EFFECTS OF SYNOPTIC SCALE DISTURBANCE ON SEASONAL VARIATIONS OF KATABATIC WINDS AND MOISTURE TRANSPORT INTO MIZUHO PLATEAU

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Abstract: Studies have been made of seasonal variations of meteorological elements at Syowa Station and Mizuho Camp. From the spectrum analysis of time series data of air pressure, wind speed and air temperature at Syowa Station and Mizuho Camp, the following are found: Katabatic wind speeds and air temperature at Mizuho Camp have each a good correlation with air pressure at Syowa Station in a cycle of about four days; a seasonal variation of each katabatic wind and air temperature at the camp coincides with that of air pressure at the station resulting from the synoptic scale disturbance. The studies also disclosed: A seasonal variation of air pressure at the station caused by a synoptic scale disturbance corresponds to a seasonal variation of moisture flux from the sea into Mizuho Plateau; the monthly means of both wind speed over the surface inversion layer and horizontal moisture flux from the sea to the continent became maximum in September 1972, when the synoptic scale disturbances became strong; the seasonal variation of horizontal moisture flux at the level corresponding to 700 mb above Syowa Station shows a fairly good correlation with that of net accumulation of snow at Mizuho Camp.

1. Introduction

The meteorological structure in a province provides a basic condition for the mass budget of the ice sheet there, which is the principal subject of the Glaciological Research Program in Mizuho Plateau; namely, the air circulation transports moisture inland from the sea, and the meteorological condition controls the climatic condition under which the ice sheet exists. Meteorological conditions in Mizuho Plateau have been studied by YAMADA (1974), SASAKI (1974) and KAWAGUCHI and SASAKI (1975) on the basis of the data at Mizuho Camp located at lat. 70°40′S and long. 44°20′E, 2230 m in elevation and about 270 km apart from Syowa Station. AGETA (1971) also studied the subject using meteorological data in the area along the traverse routes in Mizuho Plateau.

Katabatic winds can be considered to represent one of the main meteorological features in the most part of Mizuho Plateau, from the coastal region to the inland region which ranges approximately from 73°S to 75°S in latitude and from 3300 m to 3500 m in altitude (SHIMIZU *et al.,* 1978). KOBAYASHI and YOKOYAMA (1976) and KOBAYASHI (1978) made it clear that katabatic winds have such a structure that its thickness coincides with that of the inversion layer over the surface slope. SAKAMOTO and ISHIDA (1973) studied katabatic winds by a simulation model. WATANABE and AGETA (1972) and WATANABE (1978) discussed katabatic winds drawing on the direction of sastrugi.

The seasonal variation of meteorological elements at Mizuho Camp was not observed continuously throughout the year, because observations were suspended at times for a logistical reason. Since it is difficult to distinguish falling snow particles from drifting snow particles, measurements of precipitation in Mizuho Plateau were unsuccessful, which has constituted an obstacle in the way of clarifying the mechanism of precipitation onto Mizuho Plateau. However, on the basis of the analytical results of the meteorological data obtained at Syowa Station and Mizuho Camp, seasonal variations of synoptic scale disturbance and katabatic winds are found and the mechanism of moisture transport is discussed.

2. Synoptic Scale Disturbances and Katabatic Winds in Mizuho Plateau

It is considered that the meteorological feature at Mizuho Camp is characterized by katabatic winds blowing strongly throughout the year, which show a normal distribution with regard to wind speed and prevailing wind direction of ESE (SASAKI, 1974). The number of days on which the daily mean direction of wind is ESE constitutes some sixty percent of the whole year and this direction coincides with the longitudinal direction of sastrugi in the area of Mizuho Camp (SASAKI, 1974). As stated in Appendix, the climate at Mizuho Camp can be considered as that of cold katabatic winds. As for Mizuho Plateau, the meteorological feature is considered to be characterized by the katabatic winds in view of the longitudinal directions of sastrugi, which can be created by strong katabatic winds, inherent to the position and depending largely on the terrain in most of Mizuho Plateau (AGETA, 1971; WATANABE and AGETA, 1972; WATANABE, 1978). As for Syowa Station located on East Ongul Island, it is featured meteorologically by the absence of strong katabatic winds and the presence of the prevailing wind in the direction of NE, which is strengthened under the influence of a synoptic scale disturbance (MORITA, 1968; MAKI, 1972).

The results of observations by radiosondes above Mizuho Plateau suggest that there exist throughout the year not only an inversion layer over the surface slope, but a prevailing wind which has a large northerly component over the inversion layer from the sea inland (KOBAYASHI and YOKOYAMA, 1976).

Since a close relation was found between the values of ten-day mean air pressure at Syowa Station and Mizuho Camp throughout the year, it has been

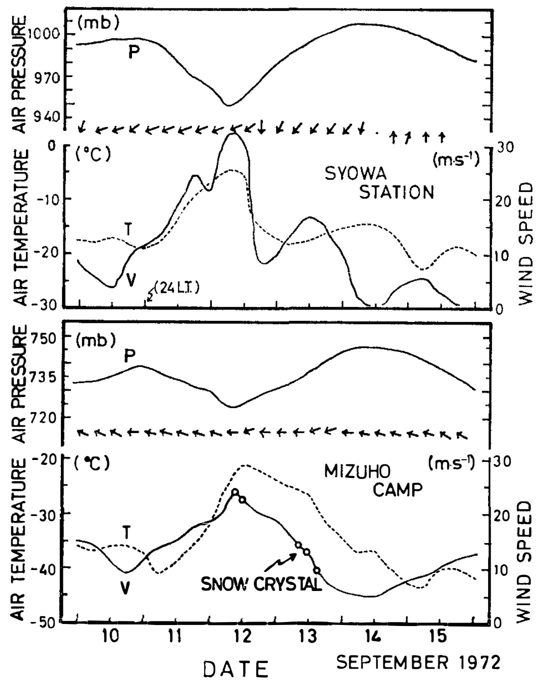


Fig. 1. Variations of air pressure, air temperature, wind speed, and wind direction at Syowa Station (top) and Mizuho Camp (bottom) from 10 to 15 September 1972. Arrows show directions of wind blow with the geographic north taken upward.

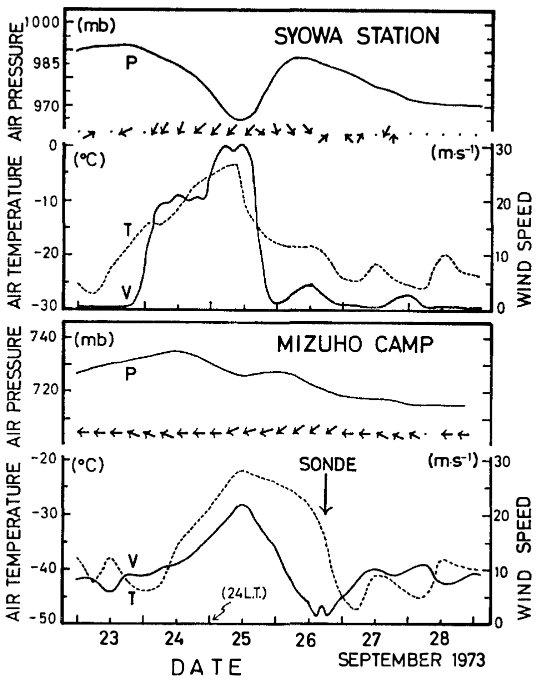


Fig. 2. Variations of air pressure, air temperature, wind speed, and wind direction at Syowa Station (top) and Mizuho Camp (bottom) form 23 to 28 September 1973.

considered that both stations are under the same air pressure field (SASAKI, 1974). Fig. 1 shows readings of such meteorological elements as air pressure, air temperature, wind speed and wind direction on the surface at both stations during the period from 10 to 15 September 1972 (JAPAN METEOROLOGICAL AGENCY, 1974; YAMADA *et al.*, 1974). The arrows show the direction of wind blow with the geographic north taken upward in the figure. It can be seen from this figure that the values of wind speed and air temperature increase at both stations as the value of air pressure decreases during a synoptic scale disturbance. When the wind reaches the maximum, the wind direction turns to NE at Syowa Station and ENE at Mizuho Camp. As regards Mizuho Camp, when the influence of the synoptic scale disturbance ceases to exist, the wind veers to ESE, which is the direction of the prevailing katabatic winds there. Each of the open circles in the line of wind speed in Fig. 1 shows the time when falling snow crystals were found in drifting and blowing snow particles at Mizuho Camp (NARITA, personal communication). It was also pointed out by NARITA that snow crystals were

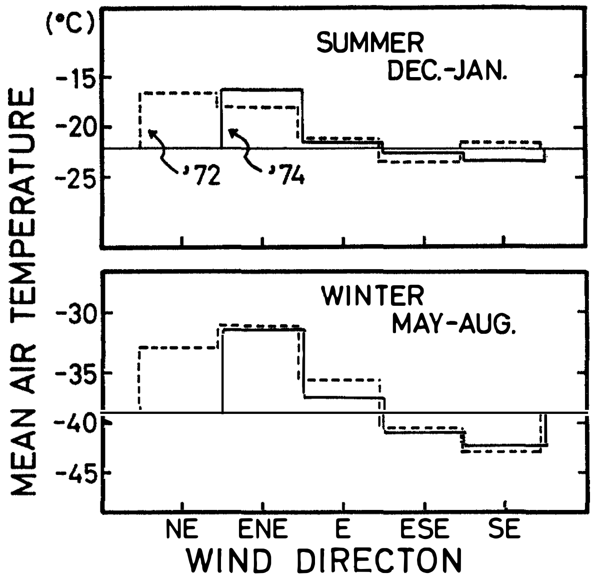


Fig. 3. Mean air temperatures with regard to wind directions from December to January (summer; top) and from May to August (winter; bottom). Broken and solid lines indicate values in 1972 and 1974, respectively.

generally detected in drifting and blowing snow particles under the synoptic scale disturbance.

Fig. 2 also shows readings of surface meteorological elements at both stations during the period from 23 to 28 September 1973 (JAPAN METEOROLOGICAL AGENCY, 1975). The variations of metorological elements in Figs. 1 and 2 strongly resemble each other as a whole. The observation by a radiosonde flown at 17^h30^m on 26 September 1973, as shown in Fig. 2, showed that katabatic wind layer over Mizuho Camp was evidently destroyed after the passing of a strong cyclone (KOBAYASHI and YOKOYAMA, 1976). The strong winds caused by the cyclone were followed by a great calm on 26 September, which would be considered as a result of destruction of the surface inversion layer. Calm katabatic winds began to recover ten-odd hours later.

Fig. 3 shows a relation between the mean air temperatures and the wind directions at Mizuho Camp during summer months from December to January and winter months from May to August. A broken line and a solid line in these figures indicate the results obtained in 1972 and 1974, respectively. Calculations were carried out using the daily means of wind direction and air temperature. It is common in both the seasons that the more the wind direction turns northerly, the higher the air temperature rises. This supports statistically the results in Figs. 1 and 2 that, when the directions of katabatic winds turn to ENE, the air temperature becomes higher, possibly due to the influence of the synoptic scale disturbance. This also strongly suggests that winds with the northerly component above the surface inversion layer are strengthened and blow inland from the sea simultaneously with the occurrence of a synoptic scale disturbance. Therefore, it would be considered that the strengthened northerly winds played a very active role in mixing into the surface inversion layer both momentum and heat energy.

3. Spectrum Analyses of Surface Meteorological Elements

Spectrum analyses were carried out for quantitative interpretation of the seasonal variations of synoptic scale disturbance and katabatic winds in Mizuho Plateau. The analyses were made on data of air pressure, air temperature and wind speed obtained by three-hourly routine readings at Syowa Station and Mizuho Camp. The time series data were passed through a band pass filter with a period from twelve hours to eight days. The frequency response function of this filter is indicated in Fig. 4. The cross spectrum of each time series was calculated using the standard package program BMD 04T (DIXON, 1973). The equivalent number of degrees of freedom for the cross spectrum estimates is about ten. The continuous data of meteorological elements throughout the year were not obtained at Mizuho Camp, since observations had to be suspended for some periods because of a logistical reason; thus, calculations were made on the consolidated data of the period from April to May 1974, from June to December 1972 and January 1975, during each period continuous observations were made (YAMADA *et al.*, 1974; KAWAGUCHI, 1975). As for Syowa Station, calculations were made on the data for the same months and years as those at Mizuho Camp (JAPAN METEOROLOGICAL AGENCY, 1974 and 1977). Therefore, the data used to compare the seasonal variations between the above two are based on an imaginary year in which different months of the two different years are arranged in the monthly order. Although resultant variations cannot reflect perfectly the real one-year long

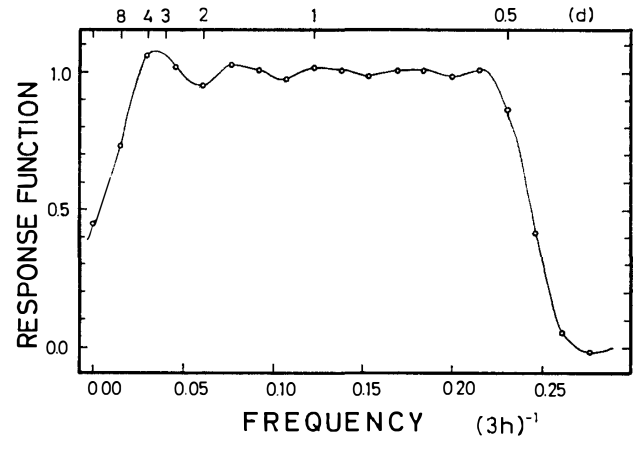


Fig. 4. Frequency response function of a band pass filter.

variations, they will help to clarify the relationship of meteorological elements between the two stations.

Air pressures at Syowa Station and Mizuho Camp show a typical wavy variation under the influence of a synoptic scale disturbance in the same way as indicated in Figs. 1 and 2, where the variation has a periodic cycle of about three days. It was found that the period of time series of air pressure became shorter and its periodicity was intensified when the synoptic scale disturbance became active for a definite time interval. Therefore, as a measure of the activity of a synoptic scale disturbance, the predominant periodicity of time series of air pressure is introduced. It can be examined from estimates of cross spectrum using time series of air pressure for a definite time interval at both stations.

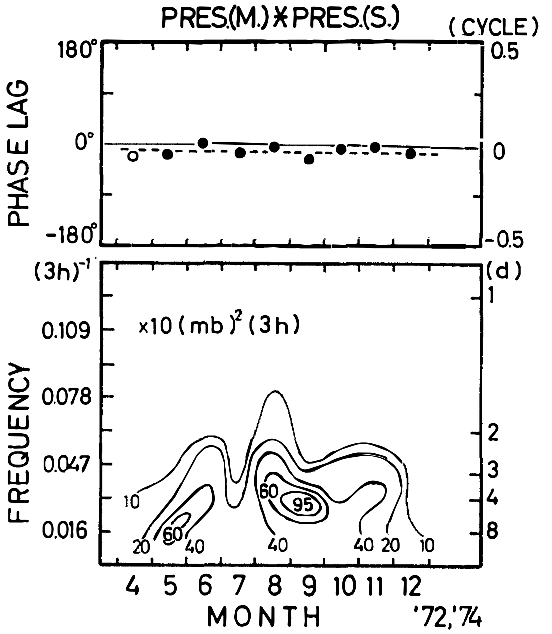


Fig. 5. Seasonal variation of cross spectrum estimates, phase lags and coherencies calculated from time series data of air pressure at Syowa Station and Mizuho Camp. Data for seasonal variations are based on an imaginary year composed of months from April to May 1974 and from June to December 1972. Solid circles and an open circle indicate that the value of the coherency is not less than 0.8 and less than 0.8 but not less than 0.6, respectively.

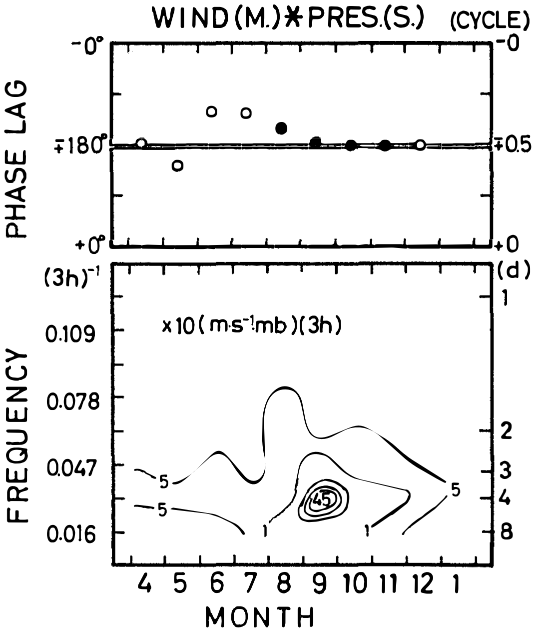
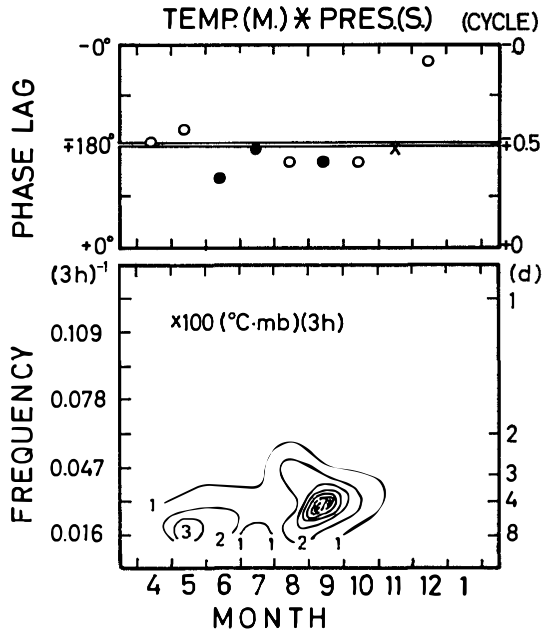


Fig. 6. Seasonal variation of cross spectrum estimates, phase lags and coherencies calculated from time series data of wind speed at Mizuho Camp and air pressure at Syowa Station. Solid circles, open circles and a symbol denoted by "X" indicate respectively that the value of coherency taken is not less than 0.8, less than 0.8 but not less than 0.6, and less than 0.6 but not less than 0.4.

Fig. 5 shows the results of the cross spectrum estimates for air pressure in each month of the imaginary year together with the results of phase lags and coherencies with regard to the predominant period. In this figure, solid circles and an open circle mean that the coherency is more than 0.8 and between 0.6 and 0.8, respectively. The phase lag computed is the phase shift of series of air pressure at Mizuho Camp with respect to series of that at Syowa Station. As seen in the figure, there is the predominant peak in the cross spectrum with a cycle of about four-day period in September 1972, which means that the time series of air pressure at both stations are closely resonant with the cycle in this month. There also exist subpeaks with a cycle of a four- to eight-day period in May 1974 and November 1972. Phase lags take about a zero degree and keep constant through the imaginary year and coherencies become large, which means that the periodic variation of air pressure at both stations may be caused by the same meteorological condition, that is, the influence of a synoptic scale disturbance.

Fig. 6 shows cross spectrum estimates, phase lags and coherencies calculated from time series of wind speed at Mizuho Camp and air pressure at Syowa Station. It is found that there is a good correlation between time series of wind speed and air pressure in a cycle of about four days in September. Phase lags having large



Ffg. 7. Seasonal variation of cross spectrum estimates, phase lags and coherencies calculated from time series of air temperature at Mizuho Camp and air pressure at Syowa Station.

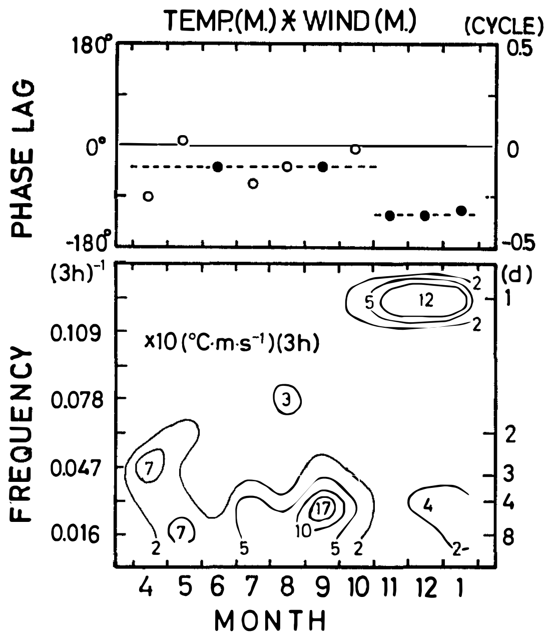


Fig. 8. Seasonal variation of cross spectrum estimates, phase lags and coherencies calculated from the time series data of wind speed and air temperature at Mizuho Camp.

values of coherency keep constant throughout the imaginary year. Fig. 7 shows cross spectrum estimates, phase lags and coherencies calculated from time series of surface air temperature at Mizuho Camp and air pressure at Syowa Station. In this case, also, the time series of air temperature are strongly resonant with a cycle of about four days in September. Phase lags with regard to the predominant period take about 180 degrees and keep constant.

Katabatic winds have a well defined annual and diurnal variation; that is, the katabatic winds blow strongly in the winter season, and the diurnal variation of katabatic winds is particularly apparent during the summer season (TAUBER, 1960); katabatic winds at Mizuho Camp are characterized by the diurnal variations of wind speed and air temperature with a constant phase lag (YAMADA, 1974). Therefore, estimates of cross spectrum of wind speed and air temperature were computed to characterize katabatic winds. Fig. 8 shows the results of cross spectrum estimates, phase lags and coherencies calculated from time series of wind speed and air temperature at Mizuho Camp. As is obvious in the figure, the one-day period is eminent as a cycle in the summer months of November, December and January, which coincides with the empirical fact (YAMADA, 1974). It is also indicated that the phase lag of the maxima in the time series of wind speed and temperature is about nine hours in the summer months. SAKAMOTO and ISHIDA (1973) analyzed katabatic winds with regard to a heat balance on the ice sheet and deduced the diurnal variation of wind speed in connection with that of temperature, which is similar to the above result. The predominant period has the value of three to eight days as a cycle in the winter months from April to September. Since the three- to eight-day period roughly coincides with the results in Figs. 6 and 7, it is concluded that the katabatic winds and the air temperature are strongly influenced by the synoptic scale disturbances. These results of spectrum analysis statistically support the results obtained in Section 2 that the katabatic winds over the ice sheet are accelerated and the air temperature becomes higher under the influence of the synoptic scale disturbance.

4. Transport of Moisture into Mizuho Plateau

From the results of the radiosonde observations at Syowa Station and Mizuho Plateau (JAPAN METEOROLOGICAL AGENCY, 1974; KOBAYASHI and YOKOYAMA, 1976), the katabatic winds can be considered to be a phenomenon within the surface inversion layer, while *northerly winds*, which have the large northerly component, flow over the inversion layer. Both the katabatic winds and northerly winds are strongly influenced by the passing of a disturbance near the coast. Observations by radiosondes in Mizuho Plateau indicate that the profiles of air temperature over the surface inversion layer at Mizuho Camp coincide fairly well with those at Syowa Station, which can be interpreted that the strong northerly winds transport relatively warm air masses horizontally from the positions above Syowa Station to the same levels above Mizuho Camp (KOBAYASHI and YOKOYAMA, 1976).

For the purpose of examining the seasonal variation of northerly winds, the meridional components of wind speeds were calculated from the aerological data of wind speed and direction in 1972 above Syowa Station (JAPAN METEOROLOGI-

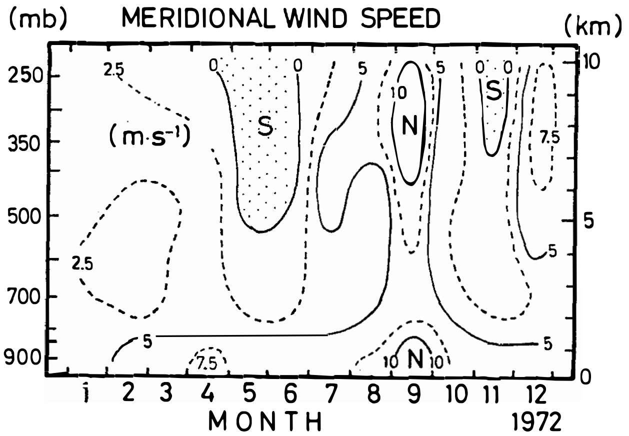


Fig. 9. Seasonal variation of monthly mean meridional wind speed components calculated above Syowa Station in 1972. The sign of wind speed is positive and negative when the wind speed has a northerly and southerly component, respectively. A wind speed in a dotted range has a southerly component, otherwise a northerly component.

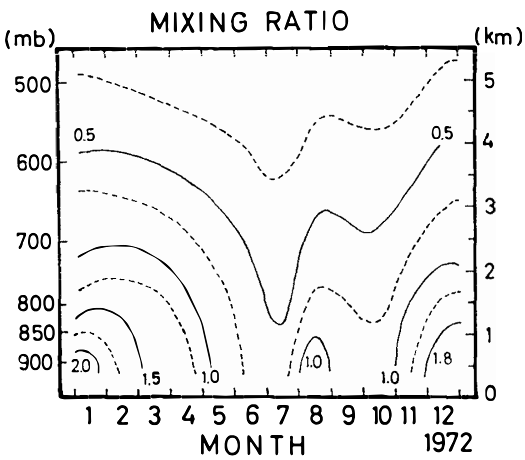


Fig. 10. Seasonal variation of monthly mean mixing ratio calculated above Syowa Station in 1972. Numbers are in grams per kilogram.

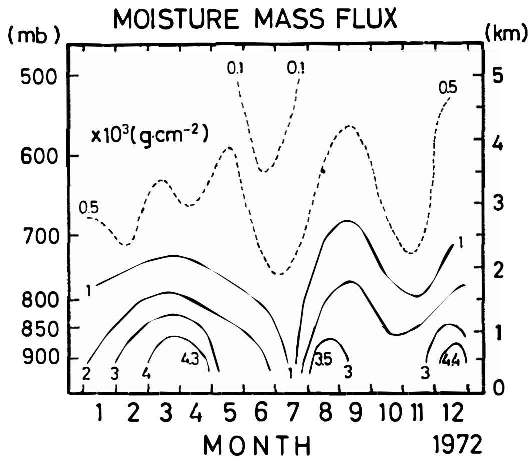


Fig. 11. Seasonal variation of monthly mean moisture mass flux from the sea to the continent over Syowa Station in 1972.

CAL AGENCY, 1974); namely, calculations were carried out using the data at the altitudes corresponding to 900, 850, 700, 600, 500, 400, 300, 250, and 200 mb. Monthly mean meridional wind speeds calculated at each altitude are indicated in Fig. 9, where a wind speed is positive and negative when a wind speed observed once every day at 00 GMT has a northerly and a southerly component, respectively. It can be seen in this figure that northerly winds are predominant throughout 1972 in the troposphere under the level corresponding to 200 mb, except for May, June and November when southerly winds become predominant over the level corresponding to 500 mb. The monthly mean mixing ratios were calculated from the aerological data of the monthly mean air temperature and relative humidity observed at 00 GMT at the levels corresponding to 900, 850, 800, 700, 600 and 500 mb (JAPAN METEOROLOGICAL AGENCY, 1974). The result for each month in 1972 is indicated in Fig. 10.

No measurements of precipitation onto Mizuho Plateau have been carried out because of the difficulties in distinguishing falling snow crystals from drifting snow particles. A moisture transport across Syowa Station may be considered as a measure of precipitation onto Mizuho Plateau. So the moisture mass flux, $\rho_i \cdot X_i \cdot V_i$, above Syowa Station was estimated; the air density ρ_i was calculated from the air temperature and air pressure which were observed once every day at the height denoted by the suffix i, while the meridional wind speed V_i and the mixing ratio X_i at 00 GMT were calculated in the same way as mentioned above. The monthly mean moisture mass flux at each level is illustrated in Fig. 11. Since air masses above Syowa Station move horizontally as noted by KOBAYASHI and YOKOYAMA (1976), the moisture may also be transported inland horizontally. From the figure, the horizontal moisture mass fluxes show a large seasonal variation; namely, the value of the flux became large in March, April, August, September and December, whereas it became small in June and July, in 1972.

Fig. 12 indicates the net moisture mass flux at the level corresponding to 700 mb which coincides roughly with the altitude of Mizuho Camp, as well as the net accumulation of snow averaged from the data obtained by the 200-stake network at Mizuho Camp (YAMADA *et al.*, 1975) during each observation period in 1972. It is seen in this figure that the August-September period shows a predominant peak in the moisture mass flux in the level corresponding to 700 mb. It is also obvious that there is a large amount of net accumulation of snow in the same period and in December, and a small amount of net accumulation in October, while a small amount of ablation was observed from May to July and in November. The seasonal variation of net accumulation of snow at Mizuho Camp shows a fairly good correlation with that of moisture mass flux in the level corresponding to 700 mb. Therefore, the moisture mass flux at this level would contribute greatly to the amount of precipitation in the Mizuho Camp area. The

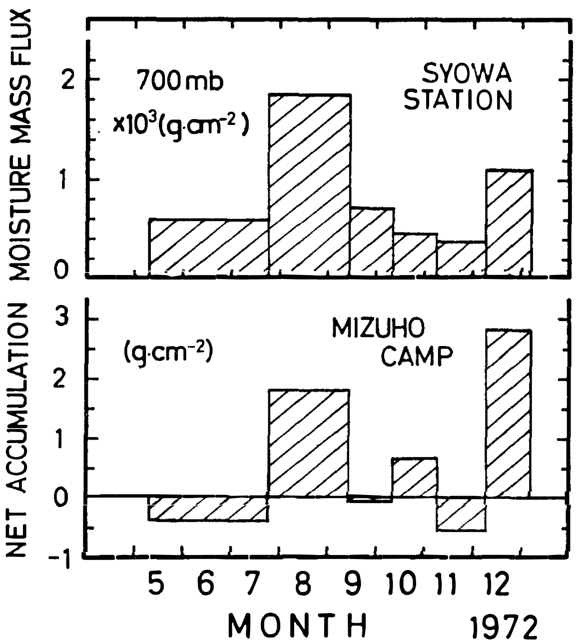


Fig. 12. Seasonal variation of net moisture mass flux at the altitude corresponding to 700 mb above Syowa Station and mean net accumulation of snow at Mizuho Camp in 1972.

above—mentioned results are supported by the fact that the seasonal variation of area—mean accumulation of snow in the area along Routes H and Z (Yamada *et al.*, 1978) indicates the same tendency as was obtained by the 200-stake network and moisture mass flux. Further studies on the relation between them are required.

5. Concluding Remarks

Meteorological conditions in Mizuho Plateau would be characterized by the katabatic winds within the inversion layer over the surface slope and the winds over this layer which have large northerly components. When the northerly winds are accelerated under the influence of a synoptic scale disturbance, a large amount of moisture is transported from the sea to the continent. The amount of moisture horizontally transported by the northerly winds was large in September 1972 when the synoptic scale disturbances were very active. There is a fairly good correlation between the seasonal variations of both the horizontal moisture mass flux at the level corresponding to 700 mb above Syowa Station and the net accumulation of snow at Mizuho Camp.

Moreover, with a view of investigating a relation between the moisture mass flux and the net accumulation of snow in Mizuho Plateau, it is necessary to measure directly the amount of precipitation and ablation. If the amount such as this can be evaluated, it will afford a clear understanding of the mechanism of accumulation in Antarctica.

Acknowledgments

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Calculations of spectrum analysis were made by FACOM 230-75, Hokkaido University.

APPENDIX

Climatic Table

In order that the climatic conditions in Mizuho Plateau are clarified, annual mean values of meteorological elements at Syowa Station, Mizuho Camp, Plateau Station and Pionerskaya Station are summarized in Table 1, where the values at Syowa Station and Mizuho Camp are averages of the monthly mean values from 1970 to 1974 (YAMADA *et al.*, 1974; KAWAGUCHI, 1975) and from 1971 to 1975 (JAPAN METEOROLOGICAL AGENCY, 1971, 1973, 1974, 1975 and 1977) respectively, and the values at Plateau Station and Pionerskaya Station are due to DARLYMPLE (1966) and SCHWERDTFEGER (1970), respectively.

From the classification of the climate on the ice sheet by DARLYMPLE (1966), Mizuho Camp and Plateau Station, which are meridionarlly located, represent typical climates defined as cold katabatic and cold interior, respectively. Considering that there is a vast area of supposedly a cold katabatic climate on Mizuho Plateau and a few stations on the katabatic slope in the Antarctic, the annual mean values at Pionerskaya Station defined as cold katabatic are also listed in Table 1. It can be easily seen that the meteorological and topographical conditions at Mizuho Camp are similar to those at Pionerskaya Station.

In this table, drifting and blowing snow frequencies at Syowa Station and Mizuho Camp are calculated from the number of days with daily maximum wind speed at the height of 1 m exceeding 7 m·sec^{-1} which can be considered to be the critical value with regard to an occurrence of drifting snow at Mizuho Camp (YAMADA, 1974). The global radiations at Syowa Station and Mizuho Camp are discussed on the basis of the observation in 1972 by KAWAGUCHI and SASAKI

Table 1. Annual mean values of meteorological elements at Syowa Station, Mizuho Camp, Plateau Station, Pionerskaya Station. The values designated by a), b), c), d) and e), are quoted from DARLYMPLE (1966), SCHWERDTFEGER (1970), KAWAGUCHI and SASAKI (1975), MAKI (1974), and KOBAYASHI and YOKOYAMA (1976), respectively.

Observatories	Syowa Station	Mizuho Camp	Plateau Station	Pionerskaya Station
Location	69°00′S, 39°35′E	70°42′S, 44°20′E	79°15′S, 40°30′E	69°44′S, 95°31′E
Elevation	15 m	2,230 m	3,625 m	2,740 m
Ice thickness	0 m	2,000 m	3,300 m	2,050 m
Items				
Annual mean temperature				
Air temp.	−11°C	−32°C	−56.4°C[a]	−38°C[a]
Firn temp. at 10 m depth	—	−33°C		−39°C[b]
Minimum air temperature	−40°C	−57°C	−86.2°C[a]	−60°C[b]
Maximum air temperature	+10°C	−4°C	−18.5°C[a]	−13°C[b]
Annual mean wind speed	6 m/s	10 m/s	5 m/s[a]	11 m/s[a]
Drifting and blowing snow frequency	27%[a]	77%	25%[a]	71%[a]
Prevailing wind direction	NE[a]	E∼ESE	N[a]	SE[a]
Annual mean air pressure	986 mb	734 mb	609 mb[a]	690 mb[a]
Global radiation	92 kly[c]	114 kly[c]		109 kly[a]
Annual mean net accumulation	0 cm of water	4.5 cm of water		16 cm of water[b]
Annual mean windchill ($kg \cdot cal \cdot m^{-2} \cdot hr^{-1}$)	1,200	2,100	2,480[a]	2,300[b]
Monthly maximum windchill ($kg \cdot cal \cdot m^{-2} \cdot hr^{-1}$)	1,520	2,440	3,010[a]	2,650[b]
	(August)	(June)	(August)	(August)
Surface inversion				
Depth	200∼400 m[d]	250∼600 m[e]		500∼1300 m[b]
Intensity (ΔT)		5∼25°C[e]		2∼15°C[b]

(1975). For getting the windchill, Siple Passel equation (DARLYMPLE, 1966) was used. The values of depth and intensity of surface inversion at Syowa Station and Mizuho Camp are due to MAKI (1974) and KOBAYASHI and YOKOYAMA (1976), respectively.

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