156

# A Newly Developed Grab Sampling System for Collecting Stratospheric Air over Antarctica

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## 南極上空の成層圏大気採取用グラブサンプリング装置の開発

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**要旨**: 南極上空の成層圏大気の各種微量成分やそれらの同位体比を測定するために，簡単なグラブサンプリング装置を新たに開発した．この装置の打ち上げにはゴム気球を用い，厳しい実験条件下でも小人数で放球作業が可能となるように設計した．大気試料の汚染防止と取り扱いの簡素化には特に配慮した．サンプリング装置の主要構成部は，電磁弁と手動弁付きの 15 リットル試料容器，試料採取の実行・装置の位置および各種動作状況データの伝送用制御装置，電池，送信機である．これらすべてを，着地時の緩衝装置付きのアルミフレーム製ゴンドラ内に組み込んだ．またゴンドラなどからの汚染がない大気を直接的に採取するために，試料採取時にはゴンドラ全体を上下反転し，その後元の位置に戻す機構を取り付けた．実験では，さらに飛翔位置追跡用の GPS 受信機とレーウィンゾンデを装備した．装置の総重量は約 11 kg であった．実際の観測には，位置情報および各種動作状況データのクイックルック表示用処理装置を用意した．さらに，ゴム気球へのヘリウムガス充填を簡単にするため，新しいガス充填システムも開発した．1996 年 1 月 22 日と 25 日に昭和基地で計 3 機のグラブサンプリング装置を放球し，基地付近の海氷上で回収することによって，この装置の所期の性能を確認した．

*Abstract*: In order to measure the concentrations of various minor constituents and their isotopic ratios in the stratosphere over Antarctica, a simple grab sampling system was newly developed. The sampling system was designed to be launched by a small number of personnel using a rubber balloon under severe experimental conditions. Special attention was paid to minimize the contamination of sample air, as well as to allow easy handling of the system. The sampler consisted mainly of a 15 $l$ sample container with electromagnetic and manual valves, control electronics for executing the air sampling procedures and sending the position and status information of the sampler to the ground station, batteries and a transmitter. All these parts were assembled in an aluminum frame gondola with a shock absorbing system for landing. The sampler was equipped with a turn-over

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mechanism of the gondola to minimize contamination from the gondola, as well as with a GPS receiver and a rawinsonde for its tracking. Total weight of the sampler was about 11 kg. To receive, display and store the position and status data of the sampling system at the ground station, a simple data acquisition system with a portable receiver and a microcomputer was also developed. A new gas handling system was prepared to simplify the injection of He gas into the balloon. For air sampling experiments, three sampling systems were launched at Syowa Station (69°00'S, 39°35'E), Antarctica and then recovered on sea ice near the station on January 22 and 25, 1996.

## 1.  Introduction

One of the most important problems for the current atmospheric environment is global climate change due to the increase of atmospheric greenhouse gases such as carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$). The concentrations of these gases have been steadily increasing over the last few hundred years due to human activities such as energy production and consumption, food production, deforestation and changes in land use (NEFTEL et al., 1985; ETHERIDGE et al., 1992, 1996; NAKAZAWA et al., 1993; MACHIDA et al., 1995).

Another important atmospheric environmental problem is the destruction of stratospheric ozone by halocarbons. This problem was first found in Antarctica in the early 1980s (CHUBACHI, 1984; FARMAN et al., 1985; STOLARSKI et al., 1986). The depletion of stratospheric ozone will lead to an enhancement of ultraviolet rays reaching the ground surface, which is a serious menace to life on Earth.

For these issues, it is crucial to monitor the concentrations of atmospheric greenhouse gases and halocarbons precisely and systematically. The Antarctic region is thought to be suitable for such monitoring, since Antarctica is fairly free from human and biological activities due to its remoteness from populated and vegetated lands. Indeed, several monitoring stations are currently operating in this region for long-term measurements of the background concentrations of these gases (TANAKA et al., 1987; NAKAZAWA et al., 1991; AOKI et al., 1992; BODEN et al., 1994).

In order to interpret temporal and spatial variations of trace gases in Antarctica, it is important to elucidate air transport processes from other latitudes to this region (MURAYAMA et al., 1995). For this purpose, measurements of relevant gases are indispensable not only in the troposphere but also in the stratosphere. Air sampling with subsequent laboratory analysis is one of the most promising methods to measure the concentrations of stratospheric minor constituents precisely (FABIAN et al., 1979; EHHALT et al., 1983; BISCHOF et al., 1985; SCHMIDT et al., 1985, 1994; GAMO et al., 1989, 1995; ITOH et al., 1989; LAL et al., 1989; SCHMIDT and KHEDIM, 1991; NAKAMURA et al., 1992, 1994; NAKAZAWA et al., 1992, 1995; BAUER et al., 1994). We have developed a balloon-borne cryogenic sampler for collecting stratospheric air at twelve different height levels over Antarctica; it is scheduled to be launched at Syowa Station (69°00'S, 39°35'E) in 1998 (HONDA et al., 1996). In addition, we also developed a grab sampling system for the same purpose. This sampler is much more simplified than the cryogenic one; it can be

prepared, launched and recovered by several untrained personnel, though air sampling is done at only one height level and the volume of sampled air is rather limited. Three samplers were actually launched at Syowa Station on January 22 and 25, 1996 and then recovered near the station after collecting air samples at 25, 20 and 15 km heights.

In this paper, we present details of the newly developed grab sampling system and then describe the collection of air samples with this sampler at Syowa Station in January 1996. We also describe a ground support system prepared for the balloon experiments at the station.

## 2.  Design of the Sampling System

The grab sampler developed in this study is illustrated in Fig. 1, and its specifications are summarized in Table 1. The sampler consisted mainly of a sample container with an electromagnetic valve and a miniature manual valve, control electronics, batteries, a GPS (Global Positioning System) receiver and a transmitter. Almost all parts were assembled in an aluminum frame with a shock absorber. The sampler was also equipped with a turn-over mechanism of the gondola. Its total weight was approximately 11 kg.

The sample container was made of stainless steel and its inner surface was electrically polished. The volume of the container was selected to be 15 $l$, to collect air samples of about 350 m$l_{STP}$ at 25 km (pressure of approximately 25 hPa and temperature of approximately 221 K). In this connection, the after-mentioned electromagnetic valve of the sample container was set to be opened for 10 s for air sampling in this study, and the efficiency of sample collection into the container under such a condition was estimated to be better than 80% from experimental results obtained previously (HONDA and ITOH, 1982). If the sampling efficiency is assumed to be 100%, the volume of air sample to be collected at 25 km amounts to about 457 m$l_{STP}$. Deterioration risk of air samples during their storage in the container was examined using air-based $CO_2$ and $CH_4$ standard gases, and it was confirmed that their concentration drifts for at least one month of storage were entirely negligible, within our analytical precision of 0.1 ppmv for $CO_2$ and 2 ppbv for $CH_4$.

Two stainless steel valves, one a miniature manual valve and one an electromagnetic valve, were attached to the sample container. The manual valve was employed to open and close the container for evacuation and sample analysis, as well as to minimize sample contamination due to leakage of the electromagnetic valve during its transportation between Syowa Station and Japan. The electromagnetic valve was adopted to introduce sample air into the container in the stratosphere; it was operated by a command from an onboard microprocessor to be described later.

In order to collect fresh air free from contamination from the rubber balloon and materials used in the gondola, air sampling was done while the sampler descended using a parachute. In addition, the sampler was equipped with a turn-over mechanism; before the sampling system was launched, the gondola was
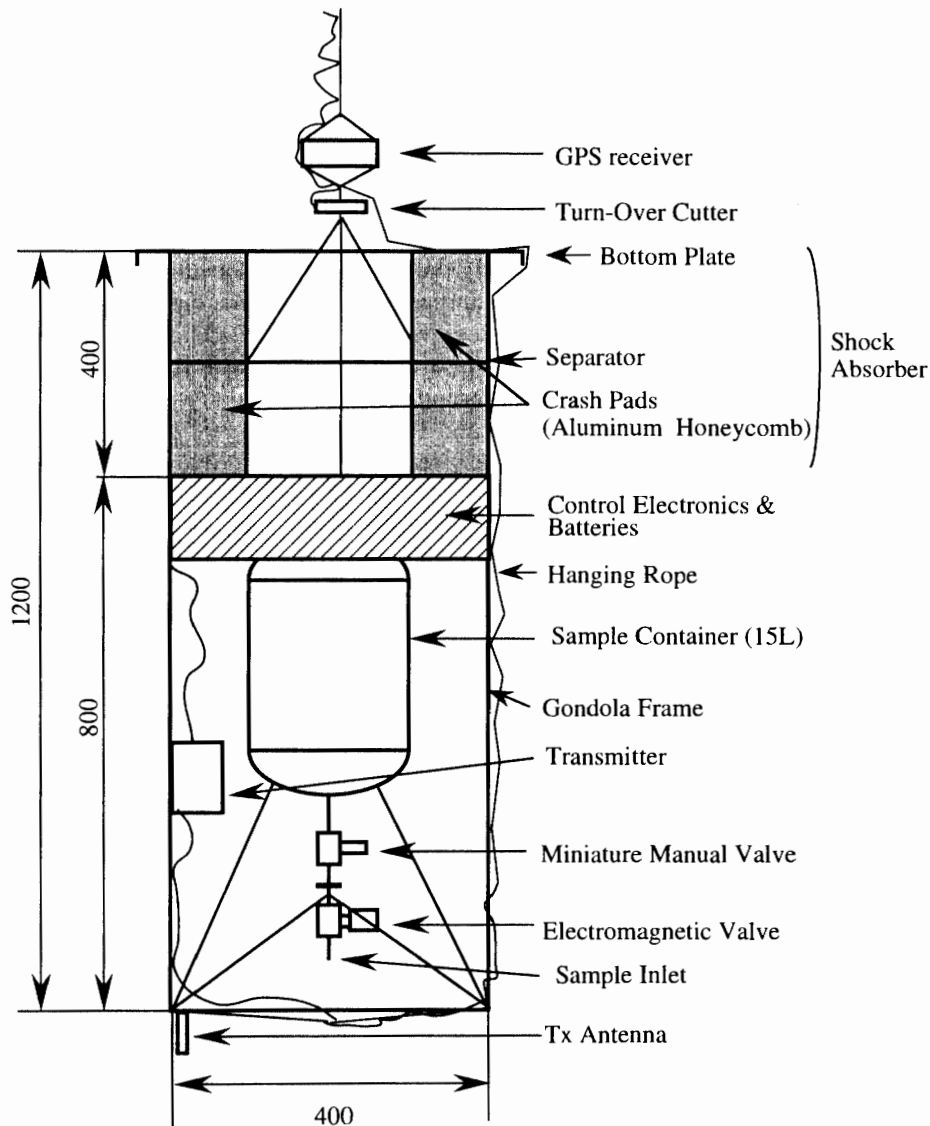
*Fig. 1.   Illustration of the grab sampler developed in this study.*

reversed and strings from its bottom were tied to the hanging rope from the GPS receiver, so that possible influence from the gondola on the sampled air was minimized. After collecting the air sample, the strings were cut by activating a squib-driven rope cutter and then the gondola was returned to its appropriate position for landing by being hung with a rope from its top, *i.e.*, the shock absorber was located at the bottom.

Since it was expected that the sampler would land on ice, the shock absorber was thought to be necessary to prevent it from damage or destruction. Therefore, an aluminum honeycomb with a height of 20 cm and a dimension of 100 cm² was selected as a crash pad, because of its light weight and good performance, and two honeycombs were connected in series and then fitted to each corner of the gondola bottom. We confirmed experimentally that the magnitude of the shock which the gondola falling at a prescribed speed of 7 m/s would receive upon landing was reduced to less than 15 G by employing this shock absorber.

*Table 1.  Specifications of the grab sampling system developed in this study.*

| | |
|---|---|
| Sample container | Cylindrically shaped stainless steel flask with a volume of 15 *l*, electrically polished inner wall, the miniature manual valve and the electromagnetic valve |
| Gondola | Aluminum frame with honeycomb-type crash pads |
| Parachute | Cross parachute |
| Balloon | 4.5 kg rubber balloon |
| Total weight | 17 kg (including the balloon and parachute) |
| Control of air sampling procedures | Onboard microprocessor with sensors, cutters and the electromagnetic valve |
| Air sampling | During the descent of the sampler with the parachute |
| Positioning method | GPS and rawinsonde |
| Sampling altitude | One of 25, 20 and 15 km |
| Search method after landing | Beacon search system |

As shown in Fig. 2, the control electronics were comprised mainly of a microprocessor, relays and their driver for actuating the electromagnetic valve, the squib-driven turn-over cutter and a main rope cutter, and a modulator for the transmitter. The position data from the GPS receiver, as well as the sampler status information, were collected by the microprocessor and then sent to the ground station through the modulator and the transmitter every 10 s. During the rest of the time, beacon signals to be described later were sent to the station. These were achieved by adopting a packet data transmission method (HONDA and YAJIMA, 1993).
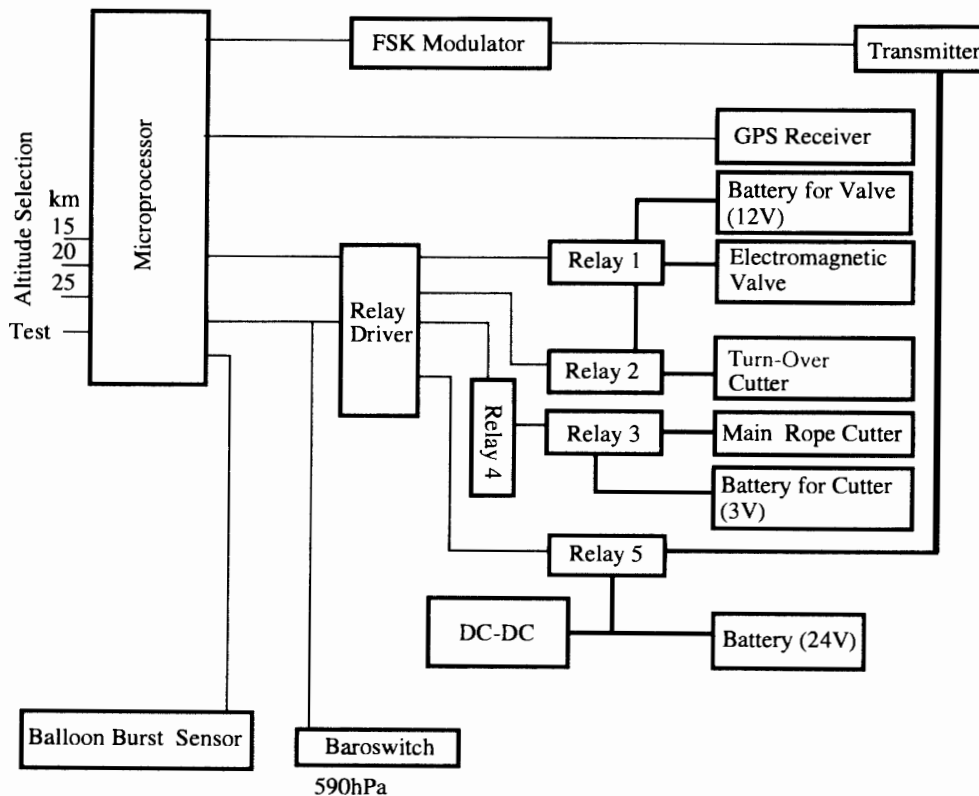


*Fig. 2.  Block diagram of the control electronics developed for the grab sampler.*

The sequence of air sampling procedures was executed by the control electronics, once one of the following three conditions was satisfied while a baroswitch was on: the GPS altitude exceeded the height assigned for air sampling, the sensor detected a balloon burst or the software timer expired. The main rope cutter was also of squib type; it was attached to separate the balloon for the descent of the sampler. The baroswitch was set for a pressure height of 590 hPa, corresponding to an approximate geometrical height of 4.3 km; the main rope cutter was disabled near the ground to avoid unexpected separation of the sampler and the balloon before and just after the launch. In case the sampling system became uncontrolled, the software timer was set to be 1.3 times as long as the time required to ascend to an assigned height.

The air sample was collected by the following procedure, in accordance with commands from the onboard microprocessor. After separating from the balloon at an assigned height, the electromagnetic valve of the sample container was opened at 2 s and closed at 12 s, and the turn-over cutter was activated at 132 s to locate the shock absorber of the gondola. Since the reversal of the gondola was thought to apply a shock to the whole system including the parachute and the gondola, we allowed a delay of 132 s for reversing it under the condition that the sway of the system due to the balloon separation decayed.

At the ground station, the signals from the sampling system were received and demodulated by a portable receiving system, and then processed by a microcomputer to display and store the GPS and status data. Using this ground support system, we could understand simultaneously the start and end heights and times of air sampling, the actuation height and time of the main rope cutter, execution conditions of air sampling and remaining time of the software timer. The GPS and status data were also stored in the onboard microprocessor, so that these can be reproduced after recovery of the sampler in case of need.

Taking account of the fact that the sampler is used under severe conditions, special consideration was given to the control electronics, by which the height to be sampled was selected easily by inserting a small pin into one of the sockets which were assigned to three heights in advance. In this study, these three heights were set to 15, 20 and 25 km. To examine the functions of the control electronics quickly before the launch of the sampling system, a test mode was also prepared so that the sequence of procedures could be simulated.

## 3. Composition of the Balloon System

The flight train for the above-mentioned grab sampler is shown in Fig. 3. The balloon system consisted mainly of the balloon, the parachute and the gondola. The system was also equipped with a balloon burst sensor, main rope cutter, rawinsonde and GPS receiver. All parts were tied together with a nylon rope. The distance between the balloon and the gondola was approximately 10 m, and the total weight of the system was 17 kg. The rubber balloon with a weight of 4.5 kg was specially developed and used for this experiment; it has the advantage of being easier to handle than a plastic one. The balloon burst sensor and the main rope cutter were
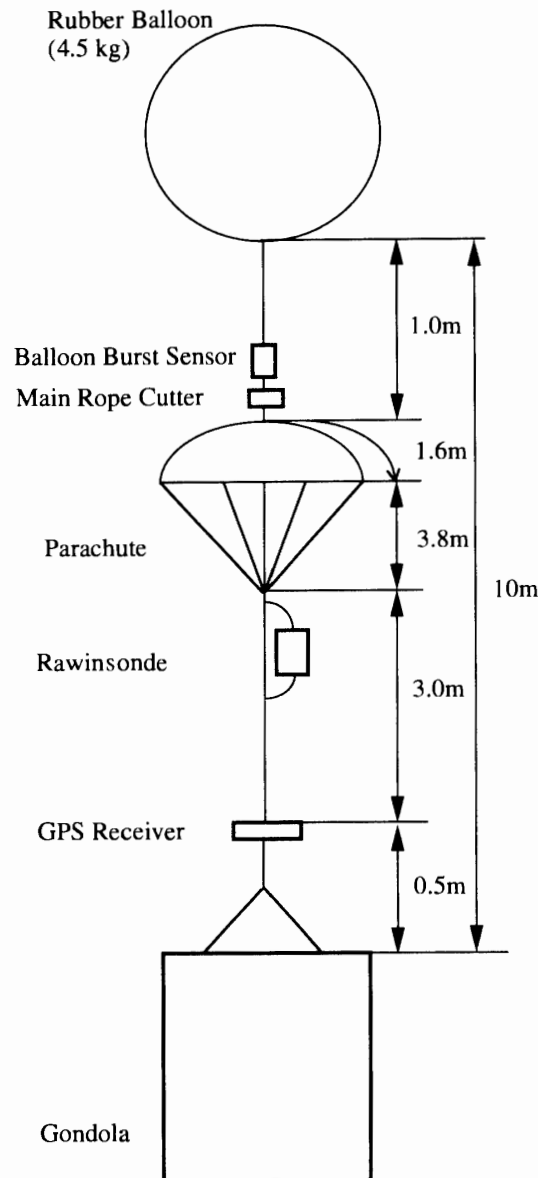
H. HONDA *et al.*

Rubber Balloon
(4.5 kg)

Balloon Burst Sensor

Main Rope Cutter

1.0m

1.6m

Parachute

3.8m

10m

Rawinsonde

3.0m

GPS Receiver

0.5m

Gondola

*Fig. 3. Composition of the balloon system at the launch of the grab sampler.*

located between the balloon and the parachute. In case of balloon burst below an assigned height, the sensor would detect it; it is activated when the gondola begins to fall. To ensure steady descent of the gondola with the parachute at a speed of approximately 7 m/s, the balloon would separate from the other parts by activation of the main rope cutter. We also employed a cross parachute so that the gondola would descend stably, with small swing. The rawinsonde was attached to track the sampling system by using its conventional meteorological receiving system.

When this sampling system was launched at Syowa Station, a total lift of 22 kg, including a free lift of 5 kg, was provided for the balloon by using a new He-gas handling system. The gas handling system was developed to introduce He gas into the balloon easily. It consisted of a stainless steel manifold, a pressure sensor, a thermometer and a stainless steel metering valve. Several high pressure gas

cylinders filled with He gas were connected to the manifold, and then He gas was introduced into the balloon through the metering valve. The amount of He gas in the balloon was determined only from its temperature before introduction and its pressure in the manifold and cylinders. The temperature change of He gas due to its inflation was neglected, because this effect on buoyancy was estimated to be less than several per cent, which is sufficiently smaller than the above-mentioned free lift of 5 kg, corresponding to the lift of 30%.

## 4.  Air Sampling Experiments at Syowa Station

In order to reduce in situ preparation work for launching the grab sampling system at Syowa Station, special attention was paid before shipping to the station. The sample container was evacuated with a turbomolecular pump at $100°C$ for 24 hours and then at room temperature for 3 days in our laboratory. After evacuation, the container was filled with dried and purified air at $1.5 \times 10^3$ hPa to equilibrate with the inner wall during its transportation to Syowa Station for three months. To minimize the leakage of the container through the electromagnetic and miniature manual valves during this period, we also connected an all stainless steel stop valve to the other end of the electromagnetic valve. The balloon was also equipped for easy introduction of He gas at Syowa Station. After these preparations, all parts including the balloon, the parachute and the gondola were tied together with ropes, as shown in Fig. 3, and then packed in a thick cardboard box with shock absorbing materials.

At Syowa Station, the sample container was evacuated with a turbomolecular pump at room temperature for one day. Then, all functions of the control electronics were confirmed to be normal using parallel signals from the outside, and the position information for the GPS receiver was updated by receiving satellite signals. When the surface wind was calm and the landing position was estimated to be within 50 km of the station, using a trajectory analysis program and the latest wind profile obtained from routine meteorological observations, we decided to launch the sampling system. The validity of this program has been confirmed by preliminary tests with the rawinsonde at Syowa Station in 1995 (HONDA et al., 1996).

The first air sampling experiment was performed on January 22, 1996. After introducing He gas into the rubber balloon, the stop valve was removed from the electromagnetic valve, the miniature manual valve was opened and the software timer was reset. Then, the sampling system was launched. The height assigned for this air sampling was 25 km. As shown in Fig. 4, the system ascended normally and sampled stratospheric air at 25.3 km, then continued to ascend until the balloon burst at 32 km, because the balloon was not separated, reflecting the fact that the main rope cutter failed to be activated due to insufficient battery power. However, since the main rope cutter was fortunately activated just after the balloon burst, the balloon was separated, the gondola was returned to its appropriate position and the sampler descended as shown in Fig. 5. During the descent of the sampler, the electromagnetic valve was opened again just below 25 km, due to software bugs in
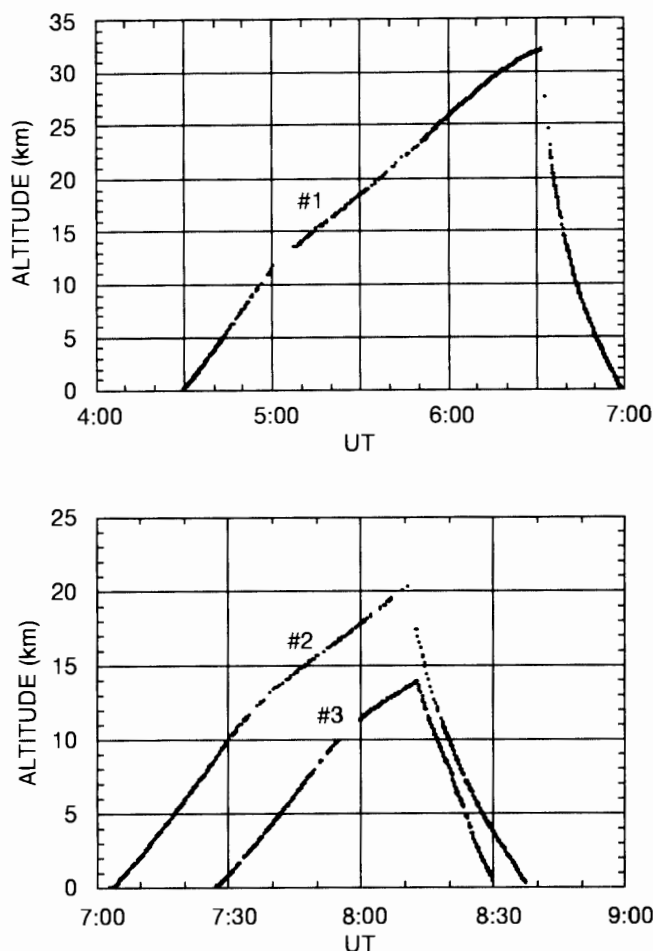
Fig. 4.  Time dependent vertical positions of the three grab sampling systems launched at
Syowa Station, Antarctica on January 22 (#1) and 25 (#2 and #3), 1996.

the onboard microprocessor.  After that, the sampler landed on sea ice about 22 km away from the station.

The position of the sampling system was watched continuously using GPS data from the sampler.  Its horizontal trajectory is shown in Fig. 6.  In addition, its position was confirmed by using a tracking system for the rawinsonde.

The recovery procedures of the gondola were essentially the same as those in the preliminary tests in 1995 (HONDA *et al.*, 1996).  Two helicopters from icebreaker SHIRASE were used; on the way to the landing position estimated from the GPS data, a big one searched for the gondola by receiving the radio beacon signal with a direction finding system, and a small one landed on sea ice and recovered the gondola.  It took about 20 min to complete the recovery.  The gondola was standing on ice, bottom down, as expected.  All GPS and status data were also confirmed to be stored completely in the onboard microprocessor.

The air sampling experiments were also performed on January 25, 1996, using two sampling systems.  The first system was launched to collect an air sample at 20 km, and the second one, with the aim of sampling at 15 km, was released 30 min after.  Their vertical and horizontal positions are shown in Figs. 4 and 6, respective-
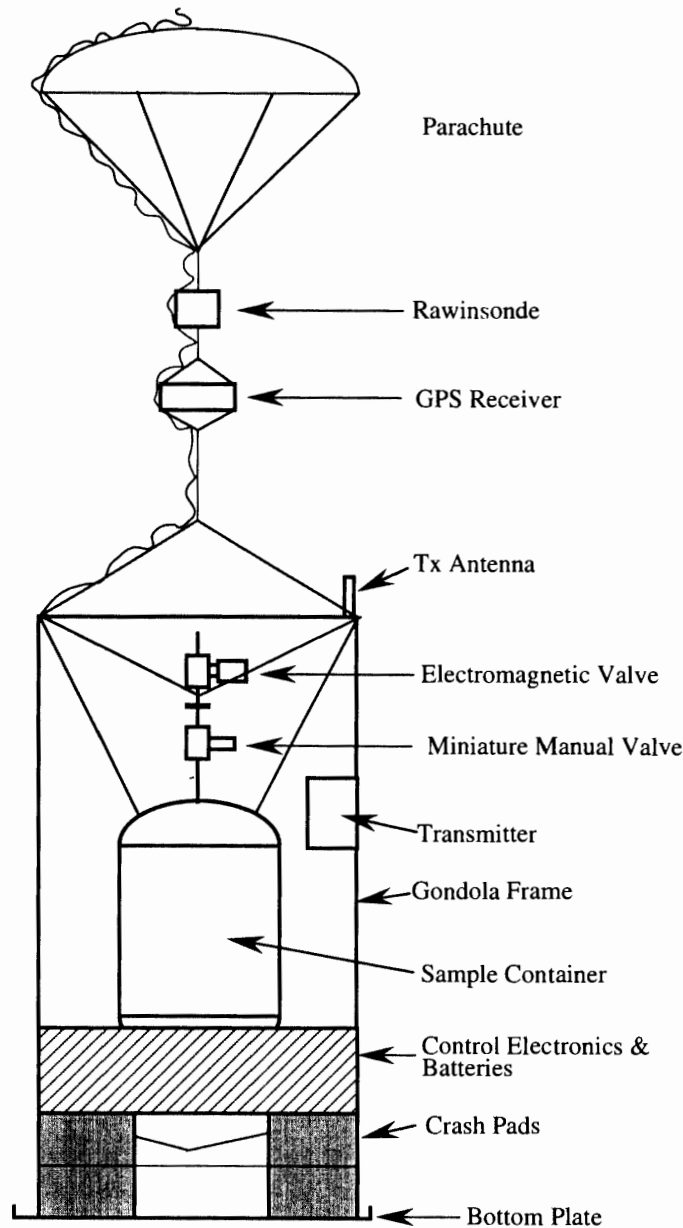
*Fig. 5. Grab sampling system descending with the parachute after the collection of an air sample.*

ly. The first system ascended normally and sampled air at 20 km, and then fell on sea ice about 5 km away from the station. All processes were completed successfully and the sampler was recovered without any damage. The balloon of the second system burst unexpectedly at 13.9 km, and the balloon burst sensor worked well to activate the main rope cutter, the electromagnetic valve and the rope cutter of the turn-over mechanism. It landed about 4 km away from the station. It was however found that the gondola was lying on ice and the inlet system of the sample container was broken so that the ground air intruded into the container. The cause was attributed to the failure of returning the gondola due to incomplete release of the hanging rope tied to its top. The rope was initially fixed to the gondola frame with
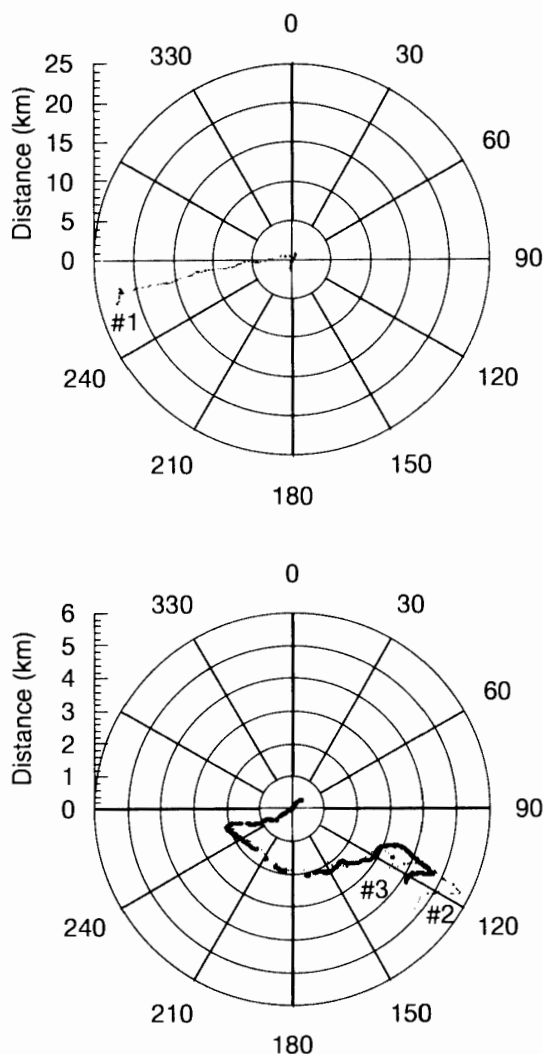
Fig. 6.   The same as in Fig. 4, but for horizontal positions.

several soft plastic clips.

## 5.   Summary

A simple, light and easy-to-handle sampling system was developed for collect-
ing stratospheric air under severe experimental conditions such as Antarctica.  The
sampling system consisted mainly of a grab-type sampler with 15 *l* container and
valves, a 4.5 kg rubber balloon and a cross parachute.  The sampler was equipped
with a turn-over mechanism for collecting fresh uncontaminated air, and a shock
absorber for preventing it from damage at landing.  The sampler was tracked by
using a GPS and a rawinsonde receiving system.  Ground support systems, such as
a He-gas handling system and a processing system for the GPS and status data from
the sampler, were also developed.

Three sampling systems were launched by a small number of untrained
personnel at Syowa Station, Antarctica and then recovered near the station after

collecting stratospheric air. However, it was found that the main rope cutter of the first sampler was not activated at the assigned height and the electromagnetic valve attached to the sample container was opened twice at that height, *i.e.* during the ascent and descent. With respect to the third sampling system, the turn-over mechanism was failed to work well. The causes of these troubles are known clearly, and can be eliminated easily.

## Acknowledgments

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