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Interannual variability of particle fluxes in the Bransfield Strait, Antarctica

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1. Introduction

The Southern Ocean, located south of the Subtropical Convergence, occupies a position of special interest because of its considerable role in atmospheric CO_2 cycle and may play an important role as in the global opal cycle as well. It is also characterized by strong dynamic links between environmental forcing variables, primary production and particle fluxes through the water column. There is large spatial and temporal variability in the magnitude and composition of biogenic fluxes in the Southern Ocean since short-lived blooms of phytoplankton take place when ice cover opens, supplying a large amount of the annual production of biogenic material (Wefer et al., 1990; Dunbar et al., 1998; Honjo et al., 2000). Particle flux in the Southern Ocean is strongly modulated by climate, via the influence of wind, ocean circulation, sea ice, and cloud cover on primary production (Dunbar et al., 1998). It is possible to elucidate the role of the Southern Ocean on climate changes by monitoring the long-term variation of particle flux.

The Bransfield Strait is a semi-closed sea, which is bounded by the South Shetland Islands and the Antarctic Peninsula. It belongs to relatively warm and humid regime with high precipitation. These climatic conditions produce a sub-polar glacial setting which can be sensitive to change in environmental factors that influence the waxing and waning of ice sheets. Thus, the Bransfield Strait is an optimum site for the long-term monitoring of particle flux due to the high sensitivity on climate change and the easy accessibility. Wefer et al. (1990) measured particle fluxes using the time-series sediment traps in the central Bransfield Strait from 1983 to 1986 for three years. They found considerable seasonal and inter-annual variability in particle fluxes. Although there are some results on particle fluxes in the Bransfield Strait, we need more data on the magnitude and compositions of particle fluxes because of their large seasonal and interannual variability.

In this paper, we examine particle fluxes measured at mid-water depths in the eastern Bransfield Strait over a 3-year period from 1999 to 2001. The objectives of this research are to determine the composition and timing of biogenic and lithogenic fluxes over three years, to elucidate the processes controlling seasonal and interannual variations of these fluxes, and to evaluate the efficiency of biological pump occurring in the Bransfield Strait.

2. Materials and methods

We deployed the time-series sediment traps on seabed-anchored mooring from December 1998 to December 2001 in the eastern Bransfield Strait (water depth 2100m). The mooring comprised a set of instrument, which was deployed at mid-water depth in the eastern Bransfield Strait. The instruments consisted of a McLane PARFLUX Mark 7G time-series sediment trap with 21 rotary sample cups and an Aanderaa RCM8 current meter. Sample collection intervals were 10 days on November, December, January, and February, 15 days on October, and 30/31 days on other months. Sediment trap samples were preserved by filling sample cups with a Na-borate buffered 5 % formalin solution prior to deployment.

Upon recovery, 250 ml trap sample bottles were removed and refrigerated at 4 ℃ prior to analysis. Samples were gently split using a Folsom plankton splitter into 4 fractions for chemical and microscopic analyses. One replicate split was centrifuged, decanted and washed several times with distilled water. The washed sediment samples were freeze-dried for two days and weighed for mass flux calculations.

Total carbon content was measured by a Carlo-Erba CNS elemental analyzer. The precision of total carbon was 3% based on the duplicate analyses. Inorganic carbon content was determined by a UIC coulometrics carbon analyzer with 2% of precision. Calcium carbonate was calculated by multiplying inorganic carbon by 8.33. Organic carbon was calculated by difference between total and inorganic carbon. Biogenic silica content was determined by time-series dissolution using 0.5N NaOH at 85 ℃. The precision of biogenic silica was 5% based on the duplicate analyses. Aluminum content was measured by the Induced Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES) in the Korea Basic Science Institute with 5% of precision.

3. Results and discussion

Mass fluxes measured over three years showed large seasonal variability (Fig. 1). In 1999, the entire three-month summer period was characterized by elevated mass fluxes over 300 mg m^{-2} d^{-1} and in the other months, mass fluxes were at least 2 orders of magnitude lower, less than 2.0 mg m^{-2} d^{-1}. Similar magnitude and phase of high summer fluxes were also observed in 2000, but in the other months, mass fluxes were several times higher than in the previous year. Mass fluxes decreased abruptly from March to April in both 1999 and 2000 (Fig. 1). This sharp drop in mass flux was probably not due to sea ice cover since the eastern Bransfield Strait was covered by pack ice from late June through September in both years. The sharp drop is probably related to changes in primary production and to inputs of lithogenic material. Primary production in the Bransfield Strait tends to decrease suddenly after March because of low irradiation and a deep mixed layer; primary production measured in late March was an order of magnitude lower than that in December-February (Holm-Hansen and Mitchell 1991). Air temperature measured at the King Sejong Station located at King George Island drops below 0 ℃ in April, suggesting that meltwater inputs, which are the main source of lithogenic material, might be significantly reduced. The sharp drop in mass flux after March, therefore, could have been caused by sudden decreases in both primary production and inputs of lithogenic material.

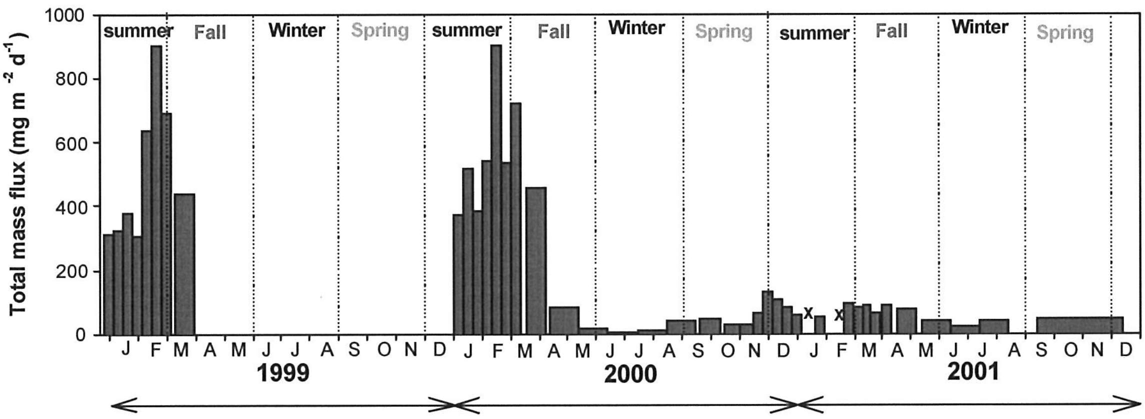

Figure 1. Interannual variability of total mass fluxes in the eastern Bransfield Strait over three years from 1999 to 2001.

In the Southern Ocean, high seasonality in particle flux is not unusual due to large seasonal variability in sea ice coverage and primary production in the surface water (Honjo *et al.* 2000). However, interannual variability in particle flux has been not reported in the Southern Ocean since long-term measurements (over 3 years) of particle flux have rarely been conducted (Wefer *et al.* 1990). Such long-term measurements have usually been carried out in tropical, temperate, sub-Arctic and Artic areas. In this study that particle fluxes were measured over three years, mass fluxes showed large interannual variability (Fig. 1). In 1999 and 2000, seasonal trend of mass fluxes was characterized by highly elevated mass fluxes over 300 mg m^{-2} d^{-1} from January to March, but such high summer fluxes were not observed in 2001, and seasonality was significantly reduced. Magnitude and phase of high summer fluxes were very similar in 1999 and 2000. In the Southern Ocean, the summer period is usually characterized by high particle fluxes compared to other seasons (Honjo *et al.* 2000). Thus, the high summer fluxes observed in 1999 and 2000 seems to be 'normal' sedimentationin the eastern Bransfield Strait. Wefer *et al.* (1990) also observed the elevated summer fluxes in the central Bransfield Strait from 1984 to 1986. Unlike our results, however, they did not found large interannual variability in particle flux, even though the magnitude and phase of the summer fluxes were slightly different every year.

Annual fluxes of mass, organic carbon, biogenic silica, $CaCO_3$, and lithogenic material are shown in Table 1. The highest annual mass flux is found in 2000, which is almost 4 times higher than that in 2001. Even though the annual fluxes of all constituents are higher in 2000 than in 1999, relative contributions of each constituent to the total mass flux are rather similar in both year; organic carbon comprises about 10% of the total mass flux, biogenic silica about 36%, $CaCO_3$ about 0.6%, and lithogenic material about 30%. In 2001 when particle flux is relatively lower, however, the proportions of organic carbon and biogenic silica are reduced to about an half of those in 1999 and 2000, but the proportion of lithogenic material increases by double; organic carbon comprises about 4% of the total mass flux, biogenic silica about 19%, $CaCO_3$ about 0.9%, and lithogenic material about 72%. In spite of such a large increase in the proportion of lithogenic material in 2001, the annual flux of lithogenic material is still lower than those in 1999 and 2000. The annual flux of bigenic material including organic carbon, biogenic silica, and $CaCO_3$ show large interannual variability, but that of lithogenic material does not display large interannual variability. Therefore, the large interannual variability in mass flux is mainly attributed to the large interannual changes in biogenic material fluxes.

Table 1. Annual fluxes of mass, organic carbon, carbonate, and lithogenic material over three year. The percentage to annual mass flux is shown in parenthesis.

Year	Mass flux ($g\ m^{-2}\ yr^{-1}$)	Organic C flux ($g\ m^{-2}\ yr^{-1}$)	Biogenic Si flux ($g\ m^{-2}\ yr^{-1}$)	$CaCO_3$ flux ($g\ m^{-2}\ yr^{-1}$)	Lithogenic flux ($g\ m^{-2}\ yr^{-1}$)
1999	49.1	5.17 (10.5)	18.2 (37.1)	0.27 (0.5)	14.1 (28.7)
2000	65.6	6.77 (10.3)	23.5 (35.8)	0.49 (0.7)	20.7 (31.6)
2001	17.6	0.68 (3.9)	3.35 (19.0)	0.16 (0.9)	12.7 (72.2)

This large interannual variability in particle flux is likely related with the interannual changes in sea ice cover in the surface waters. Sea ice existed at the mooring site from late June to early October in 1999. In 2000, it appeared for several days in late June, mid-July, and late July, and persisted for two months from August to September. Sea ice had existed mainly from June to October for about 4 months in 1999 and 2000. In 2001, however, it appeared for several days in January and persisted for 6 months from late February to mid-August. In 2001 when the high summer fluxes were not observed, sea ice had existed during the summer period.

Biological production in the surface waters could be inhibited by sea ice since it prevents light penetrating into the water column. In the Ross Sea, sea ice cover is responsible for the large seasonal variability in biogenic material fluxes (Dunbar *et al.* 1998). In this study, biogenic material fluxes show larger interannaul vatiability than lithogenic material fluxes. In 1999, high chlorophyll-*a* concentrations (over 1.0 mg m^{-3}) were concentrated south of the Antarctic Peninsula in January, extended into the Bransfield Strait in February and disappeared in March. High chlorophyll-*a* concentrations had persisted south of the Antarctic Peninsula from January to March in 2000. In 2001 when the summer fluxes were not high, however, high chlorophyll-*a* concentrations were not found around the trap mooring site for three months from January to March. In 2001, phytoplankton biomass in the surface waters during the summer was much lower than in 1999 and 2000. Therefore, the low particle fluxes during the summer 2001 appear to result from low biological production in the surface waters due to sea ice cover during this period.

Lithogenic material fluxes also showed the summer peaks in 1999 and 2000, but such a high summer flux was not observed in 2001. Even though biogenic material flux could be inhibited by sea ice, lithogenic flux may not be significantly affected by sea ice. In the Southern Ocean, aerolian and ice-melt water inputs are main sources of lithgenic material, and the lithogenic material input occurs only in summer season since lands are covered by snow/ice, and snow/ice is not melt in other seasons. Aerolian input of lithogenic material is mainly dependent on wind speed, and melt water input depends on air temperature; higher wind speed and warmer weather, more lithogenic material input. Air temperature measured at the King Sejong Korean Antarctic Station located at the King George Island over three years from 1999 to 2001 was usually above 0 ℃ from December to March, and thus most of ice-melt water input occurred during these periods. Air temperature did not exhibit large interannual variability over three years. During the summer 2001 when lithogenic fluxes were low, air temperature was mostly above 0 ℃ and thereby, the low summer lithogenic flux in 2001 is unlikely due to the decrease in melt water input.

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Wind speed showed large fluctuation with time, but any significant interannual changes were not observed. Especially during the summer when lithogenic fluxes were high, wind speed was not high in a year. Thus, aerolian input does not seem to affect significantly lithogenic flux in this study area.

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