—研究ノート—
Scientific Note

Stable Isotopic Composition of Antarctic Air Moisture and Precipitation

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南極大気の水蒸気と降水中の安定同位体組成

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要旨：日本南極観測隊の昭和基地とドームふじ観測拠点で得られた大気の水蒸気と降水中の安定同位体の分析を行った．主なサンプリング期間は 1995 年 1 月である．この短い期間にもかかわらず，重水素と ^{18}O の標準海水試料 (SMOW) との偏差である同位体比には大きな幅が出た．昭和基地における降水中の $\delta^{18}O$ と開水面までの距離との間には有意な関係が見いだされた．極端な値の同位体比は，どちらの基地においても，低緯度側から空気が運ばれてくる場合に見られた．今回の結果は，昭和基地とドームふじ観測拠点における，1997 年 1 月までの 2 年間の観測の第 1 報である．

***Abstract*:** First results of stable isotope analyses are presented which were obtained by sampling of air moisture and precipitation at the Japanese Antarctic Stations Syowa and Dome Fuji. The main sampling period was during January 1995. Even within this short period their isotopic composition, expressed in delta values of deuterium and ^{18}O relative to the standard mean ocean water (SMOW), are scattered over a wide range of magnitudes. A weak, but significant, quantitative relationship between $\delta^{18}O$ of precipitation at Syowa and the distance to the open sea was found. Extreme high isotopic delta values appear at both stations when air is transported from lower latitudes to the Antarctic continent. These preliminary results were obtained from observations in January 1995. They will be continued at these stations for about two years by January 1997.

1. Introduction

$H_2{}^{18}O$ and HDO are the main stable isotopic derivatives of normal water. Their frequencies vary between 0.018 and 0.034% respectively 0.188 and 0.201% in natural waters on the earth. From these variations conclusions can be drawn about origin and temperature at phase transitions and about the history which a probed

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water has experienced in the hydrological cycle. In polar research, deuterium and ^{18}O are important tracers for the study of ice-water-atmosphere interactions and for the reconstruction of the paleoclimate by ice core analyses. During phase transitions the temperature determines changes in isotopic ratios of air moisture and precipitation. However, there are many other impacts disturbing this relation and yielding to more or less chaotic variations of isotope contents versus temperature for single samples of air moisture or precipitation events. This is caused by the different transport conditions and sources of air masses as well as by the changes of the amount of moisture due to condensation, precipitation, isotopic exchanges and mixing with other air masses during the transport. Last but not least, there are additional disturbances by the interactions between the atmosphere and continental surfaces at the sampling sites, clearly seen by the high $\delta^{18}O$ variation of drifting snow with regard to air temperature (AGETA, 1993). Nevertheless, after final deposition of snow on the surface a metamorphism takes place leading to more smoothed isotopic values with the depth. Then seasonal variations, annual layers and periods of different annual net accumulation can be separated in ice cores by profiles of density, depth hoar level, stratigraphic elements, and oxygen isotope composition (SATOW and WATANABE, 1985). However, as discussed by OESCHGER (1994): "Due to the pressure of the overlaying ice the annual ice layers are gradually stretched and thinned and displaced to greater depth and by diffusion the seasonal variations of ^{18}O and ^{2}H get obliterated."

The temporal and spatial variations of the deuterium/hydrogen isotopic ratio of water vapor in tropospheric air masses approaching Antarctica have not been systematically investigated so far. Samples from coastal Antarctic stations do not reflect the primary isotopic input from lower latitudes, because of prevailing katabatic winds from the continent (PARISH and BROMWICH, 1987). Above the polar ice caps wet air masses from lower latitudes moving polewards above the boundary layer are adiabatically cooled (SCHWERDTFEGER, 1984), and the heavy isotopes were preferably deposited in the falling snow near the shore region. So the remaining air moisture becomes isotopically lighter. This dry and cold air is moving downwards near over the ice surface following the topographic gradient forced by gravity, and known as katabatic wind. During the air mass transport by katabatic winds an additional isotopic modulation occurs due to surface evaporation.

Synchronous air moisture sampling was performed at the Japanese Antarctic Stations Syowa (69.00°S, 39.58°E, 21 m a.s.l.) and Dome Fuji (77.32°S, 39.70°E, 3810 m a.s.l.), to investigate the assumed different deuterium content of air moisture and precipitation between the coastal and the high continental areas. First data for the period of January 1995 will be discussed in the following chapters. The sampling was continued at the Stations Syowa and Dome Fuji during the following winter period.

2. Instruments and Data Evaluation

A newly designed automatic air moisture sampler (LUFEUS) operates with changeable magazines for 12 sample traps, which are filled with granulated molecular sieve (Fig. 1). Since the instrument is controlled by a microprocessor inside, it is possible to get samples synchronously at different sites according a distinct time table without manual assistance over some periods of time. Sampling mode options can be chosen by connecting a laptop or a PC as a terminal, to run equidistant sampling in time or according to other sampling schedules. The equipment is seal covered by a so called Hensel-Box. Its size amounts of 45×30×18 cm and it has a weight of about 20 kg. The air flow through the sampling traps is driven by a micro vacuum pump and regulated by 14 magnetic valves, using 15 V direct current by a Li battery block or by DC power supply.

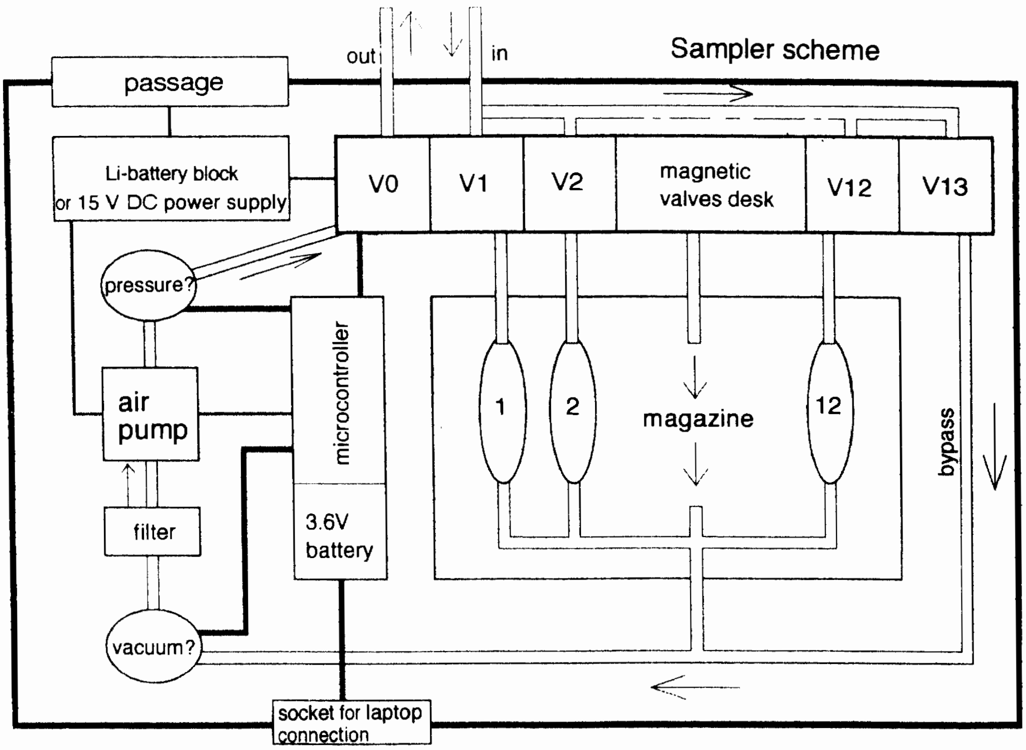


Fig. 1. Scematic diagram of automatic air moisture sampler.

During the summer party of the 36th Japanese Antarctic Research Expedition (JARE-36) in 1994/95 three automatic samplers were operated. One at Syowa Station on East Ongul Island, the second at Mizuho, and the third at the new established Japanese year-round Dome Fuji Station in Central Antarctica. Locations and topograpic details can be found in Fig. 2 by SHIRAIWA *et al.* (1996). Air moisture samples collected on molecular sieve were used for deuterium but not for ^{18}O measurements, because there may occur an isotopic exchange between the oxygen atoms of the zeolithe and the water. In order to overcome these methodical problems cryogenic sampling was established by using the liquid nitrogen generator of Syowa Station. Air was sampled through the intake and atmospheric water vapor was trapped into a glass trap cooled by liquid nitrogen. Furthermore cryogenic trapped water, which was continuously obtained by the Japanese CO_2 and CH_4 analyzing equipments (TANAKA *et al.*, 1987; AOKI *et al.*, 1992, 1994), was used for isotopic analyses. Precipitation sampling was done by collecting fresh deposited

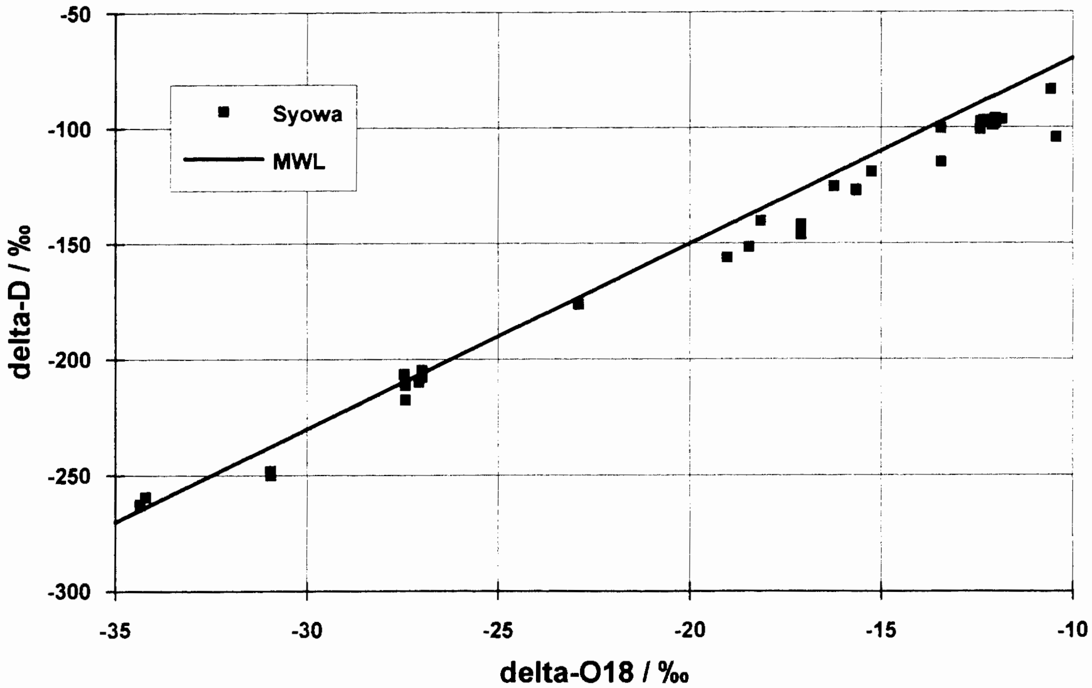


Fig. 2. Scatter plot of single δD versus $\delta^{18}O$ values of precipitation at Syowa Station in comparison to the "meteoric water line" (MWL).

snow after meteoric events. If there was obtained sufficient melted water, the electric conductivity could be measured in the laboratory of the station. Isotopic ratios of all samples of air moisture and precipitation were retrieved for all collected samples by mass spectrometric analyses. The resulting D/H and $^{18}O/^{16}O$ isotopic ratios are expressed in terms of the δ-notation as usual, *i.e.* in relation to the isotopic standard SMOW (standard mean ocean water).

3. Observations and Meteorological Data

The sampling program of air moisture has been already started on board of RV SHIRASE during the cruise from Tokyo *via* Freemantle (Western Australia) to Antarctica. On December 25, 1994 the first sample was taken at Syowa, and afterwards each second day till February 1, 1995. At Mizuho one automatic sampler operated absolutely autark from January 9 to February 1, 1995 and took samples each second day. At Dome Fuji only five air moisture samples and no precipitation could be collected because of logistic difficulties between January 17 and 28, 1995.

Synoptic meteorological data of the Stations Syowa, Mizuho, Dome Fuji, and of the RV SHIRASE were obtained. Aerological parameters (temperature, humidity, dew point temperature, windlayers) for standard pressure levels were retrieved from rawinsonde launches at Syowa and RV SHIRASE. Antarctic weather charts produced by Japan Meteorological Agency (JMA), five days backward trajectory analyses for the end locations Syowa, Mizuho, and Dome Fuji were delivered by Deutscher Wetterdienst (DWD), and sea ice charts compiled by RV SHIRASE and by NAVY-NOAA JIC (1994/95) were used for the discussion of the obtained isotopic variations. Satellite images were received by JARE-35/36. They could be used for additional information on the sampling site.

4. Results and Discussion

For the period of December 25, 1994 to February 1, 1995 isotopic compositions of Antarctic air moisture and precipitation were evaluated. An overview on the data range and variability of single delta values is given in Table 1 for the main results at Syowa and Dome Fuji Stations. The high data variability is consistent with other isotopic measurements of single air moisture and precipitation probes from Antarctica (SATOW and WATANABE 1985; AGETA, 1993; SCHWARZ *et al.*, 1995). At the British Antarctic Station Halley (75.50°S, 26.65°W) even monthly means of δD and δ^{18}O still show considerable variations ranging from −276 to −62 and from −36.38 up to −5.66‰ with standard deviations of 44.9 and 5.74‰ respectively (IAEA, 1993).

Table 1. Statistics of isotopic results (in ‰ with regard to SNOW) for air moisture and precipitation samples at Syowa and Dome Fuji Stations.

Air moisture	Syowa	Syowa	Dome Fuji	Precipitation at Syowa Station		
δD values	cryogen	molecular sieve		δ^{18}O	δD	Excess
Number of samples	18	21	5	33	32	32
Minimum	−237.9	−232.7	−211.5	−34.40	−262.5	−20.88
Maximum	−177.3	−180.2	−143.3	−10.44	−83.4	14.48
Average	−208.31	−202.80	−180.52	−19.67	−152.27	1.37
Standard deviation	4.05	3.08	14.54	1.39	10.09	1.28

A strong linear relationship was found between deuterium and ^{18}O distribution in precipitation obtained at Syowa Station (Fig. 2). The linear regression for the observed delta values is

$$\delta D = 7.43 \times \delta^{18}O - 9.56,$$

with a correlation coefficient $r=0.995$ for 32 observations. Herein especially the intercept, corresponding to the deuterium excess d, defined as $d = \delta D - 8 \times \delta^{18}O$, deviates drastically from the "meteoric water line" $\delta D = 8 \times \delta^{18}O + 10$. It might be explained by condensation under non-equilibrium conditions and by kinetic or diffusive processes playing a considerable role in the history of the air masses where these precipitations came from. Thus low excess, especially at higher delta values, is typical for isolated basins, deserts or islands (HOEFS, 1987).

In Fig. 3 the Syowa δD values of air moisture, collected by the different methods described above, are compared with δD values from Dome Fuji and with the δD means of precipitation events at Syowa. Considering that only the molecular sieve trapping at Syowa and Dome Fuji was synchronously, a good correspondence between the sampling methods is obvious. However, no satisfactory correlation could be found between delta values and local synoptic meteorological data as

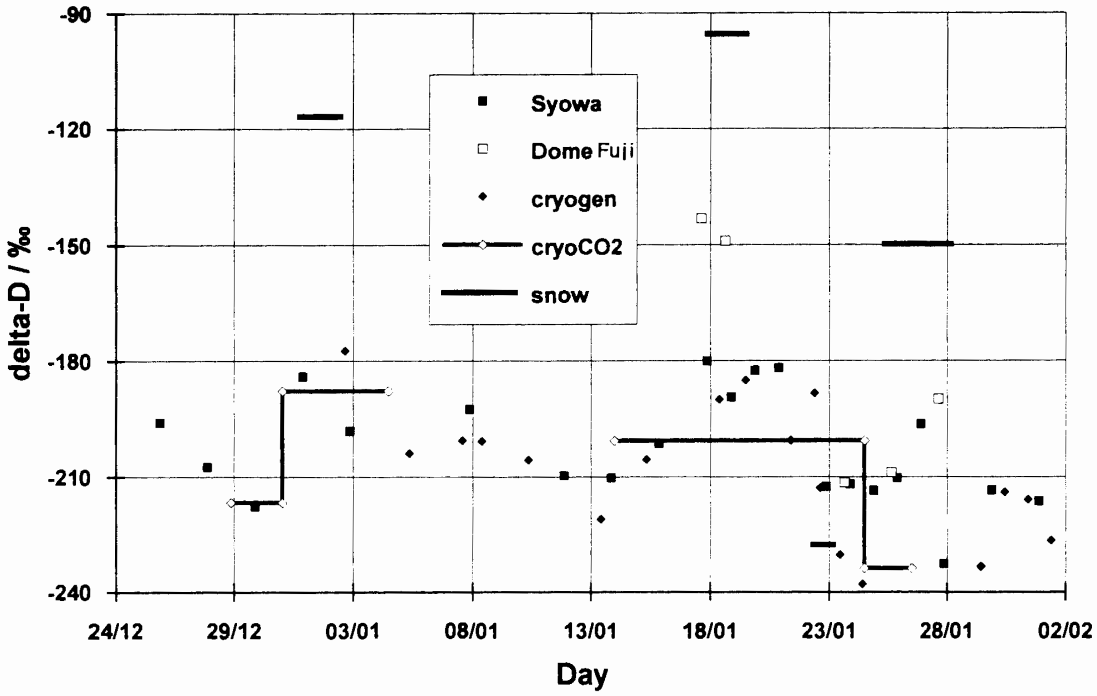


Fig. 3. Comparison of δD values of air moisture sampled by molecular sieve traps at Syowa Station (filled squares) and Dome Fuji Station (empty squares) and additionally by two cryogenic trapping methods at Syowa (see text). Furthermore, the mean δD values of four precipitation events (snow) are shown as shadowed horizontal beams.

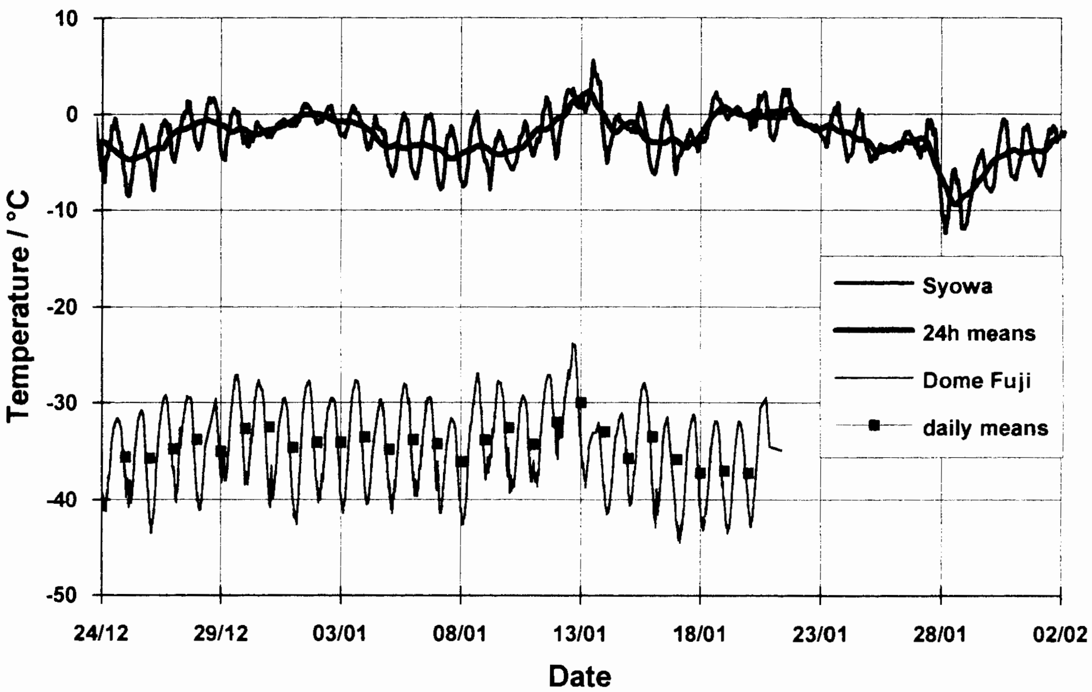


Fig. 4. Surface temperature course during JARE-36 summer party at Syowa Station and Dome Fuji Station.

station temperatures (Fig. 4), dew point temperatures, air pressure, wind speed or direction, humidity or sun radiation. We have studied the aerological rawinsonde data as well. But there was no typical temperature or humidity pattern at higher altitudes which could correspond to the isotopic data variation.

As formerly reported for Syowa by KATO (1978) and by BROMWICH and WEAVER (1983), there is a significant correlation of $\delta^{18}O$ of fallen snow with the distance of the sampling site to the open sea. We have also found a correlation of $\delta^{18}O$ to the distance of the ice edge from Syowa Station (Fig. 5). The statistical significant relationship is:

$$\delta^{18}O = 7.025 \times \delta_{ice}/100\,\mathrm{km} \times 37.665,$$

for δ_{ice} = distance of the ice edge from Syowa Station in km, obtained by RV SHIRASE and for $\delta_{ice} < 350$ km, with a weak correlation coefficient of $r = 0.571$ for 33 observations. The correlation might be weak, because the sea ice change was small during the short period of observation.

Antarctic weather charts by JMA and backward trajectories by DWD have been much more helpful for a qualitative assessment of extreme high or low isotopic values (Fig. 6). On January 2, 1995, tropospheric cyclones were located around the Antarctic continent. The backward trajectory calculations for the following day show, that air masses were transported from about 55°S to Syowa Station at higher altitudes, above 300 hPa. The corresponding precipitation and air moisture samples have increased δD values (Fig. 3). A similar meteorological pattern, but more pronounced was recorded on January 18 and 19. A strong cyclone was located over the Central Antarctic continent. The corresponding trajectories at the 850 and 300 hPa levels show an extended transport of air masses. Consequently heavy snow precipitation and air moisture were observed at Syowa Station and even at Dome

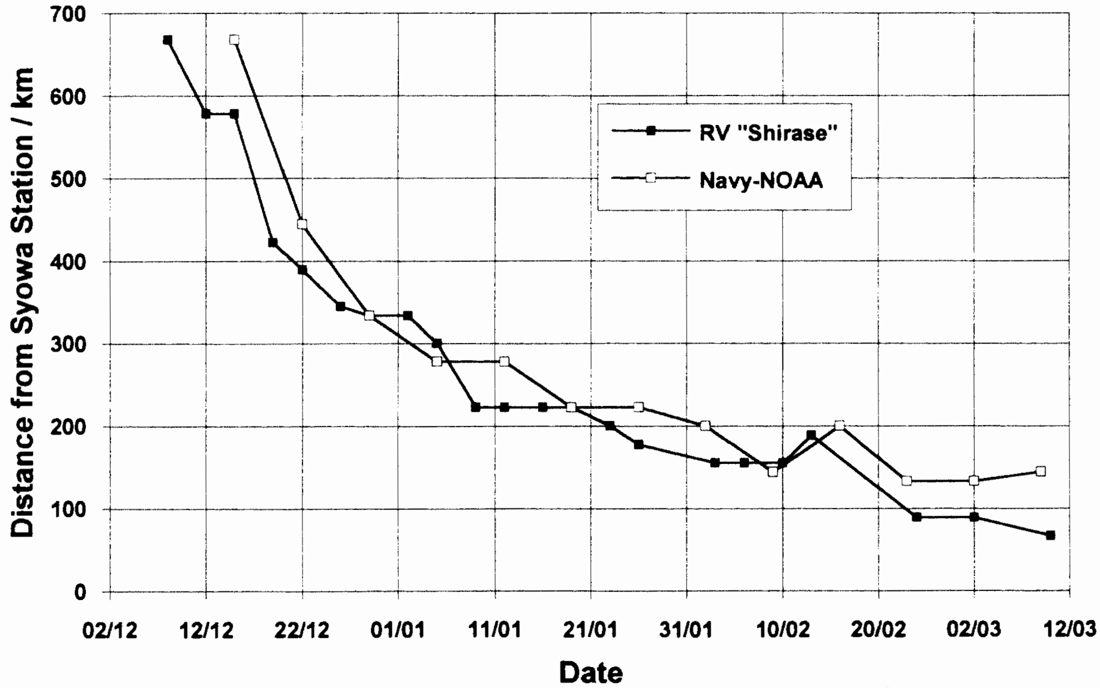
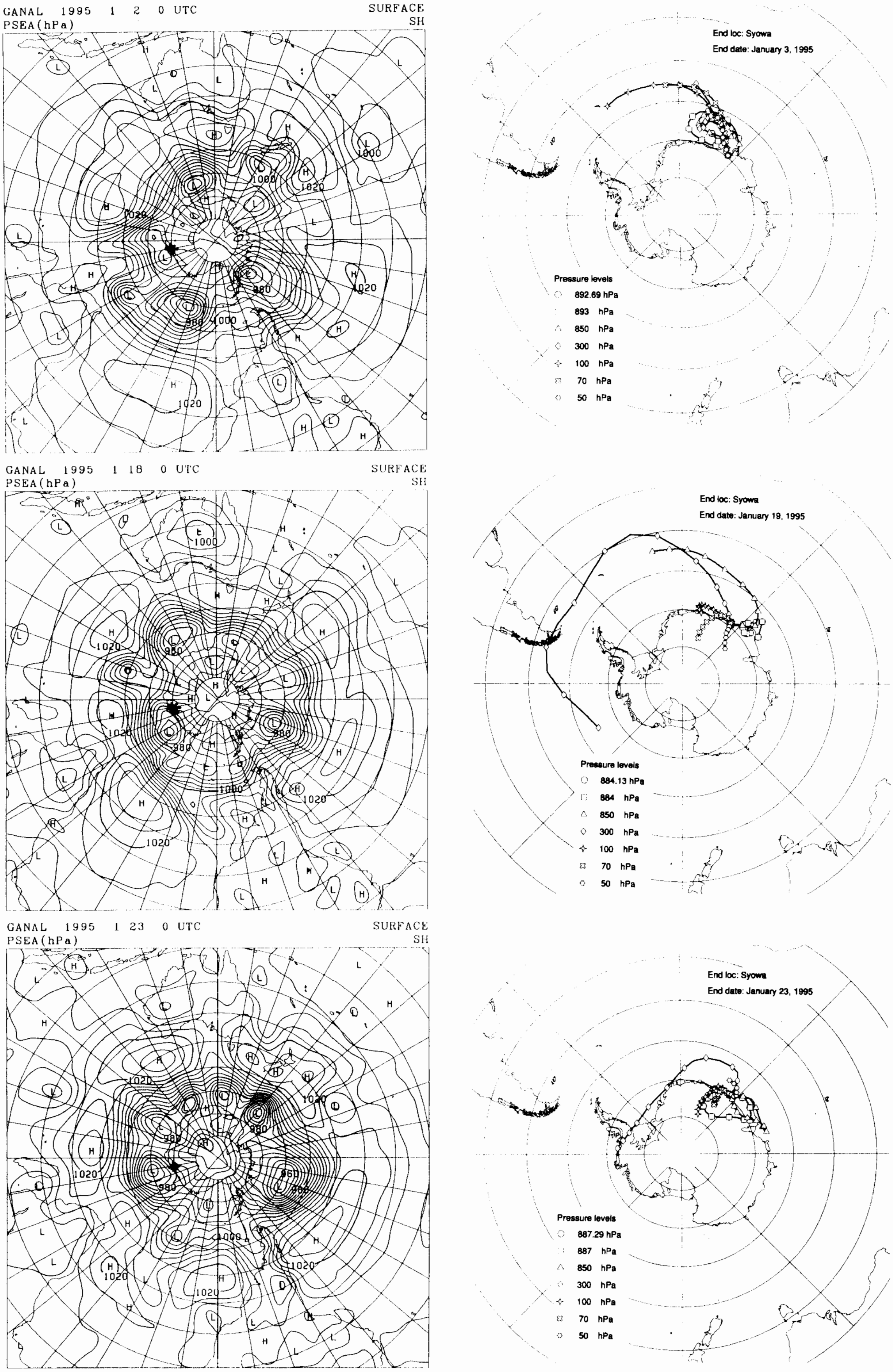


Fig. 5. Development of the sea-ice edge off Syowa Station, derived for 39.5°E from charts of RV SHIRASE and from US NAVY-NOAA JIC charts.



GANAL 1995 1 2 0 UTC
SURFACE SH
PSEA(hPa)
End loc: Syowa
End date: January 3, 1995
Pressure levels
892.69 hPa
893 hPa
850 hPa
300 hPa
100 hPa
70 hPa
50 hPa
GANAL 1995 1 18 0 UTC
SURFACE SH
PSEA(hPa)
End loc: Syowa
End date: January 19, 1995
Pressure levels
884.13 hPa
884 hPa
850 hPa
300 hPa
100 hPa
70 hPa
50 hPa
GANAL 1995 1 23 0 UTC
SURFACE SH
PSEA(hPa)
End loc: Syowa
End date: January 23, 1995
Pressure levels
887.29 hPa
887 hPa
850 hPa
300 hPa
100 hPa
70 hPa
50 hPa

Fuji Station too. But three days later, isotopic very light snow and very light air moisture were recorded. Probably from the remaining air moisture of the last precipitation event. That is also indicated by an absolute conductivity minimum of 2.2 μS/cm measured in the melted water of these snow samples, *i.e.* only a very few amount of ionic condensation nuclei was left. Later a stable high-pressure pattern developed again over the Antarctic continent with prevailing zonal circumpolar circulation of air. Hence delta values dropped down by January 25 when the next precipitation event appeared at Syowa Station.

These examples show, that the isotopic compositions of air moisture and precipitation recorded at the coastal region and inside the Antarctic continent are mainly controlled by individual events of strong mesoscale transport of air from lower latitudes towards polar latitudes. These conditions control the isotopic composition more then the local temperature at the sampling sites.

5. Conclusions

The isotopic data from single precipitation events and from air moisture exhibit considerable variations during short periods of time. They can not be explained by local temperature changes. The extent of sea ice cover seems to have some influence on the isotopic composition of air moisture and precipitation. There is no quantitative relationship to any synoptic meteorological parameter, but qualitative conclusions could be drawn by comparison of precipitation and air moisture delta values and by aid of backward trajectories and weather charts. Though monthly means from long term observations tell us about general pattern, high time resolved isotopic data are more powerful to discuss individual processes. Because wet air masses enter the Antarctic continent usually above the inversion layer, it is very essential to compare samples from the coast line, where katabatic winds prevail, with samples from the inner continent at higher elevation. Therefore the Antarctic sampling program of air moisture and precipitation for isotopic investigations will be continued at Syowa Station and Dome Fuji Station until January 1997 by kindly assistance of JARE members. On this way it is expected to get more detailed information on the recent primary isotopic input to Antarctica, on its mean seasonal variation and on individual events of strong tropospheric exchange of air between middle and polar latitudes.

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*Fig. 6 (opposite). left side: Antarctic weather charts from Japan Meteorological Agency (JMA). Herein Syowa Station is roughly marked by *, and up is 140°E. right side: Backward trajectories for Syowa from Deutscher Wetterdienst (DWD). All at 0000 UTC.*

one of the authors (G. SCHWARZ) in the summer party of JARE-36 as an "exchange scientist" under the Antarctic Treaty. For kindly meteorological and aerological data supply we express our thanks to the JARE members of JMA as well as for weather charts to Mr. KANETO, also JMA. Thanks the generous readiness of over wintering members of JARE-36 and -37 the sampling at Syowa and Dome Fuji Stations will be continued till January 1997. This work was funded by the Deutsche Forschungsgemeinschaft under grant-No. Ge 782/1-2.

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