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SEASONAL VARIATIONS OF THE SEA LEVEL AT SYOWA STATION, ANTARCTICA

Yutaka NAGATA[1], Michio KAWAMIYA[2], Yutaka MICHIDA[3] and Minoru ODAMAKI[4]

[1]*Faculty of Science, University of Tokyo, 11–16, Yayoi 2-chome, Bunkyo-ku, Tokyo 113*
[2]*Center of Climate System Research, University of Tokyo, 6–1, Komaba 4-chome, Meguro-ku, Tokyo 153*
[3]*Hydrographic Department, Maritime Safety Agency, 3–1, Tsukiji 5-chome, Chuo-ku, Tokyo 104*
[4]*Maritime Safety Academy, 5–1, Wakaba-cho, Kure 737*

Abstract: The sea level record at Syowa Station, Antarctica for the period from 1979 to 1988 is analyzed, and the seasonal variation of the sea level is investigated. The level reaches a maximum in early winter and falls to its minimum in mid-summer. The variation shape is very skewed with flat winter peak and sharp summer trough. The ascending speed of the sea-level in fall is much larger than the descending speed in spring. The correlation of the sea level change with several oceanographic and meteorological phenomena are discussed, and several possible mechanisms are reviewed. However, we cannot reach a definitive conclusion yet.

1. Introduction

Continuous observations of oceanic phenomena are hard to conduct on a long-term basis, and usually require huge amounts of funds. Tide gauge observations are an exceptional case, so that long records at many stations have been accumulated almost for one century. However, tide stations are very few on the coast of Antarctica due to severe observational conditions. The Japanese Syowa Station is the only one where the tidal records have been obtained for longer than 20 years (almost continuously from 1975 up to the present) (ODAMAKI and KURAMOTO, 1989; ODAMAKI *et al.*, 1992).

The ten-year record from 1979 to 1989 was used in this paper in order to clarify the nature of seasonal variations of the sea level at Syowa Station. The sea level tends to rise in cold winter and to fall in warm summer. This is quite different from the seasonal variations in middle latitudes, where the highest level occurs in early September and the lowest level occurs in late February to early March, reflecting the variation of water temperature of the oceanic surface layer. The variations over both seasonal and shorter periods change year after year. We tried to find correlations between the sea level and other meteorological and oceanographical phenomena, but could not find any external forces which may cause the curious variation manner of the sea level at Syowa Station. However, we believe that our results will give good suggestions for future works.

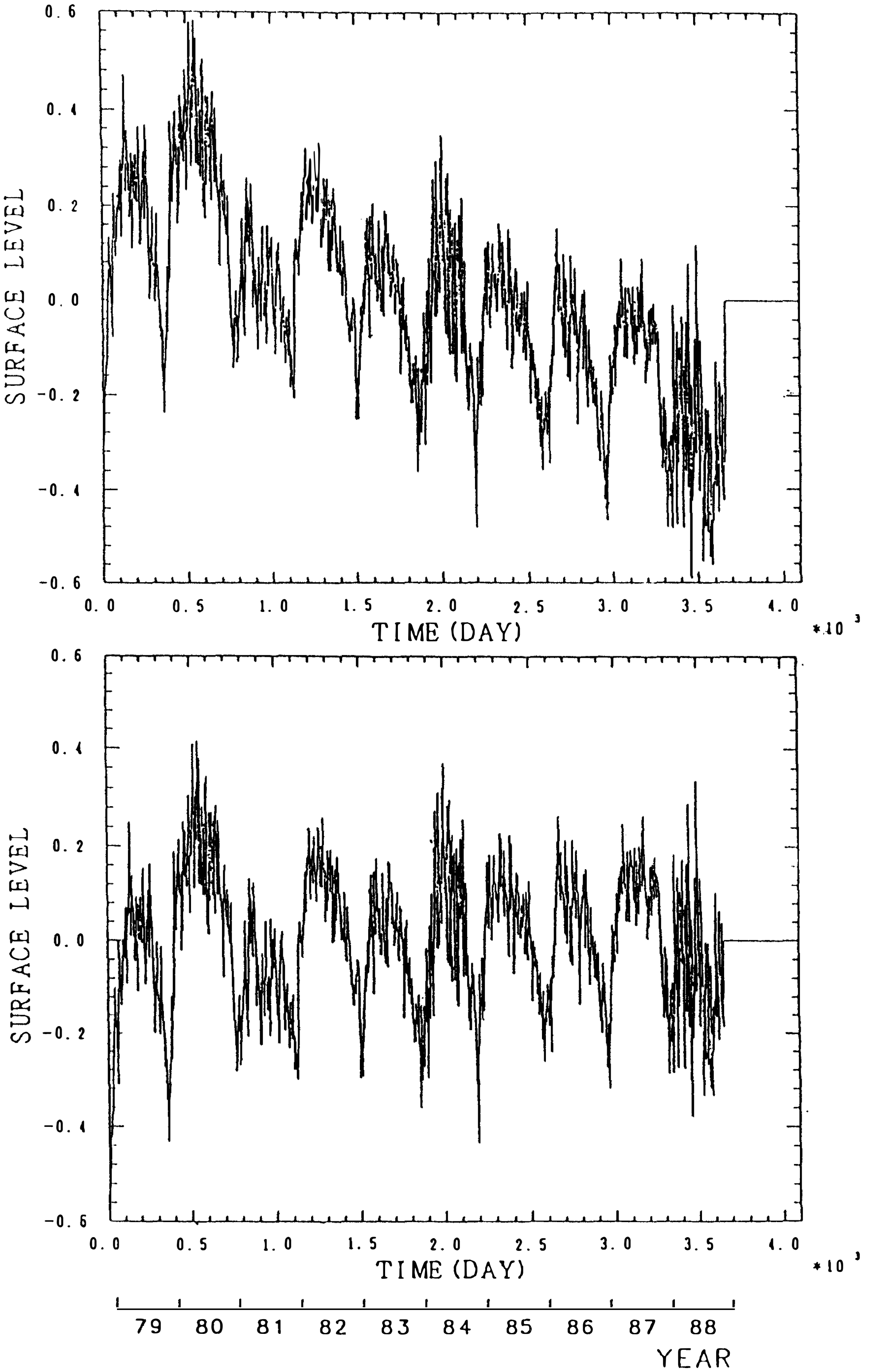


Fig. 1. Temporal variation (in m) of daily mean sea level at Syowa Station, Antarctica (69°00′S, 39°13′E) from January 1, 1979 to December 31, 1988. The 25 hour running averaged variation is shown in the upper figure, and the variation from which the linear trend has been removed is shown in the lower figure.

2. Data

Sea-level data at Syowa Station are given every one hour in the JARE Data Report series. The sea level is measured by a pressure gauge installed at the bottom in shallow water; the effect of atmospheric pressure on the sea level is removed automatically (ODAMAKI *et al.*, 1992). The hourly data were transformed to daily-mean-value time series by taking the 25-hour running mean. The resulting time series of sea level is shown in the upper part of Fig. 1. The sea level shows a long term trend of descent, indicating continuous upward movement of land. This uplift of land seems to have resulted from melting of terrestrial ice since the last ice-age, but the change may be partly due to erroneous estimation of the datum line (ODAMAKI *et al.*, 1992). In the present paper, we consider only the seasonal and shorter variations by eliminating the linear trend as shown in the lower part of Fig. 1.

In the preliminary analysis, we found that the power spectrum of the time series obtained shows low energy domain in the vicinity of the 50-day period. So, we divided the variation into two frequency ranges: seasonal variation having periods longer than 50 days, and variation shorter than 50 days. The time series resulting from the 51-day running mean is used for the analysis of seasonal variations, and the time series consisting of the difference between the original and the 51-day running mean is used for the shorter variations.

3. Averaged Sasonal Variation

The averaged variation from the ten-year data is shown in Fig. 2. The amplitude of variation is about 26 cm; the level reaches a maximum in early winter and falls to its minimum in mid-summer. The variation is very skewed; the winter peak is flat but the summer trough is sharp. The ascending speed of sea level in fall is much higher than the descending speed in spring.

PETERSON (1988) reported the data of bottom pressure measurements at 500 m depth at the north and south sides of Drake Passage for a few years as part of the International Southern Ocean Study (ISOS). The sea level variation at the south side shows a tendency to have a maximum in winter, but it is not so clear as that at Syowa Station.

The sea levels in middle latitudes show the maximum in late summer and minimum in late winter, reflecting thermal expansion due to the seasonal temperature variation in the oceanic surface layer. Seasonal variations at several stations on the Japanese coast are shown in Fig. 3 as examples. Seasonal variation at Abashiri along the northern coast of Hokkaido (the Okhotsk Sea coast) has a different nature, showing a maximum in January. The strength of the Soya Current decreases in winter season, and the saline warm Soya Water can be observed near the bottom only (AOTA, 1970). Then the surface layer is occupied by colder but fresher Okhotsk Surface Water, the density of which is much less than that of the Soya Current Water. This exchange of water masses has an effect similar to thermal expansion, and tends to increase sea level. A similar

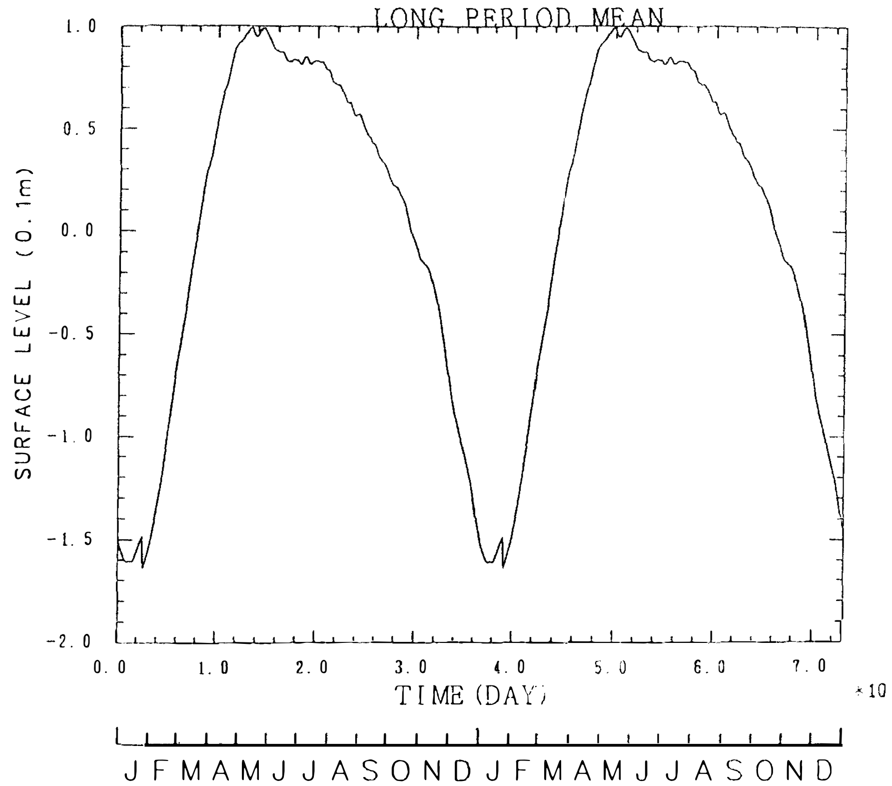


Fig. 2. Seasonal variation averaged for ten years from 1979 to 1988. The curve is shown for two years so that its skewed shape can be easily recognized.

upheaval of the sea level in winter can be also seen at the eastern coast of Hokkaido. In a low temperature environment, salinity has more effect on water density than temperature, so it is highly possible that salinity variation in the oceanic surface layer influences sea level variation, especially at high latitudes in winter.

There are few salinity and temperature data in winter in the Southern Ocean, and it is hard to estimate the salinity effect on sea level variation along the coast of Antarctica. However, changes in salinity and temperature profiles at several points in Ongul Strait in the winter of 1982-1983 were observed by FUKUCHI *et al.* (1985). The observation site is shown in Fig. 4. The temporal variation of the vertical salinity profile in the central part of Ongul Strait (Station 5) from April 1982 to January 1983 is reproduced in Fig. 5. In April, low salinity water, which could have been generated by ice melting in summer, is found near the surface. The surface salinity increases monotonously from April to September, but the thickness of the low surface salinity layer (see, for example, the depth of the 34.2 or 34.35 isohaline) increases simultaneously. Increase in salinity in the surface layer tends to lower sea level, but increase of the layer thickness causes sea level to rise. The sea level change estimated from the changes of temperature and salinity profiles at station 5 in 1982 indicates that the sea level rises a few cm from April to May at the first stage. However, soon after, the effect of the salinity increase surpasses that of the layer thickness increase, and

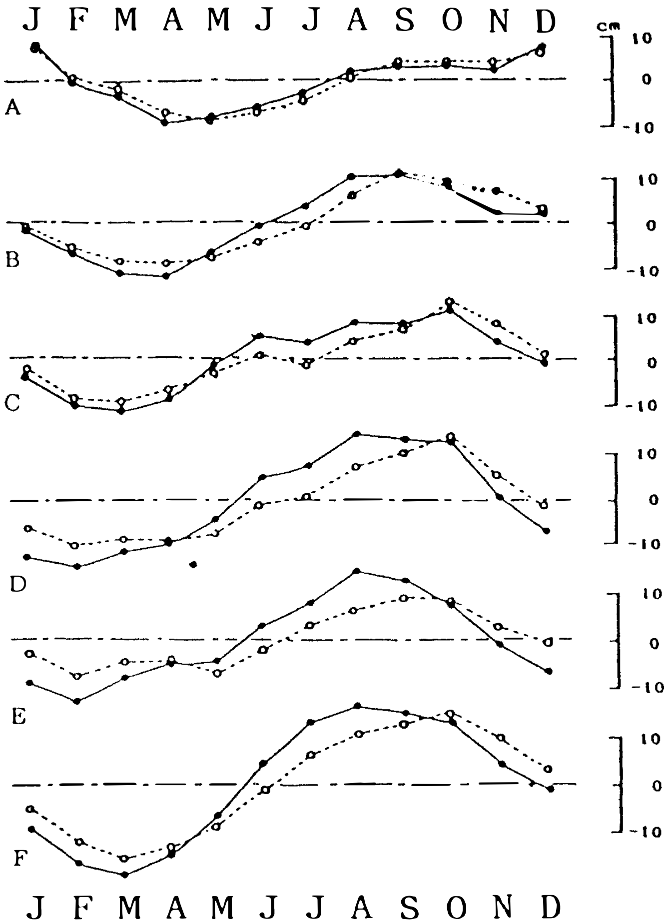
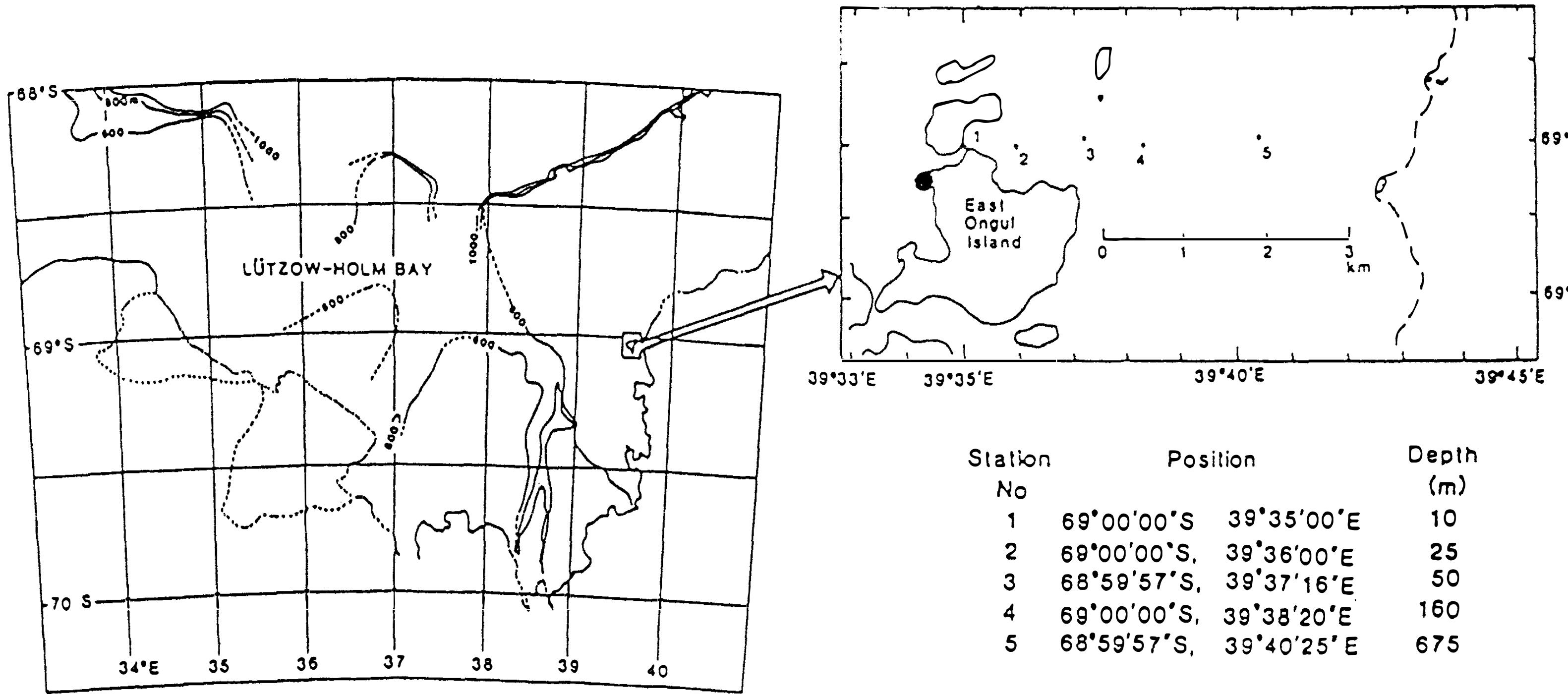


Fig. 3. Seasonal variations of sea levels at several stations on the Japanese coast. A: Abashiri, B: Ayukawa, C: Shimizu, D: Aburatu, E: Naha, and F: Maizuru. Full curve and dotted curve in each figure show variations without and with atmospheric pressure correction, respectively (KONISHI et al., 1986)

the calculated sea level starts to descend, although the real sea level at Syowa Station continues to ascend. Oceanic data in Lützow-Holm Bay in winter have considerably increased recently. From these data it is shown that the seasonal salinity variation shown in Fig. 5 is typical for the sea adjacent to Syowa Station (TAKIZAWA *et al.*, 1992; OHSHIMA *et al.*, 1993). The salinity variation in the oceanic surface layer may influence sea level at Syowa Station, but might not be large enough to explain all of its the seasonal variation.

Sea level could be affected by changes in the current system nearby. Direct current measurement in the Ongul Strait was also conducted in winter of 1982–1983. The temporal variation of the northward velocity component measure in the central part of the strait (Station 5) is shown in Fig. 6. There is a clear tendency for the northward flow to be strengthened in July–August. Increase of the northward current will cause sea level to rise along the left-hand side coast,



Station No	Position		Depth (m)
1	69°00'00"S	39°35'00"E	10
2	69°00'00"S,	39°36'00"E	25
3	68°59'57"S,	39°37'16"E	50
4	69°00'00"S,	39°38'20"E	160
5	68°59'57"S,	39°40'25"E	675

Fig. 4. Observation site of the seasonal variation of salinity profile and current velocity in winter of 1982–1983 (FUKUCHI et al., 1985). The position of the tide gauge is indicated by a large black circle.

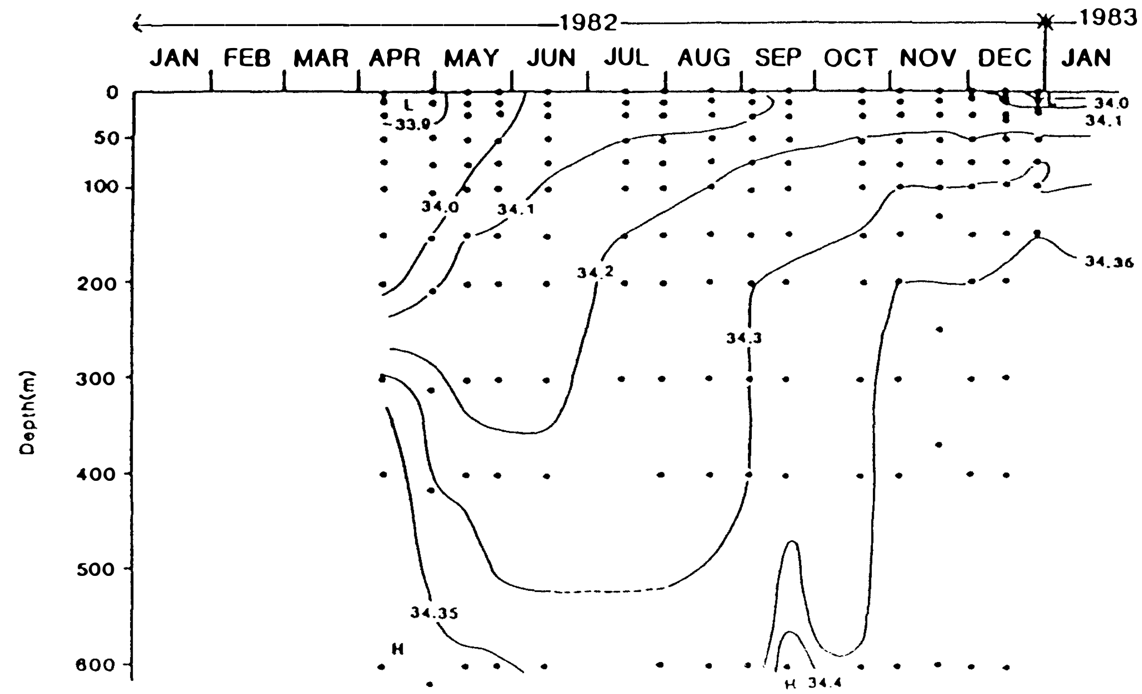


Fig. 5. Temporal variation of vertical salinity profile (in psu) at the central part of Ongul Strait (69°00′S, 39°40′E) in winter of 1982–1983 (FUKUCHI et al., 1985).

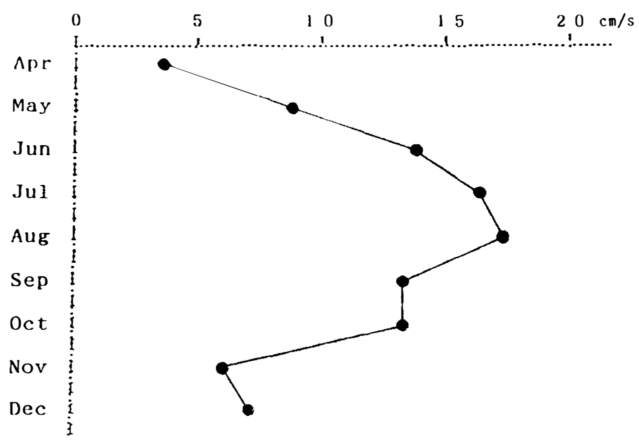


Fig. 6. Temporal variation of the north component of current velocity in the central part of Ongul Strait (69°00′S, 39°40′E) in the winter of 1982–1983 (M. FUKUCHI, personal communication).

but the current variation in a narrow strait like Ongul Strait should not cause significant sea level change. However, the current variation in Ongul Strait may reflect variation of the current system near the station. A prevailing westward current is usually observed off Lützow-Holm Bay. If the current in the strait is strongly influenced by this offshore current system, a good correlation between the changes in the current in the strait and the sea level at Syowa Station is possible.

Katabatic wind, which prevails in Antarctica, exhibits large seasonal change, and is strong in winter and weak in summer. Seasonal variations of monthly mean wind speed at various stations (see Fig. 7 for positions) in Antarctica are shown in Fig. 8 from INOUE (1988). The pattern of seasonal variation of wind speed at inland stations has a high and flat peak in winter, and a sharp trough in summer, but is symmetrical about mid-winter. Katabatic wind may be strong over the inland slope area, and weak over coastal and offshore areas. This is true for stations along the western coast of Antarctica where the monthly averaged wind speed is small and does not exhibit significant seasonal variation. However, the amplitudes of seasonal variations at several stations (classified as east coast (A) by INOUE, 1988) along the east coast from 0 to 100°E are considerably larger than those at stations on the inland slope. It should be noted that a very skewed seasonal variation just like the sea level variation at Syowa Station is seen at Molodezhnaya and at Roi Baudouin which are located in the vicinity of Syowa Station. The wind speeds at Syowa Station, Mawson and Davis (classified as east coast (B) by INOUE) are much smaller than at these stations, and the seasonal variations are not strong. The change of wind characteristics from station to station seems to indicate that wind characteristics may be influenced by local geographical features.

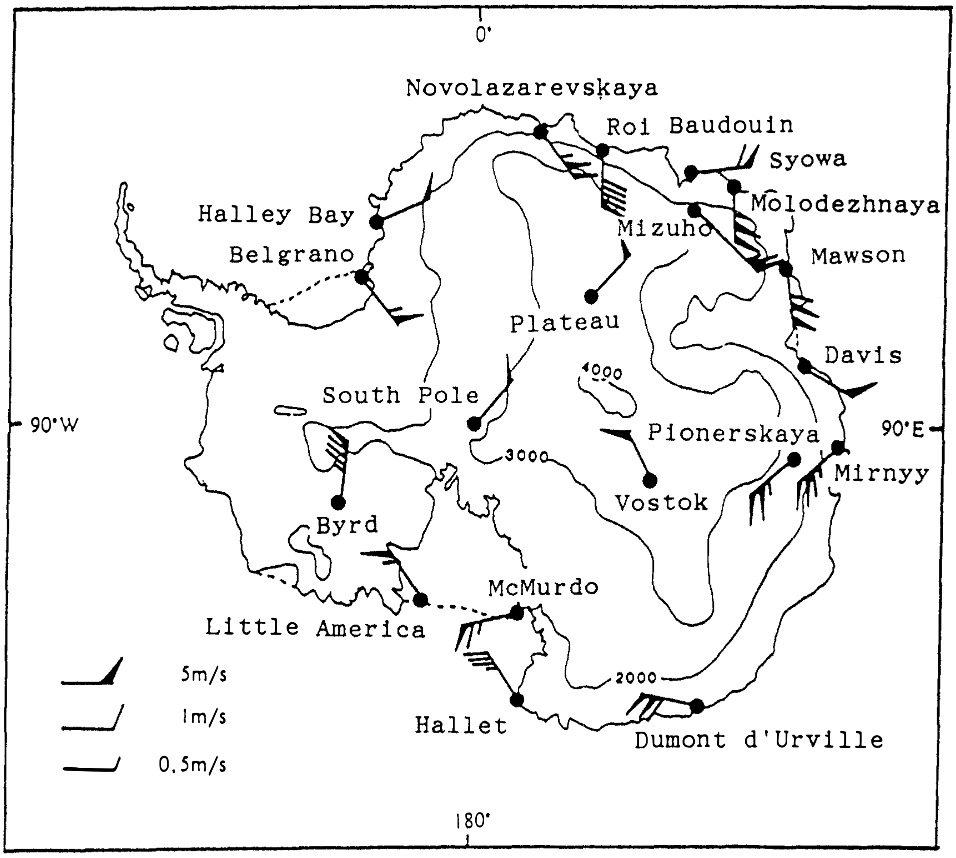


Fig. 7. Averaged wind directions and wind speeds at various stations in Antarctica (INOUE, 1988). Topographic contours are drawn at 2000 m intervals.

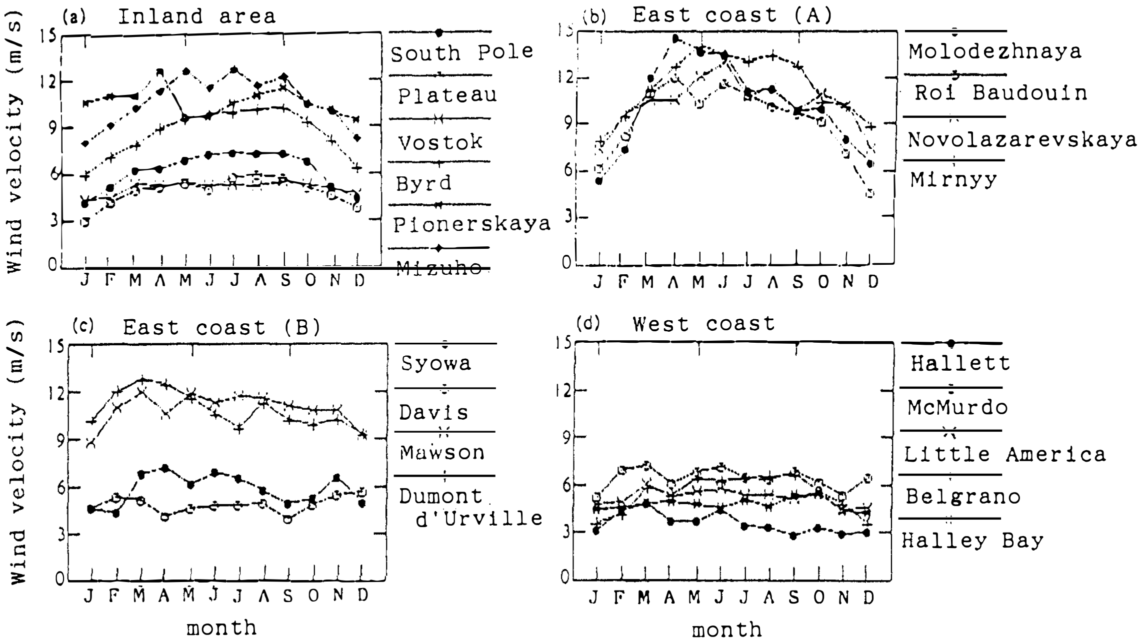


Fig. 8. Averaged seasonal variations of wind speeds at various stations in Antarctica (INOUE, 1988). See Fig. 7 for positions.

The similarity in variation pattern in wind speed at Molodezhnaya and at Roi Baudouin with that in sea level at Syowa Station suggests that the wind system over the ocean off Syowa Station may act as an external force on the sea level change. If the winds at these stations are Katabatic winds, they would be confined only to very nearshore area. However, the variation pattern at these stations is different from that at the stations on the inland slope: larger magnitude and skewed shape. The winds at these stations might be caused by meteorological conditions having much larger scale than the Katabatic wind system. Then it is plausible that oceanic current system off the east coast of Antarctica is changed by the variation in the wind system over it, so as to create the sea level change observed at Syowa Station.

3. Year-to-year Changes of Seasonal Sea Level Variations

The seasonal variation of each year is shown in Fig. 9. The amplitude and shape of the seasonal variation is very changeable year after year. We have not found any phenomena which exhibit similar variation nature as shown in Fig. 9, though such year-to-year changes would help to find the cause of the sea-level change at Syowa Station.

The pattern of the sea-level variations having periods shorter than 51-days is shown with each year in Fig. 10. Both the amplitude and period of variation are quite changeable year after year. The power spectrum of the shorter variations of each year was calculated, and the 10 obtained spectra are shown in Fig. 11, simultaneously. It should be noted that, though the heights of the peaks are very changeable year after year, spectral peaks usually appear in two frequency

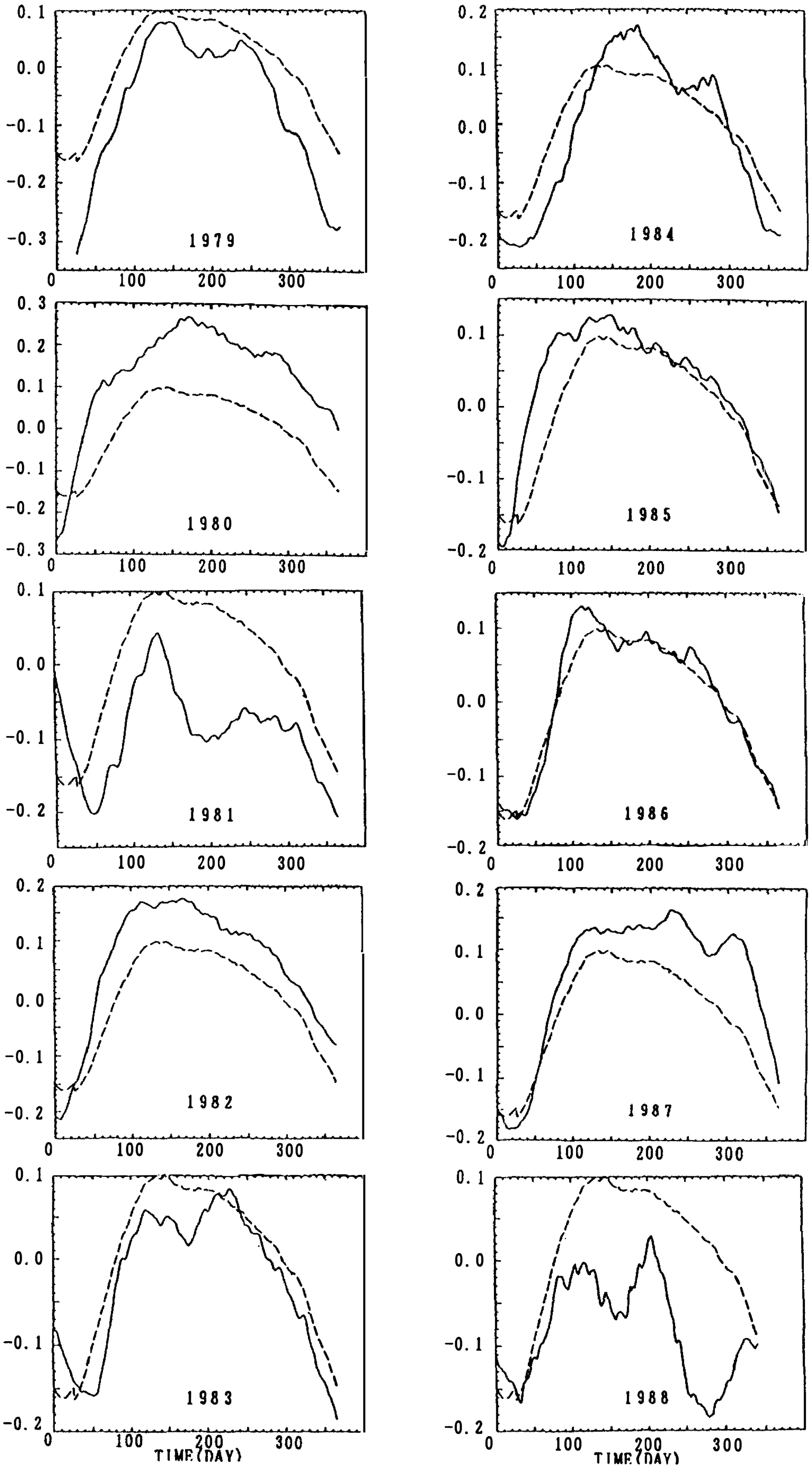


Fig. 9. Seasonal variations (51-days running averaged) of each year from 1979 to 1988 (in m). The averaged variation shown in Fig. 1 is reproduced with dashed line for comparison.

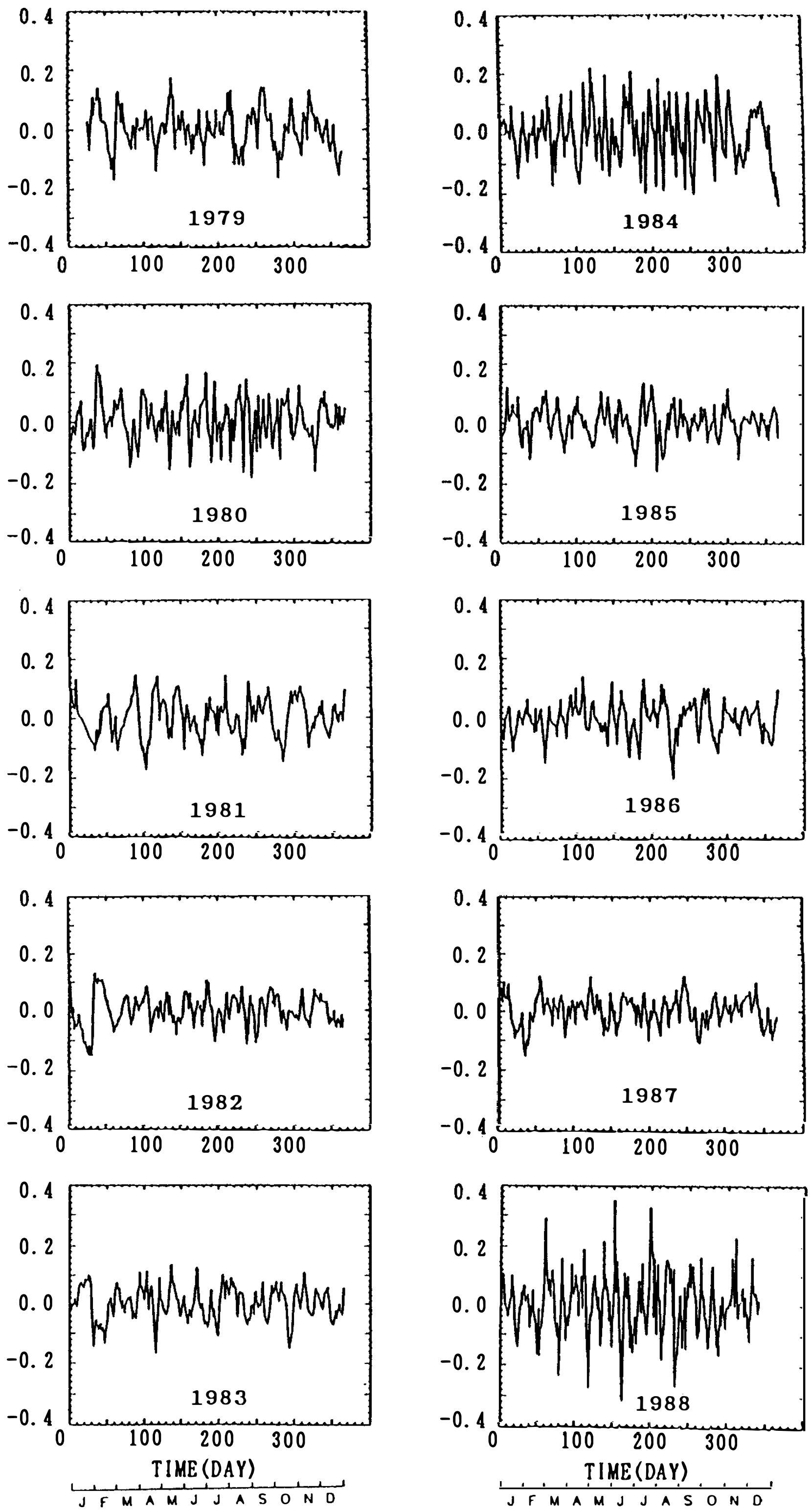


Fig. 10. *Temporal variation of sea level (in m) having periods shorter than 51 days from 1979 to 1988.*

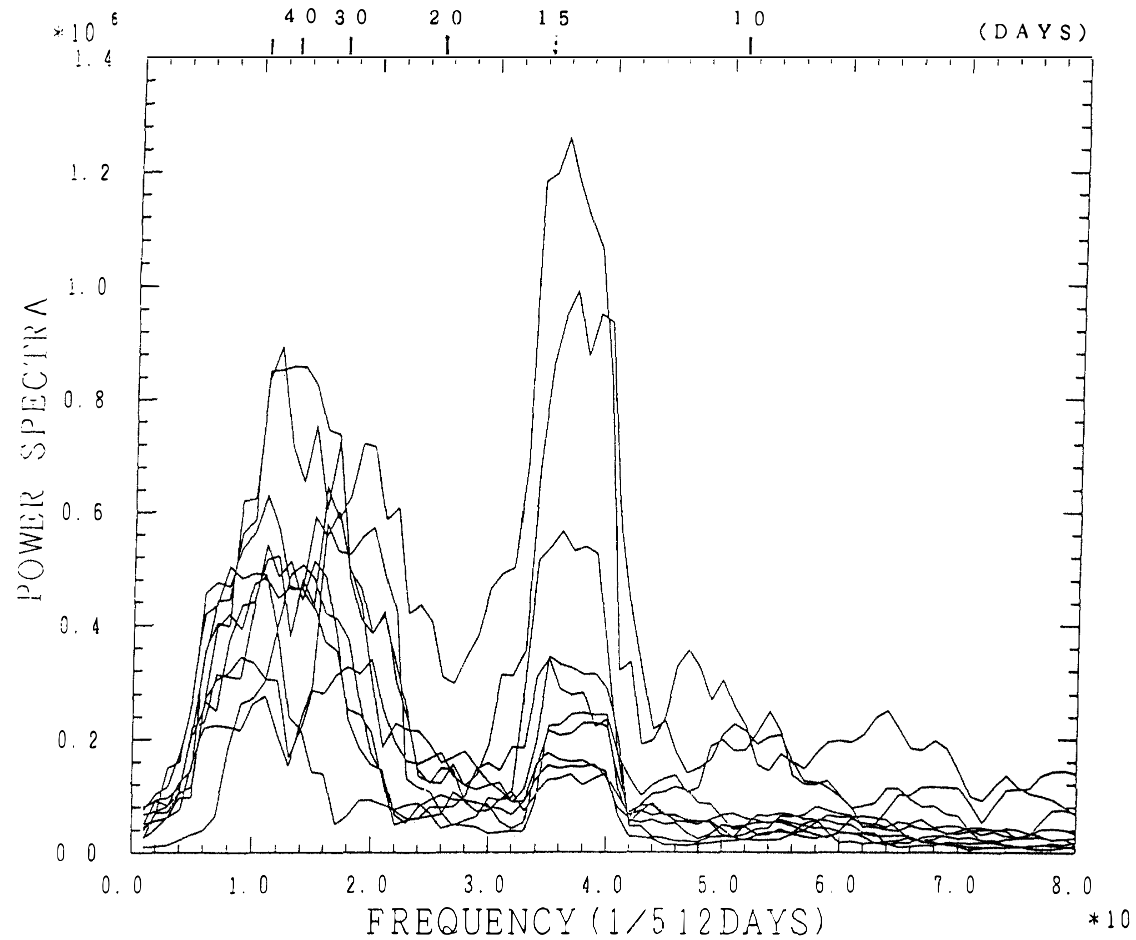


Fig. 11. Power spectra of the sea-level variation having periods shorter than 51 days. The spectrum in each year is calculated from 1979 to 1988, and shown simultaneously.

domains corresponding to periods of about 15 days and about 30–40 days.

INOUE (1988) reported that the variation with period about 40 days is dominant in daily mean wind Katabatic wind speed, and at Molodezhnaya. This suggests that sea level variations having shorter periods at Syowa Station may be caused by variations in the wind system. We checked the correlation between sea-level and daily wind velocity at Syowa Station, but the correlation is not good. It is necessary to compare the sea-level data with wind data at other places such as Molodezhnaya. However, even if we find a good correlation between sea-level variation and wind velocity variation, we need to find why and how changes in the wind system cause the change in sea level at Syowa Station.

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