Bulletin of Chinese Academy of Sciences 院刊

Volume 35 | Issue 4 Article 7

April 2020

New Perspective of Research on Cryospheric Physics

REN Jiawen

State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China

New Perspective of Research on Cryospheric Physics

Abstract

Ice is the core material in cryosphere, while the physical properties as well as physical processes of cryospheric components vary obviously because of difference in ice proportion and other material compositions. A large number of laboratorial studies and extensive field investigations in the middle and late of 20th century have determined the basic concepts of ice physical properties and the outlines of physical characteristics of these cryospheric components. With establishment of the cryospheric science system and requirement of the socio-economic development, research emphasis of cryospheric physics should be put on three aspects in future. One is further investigation of ice physical properties in details in order to provide accurate parameters for modelling, disaster prevention, and cryospheric service. Another is the laboratory simulation of combined processes of the cryosphere, especially entity and similarity simulations. The third is to promote the coupling between cryospheric models and further between models of cryosphere and other spheres.

Keywords

cryosphere physics; ice physics; hydrothermal-dynamic process; cryosphere modeling

Bulletin of Chinese Academy of Sciences No. 4

Citation: REN Jiawen. New Perspective of Research on Cryospheric Physics [J]. Bulletin of Chinese Academy of Sciences, 2020 (4): 450–455.

New Perspective of Research on Cryospheric Physics

REN Jiawen[1,2]

1. State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China;
2. College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: Ice is the core material in cryosphere. The physical properties as well as physical processes of cryospheric components vary obviously because of differences in ice proportion and other material composition. A large number of laboratorial studies and extensive field investigations in the middle and late of 20th century have determined the basic concepts of physical properties of ice and these cryospheric components. With establishment of the cryospheric science system and requirement of the social and economic development, the research emphasis of cryospheric physics should be put on three aspects in the future. One is further investigation of ice physical properties in details in order to provide accurate parameters for modeling, disaster prevention, and cryospheric service. The second is the laboratory simulation of combined processes of the cryosphere, especially entity and similarity simulations. The third is to promote the coupling between cryospheric models and further between models of cryosphere and other spheres. **DOI:** 10.16418/j.issn.1000-3045.20200302001-en

Keywords: cryospheric physics; ice physics; water-heat dynamic process; cryosphere modeling

Cryospheric physics studies the physical properties, the formation and evolution of cryospheric components, and the interaction between cryosphere and other spheres to provide theoretical support for the research of cryospheric science from all aspects. It is the core of the basic research and runs through all research aspects of cryospheric science ①.

There are various cryospheric components, including glaciers (such as ice cap), frozen soil, snow cover, river ice, lake ice, sea ice, ice shelf, iceberg, subsea permafrost, and solid water in the atmosphere. These cryospheric components are different in physical properties and process mechanism due to the differences in material composition, formation and development conditions, and evolution process. The independent research on cryospheric components for a long time in the past made the research history different and the development unbalanced.

With the establishment of cryospheric science system [1], it is necessary not only to systematically study the cryospheric physics from the whole sphere level but also to further study the physical process of each cryospheric component, which involves studies in an extensive range and at different spatial-temporal scales. Therefore, the research of cryospheric physics should be reviewed according to the dynamics of discipline development and the major demands of China.

1 Research progress on cryospheric physics

Ice is the core material in cryosphere, and understanding the physical properties of ice is the premise of revealing the physical process of each cryospheric component. Therefore, the development of cryospheric physics can be briefly reviewed from the physics of ice and cryospheric components.

1.1 Basic physical properties of ice

People have been familiar with the ubiquitous existence of ice and snow since ancient times. Although the wonderful characteristics of ice have always attracted people's interest, the research on its basic physical properties has long been dominated by visual observation and apparent perception.

With the rapid development of precise instruments and experimental techniques in the past century, ice is widely applied in many fields such as cryospheric science, atmospheric science, geology, geophysics, ice engineering, and cryobiology. The research on the microstructure and physical properties of ice has thus developed rapidly. The experimental observation in the early 20th century has made it clear that the ice in the nature is hexagonal crystal with some properties similar to those of other crystals (such as some metals and minerals). In the late 1940s, with the introduction of research methods of metallurgy and mechanics of materials, the experimental research on the physical and mechanical

Received: 2020-3-27
Supported by: Innovative Research Group Project of The National Natural Science Foundation of China (41121001); Major Projects of National Natural Science Foundation of China (41690140)

① Ren J W. Cryospheric Physics. Beijing, Science Press, to be published (in Chinese).

properties of ice became active. By the end of 1950s, researchers have made clear the basic mechanical properties of ice. Although ice as a solid has rigid brittleness, in addition to a certain elasticity, its plasticity is the most important at high temperature (the ice in the nature is close to melting point), and the main deformation belongs to creep category, which can be expressed as power function creep law. Meanwhile, massive experimental observations on other physical properties of ice have been carried out. By the 1960s–1970s, researchers had a general understanding of various physical properties of ice, establishing the basic concepts of ice physical properties [2].

The physical properties of ice are affected by many factors, such as temperature, stress, impurity composition and content, and ice structure (including fabric characteristics, crystallite dimension, density, and bubbles). These influencing factors are often uneven in space and time for huge ice bodies. The field observation and experimental study on the physical properties of various ice bodies have been kept on going, which improves basic concepts of physical properties and enriches the observation data of various types of ice.

1.2 Physical properties of cryospheric components

Since different cryospheric components undergo different physical processes, the research emphasis on their physical properties is different. Nevertheless, the studies generally focus on the water-heat dynamics.

(1) Glaciers. ① Dynamics. Ice flow and its related processes are the core of research on glacier dynamics. Therefore, the ice flow mechanism has been explored before the 19th century. However, due to the unclear understanding of the microstructure and rheological properties of ice, the mechanism of glacier movement has been in debate for a long time. It was not until the mid-20th century when experimental results of ice creep law surged that researchers reached consensus on glacier flow mechanism and established the basic theory of ice creep deformation under self-gravity and of sliding movement when the bottom temperature approached the melting point. Since the deformation of ice follows a power function, it is difficult to mathematically simulate glacier movement. Therefore, it is common to simulate the ice deformation approximately with ideal plastic body or viscous fluid. ② Thermodynamics. The research on glacier thermodynamics also has a long history. The early research mainly involved the description of temperature field. Afterwards, the dynamics simulation of ice was combined with that of glaciers. Further, the surface energy balance and material balance of glacier developed from empirical model to physical model and from single point model to distributed model [3].

(2) Frozen soil. The studies on physical properties of frozen soil focus on the coupling of water–heat transfer and the mechanical characteristics. Compared with that on glaciers, the research on frozen soil has a short history. In particular, the research on engineering-related problems in permafrost regions developed rapidly in the middle and late 20th century. The interaction of temperature and water is the key scientific problem in cyopedology. Water migration and phase transition play a decisive role in temperature, which in turn are directly affected by temperature. Frozen soil mechanics is a branch of both frozen soil physics and cryopedology, which has been attached great importance because it is the foundation of addressing the problems of frozen soil engineering. The water-heat process in freezing soil and thawing soil is accompanied by mechanical process, which causes frost heaving and thawing settlement of soil. Therefore, the temperature-water-force field coupling has become the essential problem of frozen soil research. In addition, soil and water often contain salt which influences the coupling and further the frost heaving and thawing settlement of soil. Hence, the temperature-water-force-salt field coupling has been concerned in recent years. The research on physical properties of frozen soil depends more on the observation and experiment of various soil samples in laboratory.

(3) Snow cover. Due to the existence of snow cover, the earth surface is no longer the underlying surface of the atmosphere. The high albedo of snow surface affects the surface energy balance, and the melting of snow is an important aspect of surface hydrological process. Therefore, the research on physical properties of snow cover is often associated with meteorology and hydrology. The research focuses on the quantitative description of various physical properties, the process of firnification, the migration and refreezing of water vapor in snow layer under the action of temperature gradient, the formation of depth hoar and snowboard, and the optical properties of snow and the melting of snow cover. Restricted by monitoring means, the early studies mainly focused on qualitative description and classification of the main physical properties and variation characteristics of snow. With the development of remote sensing and numerical simulation, the energy and mass transfer models of snow cover have been optimized.

(4) Sea ice. The research on the physical properties of sea ice has a short history, which can be summarized into two aspects. ① Physical mechanism of formation and evolution of large-scale sea ice (mainly Arctic sea ice and Antarctic sea ice). These studies center on the distribution of physical parameters related to sea ice, which serve to establish sea ice model and predict its change. Although the research history of Arctic sea ice is relatively long, it is basically within one hundred years. Thermodynamics is the hot topic in this research field, which is mainly studied on the basis of energy balance and material balance. Limited by field monitoring data, the early studies scattered on a certain parameter. With the development of remote sensing technology since the early 1990s, large-scale multi-parameter real-time monitoring data have been rapidly enriched, which facilitates systematic research on various physical parameters and related

processes of sea ice. ② Physical properties of sea ice engineering problems. The experimental studies on ice mechanics have been active. The studies in this field mainly focus on specific engineering problems such as ports and are scattered.

(5) River ice. Aiming at the formation, melting, disintegration, and icicle of river ice, the research in this field focuses on the coupling of ice thermodynamics and river hydraulics. Compared with that of other cryospheric components, the physics of river ice has a short research history and concentrates on engineering and disasters. Although the relevant research has a long history in North America, it has been mainly developed since the mid-20th century.

The middle and late 20th century witnessed the rapid progress of the research in ice physics and cryospheric physics. The basic concepts of physical properties of ice and cryospheric components have been roughly determined. The early studies on cryospheric components are relatively independent, and the comprehensive research on multiple components of cryosphere has attracted attention since the 21st century.

2 The research on cryospheric change and its effect needs to be supported by detailed studies of physical processes

In the scientific research of cryosphere, cryospheric change and its effect are the most concerned scientific questions. The simulation of cryosphere and its interaction with other spheres determines the prediction of cryospheric change and its effect, and the foundation of such simulation is the description of various physical processes in the cryosphere. The accuracy and detail level of describing the physical process related to cryosphere determine the reliability of simulation results. Therefore, the research on cryospheric physics supporting the simulation of cryospheric change and its effect needs to be emphasized.

2.1 The ability to acquire physical parameters of cryosphere needs to be improved

In-depth understanding and simulation of the cryospheric physical process requires comprehensive and systematic monitoring data, long enough monitoring time, and high monitoring efficiency and data sharing ability. ① The ground monitoring network should be improved. On the basis of the existing monitoring network, the layout of monitoring sites, as well as the monitoring equipment and data acquisition system should be optimized to enhance the ground monitoring capability. ② Independent remote sensing and space-based monitoring methods should be developed. The satellite remote sensing sensors for the cryosphere and the aerial monitoring technology should be developed to improve the aerospace monitoring capability. ③ The ability of data transmission and database application should be enhanced. A ground transmission system of monitoring data and a combined system of remote sensing and aerial monitoring data should be established. With the application of new technologies such as big data and cloud computing, the research and development of data products can be accelerated to achieve data sharing and improve the simulation of cryospheric physical processes.

2.2 The construction and research of cryosphere laboratory need to be strengthened

(1) Laboratory research is an important link in the research of cryospheric physics. The sample tests and simulation experiments in the laboratory can accurately measure some important physical parameters, as well as reveal important physical processes and the mutual influences of some parameters. Laboratory research needs much money to build laboratories, establishes various experimental environment control systems, and equip related instruments. Therefore, cryosphere laboratory mainly focuses on small and scattered experimental studies at present, especially the measurement of some physical parameters of samples and the experimental observation of single physical processes. Since the cryospheric change in the nature is the result of various physical processes, it is essential to investigate two or more physical processes by controlling the environmental conditions in the laboratory and reveal the mutual influences of several important physical processes for the laboratory simulation of combined processes of the cryosphere. Therefore, it is necessary to strengthen laboratory construction, especially entity and similarity simulations.

(2) Entity simulation, one of the development goals of cryosphere laboratory research, can be carried out with single targets or parameters, such as snowdrift start and movement, and static water and flowing water icing. It can also target certain comprehensive characteristics, such as frozen soil heaving-thawing and interaction between river ice and water flow. Such simulation can truly reproduce the physical process to be studied under artificial conditions, and thus establish an accurate quantitative relationship between relevant parameters. Since it is difficult to reproduce a complete cryospheric component or a large part of entity indoors, it is one of the development goals of laboratory research to build simulators similar to the natural state for observation and research. For example, we can build similarity models according to the principles of geometric similarity and physical similarity indoors to observe the movement of similarity samples by controlling the slope, water flow, pressure, and temperature, thereby revealing the movement patterns of glacier, sea ice, and river ice.

2.3 The coupling between cryospheric models and between models of cryosphere and other spheres should be promoted

As mentioned above, cryospheric change and its effect are the results of multiple physical processes, which need to be studied by the coupling between cryospheric models and between models of cryosphere and other spheres.

In the cryosphere, energy-material balance, mechanic, dynamic, and thermodynamic processes, as well as water migration and heat transfer, interact with each other. Therefore, other processes associated with it should be considered, so that a certain process can be accurately simulated. For glacier movement, temperature not only is an important parameter in the creep deformation of ice but also determines the movement and dynamics of glacier bottom, and the strain of ice and the sliding of ice body will generate heat to change the temperature. Therefore, the dynamic model and thermodynamic model of glacier should be combined for the modeling of glacier dynamics. Material balance is the driving factor of glacier change, and thus the distributed energy-material balance model showed be employed to accurately describe temporal and spatial changes of material balance. Water and heat in frozen soil are inseparable, and thus coupling of water migration with heat transfer is the core of frozen soil modeling. Besides, the mechanical problems of frozen soil are also closely related to the water-heat process. Snow cover variation involves not only the energy balance but also the infiltration and loss of meltwater. Although the increase and decrease of sea ice depends on the energy-material balance on the surface and inside, the interaction between sea ice and seawater is also important.

Cryospheric change is driven by climatic and environmental changes, which in turn affects climate, hydrology, ecology, etc. Therefore, the study of cryospheric change and its effect necessitates the model coupling of cryosphere with other spheres. For a long time in the past, on the one hand, the model development of cryospheric components is unbalanced; on the other hand, the model coupling between cryosphere and other spheres progresses slowly because of the different spatial-temporal scales and resolutions between model studies. Therefore, it is necessary to couple cryosphere model with models of other spheres to foster the research on cryospheric change and its effect.

3 Strengthening the research in cryospheric physics is the key to promote the research on cryosphere disasters and services

An important development direction of cryospheric science is to combine the research achievements with social and economic development, so as to meet the demand of the country and serve the sustainable development of local regions. According to the cryosphere distribution in China and its affected areas, as well as the national demand for ice and snow sports industry, the research on cryospheric physics in the near future should mainly center on the disaster prevention and cryospheric services.

3.1 Physical mechanism and prevention measures of cryosphere disasters

The cryosphere disasters are diverse and ubiquitous. With the rapid changes of cryosphere in the context of climate warming, the risk and influence of frequent cryosphere disasters are becoming increasingly serious. Especially in recent years, the hazards caused by glacier surging, glacier avalanche, glacier lake outburst, flood, glacial mud-rock flow, and permafrost collapse have aggravated. In addition, snowdrift, snowslide, freezing rain and snow, snowstorms, and river icicle have also attracted attention. Although the distribution, risk and risk management and control of these disasters have been studied, the engineering prevention measures that can be taken are not available. The increasing probability of cryosphere disasters necessitates engineering prevention measures. Therefore, systematic research should be carried out on the occurrence mechanism of cryosphere disasters, key physical parameters in engineering measures, disaster process simulation, and engineering efficiency, so as to provide scientific support for disaster prevention and control.

3.2 Cryospheric services—ice-snow sports and ice-snow tourism industry

Ice-snow sports and mass ice and snow entertainment are emerging products of the tertiary industry with ice and snow as the interface and belong to the humanistic services of cryosphere. Different types of ice-snow industry have different requirements for physical properties of ice and snow. China is rich in ice and snow resources, and the ice-snow sports and tourism industry have a bright prospect. Especially, the Beijing Winter Olympic Games in 2022 is an opportunity to promote Chinese people to participate in ice-snow sports and ice-snow tourism industry. At present, the ice-snow sports and tourism industry marked by the construction of skiing fields have flourished, with thousands of ski resorts built and operated in China, and more ski resorts are being built or planned. However, compared with those in foreign countries, the scale, quality, and operational efficiency of China's ski resorts are generally low. Especially, the ski tracks and snow quality are substandard. Some ski resorts in Northeast China with a long history as snow sports training bases in China, and even the ski resorts in Zhangjiakou Division of Beijing Winter Olympics, have challenges in ensuring the quality of ski tracks and snow as well as the running of the events. Therefore, it is necessary to carry out basic research on ice and snow physics to provide scientific support for it. The main research contents include the formation of snow particles under different temperature, humidity, and pressure (including wind speed) conditions, the changes of particle size, density, moisture, and hardness, the internal cohesion and surface friction characteristics of snow layer, the influence of snow-driving wind and winter fog, the technical indexes of artificial snow, and the snow storage technology of different scales. If necessary, the research on ice physical parameters in the construction and maintenance of skating rinks should also be carried out.

4 Conclusion

A large number of laboratorial studies and extensive field investigations in the middle and late of 20th century have determined the basic concepts of physical properties of ice and these cryospheric components. Since the end of the 20th century, the important role of cryosphere in climate and environment has made climatology the main line of cryospheric science, and the specialized research of cryospheric physics has been rare. At present, with the construction of cryosphere scientific system, more in-depth studies on the process of cryospheric physics are urgently needed for the quantitative study of cryospheric change and its effect as well as the services of cryosphere for social and economic development. Moreover, the microphysical properties and related processes of ice and snow should be clarified. The development of cryospheric science and the demand of the sustainable social and economic development put forward new requirements for research of cryospheric physics. The main research directions of cryospheric physics in recent years are focusing on the monitoring technology and data acquisition ability, laboratory entity and similarity simulations, multi-sphere coupling model, and detailed microphysical processes of ice and snow.

References

1 Qin D H, Yao T D, Ding Y J, et al. Introduction to Cryospheric Science. Beijing: Science Press, 2018 (in Chinese).
2 Hobbs P V. Ice Physics. Oxford: Clarendon Press, 1974.
3 Cuffey K M, Paterson W B S. The Physics of Glaciers. Amsterdam: Elsevier, 2010.

REN Jiawen, Professor of Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences. He has long been engaged in the research on glaciology and cryosphere and climate changes, with main focus on glacier physics. E-mail: jwren@lzb.ac.cn

