Arctic Change:
Implications for Central US Water and Agriculture

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1. Background

There are many reasons why the Arctic is important. Resource conservation, safe navigation, improved commerce, national security, and societal impacts of Arctic change are all of key concern. This presentation addresses the last item, summarizing scientific evidence of how the Arctic climate has changed and why such change has occurred from a physical science perspective.

The presentation then examines the question whether Arctic change is having a detectable effect on middle latitude weather and climate at this time. Initially proposed as a hypothesis by Francis and Vavrus (2012), the supposition is that Arctic amplification of global warming may trigger a chain of events that ultimately lead to increased extreme weather in middle latitudes. Various subsequent studies have explored these possible links, and they are briefly discussed to illustrate what is currently known on how the Arctic matters for weather and climate patterns.

Much of the research has examined late Fall/winter consequences of Arctic change. Here we present results of new calculations to address how Arctic change is affecting the US Corn Belt during its growing season. It has long been known that US corn production is most sensitive to July rainfall and, to a lesser degree, August temperatures, dating from Wallace's classic agro-climate study published in Monthly Weather Review in 1920. We present results from a diagnosis of parallel climate simulations, one that includes Arctic change mechanisms operating in recent years and the other omitting such drivers of Arctic change. These are compared for the specific climate variables relevant for US Corn production, and an assessment of how Arctic change is likely affecting central US water and agriculture is provided.

Finally, long historical time series of meteorological conditions during 1895-2015 are presented for the US Corn Belt region. It is shown that climate in this region has become more favorable for corn production over the last century, with a general increase of rainfall during July and a cooling of maximum daytime temperatures during August. The presentation assesses whether Arctic change has been a critical factor creating a more favorable summertime Great Plains climate.

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2. Discussion

a. What is known about Arctic change?

The Arctic has warmed, with a larger rate of surface warming than that occurring over the rest of the world---a global change pattern referred to as Arctic amplification (Serreze and Barry 2014). The timing of this warming reveals that Arctic amplification emerged during the last 10-20 years, a period coinciding with a rapid observed decline in Arctic sea ice. While the Arctic has warmed throughout the troposphere (as indeed much of the global troposphere has warmed since the 20^{th} century), little or no Arctic amplification has occurred in the free atmosphere.

Physical considerations of the surface energy balance, in particular the increase in heat transfer to the atmosphere from exposed Arctic Ocean surfaces compared to ice surfaces, indicates that the amplification of Arctic surface warming has largely been driven by sea ice loss. Such sensitivity is affirmed in climate model simulations, which also produce Arctic amplification in historical experiments of atmospheric models driven by specified time varying Arctic sea ice (e.g. Kumar et al. 2010). Furthermore, historical simulations of coupled ocean-atmosphere models (CMIP5) driven only by the change in greenhouse gases (GHG) and anthropogenic aerosols generate a decline in Arctic sea ice and a warming of the Arctic Ocean that largely reproduces the observed pattern and its rate of change.

The interpretation of observations and models is thus of an Arctic climate system undergoing rapid change that is now largely (but not entirely) responding to human-induced climate change. The observed decline in September Arctic sea ice extent of ~13%/decade since the 1990s is of a rate roughly expected from effects of increasing GHG emissions. When Arctic climate is examined over the last 10-20 yr average, Arctic amplification of surface warming is mostly a symptom of human-induced change through sea ice and snow cover feedbacks (and other factors including water vapor and cloud changes) that are strong drivers of high latitude climate. Some fraction of Arctic sea ice variability, especially on shorter time scales of year-to-year swings, is however unrelated to human-induced change. Natural factors also contribute to Arctic climate change on multi-decadal time scales, as suggested by the fact that the Arctic climate experienced a transitory warming during the first decades of the 20^{th} century when anthropogenic forcing was small.

b. What is known about Arctic change impacts?

Arctic communities have experienced direct and visible effects of climate change owing to the strong local control on weather and seasonality of climate exerted by sea ice. For instance, the impact of storms on coastal communities is now radically different as they more often traverse open water rather than ice. The overall warming of the Arctic tundra has had additional effects on permafrost and ecosystems that are key to habitation in the Arctic.

Are such major changes in the Arctic affecting lower latitudes, in particular to an extent that noticeable changes in climate and weather patterns in middle latitudes are now being detected? Francis and Vavrus (2012; hereafter FV12) posed a hypothesis that, as a consequence of Arctic amplification, mid-latitudes would experience increased extreme weather resulting from a dynamical change in the westerlies and the behavior of atmospheric waves that are linked to the jet stream.

Climate science is fundamentally a hypothesis driven discipline, and experimentation is key to testing theories. Numerous studies have thus emerged to test the FV12 conjecture. Ultimately, confirmation of theories only counts if they are the result of predictions, but to date precise forecasts of the location and timing of extreme weather events resulting from Arctic change have not been attempted. Notwithstanding, the merit of a theory lies in its refutability, falsifiability, and testability; the various chain of events envisioned by FV12 have thus undergone extensive scrutiny. For example, the key first link in the proposed causality chain was tested by Perlwitz et al. (2015), who addressed the question of why the deep Arctic troposphere has warmed in the recent decade, and whether the deep warming was due to sea ice loss. Their results, consistent with a body of modeling evidence and physical arguments, show that sea ice loss only warms the lower-most troposphere, while other processes (originating from outside the Arctic) have been driving the deep tropospheric warming over the polar cap. Their analysis thus provides an alternate interpretation of Arctic-mid latitude interactions over the past decade ---- deep tropospheric conditions over the Arctic have been more responding to lower latitude weather and climate, rather than forcing them. The results further affirm prior findings that weakening of the *surface* poleward temperature gradient due to Arctic amplification is largely ineffective in influencing the mid-latitude jet stream owing to its shallow atmospheric warming effect at this time.

The detectability of Arctic change impacts on the jet stream has been most recently considered in Barnes and Screen (2015). They present evidence for substantial decadal variability in the location and intensity of the jet using a 140-yr historical observational data set. The recent decadal conditions are shown to be neither unusual nor extreme from the perspective of intrinsic climate variability. The presence of such significant decadal variability indicates that an effect on the jet stream from Arctic change is unlikely to be detectable at this time.

The overall effect of global climate change on temperatures and the jet stream is shown to be very different from that expected from Arctic amplification alone, as shown in Barnes and Polvani (2015). Projections for the latter half of the 21st century using CMIP5 models indicate that while the primary warming in the lower troposphere will occur over the Arctic, the primary warming in the middle and upper troposphere will occur in the tropics, increasing the pole-to-equator temperature gradient through a deep atmospheric layer. There is no model consensus on how the jet stream will respond overall in the Northern Hemisphere, either its strength or its location, perhaps owing to a "tug-of-war" between tropical and Arctic effects (Barnes and Polvani 2015). In summer, when Arctic amplification of surface warming is much weaker, the jet stream is especially dependent on tropical deep tropospheric warming.

Arctic change is, however, having a clear and present impact on some types of mid latitude weather. A direct consequence of Arctic amplification is that the reservoir of cold air over the polar cap is much diminished. This leads to a significant and detectable reduction in cold air outbreak severity in mid-latitudes. Screen et al. (2015) provide evidence for a substantial reduction in daily temperature variability over the contiguous US in winter as a result of Arctic change. Two case studies of 2014 cold winter conditions over the Great Upper Midwest (Wolter et al. 2015) and the eastern United States (Trenary et al. 2015) affirm the conclusions of Screen et al., noting a reduction of daily temperature variability and showing that the frigid 2013/14 Midwest winter was 20-100 times less likely than in the late 19th century.

c. How Has Growing-Season Climate Changed in the Corn Belt?

In Louis Thompson's (1962) report on how various weather factors influence US corn production, empirical evidence was presented of a particular sensitivity to monthly mean July rainfall and August temperature. According to data at that time, climatological conditions for corn yields in Illinois were estimated to be sub-optimal, and that cooler/wetter conditions would lead to higher bushel/acre yields.

In this presentation, we show that observed summer conditions over the US Corn Belt have become cooler (for daytime maximum temperatures) and wetter since the early 20th century. Since 1990, a majority of summers have experienced cooler daytime maxima and wetter conditions than the long term average.

We present the results from a new set of climate model simulations specifically focused on identifying how Arctic change has impacted Great Plains summer climate, and especially whether it has been responsible for this more favorable growing regime in recent decades. Climate conditions in two parallel sets of historical simulations are compared, one subjected to the known changes in greenhouse gases, ocean temperatures and sea ice concentration, and a second in which the recent sea ice concentrations and related Arctic ocean temperatures are set to a 1979-1989 climatology.

For July and August, although the sea ice loss is near its maximum, the experiments reveal little impact on climate of the Arctic, and no significant effect on the corn belt of Nebraska, Iowa, Illinois, Indiana, and Ohio. The weak sensitivity in the Arctic in summer is because of the reduced air-sea contrast during the mild perpetual summer days, limiting the thermodynamic impact of sea ice removal (compared to winter). This weak Arctic change is further ineffective in driving a remote dynamical effect on the jet stream and weather patterns of lower latitudes. Thus, the various thermodynamic and dynamic links surmised to occur in association with Arctic amplification largely fail to operate in summer, with little direct effect on mid-latitudes. The more favorable climate over the Corn Belt experienced in recent decades is thus unlikely the result of Arctic change.

3. Conclusions and Next Steps

The presentation showed that sea ice loss, largely resulting from human-induced climate change, has been the main cause for an Arctic amplification of surface warming. Sea ice loss however has been found not to drive a deep tropospheric warming over the Arctic, and observations indicate no Arctic amplification of warming in the middle and upper troposphere. As a result, the critical first link in a hypothesized chain to connect Arctic amplification to mid-latitude weather extremes is weak and the jet stream is not being appreciably perturbed by Arctic change at this time. Any effect of Arctic change on mid-latitudes that may be occurring would furthermore be undetectable given the large intrinsic variability in weather and climate.   An exception is that Arctic amplification is having a substantial and detectable influence on mid-latitude weather by reducing the variability of daily temperature ---- a diminished reservoir of high latitude cold surface air reduces winter cold air outbreak severity in middle latitudes.

As has been emphasized recently, it is important to understand how a changing Arctic is affecting weather and climate in different seasons and regions (Francis 2015). Here we have examined how Arctic change has affected summertime growing season conditions over the US Corn Belt. Our model results and physical considerations indicate no effect on either July rainfall or August temperature in the Midwest, two key variables for water resources and agricultural productivity.

Yet, growing season climate has become more favorable for corn production, though for reasons that are unknown. Next steps are to evaluate physical processes linking temperature and rainfall in the corn belt, and further determine how long term change (not just Arctic sea ice loss) is affecting these processes. It is especially important to account for this “US Warming Hole”, to explore reasons for the absence of warming or unusual heat waves in recent decades, and to reconcile the current conditions with climate projections calling for a much hotter corn belt climate in coming decades.

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