Astrophysics from Antarctica
Proceedings IAU Symposium No. 288, 2012
M. G. Burton, X. Cui & N. F. H. Tothill, eds.

doi:10.1017/S1743921312016821

Dome Fuji Station in East Antarctica and the Japanese Antarctic Research Expedition

Kazuyuki Shiraishi

National Institute of Polar Research
10-3, Midoricho, Tachikawa, Tokyo 190-8518, Japan
email: kshiraishi@nipr.ac.jp

Abstract. Japanese Antarctic Research Expedition (JARE) commenced on the occasion of International Geophysical Year in 1957–1958. Syowa Station, the primary station for JARE operations, is located along the northeastern coastal region of Lützow-Holm Bay, East Antarctica (69°00′S, 39°35′E), and was opened on 29 January 1957. Since then, JARE have been carrying out research in various fields of earth and planetary sciences and life science. Astronomical science, however, has not been popular in Antarctica. In 1995, JARE established a new inland station, Dome Fuji Station (77°19′S, 39°42′E), which, at 3,810 m a.s.l., is located on one of major domes of the Antarctic ice sheet, some 1,000 km south of Syowa. The climatic conditions at Dome Fuji are harsh, with an annual average air temperature of −54°C, and a recorded minimum of −79°C. In 2007, JARE completed scientific drilling to obtain ice core samples of the Antarctic ice sheet reaching 3,050 m in depth. These ice cores record environmental conditions of the earth extending back some 720,000 B.P. In recent years, it is widely known that the high-altitude environment of inland Antarctica is suitable for astronomical observations and the Japanese astronomy community identified Dome Fuji Station as a potential candidate for a future astronomical observatory. In this article, the history of Japanese Antarctic activities are described in terms of access to the inland plateau of the Antarctic continent. The general scheme and future plans of science objectives and logistics of JARE will also be introduced.

Keywords. Antarctica, Dome Fuji, ice sheet, astronomy

1. Introduction

Antarctica is mostly covered by a thick ice sheet which contains more than 70% of the fresh water on Earth. The ice sheet has an average thickness of ∼2,450 m, making Antarctica the highest continent on the earth with mean surface elevation of ∼2,300 m a.s.l. East Antarctica, which occupies mostly the eastern hemisphere of the Antarctic continent, has a higher elevation than west Antarctica. A zone between ∼75–85°S in latitude in East Antarctica makes a high ridge along which three gentle peaks are recognised: Dome A (4,090 m a.s.l.), Dome C (3,260 m a.s.l.) and Dome F (3,810 m a.s.l.). Dome F was named Dome Fuji by the Japanese Antarctic Research Expedition (JARE) after the nearby "Fuji Toge (Pass)", which was traversed in 1968 by the Japanese traverse team to the South Pole. In 1995, JARE established Dome Fuji Station (77°19′S, 39°42′E) for an ice drilling project in order to obtain continuous ice samples down to the base of the ice sheet.

This short paper outlines a brief history of Japanese activities in the inland region of Antarctica, the scientific achievements at Dome Fuji, as well as future plans for JARE operations in inland regions of East Antarctica.

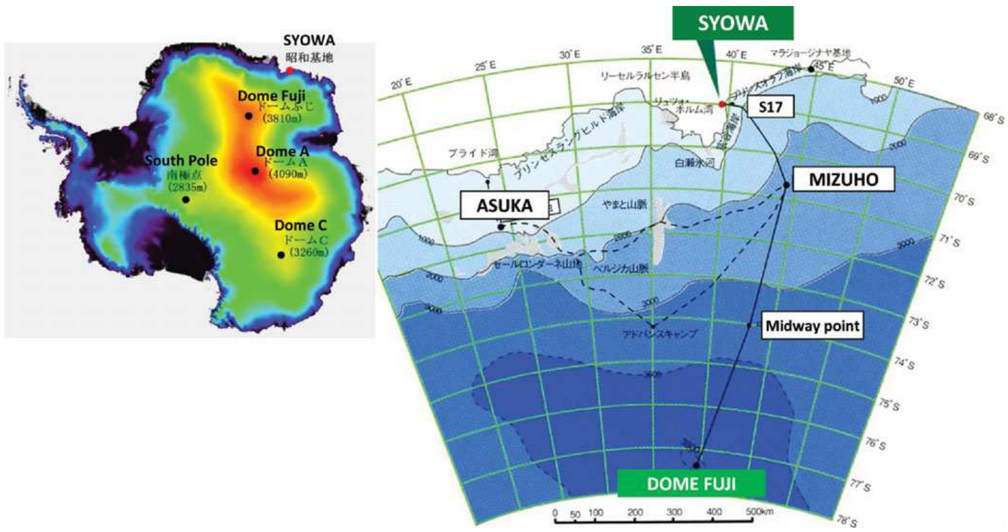

Figure 1. A map showing the stations of the Japanese Antarctic program.

2. A brief history of Japanese Antarctic Activity

Japanese Antarctic Expedition 1910–12. The first attempt to access inland Antarctica was performed by the first Japanese explorer, Nobu Shirase and his private expedition (Dagnell & Shibata, 2011). Shirase with *Kainan-maru*, a tiny ex-fishery boat of 204 tonnes, left Tokyo in November 1910 and arrived at Ross Sea via Wellington, New Zealand in January 1911. Because it was too late to continue the voyage, they returned to Sydney and wintered over there, then returned to the Ross Sea in December 1911. There they encountered the "*Fram*" of the Norwegian Expedition led by R. Amundsen at the Bay of Whales.

On 28 January 1912, the five members of Shirase's Main Landing Party using the dog sledges reached at 80°05′S in latitude and 156°37′W in longitude on the Ross Ice Shelf, where Shirase named the "Yamato Yukihara (Snow plain)". While the Main Landing Party marched to the south, *Kainan-maru* surveyed to the east along the coast which was later named as the Shirase Coast. They collected zoological, botanical and geological specimens and safely returned home.

IGY: International Geophysical Year. After 45 years, the third International Polar Year, that is, International Geophysical Year (IGY) was planned by the International Council for Science (ICSU), with the objective of detailed exploration and scientific investigation of the Antarctic continent. Japan decided to participate in this campaign which received enthusiastic support by the Japanese people. After discussions at the Antarctic sub-committee of the IGY special committee (CSAGI) in Brussels in September 1955, Japan agreed to carry out scientific investigations around Prince Harald Coast, Dronning Maud Land, East Antarctica. The first Japanese Antarctic Expedition (JARE-1) led by Takeshi Nagata on board *R/V Soya* left Tokyo on 08 November 1956. The *Umitaka-maru* of Tokyo University of Fisheries escorted her. Scientists in the summer team included meteorologists, geophysicists (seismology, geomagnetism, cosmic ray, aurora and ionospheres), marine biologists, geographers, oceanographers and surveyors. They constructed Syowa Station (69°00′S, 39°35′E) with 4 small huts and a 20 kVA generator on Ongul Island in the Lützow-Holm Bay, and officially opened it on 29 January 1957. Eleven personnel wintered over in order to conduct meteorology, upper atmospheric physics, geography and geology. Since then, Syowa has been the primary station for JARE operations both as a permanent observatory and as a supply station for field activities, although there was a three season break before the icebreaker *Fuji* was commissioned in 1966. The station has expanded in size, to more than 60 buildings and huts covering an area of 6,778 m^2 by the time of IPY 2007–2008.

After IGY, Japan signed the Antarctic Treaty as one of 12 original signatory countries in 1961.

The inland activities. During the early stages of JARE operations, Antarctica was still "*Terra incognita*". Satellite image maps were not available and topographic maps, if available, were rudimentary. A number of inland traverses were undertaken to conduct geographical surveys after 1957, finding previously unknown mountain ranges. In 1960, the Yamato Mountains were discovered from the air by a Belgian team and geological and geomorphological surveys were undertaken by JARE-4.

One of the great steps to the inland Antarctica was a traverse led by Masayoshi Murayama to the South Pole in 1968. After 141 days, after leaving Syowa Station, the 12-man party with four snow vehicles completed the return trip to the South Pole, covering a distance of 5,182 km. This overland traverse was only the 9^{th} successful expedition to the South Pole. En route to South Pole and return, the expedition conducted geophysical, glaciological and meteorological studies. This traverse illustrated significant progress and expertise of Japanese inland traverse capability and development in the technology of snow vehicles.

After the success of this South Pole traverse, glaciologists and geologists proposed to extend survey operations to inland areas. One of the first such inland operations was the "Enderby Land Project" (1969–1974), the objectives of which was to survey the catchment area of the Shirase Glacier, which is the largest glacier in the vicinity of Syowa Station, to study the ice dynamics of the glacier.

In 1970 the first inland station "Mizuho" was established ∼300 km away from the coast as a base for glaciological and meteorological studies. In 1985, a second inland station "Asuka" was built ∼630 km west of Syowa Station primarily as a base for geoscience programs. Through these inland activities, JARE accumulated extensive experience conducting remote inland activities.

Science in JARE. JARE have been conducting extensive and diverse science programs since commencing operations in the Antarctic, both at stations and in the deep field. At Syowa Station many routine observation and monitoring studies have been conducted, including meteorology, upper atmospheric geophysics, atmospheric sciences, geodesy, gravity and geomagnetic study, biology and environmental sciences, to name a few. In inland field operations and on board ship voyages, geology, geophysics, oceanography, marine and terrestrial biology, geodesy, glaciology and other studies have been conducted. Many significant scientific contributions have been reported. For example, the study of aurora has been developed because Syowa Station is conveniently located within the aurora oval. In 1982, JARE meteorologists established the existence of the ozone hole in the upper atmosphere.

Another significant scientific contribution to earth and planetary science is the discovery of a vast numbers of meteorites in the blue ice fields of the continent (Yamaguchi, this volume). Since 1969, JARE have collected 17,100 specimens (>1.5 tonnes) including Martian and lunar meteorites. Using suitable satellite images, we can predict where meteorites are concentrated. During 1976–79, a Japan–USA joint search for meteorites program was held in the Transantarctic Mountains, continuing to the current ANSMET (the Antarctic Search for Meteorites) program by NSF. Nowadays, several other national

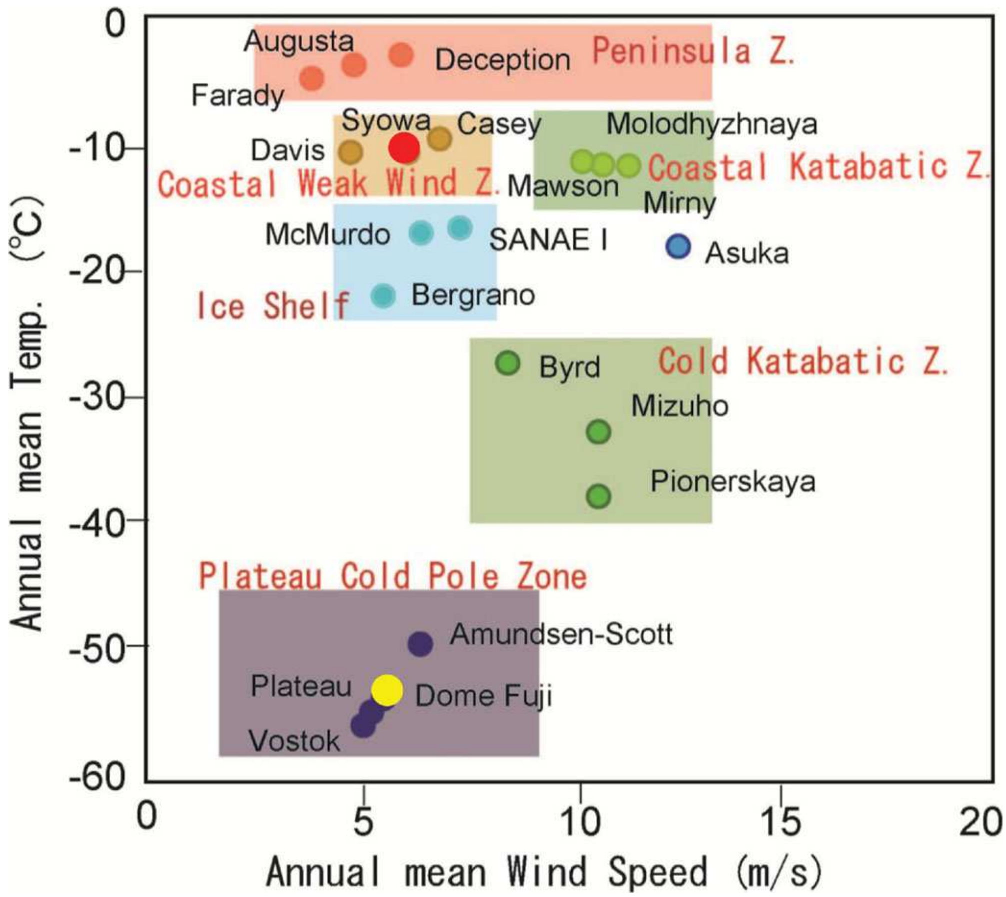

Figure 2. Climate classification of stations in Antarctica using wind velocity (m/s) *vs.* air temperature (°C).

Antarctic programs, such as China, Korea, Italy and Belgium, are conducting meteorite searches for research and have collected more than 30,000 specimens of meteorites.

3. Dome Fuji Station

The Antarctic continent is covered by a thick ice sheet. East Antarctica forms a huge dome-like shape in cross section, reaching as much as 4000 m a.s.l. at the highest point. In 1995, JARE established a new inland station, Dome Fuji Station (77°19′S, 39°42′E), which is located at ∼3,810 m a.s.l. at one of ice domes of East Antarctica.

Figure 2 shows the classification of the Antarctic stations in terms of annual mean wind speed and air temperature. The inland stations experience extreme climatic conditions on the Antarctic plateau. Records obtained at Dome Fuji during 1995–1997 show that the annual mean temperature is −54.3°C and −79.7°C minimum. The annual mean air pressure of 598.4 hPa makes conditions extremely difficult for humans to live (Watanabe *et al.*, 2003).

The snow accumulation is heavy at the coastal zone of the Antarctic continent except for the steep edge where ablation of ice is predominant. However, the rate of snow

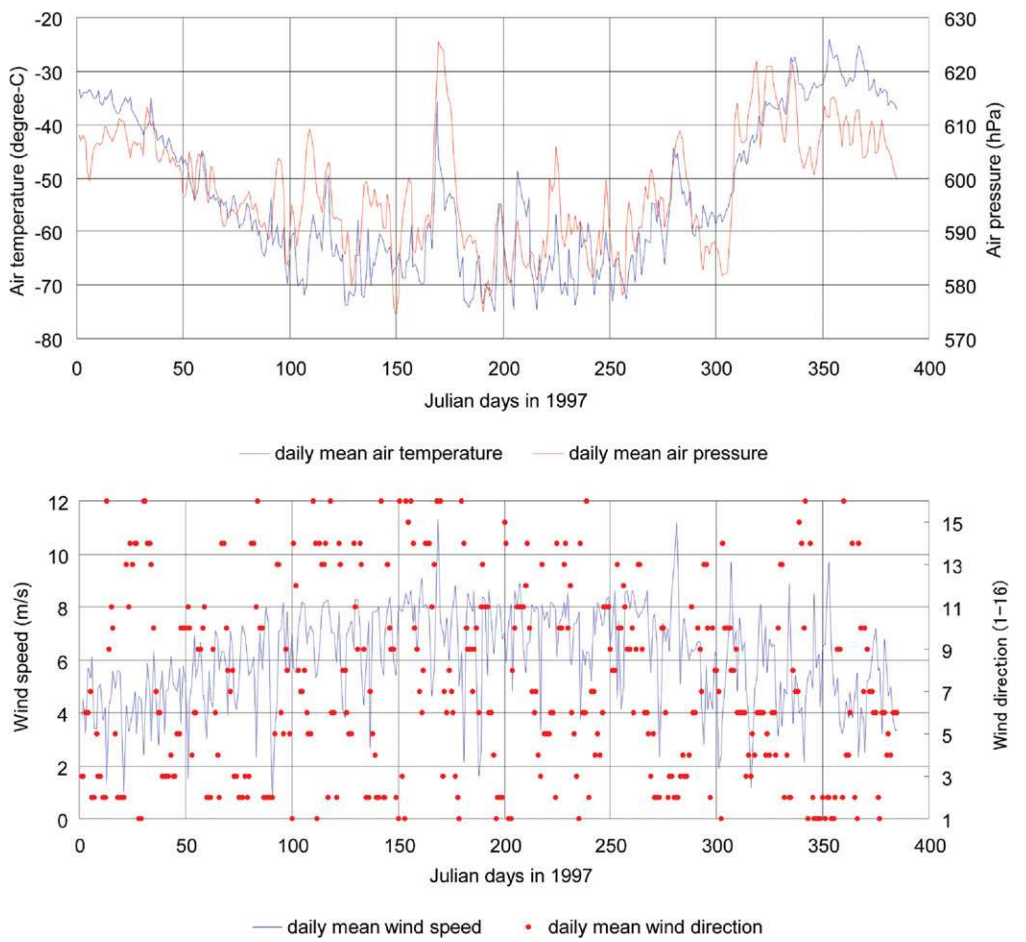

Figure 3. Meteorological data at Dome Fuji Station in 1997. (Motoyama, personal communication)

accumulation decreases inland, toward inland high plateau and, as a result, snowfall at the Dome Fuji is very rare.

<u>*Ice core drilling at Dome Fuji*</u> The ice core drilled at Dome F records the history of the snow accumulation, and with each annual layer of snow, air bubbles are trapped preserving ancient air. Therefore, an ice core is just like a time capsule of the earth's history, enabling scientists to study changes in the atmosphere back through time.

A deep ice core drilling project to obtain ice core samples of Antarctic ice sheet reaching to the bedrock was carried out in 1993–1998. During the first overwintering at the Dome Fuji, drilling commenced in 1995 and successfully collected ice core down to 2,503 m deep, an ice record that extends back 320,000 years. In 2006, second deep ice core drilling program succeeded reaching 3,035 m in depth, almost the bottom of the ice sheet. The oldest ice was estimated ∼720,000 years old. Unexpectedly, the bottom of ice was melted due to geothermal energy and could not reach the basement rocks.

Through detailed analysis, glaciologists identified climate cycles of several tens of thousands years and 100 years in scale preserved in the ice core. The deep ice core preserved volcanic ash layers and even micrometeorite layers (Misawa *et al.* 2010). It is beyond the scope of this paper to describe the glaciological results in detail and there are many

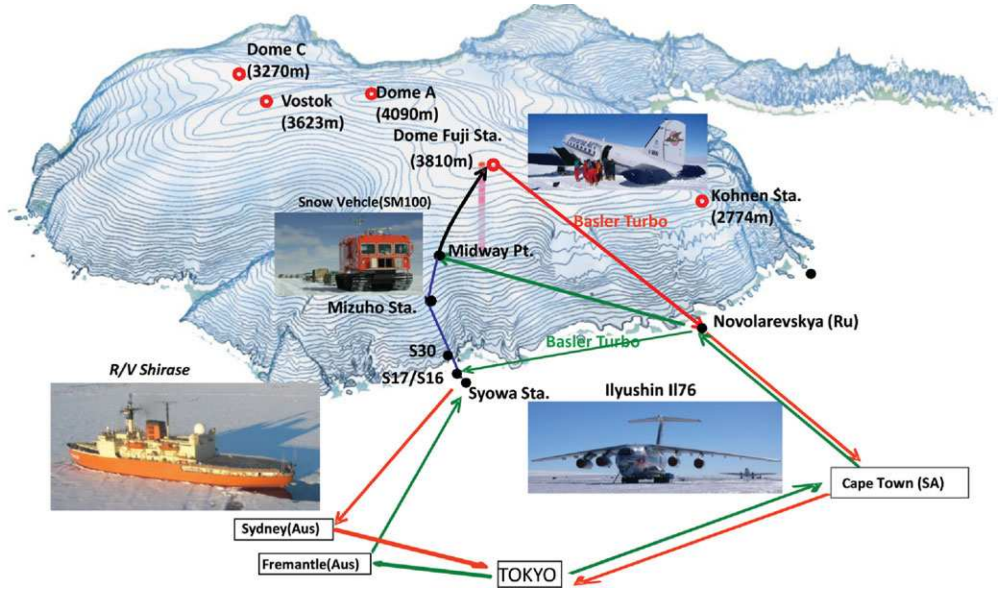

Figure 4. Access to Dome Fuji by sea, air and land.

published reports on the study of Dome Fuji ice core (*e.g.* Kawamura *et al.*, 2007, Uemura *et al.*, 2012).

4. Access to Dome Fuji

Transportation to the Antarctic is essential for Antarctic expeditions. Figure 4 illustrates an example of traverse to Dome Fuji. Normally the Icebreaker *Shirase* departs the Port of Tokyo in mid-November, and two weeks later expedition personnel depart, via air, for Fremantle, Western Australia, where the icebreaker visits en route to Syowa Station. The icebreaker *Shirase* is 12,600 tonnes displacement and 138 m in length, is operated every austral summer season and carries around 1,100 tonnes of cargo and fuel, including supplies supporting Antarctic operations. However, the fast sea ice around Syowa Station is not always in good condition. In the 2011–2012 season, the icebreaker *Shirase* could not reach Syowa Station due to extremely difficult sea ice conditions, with the sea ice reaching 8 m in thickness. It has been 18 years since the last time the sea-ice conditions were as unfavorable as this.

Transportation into the inland. The traverse party with several snow vehicles and sledges leaves from the S16 point, a coastal depot 20 km east of Syowa. As already shown, snow accumulation on the inland plateau is less than in coastal areas, in contrast, the katabatic wind (which is a cold air mass sliding down along the surface of ice sheet from higher altitudes) forms a wind sculptured rough snow surface feature called "sasturugi". Sasturugi make oversnow travel very slow and difficult and it takes roughly three weeks to travel to Dome Fuji. During the traverse, various glaciological, meteorological and geophysical observations are carried out. On the way to Dome Fuji, there are a couple of unmanned stations for meteorology, glaciology, geomagnetism and seismology.

Air transportation. Compared with other areas in the Antarctic, such as the Ross sea region and the Antarctic Peninsula area, regular air transportation has not been available in East Antarctica. However, in the last ten years an air network called DROMLAN (Dronning Maud Land Air Network) was established by the cooperation of eleven countries, including Japan. A flight takes only 6.5 hours from Cape Town to the Russian Novolazarevskaya Station with a cargo jet, Ilyushin Il76. From Novolazarevskaya, intracontinental feeder flights are carried out by Basler Turbo BT67 ski-equipped aircraft. This aircraft is a modified version of the versatile Douglas DC3. The Basler Turbo is able to land and take off at Dome Fuji, however, avoiding altitude sickness for personnel, it is safe not to fly directly using aircraft except for emergency. Normally, JARE operations use aircraft from Novolazarevskaya to the S17 point or the midway point between Mizuho and Dome Fuji. From the landing point, travel to Dome Fuji is completed on surface with snow vehicles.

5. New Era of JARE

Frontier of Earth-Planetary Sciences. At the occasion of the 50$^{\text{th}}$ anniversary of JARE, the JARE Headquarters discussed the vision of a new science strategy and selected topics on "Global Warming" as the principle research projects to be considered for high-level national and international research collaboration. In addition, there are general topics proposed by many scientists including a number of routine monitoring observations, conducted by NIPR and other Japanese government agencies such as the Japan Meteorological Agency, Geographical Survey Institute and Japan Coast Guard.

In recent years, it is widely known that the environment of the inland of Antarctica is suitable for astronomical observation and Japanese astronomical community has identified Dome Fuji Station as a candidate of the future astronomical observatory (*e.g.* IAU Aymposium 288 in 2012). In addition, the Antarctic Inland Plateau is recognised as an important area for many scientific fields. NIPR and collaborators are planning to propose new projects utilising the new Dome Fuji Station, as a part of major science projects in the next decade planned by the Japan Science Council.

The new projects at and around Dome Fuji may include the following targets:

(*a*) The oldest ice in the world, which is expected to elucidate the Earth history up to one million years ago,

(*b*) 3D-observation for aurora in cooperation with Syowa Station, which will reveal the mechanism of aurora and upper atmospheric geophysics,

(*c*) Atmospheric science in the polar vortex, which will reveal the matter cycle between stratosphere and troposphere,

(*d*) Age and composition of continental crust underneath the ice sheet and its role in the evolution of the Antarctic continent,

(*e*) Sub-glacial lakes to explore for unknown micro-organisms,

(*f*) Microbiology under extreme conditions related to the global circulation of microbes,

(*g*) Biorhythms during polar night as a physiological study under extreme environment.

New Dome Fuji Station and logistics in the inland area. To make this sciences possible in inland areas, we have to develop new technology and build the new Dome Fuji Station. Currently, it is in a design phase and several plans have been proposed.

For designing the new Dome Fuji Station, the following points are considered:

(*a*) Keeping the building on the surface for more than 10 years,

(*b*) Foundation of buildings on snow surface, avoiding unequal subsidence,

(*c*) Using light weight and thermal insulated panels of buildings, for reducing the load of transportation,

(*d*) Heating used sustainable energy,

(*e*) Effective energy consumption in terms of electricity, water *etc.*

The most difficult issue is the foundation of the buildings to avoid tilting and snow drift during the lifetime of buildings. In addition, saving energy, utilising discharged grey water, and other environmentally friendly measures are requested.

Traverse technology. Cargo transportation with a limited number of personnel is essential to maintain the station. It is necessary to carry a huge amount of cargo and fuel. One of the ideas to keep stable transportation in the future is the "unmanned tractor system" to minmise the logistic burden. Testing of an original model is now being undertaken.

6. Summary

In summary, it is safe to say that:

(*a*) Japan has a long history of conducting traverses into the inland area of Antarctica since early last century. These activities fostered development of expertise, experience, logistics and technology to successfully conduct deep inland traverses.

(*b*) Dome Fuji Station is one of the inland stations which has advantages for frontier research in earth, planetary and life sciences.

(*c*) In the future, astronomical research will be a high priority at Dome Fuji Station, but will also include atmospheric and glaciological studies.

However, there are many difficulties and challenges to maintain the year-round station, such as new buildings based on innovative concepts of construction, a new transportation system and so on.

Acknowledgements

The author would like to thank to Professors Takashi Ichikawa of Tohoku University, Michael Burton and John Storey of the University of New South Wales for inviting him to the IAU symposium in Beijing. He is also indebted to Dr. Chris Carson of Geoscience Australia for comments to the draft. The author thanks Professor Hideaki Motoyama of NIPR for information on the deep ice core drilling project at Dome Fuji.

References

Dagnell, L., & Shibata, H. (Translated into English) 2011 *The Japanese South Pole Expedition 1910–12 A Record of Antarctica*. (Compiled and edited by the Shirase Antarctic Expedition Supporters' Association. Originally published in Japanese in 1913 by Nankyoku Tanken Koenkai, Tokyo), Bluntisham Books & Erskine Press, 414pp.

Kawamura, K., Parrenin, F., Lisiecki, L., Uemura, R., Vimeux, F., Severinghaus, J. P., Hutterli, M. A., Nakazawa, T., Aoki, S., Jouzel, J., Raymo, M. E., Matsumoto, K., Nakata, H., Motoyama, H., Fujita, S., Goto-Azuma, K., Fujii, Y., & Watanabe, O. 2007 *Nature*, 448, 912

Misawa, K., Kohno, M., Tomiyama, T., Noguchi, T., Nakamura, T., Nagao, K., Mikouchi, T., & Nishiizumi, K. 2010 *Earth and Planetary Science Letters*, 289, 287

Uemura, R., Masson-Delmotte, V., Jouzel, J., Landais, A., M otoyama, H., & B. Stenni, B. 2012 *Climate of the Past*, 8, 1109

Watanabe, O., Kamiyama, K., Motoyama, H., Fujii, Y., Igarashi, M., Furukawa, T., Goto-Azuma, K., Saito, T., Kanamori, S., Kanamori, N., Yoshida, N., & Uemura, R. 2003 *Memoirs of National Institute of Polar Research*, Special Issue No. 57, 1