Seasonal and interannual dynamics of the carbon downward flux in the open NW Mediterranean Sea during the JGOFS era

IAEA MONACO

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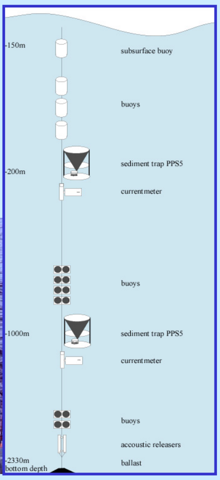
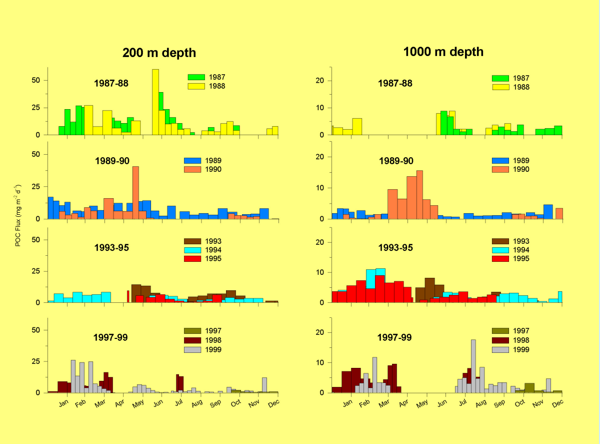
Location of the Dyfamed mooring site (43° 25' N, 7° 52' E)

Introduction

As part of the JGOFS DYFAMED program the downward flux of particles, carbon and other major elements has been studied since 1987 at several depths in the open Mediterranean Sea. The primary objective of the experiment is the quantification of carbon export and the observation and prediction of biogeochemical cycles of particles and associated compounds through a long-term study in the central Ligurian Sea, where biological productivity varies from mesotrophic in spring to oligotrophic during summer/fall. Since these characteristics are observed over large areas of the oceans, the DYFAMED site can be considered in many aspects as a model area for flux studies.



Deployment of a PPS5 Sediment trap (1 m^2 collecting area; carousel with 24 cups for sequential sampling) and schematic of the mooring line.



Seasonal and interannual downward flux of particulate organic carbon at 200 and 1000 m depth.

Mooring and currents

The mooring site is located in the central part of the Ligurian Sea, which is largely protected from terrestrial lateral transport by a geostrophic frontal structure (cyclonic gyre). The site is characterised by a strong summer and fall water column stratification, and a winter baroclinic vertical mixing.

Particles have been collected continuously at 200 and 1000 m depth using Technicap PPS5 sediment traps. Inclination of the traps and currents have also been monitored. The tilting of the traps was negligible throughout the recorded period (less than 3 degrees at both depths). Currents were very low in the summer period (up to 5-6 cm s^{-1}) and increased in winter to reach sporadically 8 to 10 cm s^{-1} at 1000 m and 12-14 cm s^{-1} at 200 m.

Time-series annual estimation of total chlorophyll *a*, total and new primary production and, mass and carbon flux at 200 and 1000 m depth.

	1987	1988	1989	1990	1991*	1993*	1994	1995*	1998	1999
Total Chl. *a* (mg m^{-2})						28	27	23	32	53
Primary production (g C m^{-2} yr^{-1})						154	140	155	135	86
New production (g C m^{-2} yr^{-1})						29	45	37	30	19
<u>200 m depth</u>										
Mass Flux (g m^{-2} yr^{-1})	40.5	32.1	33.2	14.2	36.1	37.2	29.2	13.9	32.5	33.0
Carbon Flux (g C m^{-2} yr^{-1})	6.8	5.6	4.6	2.7	5.5	3.9	2.8	1.6	4.5	2.3
Organic C Flux (g C m^{-2} yr^{-1})	5.0	4.9	3.1	2.4	3.6	2.4	1.7	1.3	3.2	1.8
<u>1000 m depth</u>										
Mass Flux (g m^{-2} yr^{-1})	8.4	16.6	10.0	13.9	67.1	18.6	34.1	21.3	21.5	33.9
Carbon Flux (g C m^{-2} yr^{-1})	1.4	2.0	1.1	1.8	6.9	1.9	2.5	2.1	2.0	2.2
Organic C Flux (g C m^{-2} yr^{-1})	1.2	1.4	0.7	1.4	3.2	1.0	1.3	1.4	1.2	1.4

* Data corrected to compensate for partial sampling during the year.

Results

• <u>particle flux</u>

Particle fluxes were highly variable and displayed a seasonal pattern with maximum fluxes occurring in winter and spring. Organic carbon fluxes showed the same pattern with the highest fluxes occurring normally in spring. At 200 m, the mean particle flux measured during period 1987-1999 was 81 mg m^{-2} d^{-1} and the average carbon flux was 11 mg m^{-2} d^{-1}, of which 70-75% was organic carbon. At 1000 m, mean mass fluxes were 65 % of those at 200 m depth whereas organic carbon fluxes represented 42% of those in surface waters. This difference results from a rapid degradation of the sedimenting particles in the water column with a preferential recycling of the organic fraction. Carbonate carbon concentration did not change significantly with depth. Despite important interannual variations, annual mass and organic carbon flux at 200 m were 30 and 2.9 g m^{-2} yr^{-1}, respectively, and 20 and 1.4 g m^{-2} yr^{-1} at 1000 m depth.

• <u>particle composition</u>

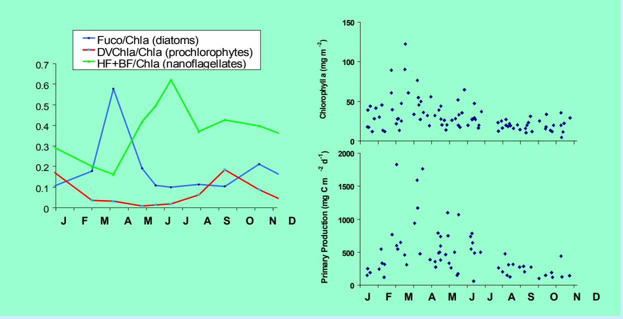
Examination of the organic compounds in the particles (*n*-alkanes, fatty acids) indicates that, at 200 m, the settling organic material in winter was characterised by a high proportion of refractory (old) organic matter and a low content of more labile (fresh) carbon. During the spring and summer period, fluxes contained undegraded phytoplankton and zooplankton detrital material (i.e. labile carbon). In the deeper trap samples, refractory organic matter was dominant confirming that a large fraction of the organic matter produced near the surface is consumed and recycled in the water column.

Because of their large size and high sinking speed, zooplankton faecal pellets are an important vector of carbon transport from surface waters to depth. Faecal material contributed 18-26% to the annual carbon flux, with the highest faeces flux occurring in spring and highest relative contribution to the organic flux in winter and spring (up to 40 % of POC flux).

• <u>particle production and standing stock</u>

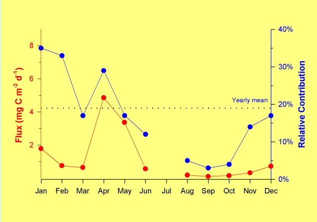
Annual primary production varied between 86 and 232 g C m^{-2} yr^{-1}, with a clear seasonal pattern. The chlorophyll *a* follows the same pattern, being highest in early spring with the development of diatom populations, and in April with the bloom of flagellates. In summer/fall, the picophytoplankton shows higher importance with respect to total biomass.

Diatom biomass was occasionally important in winter but this was not reflected in the measured production. Also, concentrations of particles and aggregates larger than 150 µm in the water column were highest from winter to late spring and lowest in summer. Thus, measured particle and carbon fluxes co-varied with biological production and suspended particle concentrations in the water column.

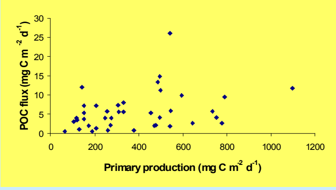


Seasonal variation of phytoplankton composition depth-integrated chlorophyll a concentration (0-250 m) and ^{14}C-derived primary production (0-100 m) for the years 1991-1999.

Trap sample showing the importance of biogenic material(zooplankton faeces, brown, 0.1 to 2 mm length).



Integrated faecal pellet carbon flux (200-1000 m) and its contribution to the total downward flux of carbon.



Primary production and contemporaneous organic carbon flux at 200 m depth.

Dynamics of carbon export

Mass and carbon flux at the DYFAMED site are regulated by physical and biological conditions. During winter there is a strong vertical mixing of the water column which results in high particle flux of lower carbon content, a combination of old refractory carbon and fresh carbon produced by a winter algal development associated with the input of nutrients in the system. With the thermal stratification of the water column, the spring bloom follows resulting in high carbon and faecal pellet flux, until nutrient depletion of surface waters. During summer most of the biological material is recycled in the stratified upper waters resulting in low fluxes, a condition that lasts until fall when the stratification weakens and there is an increase in fluxes associated with a weak bloom in late fall. Most often this seasonal cycle is reflected at all depths.

Particle flux appeared decoupled from primary production on a short time-scale. The critical link between export flux (measured at weekly scale) and primary production (measured at daily scale) is presumably the structure of the upper ocean ecosystem.

The directly measured POC flux represented a small fraction of the primary production confirming that a significant fraction of the carbon produced in the euphotic zone is recycled and/or exported as DOC.