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An outstanding example of cooperation between Arctic and non-Arctic countries in cryosphere and climate research: Sino-Finnish cooperation for more than 30 years

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Abstract The cryosphere is interconnected with other components of the climate system through global exchange of water, energy, and carbon. Long-term sustainable and pragmatic scientific and technological cooperation on the cryosphere and climatology in polar and sub-polar regions between China and Finland began in the 1980s. The fields of bilateral cooperation include joint training of young scientists, joint field observations, climatological and ecological researches of polar and sub-polar sea ice, glaciers and frozen lakes, etc. The year 2020 marked the 70th anniversary of the establishment of diplomatic relations between China and Finland. In order to celebrate the great achievements by Chinese and Finnish scientists in the fields of cryosphere and climate research, the *Advances in Polar Science* invited scientists from both sides to jointly organize a Special Issue entitled "Sino-Finnish cooperation on cryosphere and climatology in polar and sub-polar regions". In this Special Issue, we have collected 10 papers, with most papers created jointly by scientists of both sides. The fruitful scientific achievement is strongly benefited from the sustainability of cooperation. Monitoring, research, prediction, mitigation, and adaptation to the climate change in the polar and sub-polar regions will definitively stay in the focus for many decades to come. A new era of Finnish-Chinese scientific collaboration on cryosphere has begun.

Keywords **China, Finland, international cooperation, cryosphere, climate, polar region, sub-polar region**

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The Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) of the sixth assessment cycle of the Intergovernmental Panel on Climate Change (IPCC) states that in the farthest corners of the Earth – the highest mountains and remote polar regions – human caused climate change is evident and amplified (IPCC, 2019). The elements of the cryosphere, including ice sheets, glaciers, sea ice, snow, ice cover of rivers and lakes, and permafrost, are sensitive to climate change and are undergoing a drastic evolution with the global warming. Ice sheets and glaciers worldwide, including the Greenland Ice Sheet, the West Antarctic Ice Sheet, as well as glaciers outside Greenland and Antarctica (Bamber et al., 2018; King et al., 2018; Zemp et al., 2019), have lost mass, giving increasing contributions to sea level rise. Arctic snow-cover extent in June on land declined by 13.4% ± 5.4% per decade from

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1967 to 2018 (Bormann et al., 2018). Arctic sea ice extent has decreased in all months of the year, with the loss by about 40% in September during the last four decades (Stroeve and Notz, 2018).

The cryosphere is interconnected with other components of the climate system through global exchange of water, energy, and carbon. Thereby, rapid changes in the cryosphere are generating many feedbacks to the global climate system, as well as impacts, challenges and risks to ecosystems and human societies. In the Southern Ocean, the polynyas, especially due to their extremely high ice production efficiency, have become a trigger to strengthen the connections between the Southern Ocean and the global ocean (Cheon and Gordon, 2019). In recent decades, Arctic net primary production has increased in ice-free waters, and spring phytoplankton blooms are occurring earlier in response to sea ice loss (Arrigo and van Dijken, 2015). Changes of ice and snow cover in high-latitude lakes strongly affect the lake habitat (Kirillin et al., 2012). Changes in the Arctic sea ice cover have the potential to influence high- and mid-latitude weather, especially with cold winters and blizzard weather occurring in the North America, Europe and Northeast Asia (Cohen et al., 2020; Vihma et al., 2020). With the enhanced accessibility of Arctic waters, the navigable time window of Arctic sea routes, especially the Northeast Passage, is increasing (Lei et al., 2015). The Baltic and Bohai seas are sub-polar freezing waters in the northern hemisphere, where changes in sea ice conditions would not only affect the marine physical and ecological environment (Leppäranta and Myrberg, 2009; Piiparinen et al., 2010), but also have a significant impact on the lives of human communities, shipping, and industrial actions (Grönvall, 1988).

During the 30 years of research collaboration, joint international and bilateral summer and winter schools have been arranged in China and Finland for graduate and doctoral students. For example, joint sea ice summer schools, winter snow schools, and winter schools in limnology have been organized in both countries, student exchange program has been ongoing for short-term and long-term visits, and mutual supervision of students has been performed. Through this way several students have continued the collaborative researches after finishing studies.

The year 2020 marked the 70th anniversary of the establishment of diplomatic relations between China and Finland. Finland, as an Arctic country, has a high standard of snow and sea ice research and operational services, and is one of the leading countries specialized on cryosphere, climatology, engineering, and technology in cold regions. China has the lowest latitude seasonal ice-covered sea, the Bohai Sea, the lowest latitude ice-covered lake district and mountain glaciers in the Tibetan Plateau serving as the South-East Asian water tower.

Long-term sustainable and pragmatic scientific and technological cooperation on the cryosphere and climatology in polar and sub-polar regions between China and Finland began in the 1980s. Then China was further developing international collaboration in science and technology, including the ice engineering in ice-covered seas (Leppäranta et al., 2021) and the glaciology and quaternary geology research in the Northwest China (Zilliacus, 2021) as the natural fields of mutual interests with Finland in the early stage. The subsequent cooperation also promoted short-term sea ice forecasting for the seasonal sea ice zone, which has been applied for the support service of winter shipping in the Baltic Sea and oil drilling in the Bohai Sea. The collaboration was successful, and in late 1990s the research was expanded to polar seas, lakes, and to climate change and icebreaker industry applications. New forms of bilateral collaboration, such as university education and training, have evolved encompassing coming generations.

In order to celebrate the great achievements by Chinese and Finnish scientists in the fields of cryosphere and climate research, the *Advances in Polar Science* (APS) invited scientists from both sides to jointly organize a Special Issue entitled "Sino-Finnish cooperation on cryosphere and climatology in polar and sub-polar regions", leaded by the four guest editors: Prof. Matti Leppäranta, Prof. Timo Vihma, Dr. Bin Cheng, and Dr. Ruibo Lei. In this Special Issue, we have collected 10 papers, with most (7) papers created jointly by scientists of both sides, involving the fields of meteorology, oceanography, sea ice, climatology, limnology, glaciology, and engineering in polar and cold sub-polar regions. In terms of papers, there are four review papers, of which two systematically review the cooperation between China and Finland in the fields of sea ice in sub-polar regions and mountain glaciers in Central Asia for more than 30 years (Leppäranta et al., 2021; Zilliacus, 2021), and the other two summarize the latest cooperation interests, focusing on the Arctic landfast ice (Zhai et al., 2021) and the Antarctic polynyas (Wei et al., 2021), both them being important components of the polar climate system. The other six papers involve the numerical simulations of lake ice at high latitudes (Cheng et al., 2021a; Lu et al., 2021) and sea ice in the Arctic Ocean (Cheng et al., 2021b), changes of sea ice cover in the Southern Ocean (Wang et al., 2021), and the potential influence of precipitation on changes in Arctic sea ice cover (Yue et al., 2021), as well as new measurement methods of tensile strength of sea ice applied in ice engineering and sea ice dynamic modelling (Chen et al., 2021). The authors include not only senior scientists who initiated this long term sustainable bilateral cooperation more than 30 years ago, but also new generations of scientists, graduate students from both countries who have experienced and witnessed this long process, as well as other international scientists who have been collaborated with us. The cooperative research has been funded by both countries for a long time. Our fruitful scientific achievement is strongly benefited from this sustainability of resources.

Climate change brings serious major challenges but also offers certain opportunities to societies on different scales from regional to global. Monitoring, research, prediction, mitigation, and adaptation to the climate change in the polar and sub-polar regions will definitively stay in the focus for many decades to come. A new era of Finnish-Chinese scientific collaboration on cryosphere has begun.

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