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Establishment and Significance of the Scientific System of Cryospheric Science

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Abstract
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Keywords
cryosphere science; climate system; ecosystem; sustainable development

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Establishment and Significance of the Scientific System of Cryospheric Science

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Abstract: The cryosphere is one of the five major spheres of the climate system. It plays an important role in the earth system with its huge freshwater reserves, latent heat of phase transitions, greenhouses gases, and unique species and cultural structures. The formation, change mechanism, and process of cryosphere; the interactions with atmosphere, hydrosphere, biosphere, and lithosphere; the influences and adaptations of cryosphere change; the service functions for regional and global economy and society all together have rapidly developed into a new interdisciplinary discipline, which is called Cryospheric Science. Being consistent with the directions advocated by the "Future Earth" and the "Earth Commission," the establishment and development of the scientific system of the cryospheric science is internationally forward looking. DOI: 10.16418/j.issn.1000-3045.20200331001-en

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In the earth’s long history of 4.6 billion years, mankind is not only the creator of earth civilization but also the destroyer of the climatic environment and resources on the earth. Since the beginning of the Anthropocene, especially since the 1950s, the climate and environment risks have increased sharply. In 2019, the global population has exceeded 7.8 billion, which may be 10 billion in the middle of the 21st century. This further increased the pressure on the earth, accelerated the irreversible damage to the climatic and environmental ecosystems, and further restricted the ability of the earth to support human development.

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) pointed out that since the Industrial Revolution in 1750s, greenhouse gases, aerosols, particulate matter, chemicals, and other impurities emitted by anthropogenic activities, as well as changes in land use, have led to global warming. Since the 1950s, the global temperature rise was mainly because of anthropogenic activities (with a reliability of more than 95\%)\textsuperscript{[1]}: IPCC AR5 also gave the temperature rise, impacts, adaptations, and countermeasures in different economic and social situations in the future. However, for the sustainable development of the earth, in addition to the temperature rise, a set of quantitative properties, which is similar to the stipulation in the Paris Agreement that the global temperature rise should not exceed 2 °C compared with that before industrialization and we need to strive for a temperature rise of no more than 1.5 °C, should be developed for key factors of life support systems on the earth, such as energy, freshwater, food security, land, ocean, and biodiversity. This can guide the sustainable development of social economy, and finally make the 17 objectives of 2030 Agenda for Sustainable Development proposed by the United Nations come true \textsuperscript{[2,3].}

The cryosphere is one of the five major spheres of the climate system. It plays an important role in the atmosphere, water resource, water cycle, ecosystem, terrestrial environment, marine environment, and sustainable development of social economy. The zonal characteristics of the cryosphere development determine that its changes will first affect the countries and economies in the middle and high latitudes which are the most economically developed in the world, and that its impacts on the middle latitudes cannot be underestimated. Combined with the impacts of its changes on the ocean, the influence is inevitable on low-latitude regions and small island states. Moreover, since a slight move in one part may affect the situation as a whole, the whole world is bound to be affected \textsuperscript{[4].}

For the sake of comprehensively studying the internal mechanisms of cryosphere and its changes, its impacts on other spheres and social economy, and the adaptation strategies to its changes, the cryospheric science has developed from initial stage to systematization in a short period of time, and is forming a research framework with the whole sphere as the core, which not only integrates the common attributes of various elements but also deeply explores the related processes of each element. The research of cryospheric
science involves physical, chemical, and biological processes of the cryosphere, as well as climate, hydrology, ecology, resources, engineering disasters, geographical humanities, geography, geology, and landform. It extends from the Quaternary to the next few hundred years on a time scale and expands from the earth to the planets on the space scale \cite{5,6}. The research aims to continuously develop the updated discipline connotation and make important contributions to the construction of a healthy earth and the realization of sustainable development \cite{7}.

1 Cryosphere and cryospheric science

1.1 Cryosphere on the earth

Cryosphere refers to the sphere with negative temperature and a certain thickness distributed continuously on the earth surface. The water in the cryosphere is generally frozen. On the terrestrial surface, the cryosphere is distributed on the ground and tens to hundreds of meters below the ground, including glaciers (including ice sheets), frozen soils (permafrost and seasonal frozen soil), snow cover, river ice, lake ice, etc., which belongs to the terrestrial cryosphere. In the ocean, the cryosphere is distributed in the range of several meters to hundreds of meters above and below the water surface and hundreds of meters below the continental shelf, such as sea ice, ice shelf, iceberg, and subsea permafrost, which belong to the marine cryosphere. Cryosphere also exists in the troposphere and stratosphere above the 0 °C isotherm height of the atmosphere, such as snowflakes, ice crystals, and other frozen water bodies, belonging to the atmospheric cryosphere. Horizontally, the earth’s high-altitude and high-latitude regions are the main regions for the development of the cryosphere (Figure 1). Vertically, the cryosphere covers hundreds of meters below the seafloor to the middle and upper troposphere.

The earth’s terrestrial cryosphere covers 52%–55% of the global land area. Among them, mountain glacier, Antarctic ice sheet, and Greenland ice sheet cover 10% of the global land area; the occupied area of snow cover is 1.3%–30.6% on average, and the annual average maximum snow cover extent in the Northern Hemisphere can account for 49% of the land surface in the hemisphere; the permafrost area accounts for 9%–12% of the global land, and the seasonal frozen soil (including permafrost active layer) in the Northern Hemisphere accounts for 33%. Some data also show that the annual maximum seasonal frozen soil extent in the Northern Hemisphere accounts for more than 56% of the land area in the hemisphere on average, and more than 80% in extremely cold years.

In the cryosphere, 75% of freshwater resources on the earth are stored, among which glaciers and ice sheets account for about 70%. Globally, 5.3%–7.3% of the ocean surface is covered by sea ice and ice shelf. The maximum area of sea ice on the Arctic Ocean is about 15 × 10^6 km^2, and the minimum

![Figure 1](https://example.com/figure1.png)
The purpose of cryospheric science is to understand the laws of nature, serve human society, and promote sustainable development.

If the cryosphere is taken as a whole, there is a need to summarize, classify, comprehensively analyze, and systematically expound the commonness of all its elements, and the research should be conducted from the aspects of the sphere, such as physical and chemical properties of the cryosphere, the laws of its formation, development, and evolution, the biogeochemical process, the observation and simulation, the changes of cryosphere and their influence and adaptation strategies, the sustainable economic and social development, and the policy-making related to geographical factors.

There is no contradiction between emphasizing the integrity of the cryosphere and paying attention to the individuality of its constituent elements. The former is the need of the development of the discipline and the latter is the basis for the continuous and in-depth development of the discipline. In terms of the impacts on regional development, the role of the whole sphere is often the key to problems. For example, in an arid area, the upstream cryosphere has a restrictive effect on regional development. The main contradiction is the supply of water resources. There are many questions to be answered. For instance, when can water resources be provided? How much can be provided? What is the maximum carrying capacity for regional development? How do water resources change when global temperature rises by 2 °C? How can such risks be avoided? These questions are hard to be answered only with the knowledge of single-element disciplines, such as glaciology or geocryology. Therefore, a comprehensive research utilizing glacier, snow cover, and frozen soil should be carried out to integrate the hydrological characteristics of various elements in the cryosphere, understand the temporal and spatial variation of the sphere, connect the human, economic, and social conditions of the downstream areas, especially the arid areas, and then carry out comprehensive design and planning. Only in this way can the role of the cryosphere be shown as a whole.

Cryospheric science is mainly composed of hydrothermal and dynamic mechanisms and four strata (i.e., process monitoring, change, impact, and adaptation) of various elements of the cryosphere (Figure 2) [9].

The main body of the cryosphere is the natural solid water on the earth surface, which necessarily intersects with disciplines related to water (such as mountain glacier; snow cover, hydrology, and water resources; frozen soil change and biodiversity change; sea ice and ocean; atmospheric cryosphere and meteorology). In addition, the cryosphere is also related to natural disasters, engineering geology, regional development, and geopolitics. All these indicate that cryospheric science is a comprehensive science with deep intersection of nature and humanity.

Figure 2 Framework of scientific system of cryospheric science

2 Establishment of the scientific system of cryospheric science

2.1 Establishment of specialized research institutions of cryospheric science

Western scientists put forward the concept of cryosphere, and Chinese scientists developed and preliminarily established the scientific system of cryospheric science. Due to different development stages, modes, and concepts, as well as different natural conditions and population structure, although the concept of cryosphere was first put forward in the West, the development of cryospheric science is relatively slow. At the United Nations Conference on the Human Environment in Stockholm in 1972, the World Meteorological Organization (WMO) first juxtaposed the cryosphere, a unique natural environment complex, with the atmosphere, hydrosphere, biosphere, and lithosphere. The interaction and feedback among the five spheres were clarified, and the theory of climate system was established. In 2000, the Scientific Committee of the World Climate Research Program (WCRP) decided to set up the “climate and cryosphere” ( CliC ) project, which aims to quantitatively assess the impacts of climate change on the elements of the cryosphere and the role of cryosphere in the climate system.

After a long period of academic accumulation, Chinese scholars put forward the concept and theoretical framework of cryospheric science and established the first specialized research institution named after cryospheric science in the world [5] combining climate change, sustainable development, and healthy earth construction. In the early 1920s, Zhu Kezhen set up a special chapter on glaciers when he taught the General View on Geoscience. In the late 1950s, Shi Yafeng organized the investigation of modern glaciers in Qilian Mountains and Tianshan Mountains, and later
established the Lanzhou Institute of Glaciology and Geocryology of the Chinese Academy of Sciences in Lanzhou, which became the China’s research base of cryospheric science. Since the 1980s, more and more attention has been paid to the role of cryosphere in global change research. In April 2007, the State Key Laboratory of Cryospheric Science became the first research institution named after “cryospheric science” internationally. The laboratory identified the process and mechanism of cryosphere, the interaction between cryosphere and other spheres, and the adaptation and strategies to the impacts of cryosphere changes as three important research directions, hoping to serve the sustainable development of social economy. The establishment and discipline orientation of the State Key Laboratory of Cryospheric Science showed the transformation of the cryospheric science research from single elements to the whole cryosphere and the transformation to the integration of natural science and sustainable development of social economy, marking that the development of cryospheric science has entered a new era (Figure 3).

There are two main lines in the international cryosphere research: ① WCRP/CliC. The goal is to deepen the understanding of the physical processes and feedback mechanism of the interaction between the cryosphere and climate system, improve the accuracy of climate prediction, and serve for disaster prevention and mitigation. ② International Association of Cryospheric Sciences (IACS). In August 2007, the International Union of Geodesy and Geophysics (IUGG) upgraded the International Commission on Snow and Ice under the International Association of Hydrological Sciences (IAHS) to IACS, aiming to promote the link between the studies of single elements of the cryosphere.

2.2 Establishment of framework system of cryospheric science

Cryospheric science begins with the study of glaciology, geocryology, snow cover, river ice, lake ice, and sea ice. From the perspective of research content, driven by the demand of climate change and regional sustainable development, cryospheric science, according to its own characteristics and starting from momentum, energy, water quantity, economic and social characteristics, not only studies the internal mechanism and process of cryosphere, but also pays more attention to the interactions of cryosphere with atmosphere, hydrosphere, biosphere, lithosphere (terrestrial surface), and human economic society (anthroposphere). The research on the impacts of cryosphere changes on each sphere and corresponding adaptation strategies involves social economy and sustainable development, with strong practicability and urgent social demand. These contents enrich the connotation of cryospheric science and promote the improvement of the discipline system. From the perspective of research methods, cryospheric science research adopts both natural science and social science methods. Specifically, the knowledge and methods of optics, thermology, mechanics, electricity, electromagnetics, chemistry, and ecology are employed to establish a three-dimensional observation system, collect the observation data of elements of the cryosphere, improve the laboratory test system, develop the global and regional models of the cryosphere, and integrate with the earth system model. Besides, cryospheric science also applies the principles of economics and social science to study the laws of the cryosphere and its relationship with society, and analyze the impacts and fragility of cryosphere changes as well as the adaptability to them.

![Figure 3 Main development process of cryospheric science in China](image)
The research team of cryospheric science in China has sorted out the scientific development trends, summarized the research progress of cryosphere, analyzed the connotation and extension of cryospheric science, and successively completed the Cryospheric Science Vocabulary, Dictionary of cryospheric science, and Introduction to Cryospheric Science (Chinese and English versions). Meanwhile, with the main line of mechanism, change, impact, and adaptation, the Cryospheric Science Series has been compiled, including 15 aspects of cryospheric physics, chemistry, geography, climate, hydrology, ecology, microbiology, environmentalology, Quaternary, engineering, disaster, humanities, geographical relationships, remote sensing, and planetary cryosphere, covering many fields of natural and humanities & social sciences.

At present, China has established the State Key Laboratory of Cryospheric Science, the State Key Laboratory of Frozen Soil Engineering, and other specialized research institutions. In some departments and universities, a number of research entities related to cryospheric science have been established. Many universities have offered cryospheric science courses and even set up cryospheric science majors to cultivate reserve talents for the research of cryospheric science. The China Society of Cryospheric Science (CSCS) has been established. The annual academic meeting and the activities of various professional committees of the Society are rich and colorful, which has expanded the research team of cryospheric science and expanded the influence and popularization of cryospheric science.

3 Cryosphere changes and impacts

The cryosphere changes affect the sustainable development of human economy and society by changing its exchanges of mass and energy and the interaction with the atmosphere, hydrosphere, lithosphere, biosphere, and anthroposphere on different spatial and temporal scales. The influence of the cryosphere changes has both negative and positive effects, most of the studies are related to disasters and losses.

3.1 Cryosphere changes

Cryosphere changes refer to the temporal and spatial distribution changes of thermal regimes and mass in the cryosphere, which are mainly reflected in the changes of morphology, volume, and mass, such as changes in area, thickness, ice amount, and end or edge of glaciers; the area or range and thickness of frozen soil; snow cover extent and snow water equivalent; sea ice extent and thickness; freeze-up date, break-up date, freezing days, and thickness of river ice and lake ice. The changes of some aspects in the cryosphere, such as heat (temperature), material structure, material migration, chemistry, and biology, are also included. The cryosphere is the most sensitive sphere of the climate system. In the age of global warming, all elements of the cryosphere are changing significantly, mainly manifested in the reduction of scale and the increase in temperature.

The long-term variation of sea ice can be grasped in detail because of the long-term observation data (Figure 4). The Arctic Ocean and the Antarctic Ocean are the main distribution areas of sea ice. The monitoring results show that the Arctic sea ice has continued to decrease since 1979 compared with that in 1981–2010, while the extent of Antarctic sea ice is relatively stable, and has slightly increased from the last few years of the 20th century to 2015. However, in recent years, the sea ice extent in both areas has decreased significantly.

![Figure 4](image.png)

**Figure 4** Extent variation of Arctic sea ice and Antarctic sea ice from 1979 to 2019 (relative to the situation in 1981–2010 on average)

Source: National Snow and Ice Data Center (NSDIC) of the United States.

From 2006 to 2015, the average ice loss rates of Greenland ice sheet and Antarctic ice sheet reached 278 ± 11 Gt/a and 155 ± 19 Gt/a, respectively, which accelerated the global sea-level rise. The global mountain glaciers are in a state of retreat or rapid retreat. In recent years, glacier collapses occur frequently in the alpine regions of middle and low latitudes, which bring disasters to the local areas. For example, the barrier lakes in Yajiang County were caused by glacier avalanche in Nyingchi, Tibet, in 2018.

In recent decades, the range of snow cover, maximum depth, snow cover duration, and snow water equivalent have generally decreased. Permafrost is generally warming and the thickness of active layer is increasing. River ice and lake ice had shorter ice days, smaller thickness, and earlier melting time.

3.2 Impacts of cryosphere changes

Cryosphere changes interact with other spheres of the climate system and anthroposphere, affecting regional and global economic and social development.

3.2.1 Cryosphere-atmosphere-social economy

The cryosphere changes affect the climate change of different spatial and temporal scales. The albedo of the clean snow surface is more than 90%, which is 3–9 times that of the general ground surface. The difference of energy
absorbed by the ocean with and without sea ice cover is more than nine times. The reduction of Arctic sea ice makes the ocean absorb more solar radiation, leading to the regional temperature rise rate being more than two times the global average. The permafrost in the Northern Hemisphere contains 1,460–1,600 t of organic carbon [4], which is almost twice as much as that in the atmosphere. The additional greenhouse gases released by permafrost thawing exacerbate global warming. If the global temperature rise cannot be controlled within 1.5 °C, there will be the melting of (1.50–2.50) × 10⁶ km² permafrost in the 21st century, releasing about 100 Gt CO₂[9], which may lead to abrupt change of climate. This will increase the current “social cost of carbon emissions” by nearly eight times, namely that the cost of CO₂ emissions will rise from the current cost of 15 US dollars/t to 116 US dollars/t [10].

3.2.2 Cryosphere-hydrosphere-social economy

On a global scale, the retreat of the cryosphere causes a large amount of cold freshwater to enter the ocean, which results in a sharp rise in sea level, putting the world’s coastal areas and low-lying islands in danger; at the same time, it will correspondingly change the salinity and temperature of the ocean and affect the oceanic thermohaline circulation process, thus changing the global water cycle process, including ocean conveyor belt and ocean current intensity [1]. On the regional scale, the accelerated retreat of glaciers can increase glacier runoff in a short period of time, but it will lead to the decrease in runoff in a long time; the changes of hydrological processes will affect the water cycle and the supply of freshwater resources in the basin, especially in the regions highly dependent on the water resources of the cryosphere, which will bring great adverse impacts on food security, human health, ecosystem maintenance, and social and economic development [11]. The total income generated by water resources utilization in Asia is 205 billion US dollars, while the total external cost generated is 660 billion US dollars, which is about three times the total income [12].

3.2.3 Cryosphere-lithosphere-social economy

The influence of the cryosphere on terrestrial surface is mainly manifested by surface weathering, erosion, transportation, and accumulation, as well as a series of disasters. The process of glacial geomorphology, flood and debris flow caused by glacial lake outburst, freeze thawing or thermal thawing of frozen soil, spring flood caused by snow cover in mountainous areas, bank collapse and ground collapse caused by sea ice retreat and thawing of frozen soil, etc. will have serious impacts on the social economy. For example, the repair and reconstruction of about 300 km railway line between Gillam and Churchill in Canada cost more than 30 million US dollars in 1978–1983 to stabilize the settlement of frozen soil, repair bridges and culverts, restore longitudinal slope, and update sleepers [13].

3.2.4 Cryosphere-biosphere-social economy

Due to the retreat of cryosphere, the probability of succession of terrestrial ecosystems is increased and the pheno-logy is advanced, especially in the aspects of the structure, function, and spatial and temporal distribution pattern of ecosystems [4]. For example, the depth of permafrost active layer increases, the water in the soil layer moves downward, and the alpine meadow and alpine marsh, and wetlands degrade significantly. From 1970 to 2010, the alpine marsh in the Qinghai-Tibet Plateau shrunk by 25.6%, and the desertification land increased by 17.2% [14]. In addition, the change of atmospheric cryosphere can directly affect the growth of vegetation, resulting in serious crop yield reduction.

The impacts of cryosphere changes on marine ecosystem are very significant. The continuous reduction of the Arctic ice extent and thickness leads to the destruction of food web or habitats of organisms in the edge region of Arctic sea ice, and then affects population reproduction. The places for polar bears to survive and hunt are shrinking, resulting in decreases in the number and reproductive success rate of polar bears. If the sea ice continues to decrease, the number of polar bears in the future may drop by nearly 2/3 [15]. Ecosystem changes also have a great impact on the life of the circump-Arctic aborigines. Not only their livelihood and social ways have changed, but also their native language and culture are in danger of loss [9].

3.2.5 Cryosphere-anthroposphere-geopolitics

The continuous retreat of the cryosphere also causes international geopolitical issues. The reduction of Arctic sea ice and the opening of Arctic waterways have changed the shipping pattern, with obvious commercial benefits and environmental effects, prominent energy and mineral values, and increasingly obvious military and strategic games. The retreat of the cryosphere has brought potential strategic resources, and the driving force of competition for effective resources makes some countries begin to spy on Antarctic resources, which leads to the increasingly tense geopolitical situation in Antarctica. In alpine regions, the retreat of mountain glaciers leads to the shortage of freshwater resources and the water resources crisis. In the international river areas, the competition for water resources intensifies geopolitical friction. Glacier melting will also cause sea-level rise, and low-lying countries and small island states are facing the threat of territorial inundation [16].

3.3 Adaptations to cryosphere changes

In response to the cryosphere changes and impacts, the risk and fragility of cryosphere changes should be analyzed on the basis of the prediction of future changes of cryosphere through the cross-integration of natural science and social science. The assessment method of the adaptability to cryosphere changes in different regions should be established in combination with the current situation and development trend.
of regional social economy, and the adaptability to and mitigation strategies against cryosphere changes should be put forward, thereby providing technological support for the sustainable development of global and regional social economy.

China is the country with the most developed cryosphere at middle and low latitudes, but most of the cryosphere is distributed in the places with relatively backward economic development and fragile ecological environment. Meanwhile, China is also a near-Arctic country, and the influence of the cryosphere changes in Arctic region also affects China. Antarctica is not only an international science and technology arena, but also an important area of international strategic competition. Therefore, China not only needs to put forward regional-scale adaptation plans for domestic cryosphere impacts, such as formulating water security strategy of “Asian water tower,” promoting water cooperation, establishing scientific benefit sharing and compensation mechanism, improving the mechanism for settling trans-boundary river water disputes, strengthening ecological restoration and protection measures in frozen soil area, and providing schemes for cryosphere disaster risks and control. It is also necessary to improve the research on adaptation strategies to the cryosphere changes in the Arctic and Antarctic.

In a word, cryosphere changes affect not only the natural system but also humanity, economic, social, and national relations. The research on adaptations to cryosphere changes should not only focus on the sustainable development of regional social economy, but also establish the research system of cryosphere change-impact-adaptation based on resilience from a global perspective in connection with the 17 objectives of the 2030 Agenda for Sustainable Development (Figure 5).
In the context of global warming, the retreat of the cryosphere tends to weaken its unique services. Therefore, it is necessary to study the quantitative relationship between cryosphere changes and cryosphere services and to determine the relationship between cryosphere changes and the strength of service function at different spatial and temporal scales, especially for some key characteristic values, such as function enhancement period, plateau period, inflection point, decline period, and even loss period. In addition, there may also be a trade-off between different cryosphere services. For example, for meltwater service, excessive emphasis on its economic and social services may weaken its ecological services.

With the continuous expansion of the cascade effect of impacts from cryosphere changes, the connection between cryosphere and ecological, economic, and social issues is not only a necessity of discipline development, but also necessary for extending the application value of cryospheric science. The value evaluation of cryosphere service functions can build a bridge between cryosphere services and market value system and provide decision makers with cryosphere service functions and value information. It has important scientific and long-term strategic significance to promote the sustainable development of society and economy in economically underdeveloped areas characterized by "cold" and "drought" and strengthen the construction and protection of ecological environment.

4.2 Cryospheric science contributing to the earth health

A planet that maintains the state and function during the interglacial period in Holocene can benefit human and non-human organisms and enable all mankind to share equally the well-being and risks endowed by nature and bear corresponding responsibilities [5]. Whether the sub-health earth can continue to benefit the huge population and whether it can guarantee human reproduction and survival are important issues we are facing.

During the 1.2 million years of the late Quaternary period, the earth system has been in the natural alternation of glacial and interglacial periods. Since the industrialization of human society in the 1750s, anthropogenic activities have caused global warming, air pollution, sea-level rise, ocean acidification, land use change, shortage of freshwater resources, energy shortage, decline of biodiversity, and retreat of cryosphere. These adverse consequences caused by anthropogenic activities have led to the destruction of the climatic environment and the stability of the ecosystem on the planet on which we depend for survival, and the good ecological environment of the Holocene, which lasted for 12,000 years, has been irreversibly damaged, seriously restricting the ability of the earth to support human development [19]. At present, the earth’s climatic environment is at a critical point. Strengthening the management of the earth system and enhancing the earth's resilience is an option. If it is allowed to develop in a bad way, the earth will fall into an irreversible "Hothouse Earth," which is the worst outcome (Figure 7). The world population was 791 million in 1750, increased to 2.54 billion in 1950, exceeded 6 billion in 2000, and reached 7.815 billion in 2019. It is estimated that it will reach 10 billion in 2050. Facing the population of 10 times before the Anthropocene and the annual growth rate of 100 million, human beings urgently need to find a path to guide the earth system away from the potential critical point, restore the
environment of the last interglacial period, and ensure the earth health and human development.

![Image of the cryosphere and climate system]

**Figure 7** Path of the earth system from Holocene to Anthropocene

The bifurcations in the figure show two different paths of the future earth system (dotted arrow): Path 1: The earth system is currently in the greenhouse earth path, which is caused by emission of greenhouse gases by anthropogenic activities and the degradation of the biosphere. When the temperature rise exceeds the threshold of about 2 °C, the earth system will enter the irreversible “Hothouse Earth” driven by its endogenous biogeo-physical feedback. Path 2: The earth system develops to the steady-state earth, which is a feedback-guided earth system management path created by human beings and will lead the earth into a quasi-stable pit.

When studying the critical point (threshold) of surface temperature, Steffen et al. [20] estimated that when the global temperature rises about 1 °C–3 °C, the Greenland ice sheet and mountain glaciers will melt rapidly, and the west Antarctic ice sheet will disintegrate. Besides, the Arctic sea ice will disappear in summer, and the coral reefs in the sea will whiten. It can be seen that the cryosphere is most sensitive to this minimum critical point. The IPCC report also predicted that in the context of further warming in the 21st century, the elements of the cryosphere will further shrink significantly [4]. Therefore, the following questions are worth pondering: The cryosphere is the largest freshwater reservoir on earth. Then, how much freshwater (upper and lower limits) will the world need in 2050 and 2100? How much freshwater can the cryosphere provide to keep the earth healthy? Is the cryosphere the regulator and initiator of global climate change. What is the interaction between cryosphere and climate under different temperature rise conditions (such as 1.5 °C, 2 °C, and 3 °C)? What is the impact of cryosphere changes on ecosystem and surface environment under different temperature rise conditions? The rapid retreat of the cryosphere affects and restricts the survival and development of human beings from different spatial and temporal scales. Then, how can human society slow down and adapt to it to maintain sustainable development?

The retreat of the cryosphere will change the geostrategic pattern of the world. The core area of the cryosphere may become the strategic highland of the competition of interests between great powers, or a new field of global cooperation. How to embody the concept of “a Community of Shared Future for Mankind” here and some other aspects are all the subjects that need to be studied in cryospheric science. In addition, the cryospheric science can start with climate regulation, water supply and regulation, ecological regulation, disaster prevention and control, adaptation and mitigation, regional sustainable development, and global strategy to meet the challenge integrating natural and social problems faced by the earth by combining the 17 objectives of the 2030 Agenda for Sustainable Development. Thus, it can contribute to the healthy earth while promoting the new development of disciplines and deepening the connotation of cryospheric science [20].

### 5 Conclusion

Anthropogenic activities have brought many negative impacts on the earth, such as global warming, ecosystem damage, water shortage, and land degradation. The cryosphere is one of the spheres of climate system, and its changes are closely related to the above phenomena.

The cryosphere plays an irreplaceable role in the earth system and is extremely sensitive to global temperature rise. The impact of cryosphere retreat should not be underestimated, not only in the most economically developed countries and economies at the middle and high latitudes, but also in areas at middle latitudes. It also influences oceans, so the low latitudes and small island states are also suffering. The vast freshwater resources, huge phase change potential, and broad development space in the cryosphere have important impacts on water resources, energy, food security, land, ocean, biodiversity, and other key elements supporting the earth’s life system. The changes in the cryosphere can bring both losses and benefits to people.

The establishment and development of the scientific system of cryospheric science are in line with the general direction advocated by the international scientific programs of “Future Earth” and “Earth Commission” and is also the significance of the two.

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