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Arctic-midlatitude weather linkages in North America

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ABSTRACT

There is intense public interest in whether major Arctic changes can and will impact midlatitude weather such as cold air outbreaks on the central and east side of continents. Although there is progress in linkage research for eastern Asia, a clear gap is conformation for North America. We show two stationary temperature/geopotential height patterns where warmer Arctic temperatures have reinforced existing tropospheric jet stream wave amplitudes over North America: a Greenland/Baffin Block pattern during December 2010 and an Alaska Ridge pattern during December 2017. Even with continuing Arctic warming over the past decade, other recent eastern US winter months were less susceptible for an Arctic linkage: the jet stream was represented by either zonal flow, progressive weather systems, or unfavorable phasing of the long wave pattern. The present analysis lays the scientific controversy over the validity of linkages to the inherent intermittency of jet stream dynamics, which provides only an occasional bridge between Arctic thermodynamic forcing and extended midlatitude weather events.

1. Introduction

Assessment of the potential for recent Arctic changes to influence broader hemispheric weather continues to be controversial (NRC, 2014; Overland et al., 2016; Francis et al., 2017; Kretschmer et al., 2018). Despite numerous workshops and a growing literature, convergence of understanding is lacking, with major objections about possible large impacts within the scientific community (Wallace et al., 2014). There is little agreement on problem formulation, analysis methods, diverse mechanisms, or public statements from the research community. The topic, however, is meteorologically consequential and a major science challenge, as Arctic changes are an inevitable aspect of continued anthropogenic global warming, and Arctic weather linkages are a potential opportunity for improved extended-range forecasts at midlatitudes (Jung et al., 2015).

The important aspect of present Arctic weather linkages research is thus the failure to achieve consensus. Consensus is an overwhelming agreement among scientists and achieved through replication, the publication process, communication at conferences, and peer review. Kuhn (2012) noted that during periods of new scientific uncertainty that one should expect diversity, disagreements, and fragmentation of the scientific community. A recent review laid part of the controversy on shortcomings in experimental design and metrics used in some studies (Francis, 2017). The present paper hypothesizes that part of the controversy stems from internal variability in jet stream dynamics. The jet stream is a major intermediary between thermodynamic forcing in the Arctic of atmospheric circulation through the thermal wind relationship and resulting midlatitude weather elements (Cohen et al., 2014; Overland et al., 2015). We review potential North American (NA) case studies during the previous decade as a way forward to understand the role of intermittency and state dependence in Arctic/midlatitude linkages.

2. The temperature/geopotential height relationship

Whether thermodynamic changes (surface energy fluxes from warm SST anomalies and sea-ice loss, or temperature gradients) can be connected to atmospheric dynamics and wind systems, is given by the thermal wind equation and geopotential tendency equation (Holton, 1979; Overland and Wang, 2017); the latter is expressed in words as:

Geopotential Height Change (*is proportional to*) (Vorticity Advection) + decrease with height of [(*Temperature Advection*) + (*Thermal Heating*)] (1)

Geopotential heights can change, and thus modify wind fields, by (first term) horizontal propagation of existing jet stream features that can be considered primarily a chaotic part of atmospheric dynamics, (second term) bringing low-level warm, less dense air into a region, or (third term) warming a region locally at low levels. Part of the difficulty with linkage research is determining the influence of the third term,

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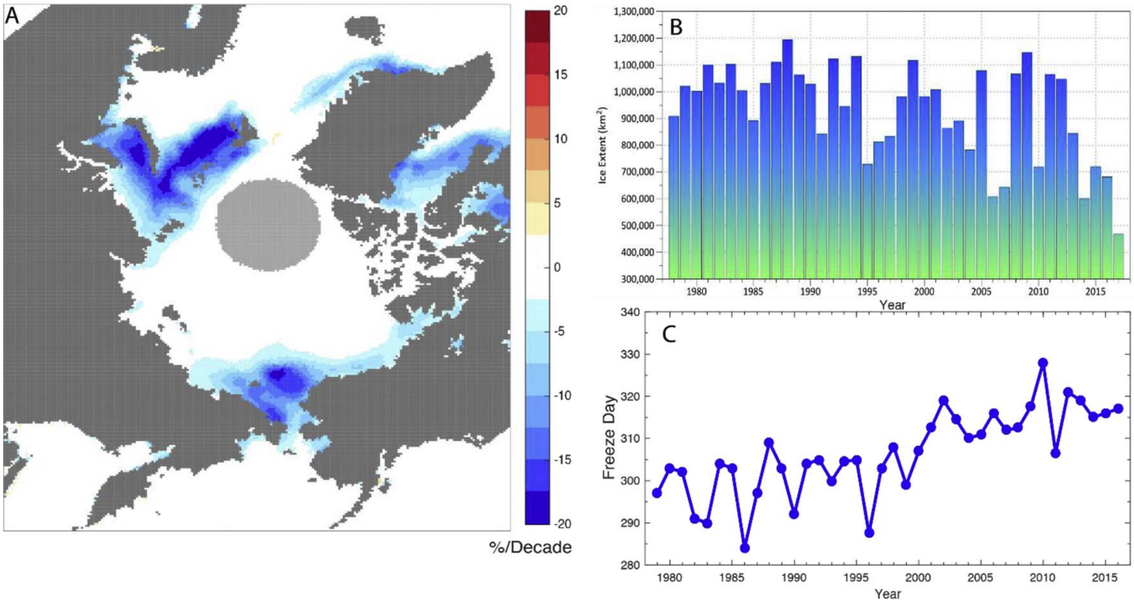

Fig. 1. A) Spatial map of the linear trend of sea ice concentration for November, the nominal time of autumn sea ice freeze-up, that implies a 40% loss in the Chukchi Sea and Baffin Bay over the satellite observation period 1979–2016). Units are percent per decade. Data are obtained from NSIDC. B) Chukchi Sea sea ice cover index for late November based on NSIDC passive microwave data (From Thoman personal communication). C) Freeze up dates for Baffin Bay (From Ballinger et al., 2017).

Arctic sources, relative to advective contributions to geopotential height changes. In particular we should look for linkage cases where the geopotential height fields are mostly stationary (lasting a week or more) so that the first vorticity advection term would be relatively small.

3. North American case studies from the previous decade

3.1. Sea ice changes

Historical decrease of Arctic-wide sea ice extent at the end of the summer season show a dramatic reduction beginning in 2007 to at or below −19% relative to the 1981–2010 mean (NSIDC, https://nsidc.org/data/seaice_index/compare_trends). Before then it is less clear whether forcing of Arctic/midlatitude weather linkages are large enough to be unequivocally detected.

Another important result is that potential linkages are regional (Overland et al., 2015). For example Fig. 1A shows the spatial pattern of the 1979–2016 trend in sea ice concentration for late freeze-up in November; units are percent per decade. Two NA regions stand out, the Chukchi Sea and Baffin Bay/northern Hudson Bay with concentration reductions of over 40% over the period of record. Fig. 1B shows the Chukchi Sea sea ice extent time series for the end of November; many but not all years since 2005 have lower values than years before 1995. 2017 was the record low autumn sea ice year for the Chukchi Sea (based on December 1st sea ice concentration). Baffin Bay had late freeze up (Fig. 1C) in all recent years since 2001 except for 2011 Note the low Chukchi sea ice and late Baffin freeze-up date in 2010. The last decade for these two regions has the potential for increased heat transfer to the lower atmosphere in late fall/early winter. However, there remains difficulties in detecting a sea ice loss signal in a noisy atmospheric response.

3.2. Previous studies for NA

We begin by assessing teleconnection patterns between eastern US cold events and high latitude atmospheric temperature and geopotential height fields beginning in 1950, regardless of potential sea ice forcing. Konrad (1996, his Fig. 3c), Messori et al. (2016, their Fig. 1h) and Xie et al. (2017, their Fig. 5c) show NA geopotential height field teleconnections during composite major eastern US winter cold events. All these figures show higher geopotential heights both over Alaska continuing along the western coast of NA, and west of Greenland. In investigating individual winters, positive height anomalies in these two northern regions can individually co-occur with cold US east coast events, or both can occur simultaneously. We label them as the Alaskan Ridge (AR) pattern and the Greenland-Baffin Bay Blocking (GBB) pattern.

With respect to AR based on models, Mills et al. (2016) note that Alaskan marine Arctic sensible heat flux anomalies during autumn can build planetary wave patterns that propagate downstream into NA midlatitudes, creating robust surface cold anomalies in the eastern US. Kug et al. (2015) show negative correlations between positive Alaskan marine Arctic surface air temperature anomalies with eastern US cold temperatures and geopotential height fields during December–February for the period 1979/1980–2013/2014 from reanalysis data. Lee et al. (2015) notes sea ice and North Pacific contributions for a cold eastern US 2013–2014 event. From inspection of the time series of Alaskan Arctic winter temperatures in these papers, it is evident that rather than showing a monotonic trend with time, there are event-like extreme cases such as winters of 2010–11 and 2013–14.

With respect to the GBB region, Ballinger et al. (2017) report that Greenland Blocking patterns [high geopotential height anomalies] and the incidence of meridional wind circulation patterns have increased over the modern sea ice decrease monitoring era, 1979–2014. They attribute this connection to ocean–atmosphere sensible heat exchange through ice-free or thin ice-covered seas. Temperature composites for years of extreme late freeze conditions, occurring since 2006 in Baffin Bay, reveal positive monthly surface air temperature departures that often exceed +1 standard deviation. Freeze onset dates were particularly late in 2010 and 2012 (Ballinger et al., 2017, their Fig. 2 and our Fig. 1C). Chen and Luo (2017) found that the frequency of Greenland Blocking events is significantly increased in the last decade because of intensified Arctic warming related to the large sea ice decline over the Baffin Bay, Davis Strait, and Labrador Sea; an associated intense cold anomaly is seen over the eastern North America.

Other authors note that cold eastern US temperatures are associated with the phasing of Northern Hemispheric-wide patterns, a wave number 5 circum-global pattern (Harnik et al., 2016) or a Tropical/Northern Hemisphere pattern (Ogi et al., 2016). With regard to