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SPORADIC INCREASE OF PARTICLE SEDIMENTATION AT THE ICE EDGE OF THE ANTARCTIC OCEAN DURING THE AUSTRAL SUMMER 1994–1995

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Abstract: Time-series sediment traps were deployed at depths of 537 m, 796 m, 1259 m, 1722 m and 2727 m at ice edge of the Antarctic Ocean (64°42′S, 139°58′E) from 26 December 1994 to 20 January 1995. During a short period from 7 to 9 January, a sporadic flux increase within a few days in terms of total dry weight of 774 mg $m^{-2}d^{-1}$ at 537 m was observed. The mass of sinking particles forming the flux maximum sank down to the deepest trap (2727 m) within 7–11 days, indicating that about 5% of these particles were transported downward to the bottom with the sinking rate of 199–313 m d^{-1} (mean 243 m d^{-1}). The considerable particle loss rate (13% $[100\ m]^{-1}$) below the mesopelagic layers in a short period suggests the occurrence of consumption processes induced by the sporadic supply of freshly produced particles from above.

1. Introduction

The transport of biologically produced particles from the surface euphotic layer has a primary importance in the organic matter cycling in the water column of the ocean (*e.g.* SUESS, 1980; SASAKI and NISHIZAKI, 1981; HONJO, 1982; WEFER *et al.*, 1982; ANGEL, 1984; MARTIN *et al.*, 1987; WASSMANN, 1990). In the Southern Ocean, the ice edge has been shown to be a region of enhanced biological activity (*e.g.* SULLIVAN *et al.*, 1988). Oceanographic and biological processes in the ice edge region stimulate primary production of biological material that is subsequently assimilated by the higher trophic animals. Several hypotheses have been proposed to explain the locally enhanced primary production and phytoplankton accumulation. Some available data show that meltwater released from retreating ice makes a highly stabilized layer in which vertical mixing decreases and thus the shallow layer provides an optimal environment for phytoplankton growth (*e.g.* SMITH and NELSON, 1985). Algal cell communities released from melting ice are also a possible source of ice edge planktonic assemblages (GARRISON *et al.*, 1987; RIEBESELL *et al.*, 1991).

The environment with pack ice influences the abundance and distribution of Antarctic krill, especially of juvenile *Euphausia superba*, which are much more abundant under the ice than in open water (DALY and MACAULAY, 1988, 1991). Some time-series observations using sediment traps in the ice edge region of the Antarctic seas show the occurrence of maximum fluxes of sinking particles, mostly krill fecal pellets, during spring to summer (BODUNGEN, 1986; WEFER *et al.*, 1988).

Studies on the variability of particulate matter sedimentation can be useful in estimating the temporal change of biological production in the upper layers. In the Antarctic ice edge region, little is known about the short term variation and the fate of sinking particles which would be associated with the ecological processes in the upper water column. The present observation shows that the particle flux is restricted to a short period in the ice edge during summer of 1994–1995, and the sinking process of the same mass of particles from the mesopelagic layer (537 m) to near the bottom (2727 m) was clearly recogized.

2. Materials and Methods

The flux variability was observed from about a one month deployment of sediment traps in an ice edge region of the Antarctic Ocean during HAKUHO-MARU Cruise KH94–4. Five time-series sediment traps, with a collection area of 0.5 m^2 (McLane Mark V and VI, HONJO and DOHERTY, 1988), were attached to a moored array located at a station (64°42′S, 139°58′E, water depth 2930 m). The real ice edge was approximately 20 miles south of the mooring site at the end of December. The traps were suspended at depths of 537 m, 796 m, 1259 m, 1722 m and 2727 m. Sampling intervals were 3 days with the exception of the last period (2 days), starting on 26 December 1994 and ending on 21 January 1995. Before the deployment, neutralized formaline solution was added to highly saline filtered seawater (*ca.* 5%) as a preservative. Three cups of the shallowest trap (from 26 December to 3 January) were lost during the deployment.

The collected particles were split into aliquots. The zooplankton swimmers (larger than *ca.* 0.1 mm in longest dimension) were removed by picking up individuals before the later analyses. Aliquots with particles (mainly 3/32 split) were filtered through Whatman GF/F glass fiber filters, and the filters were used for the determination of total mass (dry weight: DW), HCl-soluble fraction (HSF) and combustible fraction (CF). The HSF represented the carbonate content which was measured with the CHN analyzer using decalcified (with HCl) and non-decalcified samples. The HSF was calculated as $(C_{total}-C_{org})\times 8.33$. The CF (organic matter) was determined as ignition loss at 450°C. The remaining portion was taken as a non–combustible fraction (NCF) which can include biogenic and lithogenic silicates.

3. Results

The downward particle flux of total dry weight (DW) during the sampling period varied from 5 mg $m^{-2}d^{-1}$ at 2727 m to 775 mg $m^{-2}d^{-1}$ at 537 m (Fig. 1). The highest flux with a typical peak (Max–1) was recorded at the shallowest trap (537 m) in a short period from 7 to 9 January 1995. Below 537 m, the maximal flux occurred at each depth; from 7 to 9 January at 796 m (402 mg $m^{-2}d^{-1}$), from 10 to 12 at 1259 m (331 mg $m^{-2}d^{-1}$), from 13 to 15 at 1722 m (174 mg $m^{-2}d^{-1}$) and from 16 to 18 at 2727 m

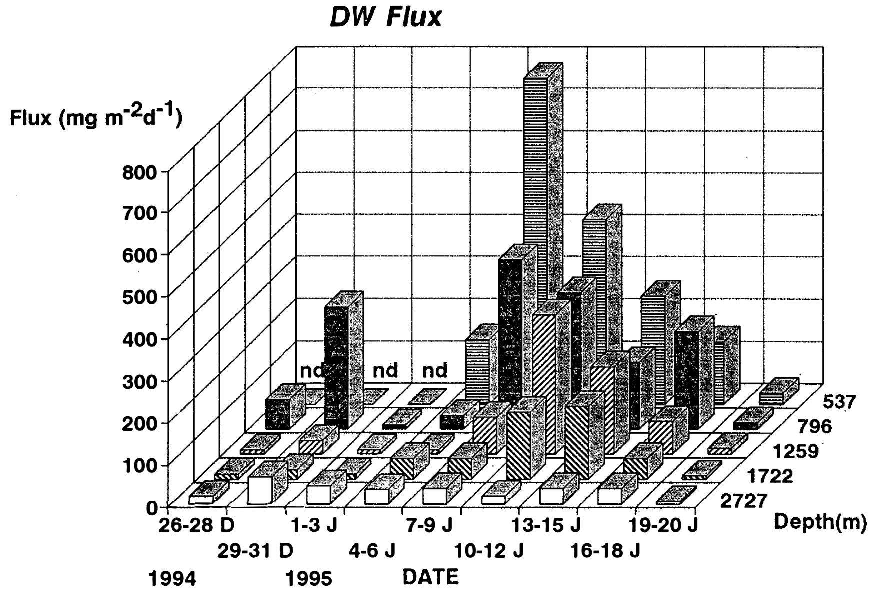

Fig. 1. Variability in downward particulate fluxes in terms of dry weight (mg $m^{-2}d^{-1}$) at the ice edge of the Antarctic Ocean during the austral summer of 1994–1995. Samples from 26 December to 3 January at 537 m were lost during the deployment (nd: no data).

(36 mg $m^{-2}d^{-1}$). The deep flux maximum exceeded the minimum flux at the shallowest depth (28 mg $m^{-2}d^{-1}$, at 537 m, 19–20 January). The flux of Max–1 gradually decreased with increasing depth and also decreased with the passage of time. The same mass of particles apparently started sinking at 537 m in Max–1, and sank down to the deepest trap depth (2727 m) in the period from 16 to 18 January. It took about 7 to 11 days for those particles to reach the depth of 2727 m, although a large proportion (95%) were lost during sinking between 537 m and 2727 m.

Another sudden flux increase of 289 mg $m^{-2}d^{-1}$ (Max–2) was observed at 796 m from 29 to 31 December 1994. The flux of Max–2, however, rapidly decreased with depth (≧1259 m) and disappeared in the following sampling interval (1–3 January).

Among the major constituents, NCF, including biogenic opal, was the dominant component of sinking particles (Fig. 2). The mean contributions of NCF at all depths were more than 50% except for that at 537 m. The contribution of CF representing organic matter was relatively high at the shallowest depth (>30% at 537 m). The variablity of DW flux approximately coincided with those of NCF and CF (Fig. 2), which showed maximal fluxes in the period of Max–1 (409 mg $m^{-2}d^{-1}$ for NCF, 288 mg $m^{-2}d^{-1}$ for CF). The HSFs were the lowest mean contributions to the total DW. While this fraction was generally high in the shallow layers, no marked coincidence with the other components was observed.

Preliminary microscopic observations (data not shown) revealed that the dominant component of sinking particles in Max–1 were cylindrical fecal pellets, more than 1 mm in longest dimension. Those pellets are morphologically similar to freshly produced fecal pellets of *E. superba* obtained by shipboard cultures. The particle compostion observed in Max–2, however, was variable. It included crustacean carcasses, phytoplankton aggregates, small detritus, gelatinous material

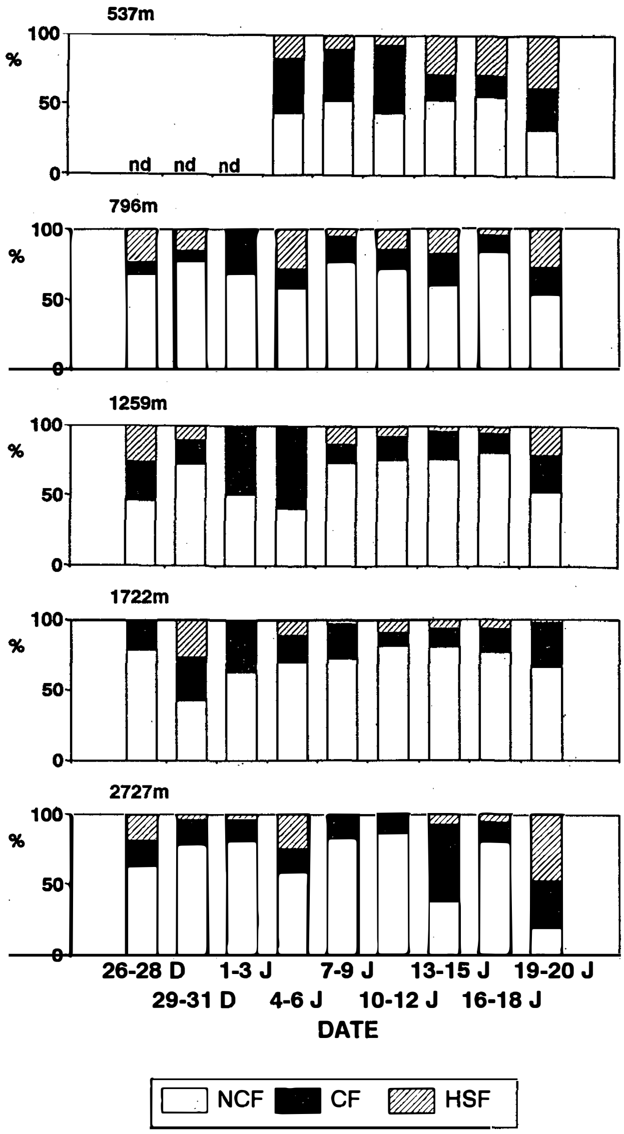

Fig. 2. Variability in the particle composition including NCF (Noncombustible Fraction), CF (Combustible Fraction) and HSF (HCl-Soluble Fraction). Samples from 26 December to 3 January at 537 m were lost during the deployment (nd: no data).

and fecal pellets, among which the last component was a little different morphologically from fecal pellets found in Max–1, suggesting the occurrence of a biologically different event above the trap.

4. Discussion

The downward mass flux in the ice edge of the Antarctic Ocean during austral summer varied on a short time scale. Flux increases (Max–1 and Max–2) appeared within one sampling interval (in a few days), suggesting the occurrence of sinking particle production in the upper water column within a few days. This particle production process appears to be related to the receding ice edge and the hydrographical and biological properties above the traps as reported by BATHMANN *et* *al.* (1991). This short term flux variability probably results in variable biological events, such as transient ice edge bloom of phytoplankton and the passage of a locally dense swarm of zooplankton above the traps. Thus the present flux increase seems to be sporadic event in the ice edge during summer.

The spatio-temporal variation of the flux after the occurrence of Max–1 showed that the same mass of sinking particles apparently sank down to the deepest trap, taking 7–11 days with considerable particle loss during sinking (Fig. 1). The flux of Max–1 decreased with depth and 5% of that reached to 2727 m on 16 to 18 January. The approximate sinking rate of these mass of particles can be estimated to be 199–313 m d^{-1}(mean 243 m d^{-1}).

The present depth—related decrease of the same mass of particles derived from Max–1 seems to be a quite drastic loss occurring in the 537–2727 m water column. This is apparently different from the previous results (*e.g.* HARADA *et al.*, 1986), one of which showed no marked difference between mass fluxes of 494 m and 1588 m at a trap site in Bransfield Strait during a mid-summer bloom (WEFER *et al.*, 1988). According to the last study, the average loss rate of biogenic particles (without lithogenic faction) during sinking is calculated as *ca.* 3% $[100\ m]^{-1}$ (282 mg loss in 494–1588 m water column). The same loss rate of particles (total mass) of this study (*ca.* 13% $[100\ m]^{-1}$; 739 mg loss in 537–2727 m water column) was larger than the data mentioned above (WEFER *et al.*, 1988). This suggests that the present trapped samples includes rather consumable fractions with less lithogenic matter.

Preliminary results from microscopic analyses imply that feeding and defecation of crustacean zooplankton, probably Antarctic krill, can be the major factors contributing to the sporadic increase of flux observed. Krill feeding on phytoplankton and/or ice algae in the Antarctic seas results in mass flux of fecal pellets to deep layers (BODUNGEN, 1986). BATHMANN *et al.* (1991) also suggested the importance of krill feeding in the marginal ice zone during summer because of the coincidence of the increase of krill fecal pellets with the receding ice. The considerable loss of sinking particles below the mesopelagic layers in a relatively short period (7–11 days) suggests that the pronounced consumption processes could be induced by the sporadic supply of freshly produced particles from above.

In conclusion, sedimentation of particles at the ice edge of the Antarctic Ocean during the austral summer is highly variable and sporadic flux increases occur within a very short period (in a few days). The sedimentation process can be dependent on variable biological processes associated with the receding ice edge and possibly the advection of different water masses in the water column. Information from particle fluxes which allows extrapolation of the pelagic processes above the traps with other oceanographic data will be needed to understand the ice edge ecosystems.

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