Southern Ocean-JGOFS : a step forward (I)

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The JGOFS effort in the Southern Ocean (SO) was coordinated by the SO JGOFS Planning Group, leaded successively by Julian Priddle (BAS, Cambridge, UK), Uli Bathmann (AWI, Bremerhaven, Germany) and Paul Tréguer (IUEM, Brest, France). From 1990 to 2002 six areas distributed in the Atlantic, Indian and Pacific sectors of the Southern Ocean were studied (***Figure 1***). SO-JGOFS addressed 6 majors questions (also see : Tréguer and Quéguiner, 1991), Le Fèvre and Tréguer, 1998), Tréguer et al., 2002 a and b).

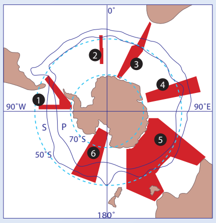

Figure 1 : *From 1990 to 2002 six major areas were studied in the different sectors of the S.O. :*
1-BOFS (United Kingdom) ; 2- ANT X/6 (Germany) ; 3- ANT XIII/2, ANT XVI /3, ANT XVIII/2 (Germany) ; 4- ANTARES & KERFIX (France) ; 5- AUSTRALIA & New Zealand ; 6- AESOPS (USA).

Question 1 : What role does the Southern Ocean play in the contemporary global carbon cycle ?

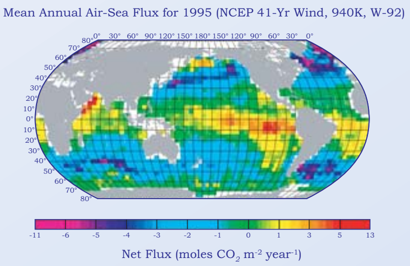

Figure 2 : *The net global mean annual air-sea flux of CO_2 has been estimated to be -2.2 (+22% or -19%) GTC yr^{-1} ; > 50°S this flux is -0.6 GTC yr^{-1} (Takahashi et al., 2002).*

Present estimates of the Austral annual sink of atmospheric CO_2 vary between -0.1 to -0.6 GT C yr^{-1} for the part of the Southern Ocean south of 50°S (Gruber et al., 2001 ; Metzl et al., 2001 ; Takahashi et al., 2002 ; ***Figure 2***). Up to day these negative air-sea δpCO_2 fluxes are not reconcilable with outputs of atmospheric inversion models validated from the few CO_2 Southern Hemisphere land stations. Increasing the number of land stations is requested. New approaches for a better integration of ocean and atmospheric data of CO_2 and O_2 are also strongly recommended.

The modelled penetration of anthropogenic CO_2 is very active south of 50°S but its storage is low because anthropogenic carbon is rapidly transported northward isopycnally into the SubTropical Convergence (Caldeira & Duffy, 2000). The modelled interannual variability of the net atmospheric CO_2 sink, due to the 7-year cycle Antarctic Circumpolar Wave (linked to ENSO), is estimated at ± 0.2 GT C yr^{-1}.

Question 2 : What controls the magnitude and variability of primary production and export production ?

Substantial uncertainty remains about the processes/factors that regulate primary productivity, and particularly its variability. Numerous studies showed the co-limitation of the primary productivity by Fe (e .g. Boyd, 2002) and/or Si. Iron fertilization experiments (SOIREE : 1999 ; EISENEX : 2000 ; SOFeX : 2001-2002) show the biological pump of CO_2 reacts rapidly to dissolved Fe addition, although the export of biogenic material out of the photic layer seems to be variable. SOFeX showed that 1 tonne of iron spread at the ocean surface could force only 1,000 T of carbon > 100 m, much lower than expected, leading to the conclusion that the Southern Ocean might not be a good target for our quest for atmospheric CO_2 sinks (Johnson, 2002). EISENEX shows much larger export, altough indirectly.

Access to satellite data has allowed more realistic estimates of the primary productivity (e.g. Moore & Abbott, 2000 ; ***Figure 3***), ranging between 60 and 100 gC m^{-2} yr^{-1}, i.e. 3 to 5 times higher than those of the beginning of the 1990s, deduced from extrapolated ^{14}C measurements. The total annual primary production >50°S is estimated at 3 - 4 GT C yr^{-1}.

There is a big gap between studies which consider export fluxes out of photic layer (especially using ^{234}Th techniques, e.g. Buesseler, 1998) and those concerned by measurements of biogenic matter in deep waters and at the water-sediment interface. To take into account the processes that control the fluxes of remineralisation and recycling in the " twilight " zone (100-1000m) is a high priority for future programmes.

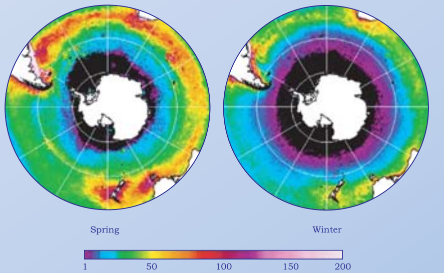

Figure 3 : *Satellite-based estimates of the primary production of the Southern Ocean (Moore & Abbott, 2000).*

Dissolved nutrient distributions have been used to derive the rate constants of biogeochemical processes responsible for the observed fields using inverse modelling. The export of POC the world ocean being 10 GTC yr^{-1}, about 1 GT C yr^{-1} is exported >50°S (Schlitzer, 2002 ; ***Figure 4***). This shows the export production of biogenic matter out of the surface layer is very efficient for the SO, which is not in agreement with satellite derived estimates. If we are to give more realistic estimates for the export and primary production of the SO these two approaches have to be reconciled. The conversion of algorithms is especially questioned, in areas like the SO where subsurface chlorophyll maxima are not detectable by satellites.

Question 3 : What are the major features of spatial and temporal variability in the physical and chemical environments and key biotic factors ?

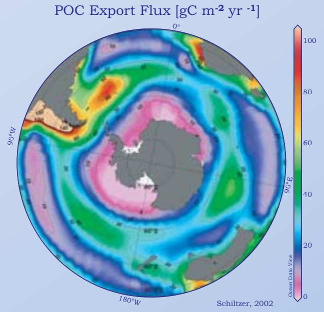

Figure 4 : *Export flux of organic particulate carbon calculated by an inverse model (Schlitzer, 2000).*

The classical view of latitudinal bands of contrasted marine environments around the Antarctic continent (Tréguer & Jacques, 1991), although still alive, has been strongly shaken as numerous SeaWIFs images reveal the importance of west-east gradients, which has to do with eastward aeolian transports of trace-metals. The importance of the physical-biological coupling at mesoscale has been demonstrated both from SeaWIFS images and from circulation models (Pollard et al., 2002). The Polar Front is now being regarded as a high export production system.

Although numerous sophisticated biogeochemical models are now available they remain preliminary tools to account for the complexity of the merry-go-round Antarctic ecosystems, characterised by the sequestration of limiting nutrients by hard or soft-armoured species e.g. large diatoms and colonies of *Phaeocystis antarctica* (Di Tullio et al. 2000). Large scale distributions of krill and salps (the two major large grazers of phytoplankton) show they usually inhabit in different environnments (e.g. Voronina, 1998 ; Pakhomov et al., 2002) and are sensible to global change. To improve the models outputs in terms of carbon retention and/or export, attention is to be put on the role of key species in the key ecosystems, on the community structure and on the dynamics of the higher trophic levels.

Several data sets are available regarding the seasonal variations of total organic carbon (TOC) *vs.* latitude and of the bacterial production in surface waters. High concentrations of semi-labile TOC have been evidenced in frontal areas. They represent high levels of CO_2 potentially produced through bacterial respiration.

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