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Ten Years of Progress of the Tianshan Glaciological Station of China*

(中国天山冰川观测试验站 10 年回顾与展望)

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Abstract : This paper presents a review of the scientific work of the Tianshan Glaciological Station over the past 10 years. The progress of scientific research, student training and construction of the station is summarized. In addition a prospect is also given.

Key words : Tianshan Glaciological Station; scientific research; review

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1 INTRODUCTION

The Tianshan Glaciological Station, CAS, is a unique station that takes the glaciers and glaciated regions as its major observation and study object. Besides, it takes charge of glaciology observation, scientific research, and student training and works as a window in communicating to the outside word. The station has played a significant role for supporting and promoting glaciology developing in China since its foundation. Overlooking the procession of its construction and development, we conclude that in all aspects the station is vitally interrelated to the development of glaciology in China. Looking back and ahead, the station will face more opportunities and more challenges.

The Tianshan Glaciological Station was founded in 1959 under the direction and organization of academician Shi Yafeng. The scientific research of the station has gone through three stages: the initial stage after foundation (1959～1966), the stage after restoration (1979～1987) and the stage as an open station of the Chinese Academy of Science (1988～present). The station has become an observation, experimental and research field base with a certain fame in the world after decades of hard work. Kang Ersi reviewed the history and research work of the station before 1987 [1]. Now, we review the achievements from 1988 to 1997, together with a prospect.

2 THE GENERAL SITUATION OF SCIENTIFIC RESEARCH AND STUDENT TRAINING

The Tianshan Glaciological Station has become one of the first open field observation and research stations of the Chinese Academy of Sciences by getting through the open demonstration organized by the Bureau of Science and Technology for Resources and Environment, CAS, since September of 1987. Opening to the outside world made the scientific research of the station step into a new phase. A fund from the CAS effectively ensures the main studies to be compre - hen-

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sive and systematic, and attracts many experts and scholars to participate in the research with us under the monitoring of the academic committee of the station. The station has systematically done research on the three balances (energy, water and mass balances, and on seven processes of the glaciated regions including processes of glaciology, climatology, hydrology, periglacial phenomena, landform, development of Quaternary glaciations and ecology. Now, scientific research in the station has become an integrated one and a research system in the alpine regions is formed that takes the station as the base, glaciology as the key and the Urumqi River valley as the subject. The station has taken on 62 projects funded by the academic committee of the station. Besides, the station has taken on or participated in 16 international cooperation projects, 13 national natural science foundation projects including key projects, 5 "Seventh - Five - Year", "Ninth - Five - Year" major projects of the CAS, 2 national climbing and key projects and 8 transverse cooperation projects over the past ten years. International cooperation and scientific exchanges have been enhanced. It has cooperated early and late with scientists scientists from America, Canada, Japan, Russia, Kazakhstan, Switzerland and others and reached a lot of high level achievements. The projects that the station managed and participated in have won 2 second prizes of Science and Technology Progress, CAS, 2 second prizes of Natural Science, CAS, and one third prize of Science and Technology Achievement, National Committee of Education. About 300 papers have been published including 70 papers published in the proceedings of international symposia or foreign journals. Seven monographs were published including two in English and one in Russian. In addition, two monographs are in press. The Tianshan Glaciological Station got past the first inspection after being an open station in August of 1991. Because of its prominent achievements in scientific research and student training, the station was appraised as a station of class A and got the title of advanced collectivity in the field work in the open station inspection of the CAS in 1997.

Student training is one of the basic tasks of the Tianshan Glaciological Station. About 30 master's students and doctoral students have worked in the station, of which 13 master's students and 9 doctoral students have finished their theses and got the qualification. In addition, about 30 undergraduate students and graduate students of universities and other research institutions have been conducting their field work in the station.

3 NEW ADVANCES OF SCIENTIFIC RESEARCH

3.1 Research on the Movement Mechanisms and Physics of Glaciers

The Tianshan Glaciological Station has made a good contribution to further understanding owing the continental mountain glaciers by studying the movement mechanisms of the Urumqi Glacier No. 1. The station studied the water and heat transfer process of the wide wet snow zone that extensively exists in the continental alpine mountain in China and the influence of percolation process on the temperature of the upper wet snow zone. Besides, temperature distribution change models of glaciers in this region have been established [2,3] and some knowledge of the physics of glaciers has been renovated. Especially by field observation and test on the artificial ice tunnels excavated at the end of the Glacier No. 1, the movement mechanisms of glaciers have been studied in detail. Four kinds of movement mechanisms in the Glacier No. 1 have been put forward; they are deformation in ice, deformation in ice bed, shear layer and basal sliding [4~8]. Combining the temperature distribution of the Glacier No. 1 [9] and the temperature distribution of continental glaciers in China [10], three movement models of continental glaciers in China have been systematically summarized and put forward [6,7,11,12].

3.2 Research on Hydrology and Water Resources in Cold Regions

Hydrology and water resources in the alpine cold regions are one of the major research items of the Tianshan Glaciological Station. The station has made a long and systematic research on precipitation, evaporation and the forming process of runoff over the past 10

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years.

The error in precipitation measurement, evaporation and heat balance in alpine regions at the headwaters of the Urumqi River have been studied from 1985 to 1987. The results indicate that the systematic error of the ordinary precipitation observation is about 30 % at the headwaters of the Urumqi River, while about 20.5 % at the plains and the front regions of the mountain [13]. The annual capacity of evaporation is about 270 mm at the headwaters and the alpine meadow regions but about 127 mm at the surface of the Glacier No.1 [14, 15]. An energy - water balance model for the alpine region including glaciers and snow pack was worked out [16~19] that can better calculate the formation and variation of the runoff from glacier and snow melt. Moreover, the forming process of runoff in mountainous regions was systematically summarized [20]. By studying in Binggou Station in the Qilian Mountains for 6 years and the ice - free cirque at the headwaters of the Urumqi River for 5 years, a great deal of basic experimental data in cold regions has been accumulated, including the water balance components and the heat and water conditions in the active layer of permafrost. Based on the experiment and the water balance principles, the runoff formation and the water storage variation, the exchange between the surface water and the ground water and the impact of climate change on runoff in the alpine permafrost regions has been investigated. Furthermore, the impact of climate change on runoff in the cold regions was also studied [21,22]. All the results show that the runoff coefficient in the cold regions, 0.7～0.8, is higher than that in the regions without permafrost. Besides, the runoff coefficient varies with climate change and may drop to 0.45 in a drier year.

Global change has been a popular research field over the past 10 years. As snow and ice and runoff in mountainous regions are very sensitive to climate change, based on a great deal of observations in the Tianshan Glaciological Station, the variation of runoff from glaciers under different climate scenarios were estimated by using different models. The models used include the water balance model in abasin [23~25], the energy - water balance model [26], and the degree - day model [27]. All the results show the glacier runoff will increase more than 50 % of the present if temperature rises 1 K. Meanwhile, the impact of climate change on glaciers and runoff from glaciers was estimated by using the glacier dynamics method [28]. From the water balance method, the results of the impact of climate change on runoff at the headwaters of the Urumqi River and the Yili River indicate that the seasonal distribution of runoff will change under climate warming. That is, runoff will increase in spring and decrease in the other seasons, the range of the increasing and decreasing is determined by the nourishment ratio of the meltwater and the rising range of temperature. Another consequence of temperature increasing is increasing the long - term variation of runoff. In addition, the forming process of snow cover and its nourishment to the river was also studied [29~31]. An observation on river ice at the headwaters of the Urumqi River indicates that the river ice storage is 1.9×10^6 m^3 in a normal year. Most of the river ice melts in April and May and occupies 6.4 % of the runoff during the same period, which mitigates the shortage of agricultural water in spring.

In addition, the chemistry of meltwater was also studied [32~34]. The chemical components of winter snow at the headwaters come from the local weathering substances. The stream flow has alkalinity because of the high concentration of HCO_3^- produced by the interaction between water and rock, though the concentration of SO_4^{2-} is as high as 550 $\mu eq \cdot L^{-1}$. An "ion pulse" phenomenon in snow meltwater in the alpine regions of China was discovered firstly [35]. That is, the ions in the runoff from snow melting are as high as a pulse, similar to an electric one, during the days when snow begins to melt in spring. The primary reason of the phenomenon is the eluviation of free water and the transportation and enrichment of the ions produced by the eluviation before snow ablation.

3.3 Research on the Fluctuation of Glaciers Relating to Climate Change

3.3.1 Glacier monitoring

Mass balance of glaciers and glacier fluctuation are the major observing items of the Tianshan Glaciological Station. Thus the Glacier No. 1 has become one of the

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key international glaciers and the observation data has been quoted extensively. The observations in the Glacier No. 1 have been periodically published on the *Fluctuation of Glacier* (one issue every 5 years) which was edited by the International Association of Hydrological Science (International Commission on Snow and Ice), the United Nations Environment Programme and the United Nations Educational, Scientific and Cultural Organization (IAHS (ICSI) - UNEP - UNSCO). At the same time, the Glacier No. 1 was selected as one of the 10 global representative glaciers for 4 times, the detailed observation data was published in the *Glacier Mass Balance Bulletin* (one issue every 2 years) which was also compiled by the IAHS (ICSI) - UNEP - UNSCO. The data as an Asian representative was also recomposed and periodically published on the *Environmental Data Report* that was sponsored by United Nations Environmental Programme (UNEP).

3.3.2　Study on the mass balance of glaciers

Mass balance of glaciers is a major research item of glaciology. The Tianshan Glaciological Station did research on the formation process of glacier mass balance in detail based on an observation in the Glacier No. 1 [36]. In combination with observations other glaciers, estimation and reconstruction of mass balance and its variation were studied by using the method of comparing temperature, precipitation and mass balance [37], the energy balance model [17,18,38], the degree - day method [27,39], and the precipitation - summer temperature method (P - T method) [40] *et al*. At the same time, the mass balance observation series of 17 glaciers on the High Asia were analyzed using numerical filter, period analysis, principal element analysis and non - parameterized graded statistics [41]. It was found that variation of the mass balance is similar within a certain space distance and the regional difference becomes evident as the distance increases. Meanwhile, it was found that there exists a quasi - 2 - year cycle of mass balance, similar to the climate variation, and an abrupt variation during the middle of the 1970's in this region.

3.3.3　Study on the glacier fluctuation in different time scales

The Tianshan Glaciological Station studied the glacier fluctuation in different time scales and space scales in recent years using different comparison methods. The Glacier No. 1 at the headwaters of the Urumqi River retreated 146 m, equivalent to a mass balance of 6 014 mm, from 1959 to 1977. The causes of the fluctuation and the climate change trend and range resulting in the retreat were analyzed in detail [42～45]. The glacier fluctuation at the headwaters of the Urumqi River was also studied using repeated aerial photogrammetry [46,47] from 1964 to 1992, that is a method for studying the glacier fluctuation in a large region. The glacier fluctuation in the Tianshan Mountains and Qilian Mountains since the Little Ice Age was studied by in - situ investigation and on topographic maps [48]. The glacier development condition and its response to climate change were researched by means of space comparison method and the glacier dynamics method [28,49,50]. The results from different methods show that the larger the scale of the glacier, the larger the absolute change of the glacier, and the less the relative change. The sensitivity of glaciers to climate change increases from continental climate to maritime climate of the glaciated region. The change of the glaciers under future warming scenarios was estimated by using many methods. It was revealed that the glacierized area in Northwest China will decrease 15 % ～45 % if the future temperature goes up 1 K [28,48～50].

3.3.4　Study on the glaciers in the Tianshan Mountains

The Tianshan Glaciological Station carried out and cooperated with the Geography Institute of the Russian Academy of Sciences to firstly systematically investigate glaciers on the Tianshan Mountains in Central Asia [51]. It was found that there are about 15 973 glaciers on the Tianshan Mountains, with an area of 15 416.41 km^2 and a volume of 1 048.14 km^3, respectively. The glaciers are mainly concentrated in the Central Tianshan Mountains and the water systems around the Tarim Basin. Glacier scale and the snow line altitude depends on latitude rather than longitude. Most of the rivers in the Tianshan Mountains belong to Tianshan type according to their forming process of runoff, characterized by two peaks each year due to snow melt and

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glacier melt in the ablation season. The annual mean meltwater of all the rivers is approximately 1.32×10^{10} m^3, accounting for 20 % of the overall river runoff from the Tianshan Mountains. The nourishment ratio increases with increase in glaciated extent and dryness. Therefore, water systems around the Tarim Basin has the maximum nourishment ratio, 47 % [52, 53].

3.4 The Modern Process of Ice Records

Together with the Laboratory of Ice Core and Cold Regions Environment, the Tianshan Glaciological Station carried out the research of recovering the ice core records and the exchanging process of chemical substances between the cryosphere and the atmosphere. The research was supported by the newly built Atmospheric Chemical Observation Net. As a part of the research items, the station founded a spot for snow sampling and observation, collected samples for one year and extracted an ice core to bedrock, 80.04 m in depth, and a shallow ice core, 6.62 m in depth, at the elevation of 4 035 m in the Glacier No. 1. This study is a focus and frontier project for global change and cryosphere research at present and is cooperating with the ice core research institution of America, Norway, etc.

3.5 Research on the Change of the Ecology System in Alpine Regions

The ecology system in the drainage area of the Urumqi River is a representative for studying the vegetation types of different climate zones and the alternate change of species in the alpine regions. In addition, the ecology system in the cryosphere is very sensitive to climate and environment changes because of its vulnerability. Therefore, the research on the ecology system in the regions can provide a theory foundation for studying the regional environment and resources and for their conservation. This work cooperating with the Institute of Plateau Biology, CAS, funded by the station, has made a good foundation for further research. The work included investigating the vegetation types at the headwaters of the Urumqi River, inventorying the seed plant and drawing sketch maps showing the distribution of various plant categories.

Many peculiar biological properties of snow lotus such as cold - relief, ability to effectively utilize the heat resources and to endure oxygen - shortage were revealed by a key project of the Xinjiang Science and Technology Committee cooperating with the Xinjiang Agricultural University and Xinjiang Normal University. The know - how of cultivating and artificially growing seedlings of wild snow lotus (saussurea) was acquired and seeds for artificially cultivating can be provided [54]. An artificially cultivated experimental field and an artificially grown seedlings laboratory of snow lotus was founded at the Tianshan Glaciological Station. The results of this project are valuable for developing snow lotus. In addition, research on medical components of snow lotus and coccinea is going on, and data for further study is accumulating.

3.6 Research on Permafrost and Its Temperature Variation in Alpine Regions

The formation conditions, the influencing factors and the distribution conditions of the alpine permafrost were researched in detail by cooperating with the Russian Academy of Sciences [55~58]. It was found that there are about 6.3×10^4 km^2 permafrost in the Tianshan Mountains in China. Less snow in winter and more snow in summer is rather favored for the formation and conservation of permafrost in the mountains. In addition, the glacial troughs being seriously uplifted and the sediments in the troughs being thickened provide a good substantial condition for the formation of permafrost in the valleys of the Tianshan Mountains. Permafrost at the headwaters of the Urumqi River appears in the region above 2 900 m in the shady slopes and 3 250 m in the sunny slopes, that is, the low limit of permafrost is approximately identical with the 2 ℃ isotherm. The thickness of permafrost increases with elevation. The annual mean ground temperature decreases from 0.7 ℃ at the elevation of 3 348 m to 4.9 ℃ at the elevation of 3 900 m, and the depth of the annual temperature variation layer is from 10 to 18 m. Moreover, the variation process of permafrost since the Last Glacier Maximum has been explored using a pollen and mineralmethod [59]. Part of the results of this project were presented at the Sixth International Con-

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ference of Permafrost in 1993 and was appreciated by the experts who participated in the Conference. The major results of this project were published in *Studies of Alpine Permafrost in Central Asia*(1) (*Yakutsk*), which was co - authored by the Lanzhou Institute of Glaciology and Geocryology, CAS, and the Permafrost Institute, Siberrian Branch, Russian Academy of Sciences.

Permafrost temperature in the alpine regions in Central Asia is a major aspect for studying the mountainous climate change in the Central Asia. Based on joint research of China and Russia, and a joint project of China and Japan in monitoring permafrost temperature at 43°N, a successive stationary monitoring on ground temperature at the headwaters of the Urumqi River was made for 6 a. It was found that at the ground temperature between 0.5 and 2.0 m deep a rising trend appeared while a slowly decreasing trend appeared between 10 and 18 m deep from 1990 to 1996 at the elevation of about 3 300 m in theheadwaters [60,61]. At present the monitoring on the permafrost temperature at the headwaters has become a basic permanent observation item and will provide a credible foundation for studying the environmental change in the alpine permafrost regions.

3.7 Research on Glacial Landforms and Quaternary Glaciations

The glacial landform and the sediment process has been observed successively in fixed sites over the past ten years at the region of the Tianshan Glaciological Station and at the headwaters of the Kiines River. The observation objects are the rock glacier, sorted polygon, rock river, qilifluction, talus and frost mound etc. The formation features and developing process of the glacial landforms were comprehensively analyzed [62~73]. The achievements of this project promoted the research on the glacial landform from qualitative to quantitative, from describing phenomena to exploring formation mechanisms, from statics to dynamics, and established a good foundation for dynamic simulation in future. Therefore, these achievements have important theoretical and practical meanings and provide a wealth of basic data for researching the process of glacial geomorphology and for highway planning in mountain regions. The major achievements acquired were summarized in the *Land Processes and Sediment Features of Cryosphere in Tianshan Mountains, China* [64] and *Research on Modern Periglacial Land* [74].

There are glacial relics of the Last Glacier Maximum preserved perfectly in the alpine regions in Northwest China. The drainage of the Urumqi River is a key region for studying the glaciation in the Last Glacier Maximum. The extent of the glaciers and the climate condition in the Last Glacier Maximum were estimated at the headwaters of the Urumqi River by means of in - situ investigation and on topographic maps [75]. At the same time, the research area of the Quaternary glaciations was extended to the east Tianshan Mountains, such as the Bogda Mountains, Barkol Mountains and Karik Mountains. A large - scale map showing the glacier distribution at the above - mentioned regions in the Last Glacier Maximum has nearly been finished.

3.8 Reestablishment of the Time Series of Tree Rings and Paleoclimate

Choosing 9 sample sites, collecting 190 tree samples and 280 time series, Li Jiangfeng *et al*. established 9 time tables, with the longest of 452 a and the shortest of 195 a in the 800 km^2 headwaters of the Urumqi River, and then reestablished a 250 a series of the annual mean temperature and runoff by using a tree - ring climatology method [76]. The series is favorable for studying the environmental changes since the Little Ice Age in the Tianshan Mountains.

3.9 Information System

As a observation and research base, an advanced system of information and data management is very important. The Tianshan Glaciological Station has begun to establish its information system since 1995. The major task of the information system is to quantitatively manage all kinds of research items and observation data of the station by using computers and provide an advanced means for communicating information.

4 REALITY AND PROSPECT

The superiority and its peculiarity are the foundations for the Tianshan Glaciological Station to develop

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in the future. The station has gradually formed its bright character through many glaciologists making their unremitting efforts. The station has become a representation located in the Central Asia interior region for monitoring the cryosphere dynamic variation connected with the global change observation net, a experimental base of the basic research on the cryosphere and a testing field for studying water resources in the cold and arid regions. The scientific activities are performed taking glaciers as a major object and studying all the components of the cryosphere. Therefore, it is more integrated and joined to international cryosphere research. Monitoring the cryosphere dynamic variation and basic research will be the principal research direction for the station.

The Chinese Academy of Science emphasizes the importance of field work, especially observation in field stations. The dean Lu Yongxiang warmly praised the great success in basic research of the Tianshan Glaciological Station when he visited the station in September 1996. He said it was very honorable that the station had acquired such high level achievements in such hard conditions and impressed him very much. The water resources change due to the glacier change was attracted the vice premier Jiang Chungyun's attention when he had an informal discussion with the deputies of the Second Field Working Meeting, CAS, Beijing, December of 1997. Lu Yongxiang highly praised the great achievements in the field work of the CAS and pointed out that the field work is unable to be substituted for. In the meanwhile, a proposal that takes the excellent field observation stations as the state key laboratory is under discussion to put into effect. The Tianshan Glaciological Station is now situated in an advantageous position facing the new opportunity and challenge. Grasping opportunity and sparing no effort to strive, it is sure to have a new and rapid development. We should get a clear understanding of the present situation of the station when looking forward tomorrow permeating with hope. The history of the station is nearly as long as the Lanzhou Institute of Glaciology and Geocryology, CAS. From the beginning of its foundation, many glaciologists struggled and dedicated their youth to the station. The older and younger generations of glaciologists lay their hope on it. Each session of leaders makes effort to find new growing points to meet the new situation because of its importance in glaciology development.

Among institutions of scientific research, competition for survival and development is going on with the deepening of the science and technology system reform in recent years. If a field station wants to survive and develop, it must have a distinct development direction, high level scientific achievements, and strong competition power and agglomerate ability. The Tianshan Glaciological Station has its superiority and peculiarity at present, but superiority and opportunity can vanish easily and lag behind in the keen competition. So the station is facing enormous pressure and challenge. The station not only needs its leaders having responsibility and a devoted spirit but also needs to be collectivity united and good at fighting. For instance, the station has depended on the wisdom and power of the collectivity to fight the serious flood in July 1996. The basal hydrologic section was reconstructed, and the road to the Glacier No. 1 and the power supply line of the station were repaired in a short time with less cost at that time.

The competition of science and technology is the competition of talents in the final analysis. The Tianshan Glaciological Station has made progress in cultivating talent in recent years, but still has a long way to go compared with other 14 key stations. With the present condition of the station, it is very hard to keep a stable group of outstanding youth. The way out is to establish our own group of graduate students as far as possible, and cultivate more graduate students facing the station's future.

Shortage of funds is the major problem that the Tianshan Glaciological Station faces for the long term. The station has been operated with dificits in recent years. The development of the station mainly depends on the support of the extra income besides the foundations and operating expenses. The foundations and operating expenses were about 1 700 000 yuan from 1992 to 1997, while the other incomes were about 2 000 000

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yuan at the same time. Therefore, financial support from all aspects is the basic guarantee for sustainable development of the station.

The experience for years makes us understand that the Tianshan Glaciological Station can not move without the support of the LIGG and the CAS, as it is a part of the LIGG, as well as the support from the glaciologists of the older generation. Their high attention to and support for the work of the field station makes the Tianshan Glaciological Station have great opportunities to develop. They are always the powerful backing of the station. In the same way, the station can not move without the highly effective work of the experts, scholars, and graduate students inside and outside the institute. Their scientific achievements are the foothold of the station. In addition, it is the observers and the casual laborers who are far away from their family and relatives dedicate their time to the station. Let us jointly make great efforts hand in hand and work hard for making the Tianshan Glaciological Station become an first - class international glaciological station in the near future.

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