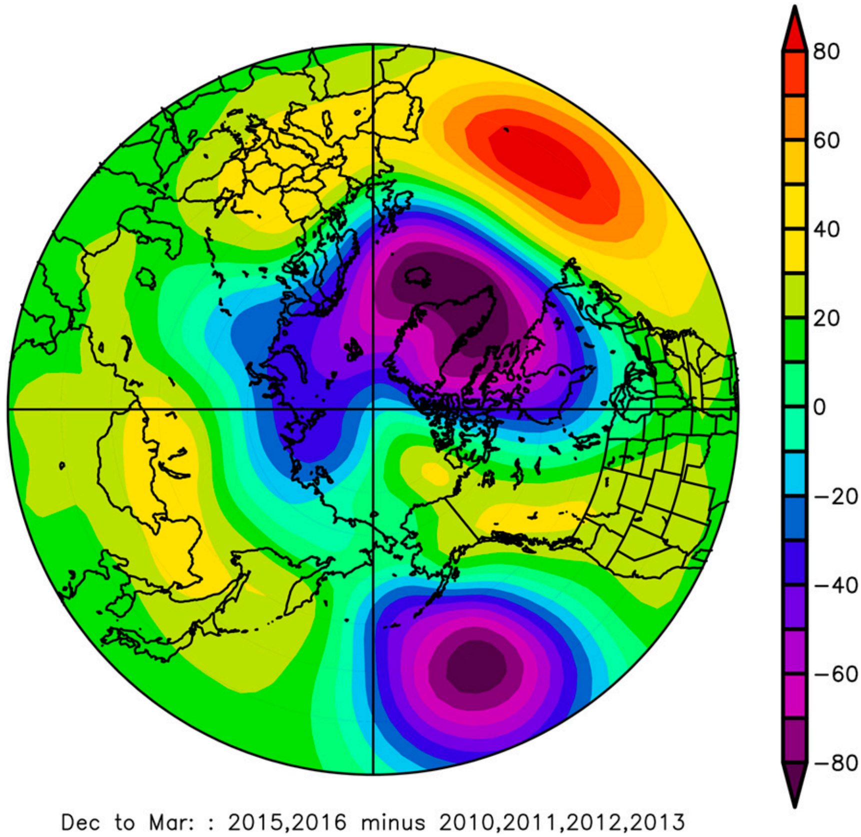

FIG. 5. Difference in the 700-hPa geopotential height field between winters (December–March) 2015–16 and 2010–13.

phasing of the atmospheric longwave pattern is a well-known phenomenon (Namias et al. 1988; Baxter and Nigam 2015; Lee et al. 2015). The year of 2014 was characterized by positive sea surface temperature (SST) anomalies in the central Pacific referred to as the ''blob'' and is considered to be initiated by a reduction in zonal winds (Bond et al. 2015). In 2015 and continuing into 2016 a positive SST center is found in the northeastern region of the North Pacific and has the signature of the positive phase of the Pacific decadal oscillation (PDO) index (https://www.ncdc.noaa.gov/teleconnections/pdo/). Associated lower-tropospheric positive air temperature anomalies near the North American coast increase the geopotential thickness and reinforce the higher-tropospheric geopotential height anomalies in that region (Francis and Vavrus 2012). Thus, the PDO supported the eastward shift in the longwave pattern and directed warm air west of the ridge into Alaska starting at the end of 2014. This midlatitude eastward shift in the longwave pattern contributed to atmospheric circulation changes over the Atlantic and the recent Arctic warming. Midlatitude contributions from both the Pacific and Atlantic basins provide an answer to why there were such new Arctic temperature extremes.

Until recently, the PDO had been negative since the mid-2000s. The PDO signature contains some multiyear memory (Overland et al. 2006). A continued shift away from a negative PDO would favor a future 2015–16 phasing of the longwave pattern as opposed to that of the earlier part of the current decade.

What about a potential contribution to current Arctic temperature extremes from the concurrent El Niño? Direct connection seems unlikely as ENSO is not correlated with the AO circulation pattern and the tropics have been mostly favoring a La Niña condition during the two previous decades of Arctic temperature increases (Cohen 2016). The major El Niños of 1983/84 and 1997/98 did show positive temperature anomalies in Alaska, but they did not have the Arctic-wide positive temperature anomaly pattern seen in 2016. Newman et al. (2016) notes that the PDO is not a single phenomenon, but is the result of a combination of different physical processes, including both remote tropical forcing and local North Pacific atmosphere–ocean interactions.

Thus, we cannot rule out an El Niño contribution to the current positive PDO.

If we consider that positive low-level temperature anomalies over the northeastern North Pacific help lock in the tendency for the current phasing of the longwave pattern, might we likewise speculate whether the concurrent cold temperature anomalies in the North Atlantic might support the trough–ridge pattern in Scandinavia–Eurasia and set up a hemispheric-wide contribution to Arctic temperature extremes?

5. Discussion and conclusions

Extensive regions of Arctic temperature extremes in January and February 2016 are a continuation of a series of major events or surprises in the Arctic climate system. As with other Arctic events, the 2016 air temperature events have multiple causes. In the case of January the Arctic-wide temperature anomaly was 2.0°C greater than the previous record value with regional anomaly values of >6°C, based on four reanalysis products and supported by station data. According to the National Snow and Ice Data Center (NSIDC), the Arctic sea ice extent for February 2016 averaged 14.2 million km^2, the lowest February extent in the satellite record. The 1981–2010 long-term February average is 15.4 million km^2. Arctic sea ice cover has been on a downward trend, with more thin, first-year ice dominating the central Arctic Ocean. The new large January and February air temperature anomalies suggests evidence that the thinner, more mobile Arctic sea ice could be contributing to warmer winter surface air temperatures (Semmler et al. 2016).

It is clear, however, that atmospheric circulation played a major role in producing such extreme winter 2016 Arctic temperatures. Extensive troughing of geopotential heights extended over the southeastern United States, across the Atlantic, and well into the Arctic. Troughing along the Aleutian Islands and ridging along northwestern North America contributed southerly wind flow. The two regions were seen as an increased split in the tropospheric polar vortex over the Arctic. Southerly wind flow and positive temperature advection north of Novaya Zemlya reinforced the ridge that split the flow near the North Pole. The 2016 event started with the North Pole reaching record temperatures on 29 December 2015 due to a single unusual weather event (Fritz 2015). But the main climate feature was the following four-month persistence of extensive warm temperatures (January–April 2016). Certainly Arctic amplification will continue, and 2016 shows that there can be Arctic contributions from midlatitudes based on the longwave atmospheric circulation pattern. Whether Arctic amplification is accelerated by the combination of continued sea ice loss, increased water vapor (Park et al. 2015), and occasional midlatitude atmospheric circulation contributions is an interesting conjecture.

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