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Workshop on Polar Climate Changes and Extreme Events

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Polar Climate Change: Driving Processes, Extreme Events, and Global Linkages
What: The first international workshop focused on the Arctic and Antarctic climate systems was held, with over 130 attendees from eight countries presenting and discussing polar climate changes and driving processes, extreme events, and their global linkages.
When: 23–24 October 2017
Where: Hohai University, Nanjing, China

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1 Introduction

Polar climate systems have experienced a number of dramatic changes (Wang et al., 2017; Turner et al., 2016; Gordon, 2014; Rignot et al., 2013; Meier et al., 2012; Kwok and Rothrock, 2009; Thompson and Solomon, 2002), which have influenced climatic conditions across large parts of the globe through large-scale atmospheric and oceanic teleconnections (Dou and Wu, 2018; Zhang et al., 2018; Overland et al., 2016; Wang et al., 2015; Cohen et al., 2014; Vihma, 2014; Martin et al., 2013; Thompson and Solomon, 2002). Furthermore, future global sea level change will be significantly controlled by the mass balance of polar ice sheets in a warming world (DeConto and Pollard, 2016; Golledge et al., 2015). However, processes associated with these changes, linkages, and impacts have not been fully explained due to complex interactions involving the atmosphere, ocean, and ice. To review the recent progress, identify existing problems and future research priorities, and, in particular, promote collaborations between Chinese and international researchers, an international workshop on the Arctic and Antarctic climate systems and their global linkages was convened during 23–24 October 2017, at Hohai University, Nanjing, China.

More than 130 participants from eight countries attended the workshop, including a large number of early-career scientists and graduate students, to present their latest research accomplishments and results. The attendance of a large number of scientists from China was particularly gratifying. This was due to a rapid increase in research, economic interest in the Arctic, and investment by Chinese government agencies. Workshop presentations covered many current cutting-edge topics, ranging from amplified Arctic warming, accelerated retreat of Arctic sea ice, Arctic-midlatitude linkages, Antarctic extreme events, and ice shelf-ocean interactions. Specific outcomes from these presentations and discussions are highlighted below.

Since the late-1990s, Arctic climate change has been substantially amplified (the so-called Arctic Amplification)

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and sea ice retreat has accelerated (Vihma, 2014; Kwok and Rothrock, 2009). It was hypothesized that three strongly linked atmospheric dynamic pathways connected changes in the Arctic and mid-latitudes (Zhang et al., 2018; Overland et al., 2016; Cohen et al., 2014): changes in storm tracks, the jet stream, and planetary waves and their associated energy propagation. Explanations for the recent increase in occurrence of extreme events in mid-latitudes included a slowdown of upper-level Rossby wave propagation, more frequent occurrence of Ural/Scandinavian blocking, and intensification of the Siberian High. It has been suggested that sea ice reduction in some regions, e.g. the Barents/Kara Seas and Chukchi Sea, has had an important influence on mid-latitude climate and weather. The linkages between Arctic climate change and Eurasian, in particular East Asian, climate and weather have been a major focus of research and interest in the Chinese climate community, the general public, and government policy and decision makers.

Ice loss from the Greenland and Antarctic ice sheets and glaciers is an important contributor to global sea level rise. Interactions between the ocean and floating outlet glacier tongues and ice shelves are critical factors in changing the mass balance of polar glaciers (Wang et al., 2017; Rignot et al., 2013). Significant progress has been made over the past decade in understanding ice shelf-ocean interactions, including new observational techniques and improved modelling approaches. China has also initiated research concerned with ice shelf mass balance by conducting oceanographic observation in Prydz Bay, developing a hot water drilling system, and developing a coupled ocean-sea ice-ice shelf model to simulate Circumpolar Deep Water (CDW) intrusions onto the continental shelf of Prydz Bay.

Arctic-lower latitude linkages. Since the late 1990s, Arctic warming has been amplified and sea ice decline has been accelerating (Vihma, 2014; Meier et al., 2012; Kwok and Rothrock, 2009). In addition, extent and magnitude of increasing oceanic acidification the western Arctic Ocean has been observed by the Chinese National Arctic Research Expedition (CHINARE) over the last few decades. Arctic amplification has a number of causes, often interlinked, which include ice-albedo feedback, feedbacks related to water vapor, clouds and aerosol, lapse rate feedback, Planck (temperature) feedback, and also poleward heat and moisture transport in the atmosphere and ocean.

Recently, there have been more frequent extreme weather events in North America and Eurasia (Zhang et al., 2018; Cohen et al., 2014). For example, there were eight cold surge events in the southern part of China after the 1950s, with five of them occurring after the late-1990s. In addition to these extreme events, there were also notable climatic change events, for example, a warmer Arctic and colder Eurasia. These phenomena have triggered a great deal of debate on the mechanisms responsible.

Atmospheric and oceanic connections between Arctic and lower latitudes have been proposed to explain changes in climate and the number of extreme events at lower latitudes. For instance, it has been suggested that the slowdown of Rossby wave propagation is responsible for more frequent extreme events in mid-latitudes. The shift in the Arctic Oscillation (AO) towards its negative phase beginning in the mid-1990s has also been suggested to have important influences on mid-latitude climate. Associated with this AO shift, the Siberian High has intensified and the East Asian trough deepened. These could have resulted from interactions between sea ice and stratospheric variability, which caused the polar vortex to become less stable (Jaiser et al., 2016; Kim et al., 2014). These changes have led to significant climatic impacts in East Asia and appear to be linked to the negative phase of the Pacific Decadal Oscillation (PDO). A regime shift in atmospheric circulation, from its typical AO-like pattern before the mid-1990s to a pattern of Arctic rapid change after the mid-1990s (Zhang et al., 2008), forms an important atmospheric bridge connecting the Arctic and mid-latitudes.

The analysis of ERA-Interim reanalysis and sea ice concentration data suggests a strong connection between Arctic anomalous sea ice extent and the following winter's atmospheric circulation (Jaiser et al., 2016), both in terms of the sea ice retreat and the subsequent modification of local air-sea heat fluxes. In particular, anomalous low Arctic sea ice conditions were associated with the negative AO phase in late winter (February–March). In addition to the dynamic effect of sea ice loss, it was suggested that autumn Eurasian snow cover had great potential to influence wave trains propagating downstream of Eurasia over the North Pacific and vertically into the stratosphere, with a lagged impact onto the negative AO/North Atlantic Oscillation (NAO). However, modelling researchers have not reached a consensus on the mechanisms responsible. On the one hand, the application of the Atmospheric general circulation model For Earth Simulator (AFES) revealed two circulation patterns that occurred more frequently for low Arctic sea ice conditions: a Scandinavian blocking in December and January, and a negative NAO pattern in February and March. This result is in agreement with reanalysis data. On the other hand, results from other simulations, including atmospheric-only model runs (the CFSv2 Atmosphere-only model) forced with specified 10-year mean sea ice concentration (SIC) and sea surface temperature (SST) covering 1981–1990 and 2005–2014, and for coupled model runs (CFSv2, CMC1, CMC2, NASA, CCSM4, GFDL) for 1982–1990 and 2005–2013, suggest that the inter-model spread is large. So far, few studies have reproduced the observed conditions and many studies showed no sign of cooling trends or linkages. There are two possible reasons: (a) large internal variability and our realization of "the world" is just one of the many unlikely; (b) models are not good enough as important processes are not well represented (e.g. unresolved boundary layers and parameterized surface fluxes, which are important for ice/ocean/land-atmosphere interactions and gravity waves in the stratosphere that are often used for tuning but not for physical representation).

Observational and modelling studies of Arctic processes and events. To improve models and enhance our understanding of processes and events in the Arctic system, it is important to expand the observational network. Comprehensive observation would help reveal more complete signals and processes. For example, using data from an expanded monitoring network with 31 stations in the Alaskan Arctic, it was found that the surface air temperature (SAT) increased by 0.71 °C·decade^{-1} during 1998–2015, which is two to three times faster than the rate estimated by existing gridded datasets CRU (Climate Research Unit) and GISS (NASA Goddard Institute for Space Studies). By collecting and analyzing data from vegetation biomass, permafrost, snow depth, and river discharge, it was found that river heat flux flowing into the warming Arctic Ocean increased. This increase was statistically significant in the spring season and possibly had an impact on sea ice melting. By making in situ observations onboard the R/V Araon icebreaker, in August of 2016 a long-lived, intense storm was observed. The storm accelerated sea ice decline in this region by inducing upwelling of Pacific-origin warm water, the result of Ekman pumping, and enhancing upper ocean mixing. Data from ice-tethered GPS buoys and sea ice mass balance buoys, combined with remote sensing data, were used to characterize how the atmospheric circulation influenced sea ice kinematic and thermodynamic properties in the Arctic outflow region.

Atmospheric reanalysis fields provide Arctic-wide spatial and temporal coverage, and are therefore useful for analyzing synoptic atmospheric processes and determining their impacts on sea ice and the ocean. Analysis of the intrusions of North Atlantic extra-tropical cyclones associated with the Icelandic Low into the western Arctic, revealed an unprecedented wintertime reversal of the surface winds and ice motion in the Beaufort Sea, as well as the collapse of the Beaufort High. As Arctic sea ice continues to decline, such reversals may become more common; this has strong implications for ocean circulation, sea ice distribution, and biological productivity.

Global and regional ocean reanalysis (ORA) products are increasingly used in polar research. However, their quality needs to be systematically assessed. The Polar ORA Intercomparison Project (PORA-IP) has been established for this purpose. The PORA-IP diagnostics target the following topics: hydrography, heat, salinity and freshwater content, ocean transports, mixed layer depth, sea-ice concentration and thickness, and snow thickness over sea ice. Based on these diagnostics, differences between ORA products and observed data were quantified, and possible reasons for these discrepancies were discussed.

Regional high resolution atmospheric modeling is an important dynamical downscaling approach used to depict the fine-scale structure of Arctic storms and mesoscale system. The recently developed Chukchi–Beaufort High-Resolution Atmospheric Reanalysis (CBHAR) has been used to analyze the mesoscale structure of surface winds in the Chukchi–Beaufort Seas and adjacent Arctic Slope region. Sea breezes, upslope and downslope winds, and mountain barrier jets were all clearly captured by CBHAR. Using the WRF-3DVAR modeling system, which assimilated extra Arctic radiosonde sounding data obtained during 2016 Araon cruise over the Chukchi and East Siberian seas, it was shown that the additional data significantly improved the cyclone's central pressure forecasts during its lifetime peak period.

Results from ensemble simulations using the coupled regional climate model HIRHAM-NAOSIM suggest that the realistic simulation of the atmospheric circulation during the summer months is a necessary, but not sufficient, condition for capturing observed summer sea-ice anomalies. Other factors and feedbacks are also important, including, sea ice preconditioning, ice-albedo effects, cloud radiative forcing, and ocean circulation changes. In contrast, the regional atmospheric circulation responds to summer sea-ice anomalies. Here, the Barents/Kara and Beaufort Seas appear to be key regions where sea-ice changes can strongly affect the atmosphere.

Coordinated observational and modeling activities. Further enhanced observational activities and process studies need to be coordinated, as many of the processes involved in Arctic change still present great modelling challenges. The Multi-disciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) is specifically designed to improve our understanding of coupled atmosphere-ice-ocean-ecosystem processes, address the model challenges encountered in the central Arctic, support improved sea ice forecasting, regional weather forecasting, and climate predictions. The primary question being addressed by the project is: What are the causes and consequences of an evolving and diminished Arctic sea ice cover? There are several distinctive features of MOSAiC, including filling observational gaps, year-round observations, the climate system's spatial and temporal heterogeneity, and international efforts. Being international in nature, MOSAiC has received significant and coordinated support from a broad range of funding agencies within Europe, North America, China, Japan and Korea. China is now increasing promotion for its polar programs, which will lead to more significant contributions to MOSAiC. China will contribute to all three tiers of field observations (Central Observatory, within 5 km; distributed network around the Central Observatory, within 50 km; across the Arctic, within 1000 km) and modeling efforts, aside from oil supply/logistic support.

Related to observational-modeling activities during MOSAiC, Polar CORDEX (Coordinated Regional Climate Downscaling Experiment), a CliC (Climate and Cryosphere) targeted activity, is organizing a regional climate model intercomparison and process evaluation based on the summer 2014 Arctic Clouds in Summer Experiment (ACSE). This is being done in preparation for MOSAiC activities that will help improve process understanding. Specifically, these modeling activities will include column and process modeling, forecast studies, and improved parameterizations in 3D models.

The Southern Annular Mode and Antarctic extreme events. The most pressing scientific questions in Antarctic science are centered around how the mass of the Antarctic ice sheet and the stability of the ice shelves evolved in the past and how they might change in the future (Rignot et al., 2013). To understand Antarctic ice sheet mass balance and ice shelf stability, it is essential to investigate atmosphere-ocean-ice interactions on various scales. The Southern Annular Mode (SAM) (Thompson and Solomon, 2002) is the leading mode for atmospheric variability on time scales from a week to the multi-decadal, and longer. This mode has strong connections with variability in ocean circulation and ice mass balance at southern high latitudes. Decadal and longer time-scale SAM variability could be induced by increased greenhouse gases and ozone depletion in the lower stratosphere over Antarctica (Wang et al., 2015). SAM variability during the past 300 years was examined by analyzing the geochemical record of 15 annually resolved ice cores. It was found that the recent positive-phase shift in the annual mean SAMI, since the 1970s, is unprecedented. In addition to external forcing, it was found that synoptic eddies, low frequency planetary eddies, and the mean flow work together to enhance the dominance and extend the persistence of the phase of the SAM.

Extreme events are critical processes in atmosphere-ocean-ice interactions (Wang et al., 2014; Turner et al., 2009). Polynyas form in the Antarctic coastal region when strong winds push new ice offshore. Such polynyas are often accompanied by the formation of high salinity shelf water, which is one of the sources of Antarctic Bottom Water and an important component in ocean circulation of the sub-ice-shelf cavity. In Prydz Bay, the best known of such polynyas is the Mackenzie Bay Polynya (MBP). It is located in the southwest corner of the bay, where strong cold katabatic winds lead to deep convection, characterized by vertically homogenous cold and saline shelf water. These conditions extend from the surface to a depth of 1000 m by intense cooling and brine release. Since the earliest days of Antarctic exploration, it has been known that very strong surface winds occurred in the coastal region, especially during winter and at the base of glacial valleys. The analysis of atmospheric reanalysis datasets has revealed that the strong katabatic winds were often induced by synoptic scale weather systems within the circumpolar trough around the continent.

Ocean-ice shelf interactions. It has been observed that the mass loss of ice shelves is the result of basal melting induced by warm ocean water intrusions (Golledge et al., 2015; Rignot et al., 2013). However, it is a great challenge to observe the ocean water properties in sub-ice-shelf cavities and special observational techniques have to be developed for this purpose. For example, to deploy CTD and mooring instruments, a hot water drilling system was developed to make boreholes, and autonomous vehicles were used to measure ocean temperature and salinity in the cavities. In addition to these expensive observational methods, the British Antarctic Survey, along with University College London, has developed an efficient approach (Autonomous phase-sensitive Radio Echo Sounder, ApRES) to measure the thickness of ice shelves at high temporal frequency. So far, about 35 such radars have been deployed over the ice shelves around Antarctica. Ice thickness data collected by these radars are useful time series for describing basal melting, for validating models, and for detecting climatic signals in the Antarctic continental shelf region.

Chinese polar researchers have started to plan field work that would investigate ocean-ice shelf interactions after a hot water drilling system has been developed. This hot water drilling system will be capable of making a borehole of more than 2000 m deep. It will be used on the Amery Ice Shelf to facilitate direct oceanographic observations near the deep grounding line of the Amery Ice Shelf, over the next five years.

Another significant advance is the development of a high resolution coupled ocean-sea ice-ice shelf model. This model was developed in China and is used to study the mass balance of the Amery Ice Shelf. The intrusion of CDW onto Prydz Bay and ocean circulation in Prydz Bay have been simulated, and several pathways of warm water intrusion have been identified, providing increased understanding of basal mass balance of Amery Ice Shelf.

During the workshop, several other researchers presented new results about ice shelf or glacier mass balance. For all Antarctic ice shelves, an iceberg calving rate of 755 ± 24 $Gt \cdot a^{-1}$, and a basal melt rate of 1516 ± 106 $Gt \cdot a^{-1}$ have been obtained from analyzing multi-source satellite data and model derived products between 2005–2011. For an outlet Greenland glacier without an ice shelf, it was found that intra- and inter-annual varying ocean warm-water intrusions still lead to grounding line retreat, rapid thinning at the terminus, and the speedup of a glacier. This response to warm-water intrusions indicates that outlet glaciers, even those without floating ice shelves, are also highly sensitive to oceanic temperature change. By considering the combined nonlinear effects of vertical structures of frazil ice concentration and thermal forcing within an ice shelf water plume, the simulated supercooled area, supercooling level, and suspended frazil ice and marine ice productivities are all significantly improved over the original models, with assumed vertically-uniform frazil ice concentration and freezing temperature within a plume.

It was the first time that such an international workshop on polar climate change and extreme events was held in China. The workshop attracted more than 130 participants from eight countries. Many participants felt that this workshop was enlightening and informative, and it was suggested that another be held in the near future. The next meeting on polar climate change and extreme events has thus been planned for 2019. The rapid growth in the Chinese polar research program and the need to promote international collaborations between graduate students and early career polar researchers, an international summer school on polar climate change and extreme events was held over 21–25 May 2018.

Recommendations from the meeting:

(1) We need to enhance the coordination and collaboration of field work and modeling activities for MOSAiC between Chinese and international polar researchers. The primary aim is to improve Arctic process and feedback understanding.

(2) A high-resolution horizontal field of Antarctic near-surface winds should be created. We need to study how the Antarctic coastal extreme wind events have changed since the 1950s, and how these extreme wind events interact with ocean and ice.

(3) To enhance our capability of simulating ocean-ice shelf interactions, we need to advance the inter-comparison of glacier and ocean models, including coupled and uncoupled models. Several participants also suggested that attendees participate in a workshop convened in Abu Dhabi during 7–9 May 2018 for such a purpose.

(4) The formation of the Weddell Polynya reflects the occurrence of deep convection in the Weddell Sea, and may have important impacts on local and global ocean circulation (Gordon, 2014). The Weddell Polynya started to appear again in 2016 and 2017. We need to pay attention to the evolution of the Weddell Polynya in the next few years by coordinating in situ observations and modeling activities.

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