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Characteristics, Influence of Cryosphere Disaster and Prospect of Discipline Development

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Abstract

Cryosphere disasters include continental cryosphere disaster, marine cryosphere disaster, and aerial cryosphere disasters and these disasters are widespread and have caused great loss and influence. With the increasing frequency and intensity of cryosphere disasters caused by climate warming, the cryosphere region faces severe challenges in poverty eradication, climate change mitigation and adaptation, and sustainable economic and social development. Early cryosphere disaster studies mainly focus on the disaster events, disaster effects, and prevention of single disaster, concentrating on avalanche, glacial lake outburst, and glacier debris flow disasters. Since the 1980s, the research scope of cryosphere disaster science is gradually expanding, some of cryosphere disaster received extensive attention and further research such as permafrost disasters, sea ice disasters, and ice jam/flood disaster. In recent 10 years, with the establishment and improvement of cryosphere science system, the discipline system of cryosphere disaster science is developing and making significant progress in cryosphere disaster risk, impact and adaptation. Based on previous studies, this paper elaborates on the connotation of cryosphere disaster science, reviews the spatiotemporal characteristics of cryosphere disaster and its comprehensive influence, and then puts forward some suggestions on the construction and development of cryosphere disaster science in the future.

Keywords

cryosphere disaster; discipline construction; future prospect

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Characteristics, Influence of Cryosphere Disaster and Prospect of Discipline Development

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Abstract: Cryosphere disasters include continental cryosphere disaster, marine cryosphere disaster and aerial cryosphere disasters, which are widespread and have caused serious loss and influence. With the increasing frequency and intensity of cryosphere disasters caused by climate warming, the cryosphere region faces severe challenges in poverty eradication, climate change mitigation and adaptation, and sustainable economic and social development. Early cryosphere disaster studies mainly focus on the disaster events, disaster effects, and prevention of single disaster, concentrating on avalanche, glacial lake outburst, and glacier debris flow disasters. Since the 1980s, the research scope of cryosphere disaster science is gradually expanding, some cryosphere disasters such as permafrost disasters, sea ice disasters, and ice jam/flood disaster have received extensive attention and further research. With the establishment and improvement of cryosphere science system in the last decade, the discipline system of cryosphere disaster science is developing and achieving significant progress in the research on cryosphere disaster risk, impact and adaptation. Based on previous studies, this paper elaborates on the connotation of cryosphere disaster science, reviews the spatiotemporal characteristics of cryosphere disaster and its comprehensive influence, and then puts forward some suggestions on the construction and development of cryosphere disaster science in the future.
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Low temperature, rain, snow and frost attacked 19 provinces (municipalities, autonomous regions) in southern and central China in early 2008, and the extreme weather (lasting for over 20 days) led to the severest freezing rain and snow disaster in China in the past 50 years. On October 16, 2018, Milin County, in the middle and lower reaches of the Yarlung Zangbo River, was attacked by an ice avalanche, which, together with the glacial till, formed a dammed lake, blocking the Yarlung Zangbo River and raising the water level. On October 29, 2008, the river was blocked by an ice avalanche again, arousing widespread concern. There are various types of cryosphere disasters, which may occur frequently and cause serious losses and impacts. With climate warming, the frequency and intensity of cryosphere disasters have been intensified, making them the common natural disasters. The frequent cryosphere disasters have severely threatened the life and property security of residents, industry, agriculture and animal husbandry, transportation, infrastructure, tourism development, and national defense security, even destroying the socio-economic system in the cryosphere region. Especially, the cryosphere regions are mainly remote alpine regions and underdeveloped regions with a high proportion of the poor, who are unable to withstand natural disasters. Therefore, cryosphere disasters have become a major challenge in poverty eradication, climate change mitigation and adaptation, and sustainable economic and social development.

In view of the important role of cryosphere disaster science in disaster risk science and sustainable development, we briefly elaborate on the connotation of cryosphere disaster science, review the spatiotemporal characteristics of cryosphere disaster and its comprehensive influence, and then put forward some suggestions on the construction and development of cryosphere disaster science in the future.

1 Emergence and development of cryosphere disaster science

Early cryosphere disaster studies mainly focus on the disaster events, disaster effects, and prevention of single disaster, concentrating on avalanche, glacial lake outburst,

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and glacier debris flow disasters. Since the 1980s, the research scope of cryosphere disaster science has been gradually expanding, and cryosphere disasters such as permafrost disasters, sea ice disasters, and ice jam/flood disaster have received extensive attention. With the advancement of technologies and increased attention to disaster prevention and mitigation, the research on cryosphere disasters has been rapidly developed in the 21st century. With the establishment and improvement of cryosphere science system, disaster risk science and related technologies in recent years, as well as the urgent need for sustainable development in cryosphere regions, the research on comprehensive impact of cryosphere disasters, cryosphere disaster mechanism, risk characteristics, risk assessment, disaster warning and risk management, which marks the emergence and development of cryosphere disaster science.

Cryosphere disaster science aims to comprehensively analyze the spatio-temporal characteristics and impact of cryosphere disasters and risks, clarify their formation mechanism and process, and determine the measures for the prevention and mitigation of disasters. The relevant studies can help to reduce the risks and losses and enhance the restoration of cryosphere communities for achieving sustainable development in the cryosphere region. This science, with the attributes of natural science, engineering and social science, is the basis for prevention, mitigation and relief of disasters. Cryosphere disaster science mainly studies the cryosphere disaster risk system, which is an earth surface system consisting of disaster-pregnant environment, hazard and exposure and vulnerability of hazard-affected body.

Cryosphere disaster risk is the integrated result of hazard, exposure and vulnerability. As shown in Figure 1, the triangle area represents the size of a cryosphere disaster risk, which depends on the intensity and frequency of cryosphere hazard (also known as the risk of hazard) and the exposure and vulnerability of hazard-affected body.

The disaster-pregnant environment, including natural, social and economic factors, drives the spatio-temporal dynamics in risk and its three elements (Figure 1). The interaction and evolution of multiple spheres, especially the climate change, environmental degradation, population migration, and urbanization and economic development, are the key driving factors for the dynamics in risks of cryosphere disasters.

Cryosphere disaster science focuses on both basic theory and practical application, and its content has been enriching with the development of the sciences of cryosphere and disaster risks. The basic theory of cryosphere disaster science mainly involves the disaster risk system, mechanism and process of cryosphere, cryosphere disasters and risks, and the characteristics, types, distribution, dynamics, losses, impacts and interactions of hazard, exposure and vulnerability. Besides, cryosphere disaster science focuses on the root causes of the disaster risks and the driving mechanism of climatic, social and economic factors on the formation of cryosphere

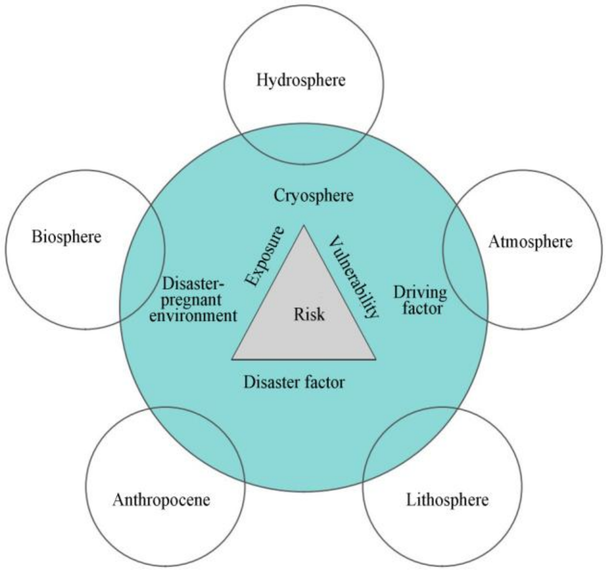

Figure 1 Cryosphere disaster risk system

disasters. In terms of research methods, cryosphere disaster science mainly involves the observation, statistics, analysis, modeling, prediction, forecasting and warning of the disasters and risks, the drawing and zoning of disaster risk map and integration and management of risk information. At present, the methods for analysis on the risk of hazard, exposure and vulnerability of hazard-affected body, loss and risk have been widely used. The practical application of cryosphere disaster science focuses on disaster risk and emergency management as well as adaptation to cryosphere climate changes. Specifically, it involves the evaluation of acceptable risk level, engineering and non-engineering measures and cost-benefit analysis, cryosphere disaster risk decision-making in uncertain scenarios, major project and infrastructure protection, land and space planning, social security for vulnerable groups, adaptation to climate change in cryosphere, disaster risk management, and restoration and sustainable development of cryosphere disaster region. Cryosphere disaster emergency management involves disaster warning, disaster preparedness, emergency response, disaster relief and reconstruction.

2 Spatio-temporal characteristics of cryosphere disasters

(1) Cryosphere disasters include continental cryosphere disasters, marine cryosphere disasters and aerial cryosphere disasters. Continental cryosphere disasters include ice avalanche, glacial lake outburst, glacier flood, glacier debris flow, freezing and thawing, avalanche, snowmelt flood, snowdrift, ice jam/flood disaster, and water resource shortage. Marine cryosphere disasters include iceberg, sea ice, coastal erosion, and sea level rise. Aerial cryosphere disasters include snowstorm, hail, freezing rain and snow, frost and

snow disaster in pastoral area. These disasters affect the global transportation, electric system, hydraulic engineering, communication, agriculture, forestry, animal husbandry, fishery, ice and snow tourism, cultural landscape, as well as people's life safety and property safety (Figure 2).

(2) There are differences in spatio-temporal scales of occurrence and impact of cryosphere disasters. Cryosphere disasters usually occur instantaneously, and some may occur in a periodic or long-time manner. Some disasters may occur in local areas, and some may occur on a regional or even larger scale. Snow disaster has the widest range among cryosphere disasters, including avalanches, snowdrift, snowstorm, snow disaster in pastoral area, snowmelt flood and freezing rain and snow, all of which interact with and affect each other. These disasters often endanger the social and economic development in terms of agriculture, animal husbandry and regional transportation (Figure 2). Ice avalanche, avalanche, and glacial lake outburst, known as sudden disasters, usually take place in a short duration and are hard to be warned and prevented. Freezing and thawing disaster, water resource shortage and sea level rise, known as delayed disasters, usually occur in a long duration, which may cause severer harm in the long run while receive little attention [1].

(3) Continental cryosphere disasters mainly occur in countries around the Arctic and high-latitude mountainous countries. Ice/snow avalanches mainly take place in mountainous areas at middle and high latitudes of the Northern Hemisphere [2]. The flood/debris flow caused by glacial lake outburst mainly occur in Hindu Kush-Himalaya Mountains, Nyenchen Tanglha Mountains, southwestern coast mountains of Canada, the Andes, the Alps and the Iceland [3–5]. Glacier surging disasters concentrate in the Svalbard Archipelago of Norway, Novaya Zemlya of Russia, Iceland, Alaska, Karakoram Mountains and Pamirs [6,7]. The freezing and thawing disasters mainly take place in permafrost regions around the Arctic, Qinghai-Tibet Plateau, and Northeast China [8]. Snowmelt floods mainly occur in arid regions of Central Asia.

(4) Marine cryosphere disasters mainly occur in coastal countries and lowlands. Iceberg disasters concentrate in areas around Greenland, and sea ice disasters in coastal areas of countries around the Arctic and in the Circum-Bohai-Sea Region of China [9–11]. Coastal erosion of permafrost mainly takes place in Kanin Peninsula-Yamal Peninsula-Teral Peninsula at the northwest coast of Russia, the coast of New Siberian Islands, the southwest coast of East Siberian Sea, the north coast of Alaska and the north coast of Yukon, Canada [12,13]. The accelerated rise of sea level is known as one of the major risks to the human society, which poses severe challenges especially in coastal cities and low-lying small islands [14].

(5) Aerial cryosphere disasters mainly take place in mid- and high-latitude regions. Specifically, snowstorm disasters mainly occur in northeastern US, southwestern Canada, northwestern Europe and Japan, hail disasters in central and eastern US and some areas in Europe and Central Africa, snow disasters in pastoral area in China, Mongolia and Caucasus [15,16], and freezing rain and snow disasters in southern China, northeastern US and other high-latitude countries [1].

3 Influences of major cryosphere disasters

(1) The instability of continental cryosphere may cause avalanches, ice avalanches, and glacier surging. Meanwhile, the accelerated melting of cryosphere may result in floods and debris flow disasters [17,18]. In Europe and North America, about 1 900 people died of avalanches from 2000 to 2010 [2]. The recorded number of glacial lake outbursts has reached 1 348, causing at least 393 deaths in the Alps, 5 745 deaths in South America and 6 300 deaths in Central Asia [19]. Since 1970, the permafrost in most areas of the Arctic has been warming, with temperature rise of 0.50 °C–2.00 °C [20]. Additional 3.6–6.1 billion US dollars will be invested to infrastructure maintenance in Alaska due to the impact of freezing and thawing process in 2010–2030, which will increase to 7.6 billion US dollars in 2010–2080 [21].

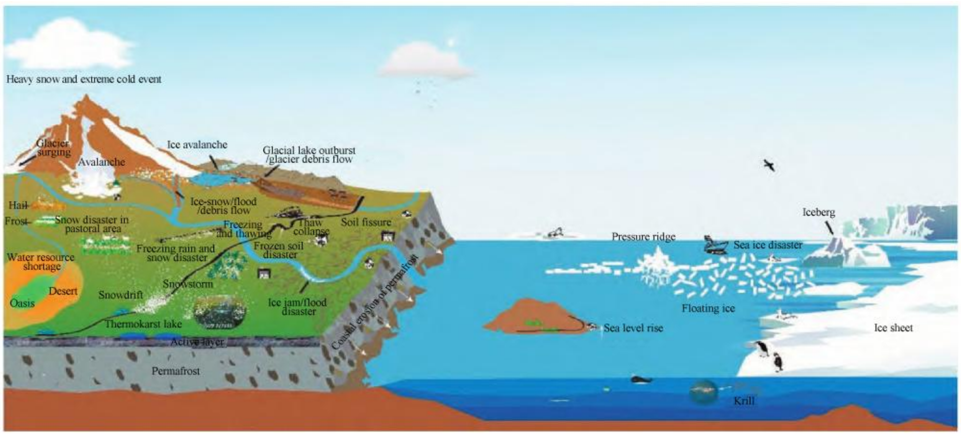

Figure 2 Spatial distribution of major disasters in terrestrial, ocean and aerial cryosphere

(2) Marine cryosphere disasters generally affect the human activities and safe operation of facilities on the coast and at the sea. Since 2010, the economic loss directly caused by sea ice disasters has reached CNY 7.7 billion in China, and the loss is especially severe in Liaoning and Shandong [22]. The Arctic permafrost coast accounts for about 34% of coast on the Earth, and the erosion rate may reach 24 m/a [12]. The annual land loss due to coastal erosion in the Arctic is about 51 km^2 [13]. Sea level rise caused by cryosphere and marine thermal expansion have the severest effect on low-lying coastal areas. With the rise of sea level, the risk of damage may increase obviously, and the potential damage may reach 10% of the world gross domestic product at the end of the 21st century in the case of no effective measure being taken [23].

(3) Snowstorm, freezing rain and snow, hail and frost are common aerial cryosphere disasters. From 2010 to 2017, Europe was swept by snowstorm for many times. Blizzards attacked many countries, which resulted in traffic jams, flight cancellation and power outage, seriously affecting people's life. In February 2015, snowstorm occurred in northeastern US, which resulted in emergency in six states and affected 60 million people. About 7 000 flights were canceled in February 26–28. In 2008, the freezing rain and snow in China caused different levels of disasters in 19 provinces (municipalities, autonomous regions) and Xinjiang Production and Construction Corps, leading to 107 deaths and direct economic loss of CNY 111.1 billion [24].

4 Suggestions for development of cryosphere disaster science

4.1 Deepening the understanding on single-disaster mechanism in the cryosphere

Revealing disaster mechanism is the basis for early warning, prevention and management of cryosphere disasters. The risk of cryosphere instability is increasing due to climate warming and cryosphere disasters have an increasing probability of occurrence. Meanwhile, the disasters have crossover or chain effect. For example, snowmelt flood and glacial lake outburst may induce secondary disasters such as landslide and debris flow. The ice/snow avalanches, glacier surging and snowmelt flood may also induce landslide and debris flow, whose deposits may block the rivers to form dammed lakes, thus threatening the downstream regions. The low temperature caused by cold waves may lead to biological cold damage, ground freezing and freezing rain and snow. Therefore, the research on the development law, formation process, spatial differentiation and formation mechanism of cryosphere disasters and disaster chains should be deepened in the future. In addition, attention should be attached to the formation and evolution mechanism of cryosphere disaster chains.

4.2 Strengthening the evaluation on cryosphere disaster risks

The evaluation on cryosphere disaster risks mainly focused on single disasters rather than multiple disasters. In the future, a comprehensive evaluation system needs to be established based on the type, probability, scale and death toll of each disaster. The spatial differentiation and characteristics of cryosphere disasters can be taken as reference for uncovering of the evolution of regional cryosphere disasters and determining the attacked sphere and degree of different cryosphere disasters in different regions. Systematic evaluation on the risks of cryosphere disasters should be made using risk analysis, modeling, and loss assessment based on the type, damage, association and relative importance of different cryosphere disasters. The maps of the type, situation, frequency and risk of cryosphere disasters should be drawn, based on which the measures for disaster prevention and mitigation can be formulated.

4.3 Enhancing the comprehensive research on cryosphere disasters

Instead of existing independently, cryosphere disasters are associated with multiple disaster-pregnant environments and accompanied by one or more secondary disasters, like other natural disasters. Therefore, the research should cover the disaster system composed of disaster-pregnant environment, disaster factor, and environment of affected area, and the complexity and systematicness of cryosphere disasters should be considered. The quantitative and systematic research should be carried out on the correlation, spatio-temporal dynamics and coupling properties of regional cryosphere disasters, as well as the vulnerability and adaptability of the affected area. Further, a cryosphere disaster prevention and emergency system can be established to strengthen the preparedness and reconstruction systems based on comprehensive risk evaluation of cryosphere disasters, thus improving the operability and scientificity of comprehensive management and control on cryosphere disaster risks. Meanwhile, the structural and non-structural measures (or engineering and non-engineering measures) should be developed to improve the restoration after cryosphere disasters [25].

4.4 Improving the scientific system of cryosphere disasters

Cryosphere disaster science covers the content of different disciplines such as agrometeorology (hail and frost disasters) atmospheric science (snowstorm, freezing rain and snow disasters) and marine science (disasters caused by sea ice and sea level rise). The emerging cryosphere disaster science integrates previously scattered cryosphere disasters to re-examine the mechanism, influence, and spatio-temporal characteristics of the disasters from the perspective of cryosphere. However, the emerging discipline should be improved from the following three aspects. (1) The content of cryosphere disaster science in the related disciplines of natural disasters and risk management should be emphasized to raise the status of this discipline. (2) The international cooperation and communication should be enhanced to promote academic exchanges within the discipline or with other disciplines. The academic conference with the theme of cryosphere disasters and the training courses for young teachers in colleges and universities should be held to cultivate backbone teachers in this field. (3) Some major projects related to cryosphere disasters should be sponsored to foster the development and condense the consensus and development strategy of this discipline.

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