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Meteorological observation and chemical compositions of precipitation during the winter and spring season in 1997/98 at Siorapaluk, northwestern Greenland

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Abstract

Meteorological observations and snow samplings were carried out in Siorapaluk, northwestern Greenland from November in 1997 to May in 1998. Snow samples were melted and were analyzed for chemical compositions and oxygen stable isotope fractions. Through the observations, remarkable differences of climatic condition and chemical compositions of precipitation between winter and spring were found. In winter, precipitation amount was low, northeastern wind which blows from high elevation of ice sheet was enhanced. In spring, by contrast, precipitation amount increased, Na^+, Cl^-, Ca^{2+}, $CH_3SO_3^-$ and NO_3^- fluxes were increased, and sporadic increases of these species occurred. These differences are assumed to result from a migration of an anticyclone from center of Greenland toward north in spring.

1. Introduction

Ice cores are important archives which record past environmental and climatic changes. The variations of chemical species in ice cores are interpreted as indicators of records of past aerosols at the ice core drilling site. Several studies for chemical substances including in shallow ice cores obtained from the Greenland ice sheet showed drastic increase of pollution after industrial revolution (e.g. Mayewski *et al.*, 1990a; Fischer *et al.*, 1998b; Hong *et al.*, 1994).

Comparative studies of ice core records from various regions in Greenland ice sheet show the spatial variations of chemical composition, and the spatial variations result from the differences of scavenging efficiency, seasonality of precipitation, and contribution of wet and dry deposition (Davidson *et al.*, 1989; Chen *et al.*, 1997; Fischer and Wagenbach, 1996). These indicate that it needs for ice core studies to comprehend the wide-range depositional conditions of chemical substances over ice sheet and glacier in present state. Several glaciological investigations in northwestern Greenland have been reported. However, the investigation of coastal region did not observed chemical substances, and the investigation for chemical substances were done in only high altitude (Mayewski *et al.*, 1990b; Fischer *et al.*, 1998a).

We carried out a meteorological and glaciological investigation on northwestern Greenland in 1997/98. The aims of the investigation are to evaluate the depositional conditions of chemical substances in coastal region of northwestern Greenland ice sheet, and to feed back them to ice core studies in Greenland. Under this investigation, we also carried out meteorological observations and precipitation samplings from November 1997 to May 1998 in Siorapaluk, where we founded the base camp for the expedition. This paper presents the features of the meteorological conditions and the temporal variation of chemical substances in precipitation in Siorapaluk.

2. Methods

2.1. Location of field work

The observations were carried out at Siorapaluk, Pitffik area in northwestern Greenland (Figure 1). Siorapaluk is located at 77°47′N, 70°45′W, and the most northern village in Greenland. In Siorapaluk, materials emitting exhaust are a snow-bike, a power station built in eastside of Siorapaluk, and kerosene heaters equipped in each house. South side of Siorapaluk faces the Robertson Fjord, which was frozen from the beginning of November 1997 to May 1998. The westside of Pitffik area faces the Baffin Bay. In this season, the Baffin Bay was opened and the Smith Sound was frozen from November 1997 to May 1998.

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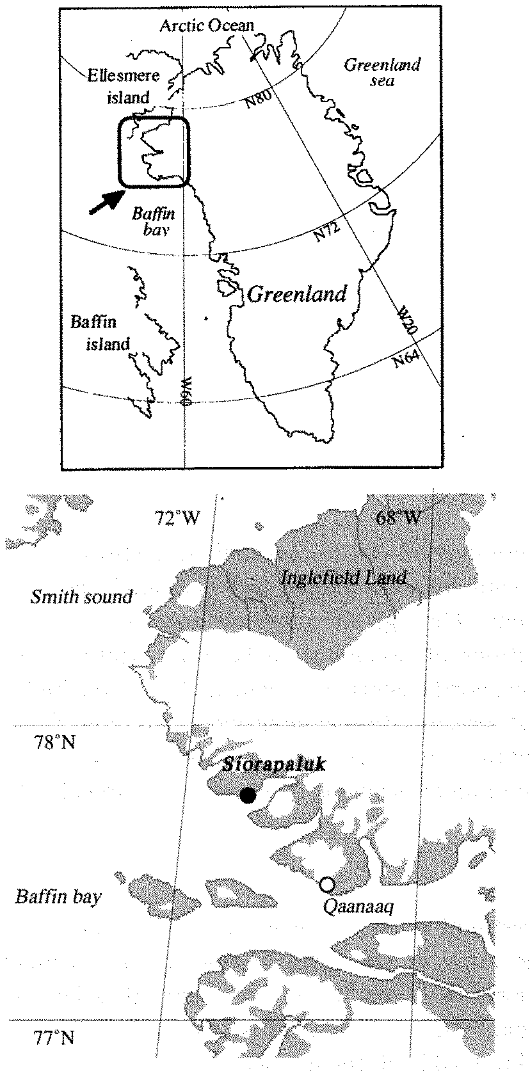

Fig. 1. Map of Pitffik area. White area in the land denote snow and ice covered surface. Siorapaluk where observation was carried out is denoted solid circle.

2.2. Observation and chemical analyses

The meteorological observation was carried out two times a day (8h and 20h L.T.) at the center of Siorapaluk from November 1997 to May 1998. Measured meteorological elements and instruments are summarized in Table 1. Air temperature and wind speed was measured at height of 1.0m.

During the observation period, precipitation was snow except for that in April 5. Measurements of snow depth and snow density, and snow samplings were carried out within 6 hours after snow falling at north side of Siorapaluk, where was not affected by pollution emitted from Siorapaluk life activities. Previous snow surface was marked by a polyethylene sheet. Daily amount of precipitation was determined by snow depth and snow density. Snow samples were collected into polyethylene bags with a polycarbonate sampler. After they were melted at room temperature, they were transported to the 50-ml polypropylene bottles cleaned by ultra pure water in an ultra sonic bath. All samples were kept frozen out of doors until they were transported to Japan. Meteorological observation was also carried out when the snow sampling was carried out.

Cation species (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anion species ($CH_3SO_3^-$; methane sulfonate, Cl^-, NO_3^- and SO_4^{2-}) in the snow samples were determined by an ion chromatography system (Dionex model 500x) with the analytical conditions described in Watanabe *et al.* (1997) with minor modifications. Oxygen isotope was measured with a mass spectrometer (Finigan MAT Instrument model δE). All analysis was carried out in National Institute of Polar Research, Japan.

3. Result

3.1. Meteorological observations

Variations in meteorological elements measured are shown in Figure 2. Monthly maximum and minimum of air temperature and monthly mean of air temperature, atmospheric pressure, wind speed, and cloud amount are shown in Table 2.

Minimum air temperature during observation period was −34°C, and was observed in January 20, 23 and 26. Air temperature rose gradually from beginning of March. Rapid rising of air temperature over 5°C was observed in January 28 and April 10. In January 28, simultaneously rapid atmospheric pressure decrease, strong northeast wind, and strong blizzard were observed. On the other hand, in April 10, northeast wind and strong blizzard was not observed while rapid atmospheric pressure decrease was also observed, but west wind and heavy precipitation was observed.

The direction of prevailing wind was northeast and did not change during the observation period. The

Table 1. Meteorological elements observed in Siorapaluk.

Elements	Instrument	(Maker: Type)
Atmospheric Pressure	aneroid barometer	(CASIO: DPX-410)
Air Temperature	Thermister thermometer	(Anritsu Meter:TFT-60)
Snow Temperature	Thermister thermometer	(Anritsu Meter:TFT-60)
Wind speed	Propeller anemometer	(ONDO: AK-666)
Wind direction	Eye observation	
Cloud amount	Eye observation	
Cloud genus	Eye observation	
Visibility	Eye observation	
Precipitation amount	Scale and Weight	

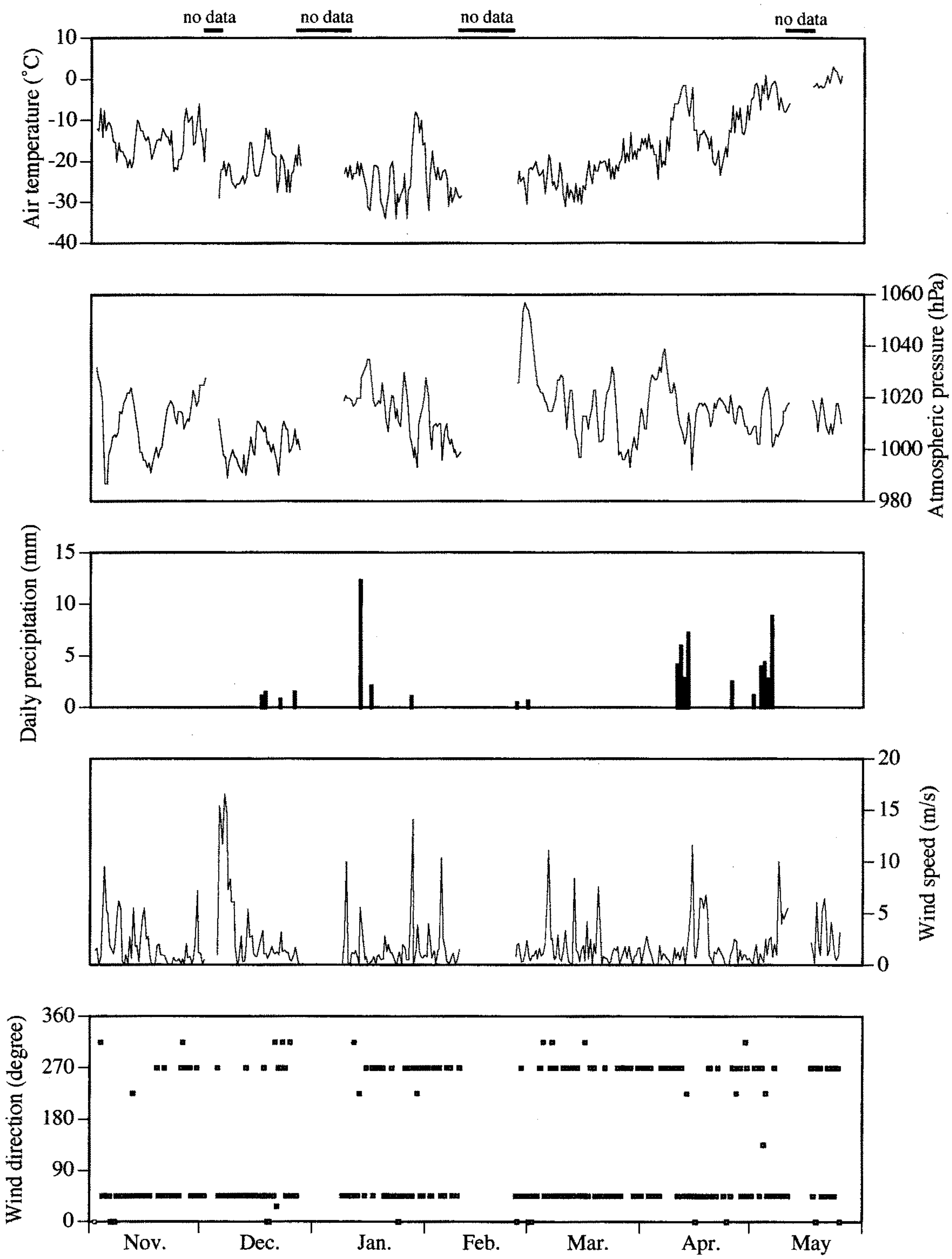

Fig. 2. Variations in meteorological elements observed in Siorapaluk from November 1997 to May 1998.

Table 2. Monthly maximum and mimimun of air temperature and monthly mean air temperature, atmospheric pressure, wind speed, and cloud amount.

		'97 Nov.	Dec.	'98 Jan.	Feb.	Mar.	Apr.	May
Air temperature	Mean (°C)	−14.7	−21.0	−23.2	−25.4	−22.6	−12.8	−2.3
	Max (°C)	−6.0	−12.0	−8.0	−17.5	−13.0	−1.5	3.0
	Min (°C)	−22.5	−29.0	−34.0	−32.0	−31.0	−24.5	−8.0
Atmospheric Pressure (hPa)		1010	1003	1017	1015	1014	1017	1012
Wind speed (m/s)		2.0	3.2	1.6	1.6	1.7	1.7	2.5
Cloud amount (1/10)		4.6	4.1	4.1	3.8	1.8	4.6	6.4

prevailing wind blew from the high elevation in the interior of the Greenland Ice Sheet towards coastal area. It seems to be associated with katabatic wind on Greenland ice sheet. The frequency of westerly was increased in April and May. It is probably because that distribution of atmospheric pressure changed.

Amount of precipitation and number of days with precipitation increased in April and May. Heavy precipitation occurred in January 14, April 14 and May 6-7 during the observation period. In January 14, atmospheric pressure and air temperature decreased. On the other hand, in April 14 and May 6-7, atmospheric pressure decreased similarly, but air temperature rapidly rose and wind speed increased over 10 m/s in a few days. Since decrease of atmospheric pressure was observed in the day with the heavy precipitation, it is assumed that the precipitation was caused by water vapor brought by cyclone low. The differences of the behaviors of air temperature and wind speed between January, and April and May might be caused by the difference of transport process of water vapor.

The relationships between wind direction, wind speed and air temperature are shown in Figure 3. When wind speed was over 10m/s, atmospheric pressure was under 1020 hPa and wind direction was northeast. But there is no significant correlation between them mutually.

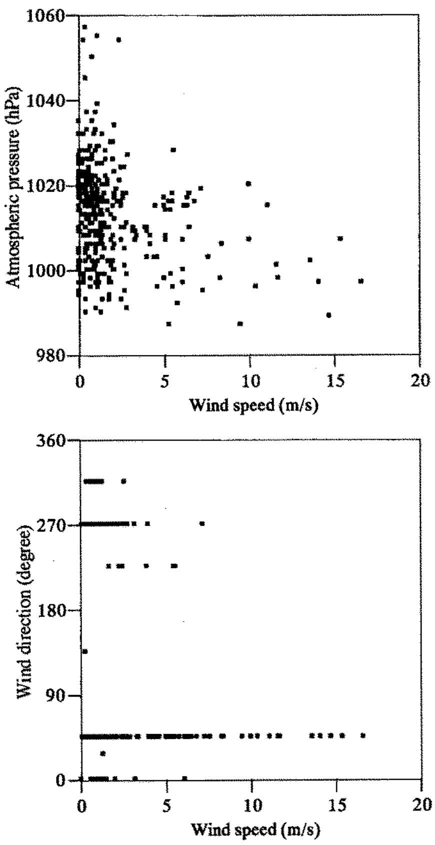

Fig. 3. Relationships between wind speed and atmospheric pressure, and between wind speed and wind direction during the observation period.

The relationships between air temperature and atmospheric pressure in winter (from November to December) and spring (from April to May) are shown in Figure 4. In spring air temperature tended to increase with the decrease of atmospheric pressure while in winter there is no correlation between them. It is assumed that wind speed was controlled by cyclone lows in spring.

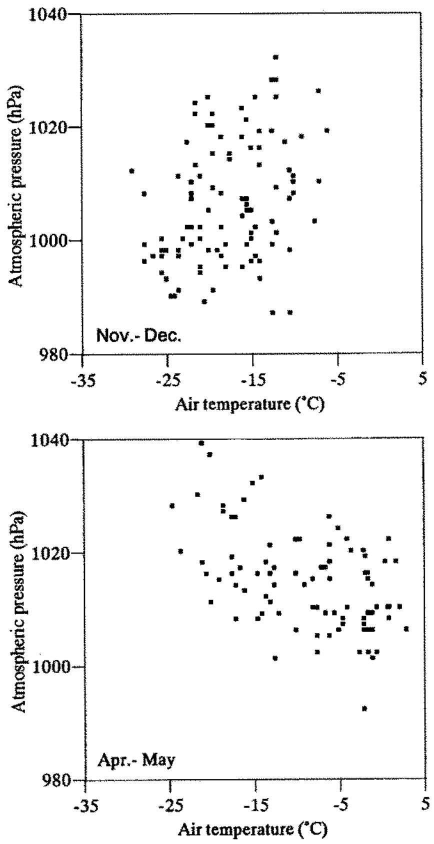

Fig. 4. Relationships between air temperature and atmospheric pressure from November to December in 1997, and from April to May in 1998.

To sum up these observation results, amount of precipitation and west wind frequency was increased, and air temperature tended to increased with the atmospheric pressure decrease in April and May.

3.2. Chemical composition in precipitation

Temporal variations of daily fluxes of chemical substances and the fraction of $\delta^{18}O$ in precipitation are shown in Figure 5.

Fluxes of Na^+ and Cl^- showed remarkable high values (>150μmol・m^{-2}) in April 14 and May 5. They corresponded to the end of air temperature rising and the sudden drop of atmospheric pressure (Figure 2). Since the variation of air temperature and atmospheric pressure indicates that cyclone low brought warm air mass from south, high value of flux of Na^+ and Cl^- in April 14 and May 5 are assumed to be brought with warm vapor from the Baffin Bay by a cyclone.

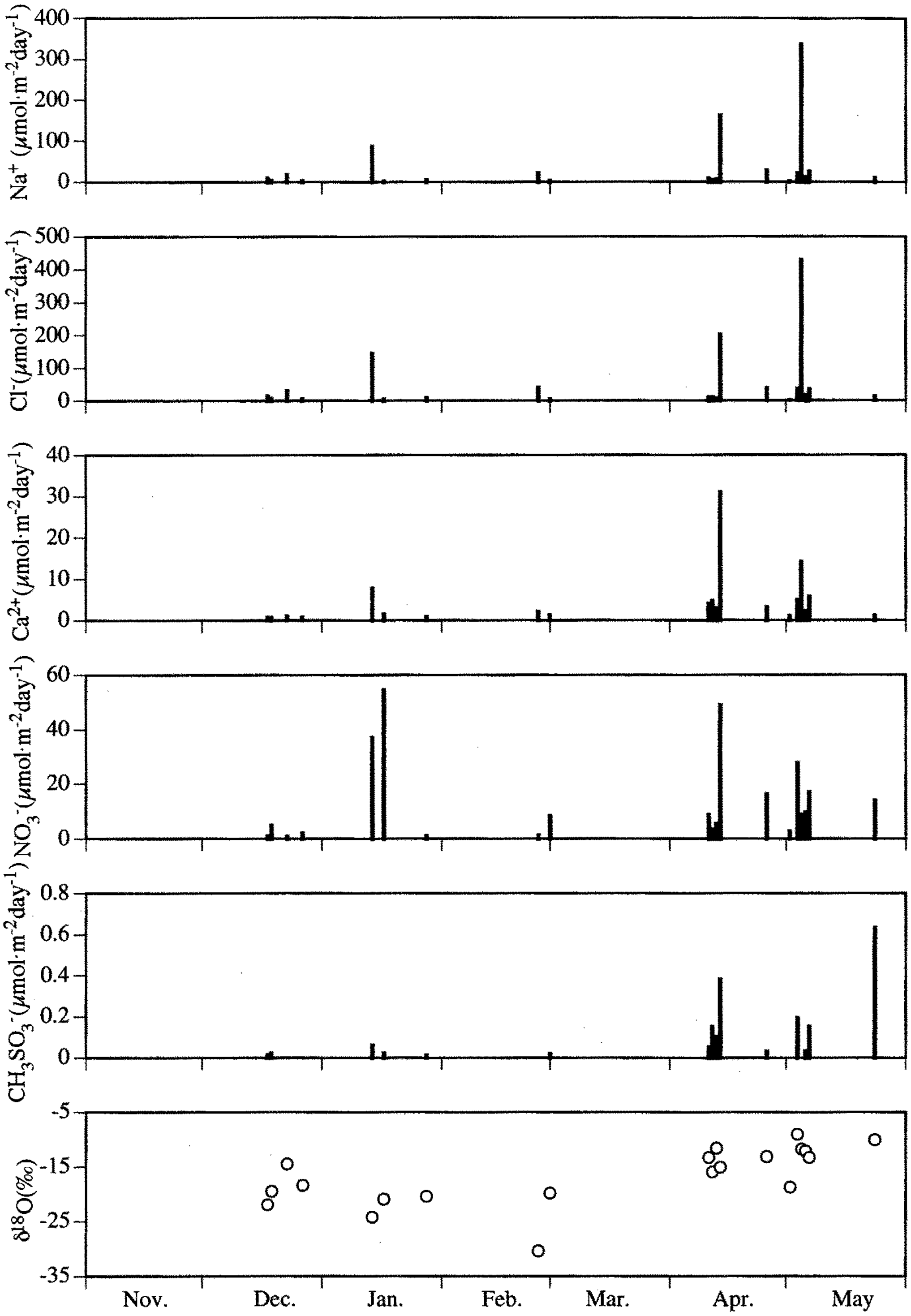

Fig. 5. Daily fluxes of chemical substances in precipitation.

Flux of Ca^{2+} showed relative higher value from April to May than that from November to March. Ca^{2+} is predominantly originated from continental dust. Studies for central Greenland also showed that peak of non sea salt (nss) Ca^{2+} concentration appeared in spring snow (Langway *et al.*, 1975; Steffensen, 1988; Whitlow *et al.*, 1992). They conclude that the spring peak of nss Ca^{2+} results from that winter aerosols which reserved in arctic troposphere due to the lack of precipitation during the winter are deposited when polar vortex breaks up and vertical mixing enhance in spring. The phenomenon is probably associated with the high value of Ca^{2+} flux from April observed in Siorapaluk.

Flux of $CH_3SO_3^-$ increased obviously in April and May. Since MSA [CH_3SO_3H; methane sulfonic acid] is produced by oxidation of DMS [$(CH_3)_2S$; dimethyl sulfide] emitted by marine biological activity, the increase of $CH_3SO_3^-$ flux reflected the enhancement of marine biological activity in spring.

High NO_3^- fluxes were observed in January and from April to May. NO_3^- is originated from anthropogenic emissions, biomass burning, soils exhalation, and fixation of nitrogen by lightning and by oxidation of NH_3 in upper troposphere and stratosphere. In this region, biomass burning and soil exhalation are negligible because the area for this observation is so far from possible source region. Since the behavior of NO_3^- in April and May were similar to Ca^{2+}, increase of NO_3^- are supposed to be caused by the break up of polar vortex and the intrusions of cyclone lows. Hence possible source of NO_3^- in April and May is supposed to be anthropogenic emissions.

NO_3^- flux was characteristically high in January 17 precipitation. The precipitation amount was low and sea salt concentration was also low in this day. Ratio of Cl^-/Na^+ in the precipitation was 9.5 (1.16 is the ratio for seawater) indicating remarkable Cl^- enrichment. In central Greenland, Cl^- enrichment showed seasonal cycle in accumulated snow, and it is interpreted as an indicator of long-range transport (Whitlow *et al.*, 1992; Legrand and Delmas, 1988). Though it is not clear that Cl^- enrichment can exactly show long-range transport, it can be conjectured that high NO_3^- flux and Cl^- enrichment were caused by different transport process of aerosols.

The relationship between air temperature and $\delta^{18}O$ is shown in Figure 6. Air temperature correlates well with $\delta^{18}O$ during the observation period.

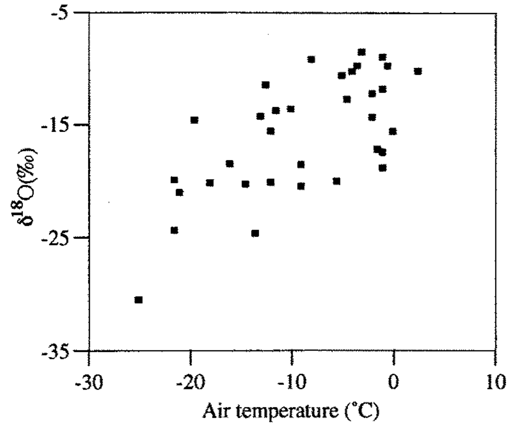

Fig. 6. Relationship between air temperature and $\delta^{18}O$ of precipitation.

Distributions of monthly sea level pressure of January, March, April and May in 1998 are shown in Figure 7. These images are provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/. In January, central Greenland was covered with an anticyclone. From March to May, the anticyclone moved toward northeast and cyclone low was drawing into Greenland from southwest. It is supposed this change of meteorological features caused the difference of meteorological conditions and chemical composition in precipitation between winter and spring observed in Siorapaluk.

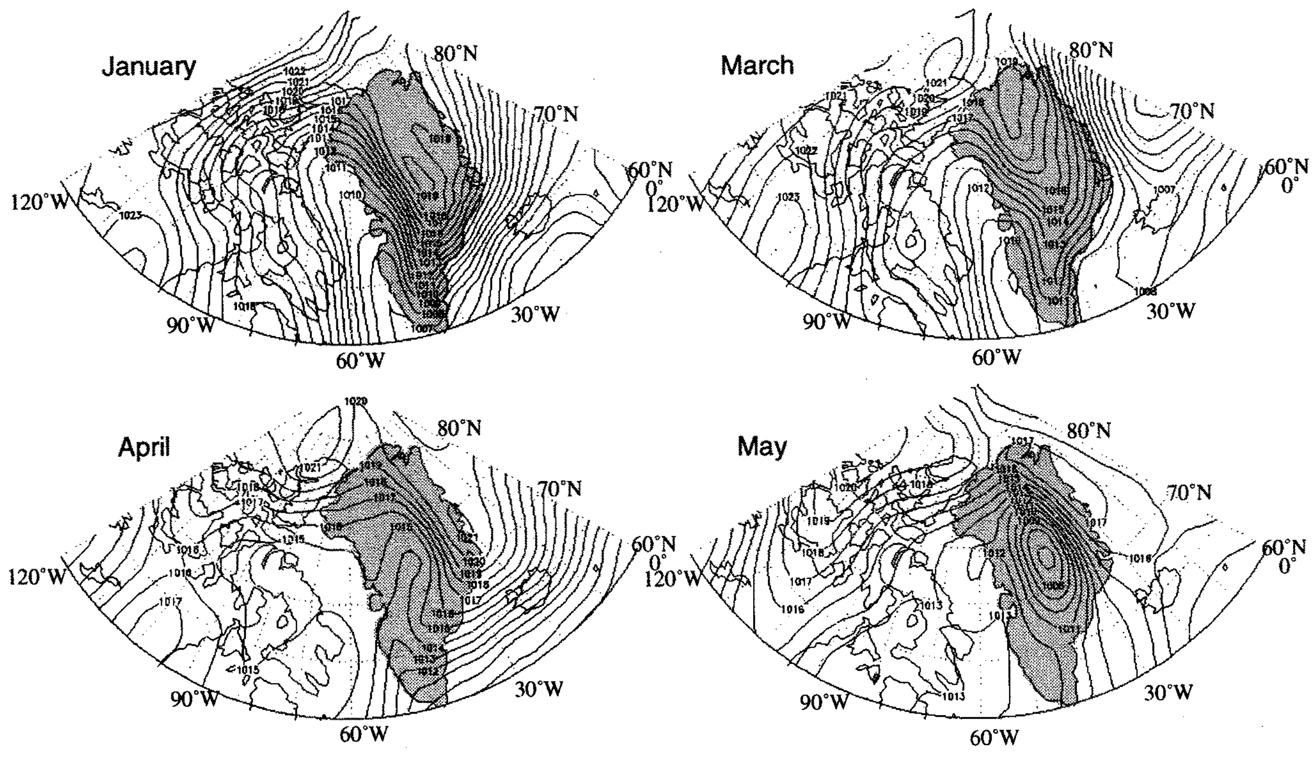

Fig. 7. Distributions of monthly sea level pressure in January, March, April, and May in 1998. These images are provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/.

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