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Overview of China's Antarctic research progress 1984–2016

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Abstract It is more than 30 years since the first Chinese National Antarctic Research Expedition (CHINARE) landed in Antarctica in 1984, representing China's initiation in polar research. This review briefly summarizes the Chinese Antarctic scientific research and output accomplished over the past 30 years. The developments and progress in Antarctic research and the enhancement of international scientific cooperation achieved through the implementation of the CHINARE program have been remarkable. Since the 1980s, four permanent Chinese Antarctic research stations have been established successively and 33 CHINAREs have been completed. The research results have been derived from a series of spatiotemporal observations in association with various projects and multidisciplinary studies in the fields of oceanography, glaciology, geology, geophysics, geochemistry, atmospheric science, upper atmospheric physics, Antarctic astronomy, biology and ecology, human medicine, polar environment observation, and polar engineering.

Keywords **China's research, in situ observation, multidisciplinary research, Great Wall Station, Zhongshan Station, Kunlun Station, R/V *Xuelong*, Antarctica**

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1 Chinese National Antarctic Research Expedition

The Antarctic has an important role in global climate change, human survival, and social sustainability. It is therefore a mission of common interest for the communities of the world to explore and protect the Antarctic in order to enrich scientific knowledge and to facilitate sustainable development. To this end, over the past three decades, China has undertaken many Antarctic research programs and projects, which have elicited innovative cognitions.

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The Chinese National Antarctic Research Expedition (CHINARE) program, established in 1984, has undergone a warm-up phase (1980–2000) and a booming period (2001–2015). Two young Chinese scientists were dispatched to participate in the Australian Antarctic expedition from December 1979 to March 1980 (Wu, 1994). The Chinese National Committee on Antarctic Expedition was founded in May 1981 (CAA, 2015). China dispatched its first national Antarctic expedition team to land on King George Island, Antarctic Peninsula and to perform surveys in the Southern Ocean in November 1984 (Wu, 1994). Over the past three decades, a Chinese Antarctic observational network has taken shape, and a basic Antarctic exploration and research system that was supported by government departments, institutions, and universities has been established. China has launched 33 CHINAREs that have involved multidisciplinary surveys covering geosciences, life sciences, physical sciences, and astronomy. In particular, 10 integrated oversnow traverses and two extensive aeronautic geophysics surveys around the inland ice sheet of East Antarctica (SOA, 2017), as well as 27 oceanographic surveys in the Southern Ocean have been conducted. A reference base station of the Beidou Satellites Navigation System has been established in Antarctica and a geodetic datum system of the Antarctic region has been developed. The CHINARE surveying and mapping programs have resulted in over 400 maps covering nearly 300000 km^2 of Antarctica being compiled, over 300 Antarctic locations being formally named, and the publication of the Atlas of Arctic & Antarctica. China has now collected 12665 pieces of meteorite in Antarctica (CAA, 2017), which ranks the third in the world, and these have played a significant role in China's initiative of deep space exploration of the Moon and Mars.

1.1 Antarctic expedition infrastructure

Reflecting its national economic development and the rapid progress in science and technology, China has been gradually constructing and upgrading the infrastructure of its Antarctic expeditions and scientific research platforms to facilitate further Antarctic science programs and projects (CAA, 2015; SOA, 2017).

China has established its national Antarctic observation network, which is integrated with land-based, airborne, sea-based, vessel-borne, ice-tethered, and seabed-based platforms, and provides dynamic logistic support to China's Antarctic expeditions and research (Table 1).

Table 1 Key Chinese Antarctic logistical platforms

Year	Name	Location	Detail
1985	Great Wall Station	King George Island in West Antarctica	The first permanent station
1986	*Jidi* vessel	Its maiden voyage to Antarctica in 1986/1987	Retired
1989	Zhongshan Station	Larsemann Hills, East Antarctica	The second permanent station of China
1994	R/V *Xuelong* (Snow Dragon)	Its maiden voyage to Antarctica in 1994/1995	Still in service
1996–1997 austral summer	Inland expedition detachment	First traverse expedition during CHINARE-13, travelling 300 km	Traverse from Zhongshan Station towards Dome A
2005	First traverse reached Dome A, the summit of Antarctic ice sheet		China became the first country to reach Dome A overland
2007	Domestic base of polar expedition	Shanghai	Mother port of R/V *Xuelong*
2009	Kunlun Station	Dome A, 1258 km fromZhongshan Station	Inland station, summer station
2014	Taishan Station (relay station)	Princess Elizebeth Land, 520 km from Zhongshan Station	Inland station, summer station
2015	*Xueying* 601(Snow Eagle)	Maiden flight in 2015/2016 during CHINARE-32	The first fixed wing aircraft

1.2 Survey areas and scopes of Antarctic expeditions

Since its first expedition to the South Shetland Islands of West Antarctica in 1984 and the foundation of Great Wall Station in 1985, China has been dispatching multidisciplinary Antarctic expeditions annually. The ongoing evolution of the CHINARE program in the Antarctic is presented in Table 2.

2 CHINARE progress and scientific output

The ethos of the CHINARE program is to undertake Antarcticscientific studies in the pursuit of greater understanding, protection, and peaceful utilization of Antarctica. By intensifying its basic scientific research and promoting active studies on the frontier scientific issues of Antarctica, China has attained some outstanding achievements in fields such as glaciology, space science, and climate change studies. Nationally, scientific research institutes and resources have been organized to participate in Antarctic research with the CHINARE program as a platform. A stable scientific research force dedicated to Antarctic study has been formed, which embraces a wide range of disciplines and systems. Furthermore, key laboratories

Table 2 Important events of the CHINARE program

Year	Event/program	Detail
1989	The first expedition to Larsemann Hills and Prydz Bay region in East Antarctica;	Zhongshan Station was built, a research base and a logistic base for Antarctic traverse expeditions.
1996	The first traverse expedition on the Antarctic ice sheet	China became one of eight countries with capability of Antarctic inland expeditions
1998	The first expedition to the Grove Mountains region, inland of the East Antarctic ice sheet	Multidisciplinary investigation in nunatak region
2005	Expedition to the Dome A, reached the summit of Antarctic ice sheet	China became the first country to reach Dome A overland
2007−2008	China undertook Prydz Bay, Amery Ice Shelf and Dome A Observatories (PANDA) project during the International Polar Year (IPY) 2007−2008	PANDA was the major Chinese-led contribution to IPY 2007−2008. The distance between Dome A and Prydz Bay, is more than 1200 km
2012−2017	Chinese Polar Environment Comprehensive Investigation and Assessment Programs	A special nationally supported project for Arctic and Antarctic research, with five years duration
1984−2016	27 cruises to the Southern Ocean	*Xiangyanghong 10* vessel (one cruise, 1984)*; Jidi* vessel (six cruises, 1986−1993); R/V *Xuelong* (19 cruises, 1994−2016). In 2012, China joined the South Ocean Observation System (SOOS)

Notes: Information from Wu (1994), and CAA (2015), and SOA (2017) with minor modification.

have been established to advance research in areas such as Antarctic oceanography, surveying and mapping, remote sensing, and atmospheric chemistry. Since its inception more than 30 years ago, the CHINARE program has evolved from monodisciplinary studies toward an integrated multidiscipline exercise.

Chinese scientists have made great progress in Antarctic research following each CHINARE. The number of papers on Antarctic studies published in SCI indexed journals and by Chinese scientists increased from 19 in 1999 to 157 in 2016, placing China amongst the top 10 countries with published Antarctic scientific research (SOA, 2017). Four papers have been published in top international journals such as Nature and Science, which represents a major breakthrough for China within the Antarctic research community (Zhang et al., 2013; Wu et al., 2011; Sun et al., 2009; Sun et al., 2000). Research undertaken by China in Antarctica has covered the entire range of vertical spheres from outer space, to the atmosphere, ocean, glaciers, and the surface and interior of the Earth. The Natural Science Foundation of China and other Chinese science and technology programs have continuously increased their contributions of funding for Antarctic research. According to incomplete statistics, the funding budgets on Antarctic science programs during 2001–2016 totaled RMB 310 million, 18 times as budgets during 1985–2000 (SOA, 2017).

2.1 Oceanography and Southern Ocean changes in response to climate change

In the fields of marine survey and research, a multidisciplinary marine observation system has been completed to embrace various in situ observation techniques that include moorings and buoys, in addition to the deployment of ship-borne platforms. Substantial progress has been made in the research fields of physical oceanography, marine chemistry, and marine biology and ecology (Chen et al., 2017; Li et al., 2017; Li and Yang, 2017; Gao et al., 2016; Shi et al., 2013).

In studies of climate change, the multidisciplinary monitoring section off East Antarctica at 73°E in Prydz Bay has been incorporated as a long-term monitoring section and monitoring system of the Climate and Ocean: Variability, Predictability and Change (CLIVAR, one of the four core projects of the World Climate Research Programme). Studies have been undertaken focusing on the patterns of change of the Southern Ocean sea ice and on the correlations between sea ice change and Earth's climate system, particularly in relation to China (Bian et al., 2008; Xue et al., 2003; Chen et al., 1996; Dong and Liang, 1993). Success has been underscored by the identification of various trends of the response of the Southern Ocean water mass to global climate change (Shi et al., 2013). These have revealed various biogeochemical features of the impact of climate change and the associated behavioral patterns of the principal biogenic elements of this region. Furthermore, the research has prompted the development of techniques for estimations of the cycle and flux of carbon in the Southern Ocean (Chen et al., 2017, 2011; Xu et al., 2015; Zhan et al., 2015; Lei et al., 2010; Lu et al., 2008; Huang et al., 2004; Gao et al., 2001; Hu and Zhang, 2001). Substantial progress has been recorded in relation to the Antarctic Circumpolar Current (ACC), Southern Ocean front and eddies, circulation in Prydz Bay, and ocean–ice shelf interactions (Chen et al., 2017; Gao et al., 2016, 2013; Shi et al., 2013; Chao and Li, 2011; Pu and Dong, 2003; Xue et al., 2003; Le and Shi, 1997).

2.2 Glaciology

In the research field of Antarctic glaciology, China has

completed an integrated investigation on the traverse route between Zhongshan Station and Dome A. Along this traverse, several automatic meteorological stations have been installed, and massive data sets on glaciochemistry, glaciological physics, meteorology and climatology, and subglacial topography have been acquired (Bian et al., 2016a; Shi et al., 2015; Ding et al., 2011; Lu and Bian, 2011; Cui et al., 2010; Zhang et al., 2008; Hou et al., 2007; Ren et al., 2001; Yan et al., 2001). Detailed surveys on the ice-thickness distribution of Dome A and the terrain of the Gamburtsev Mountain Range underneath the ice sheet have been accomplished. These have revealed for the first time the actual terrain of the mountains and valleys in the core region of this mountain range, which represents a substantial breakthrough in the exploration of the origin and evolution of the Antarctic ice sheet (Cui et al., 2010; Sun et al., 2009). In addition, the chemistry of the surface snow along this traverse, i.e., the major chemical ion concentrations and water isotopic compositions, has been investigated in detail (Ma et al., 2017; Yu et al., 2017; Shi et al., 2015). Furthermore, a deep ice-core drilling program began in summer 2012/2013 at the Chinese Kunlun Station on Dome A. By summer 2016/2017, a total of more than 800 m of ice core had been retrieved. From the associated modeling work on ice sheet dynamics, it is expected that the Dome A deep ice core will provide a record of climate change of up to one million years (Sun et al., 2014; Tang et al., 2012).

2.3 Geology and geophysics

In the area of scientific observation and research of the solid earth, China has established the stratigraphic sequence of Fildes Peninsula on King George Island, dating the volcanic strata and identifying the Pan-African tectonothermal event in Prydz Bay (Zhao, 2003). This has modified the accepted idea of the formation of the East Antarctic continent. Geological surveys and studies in the Grove Mountains region have resulted in a detailed description of the historical process of the advance and retreat of the East Antarctic ice sheet since the early Pliocene epoch (Liu et al., 2006, 2004), which has enriched the understanding of global sea level eustasy. The coastal geological survey along the eastern edge of the Amery Ice Shelf–Prydz Bay, from which a 1∶500000 scale geological map of the Prydz Bay orogenic belt has been produced, has verified that the Pan-African Prydz Bay tectonic belt of Antarctica represents a collisional orogenic belt (Liu, et al., 2009; Chen, 2008; Zhao, 2003). Surveying and mapping for 1:50000 scale topographic maps of the Prince Charles and Grove mountains regions have been completed with the help of autonomous remote sensing satellite data (E and Zhang, 2012; E et al., 2000). The investigation of erratic rocks and sands of a boulder clay band to the southeast of the Vestfold Hills in East Antarctica has confirmed the existence of Archean rocks (of 3.5 Ga age) and ascertained their petrographic provenance. Ten natural earthquake seismometers have been installed successfully in inland Antarctica. These represent an initial capability for continuous monitoring of natural earthquakes in the Dome A, Grove Mountains, and Larsemann Hills regions, and they will help in the acquisition of high-precision data on the crustal and lithospheric structures of the East Antarctic plate (An et al., 2016; Feng et al., 2014). Aerial photogrammetry of Antarctica has resulted in the acquisition of aerial images and aerial topographic maps of the Larsemann Hills and Fildes Peninsula regions. The accomplishment of on site acquisition and calibration of Antarctic remote sensing data has promoted research on topographical and geological mapping, ice flow velocity, and ice and snow changes.

2.4 Atmospheric science

At the forefront of CHINARE atmospheric observations and studies, the Great Wall Meteorological Station (62°12′S, 58°57′W) and Zhongshan Meteorological Station (69°22′S, 76°22′E) were established in 1984 and 1989, respectively. These have since been incorporated into the Antarctic Basic Synoptic Network, Antarctic Basic Climate Network, and the observation network of the World Meteorological Organization. The observational data from both stations have become the foundation for studies of climate change in Antarctica. Seven automatic meteorological stations have been installed on the Antarctic ice sheet since 2002, and their data fill the observational gap between Zhongshan and Kunlun stations (Bian et al., 2016a, 2011; Lu et al., 2011). Substantial achievements have been realized in terms of the structure and the energy balance of the atmospheric boundary layer in polar regions (Wang et al., 2014; Rinke et al., 2012; Ma et al., 2010), evaluation of the atmospheric environment (Bian et al., 2016b, 2012; Ye et al., 2016; Sun et al., 2014), sea–ice–atmosphere interactions, and the teleconnection mechanism of polar climate impact on China (Bian et al., 2008; Chen et al., 2003).

2.5 Upper atmospheric physics

In the field of space physics studies, a comprehensive upper atmospheric physics observational system that includes auroral, polar ionospheric, geomagnetic field, and space plasma wave observations has been established at Zhongshan Station to exploit its special geographic location at a cusp latitude (He et al., 2016; Liu and Yang, 2012). The cusp is a unique entrance of solar wind energy and particles in geospace. Zhongshan Station is involved in the national key science and technology infrastructure program called the Meridian Space Weather Monitoring Project (Meridian Project) and the international Super Dual Auroral Radar Network (Hu et al., 2013). Zhongshan Station and the Chinese Yellow River Station at Svalbard in the Arctic form a unique conjugate pair at cusp latitudes. Research based on their observations has produced new findings on aurora (Han et al., 2017, 2016; Hu et al., 2017, 2014; Yang et al., 2000), the polar ionosphere (Zhang et al., 2004), plasma convection (Hu et al., 2006), and space plasma waves (Liu

et al., 2008, 2003, 1999). For example, an abnormal phenomenon in the polar ionosphere at cusp latitudes was found around local magnetic noon (Liu et al., 1999), which was explained by cusp precipitation and plasma convection based on the polar ionospheric model developed by Zhang et al. (2015). In addition, a transient decrease of discrete aurora and simultaneous ionospheric plasma flow reversal for a short period just after shock arrival, i.e., during the preliminary impulse of a sudden commencement event, was first reported by Liu et al. (2011). Moreover, direct observation of the evolutionary cycle of a polar patch during a major storm was first reported by Zhang et al. (2013).

2.6 Antarctic astronomy

In the area of Antarctic astronomy, three sets of Antarctic astronomical assurance platforms have been installed at Kunlun Station. These have provided actual measurements of ground-based astronomical "seeing" at Dome A, acquiring measured data of sky brightness during the polar night, atmospheric transparency, and auroral impact (Yang et al., 2017; Zou et al., 2010; Yang et al., 2009). Monitoring has been undertaken both on the altitude of the atmospheric boundary layer and on atmospheric turbulence intensity (Bonner et al., 2010). Furthermore, continuous monitoring of terahertz transmittance has been performed (Yang et al., 2010). Substantial amounts of sky survey data have been acquired through the use of two Antarctic sky survey telescopes (with an effective aperture of 50 cm) (Yuan et al., 2012) and an Antarctic bright star survey telescope (with an effective aperture of 30 cm) (Li et al., 2015). A solid foundation has been established on which China is set to expand its outer space observations from the northern to the southern celestial hemisphere (Wang L et al., 2017, 2013, 2011; Wang S et al., 2015, 2014, 2012; Yang et al., 2015; Zong et al., 2015; Zhou et al., 2010).

2.7 Life science

By developing life science studies of different environments, such as land, freshwater, intertidal zone, and shallow water ecosystems of Fildes Peninsula and Prydz Bay, long-term monitoring has resulted in quantitative analyses of the key elements and the main features of each ecosystem, and the establishment of models of interactions amongst the ecosystems (Li et al., 2017; Yang G et al., 2017, 2016, 2013, 2011; Yang L et al., 2017; Li et al., 2017; Yang et al., 2017; Gao et al., 2015; Li, 2004; Zhang and Sun, 2000; Ning et al., 1996; Sun et al., 1995; Zhu and Wang, 1995; Zhu, 1991). The ecosystem background survey at Great Wall Station, which commenced in 2012, has initially determined long-term observation locations, elements, and methodologies (Ma et al., 2013; Lu et al., 2011; He et al., 2011; Zhu et al., 2004).

Chinese scientists have also systemically studied the interactions between Antarctic extreme environments and human health. Such investigations have revealed the physiological and psychological adaptation mechanism of Antarctic expeditioners to extreme environmental factors. For example, the adaptation patterns of Chinese Antarctic expeditioners in relation both to different environmental factors and to the durations and requirements of research tasks have been obtained, and the underlying pathophysiological mechanism involved in their adaptation to Antarctic extreme environments has been explored (Chen et al., 2016; Xu et al., 2003a, 2003b, 2015; Xu et al., 1997; Xue et al., 1994; Xue and Xue, 1994; Yu et al., 1994).

2.8 Basic research associated with Antarctic bioprospecting

In developing a pivotal role in Antarctic scientific and technological advancement in relation to sustainable resource utilization, China has launched an exploratory project to assess the potential of Antarctic marine biological resources e.g., the Antarctic krill, *Euphausia Superb*a. The survey area was distributed mainly around Antarctic Peninsula, Prydz Bay and Rose Sea. Until now, two cruise surveys surrounding the Antarctic continent were complete. The main research focused on basic biology, abundance, distribution, life history, and so on (Li and Yang, 2017; Shi et al., 2014; Sun et al., 2002, 1995; Wang et al., 1998, 1993a, 1993b; Chen et al., 1996; Zhong and Wang, 1995;). Since China commenced Antarctic krill fishing in 2009, its average harvest had amounted to around 30000 t annually by the end of November 2016 (SOA, 2017).

China has been steadily undertaken the basic research associated with Antarctic bioprospecting, extracting various new knowledge on such important research fields as fish genome and evolution (Deng et al., 2010; Chen et al., 2008; Xu et al., 2008; Chen et al., 1997), microbial diversity (Zhou et al., 2013; Yu et al., 2011, 2010;), microbial genomics (Che et al., 2013; Qin et al., 2011), enzymology and new enzymes (Wang et al., 2015; An et al., 2013a, 2013b; Cui et al., 2011; Xu et al., 2011; Yang et al., 2008; Zhang et al., 2007), and active secondary metabolite (Lin et al., 2013; Wu et al., 2013, 2012; Li et al., 2012; Li et al., 2008; Lu et al., 2002), etc. China has underscored significant headway in preservation and relevant research on Antarctic microbe strains, with substantial improvement of microculture and non-culture techniques. China has established microbial culture collection center with over 5000 polar microbe strains in preservation. Five new genera (Liu et al., 2014; Yu et al., 2012, 2011; Li et al., 2011; Li et al., 2010) and 28 new species (Chen et al., 2013; Zhang et al., 2010; Yu et al., 2008) has identified and published in International Journal of Systematic and Evolutionary Microbiology (IJSEM) and other international peer-reviewed journals.

3 Other aspects of the CHINARE Antarctic program

In parallel with its fundamental scientific studies in

Antarctica, China attaches great significance to the application of the results of its Antarctic research and exploration, and it has established a service system and institutional mechanism to expand the coverage of that service. With funding from the National High Technology Research and Development Program, National Basic Research Program of China, and National Science-Technology Support Program, studies have been undertaken on subjects of major international importance, e.g., ice sheet stability, sea-ice/ice-shelf–atmosphere interactions, and ocean acidification. These represent substantial contributions to the effort of scientific assessment of global climate change by the Intergovernmental Panel on Climate Change. A numerical Antarctic sea ice and atmosphere forecasting system has been established, which provides numerical forecast products of Antarctic weather and sea ice on a daily basis. Furthermore, China has joined the international Antarctic data sharing platform by establishing the China polar scientific data sharing network (CN-NADC, 2017a) and the specimen resource sharing platform (CN-NADC, 2017b). Analysis of remote sensing data of Antarctic sea ice concentration is also underway, which will provide Chinese and international maritime activities with a reference for polar navigation route planning and ice navigation services (Zhang et al. 2014).

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