Southern Ocean-JGOFS : a step forward (II)

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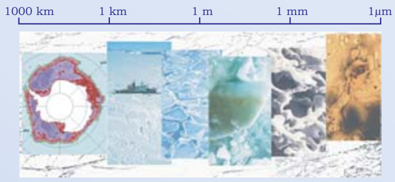
The JGOFS international effort in the Southern Ocean was coordinated by the SO JGOFS Planning Group, leaded successively by Julian Priddle (BAS, Cambridge, UK), Uli Bathmann (AWI, Bremerhaven, Germany) and Paul Tréguer (IUEM, Brest, France). SO-JGOFS adressed 6 majors questions (see the companion poster " SO-JGOFS : a step forward I " for answers to the 3 first major questions, Tréguer et al. 2002).

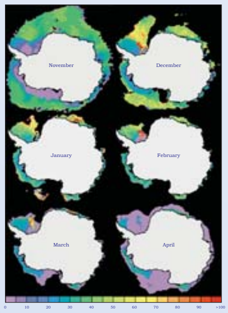
Question 4 : What is the effect of sea ice in and to the Southern Ocean ?

__Figure 1 :__ Antarctic sea ice extends up to 20 Mkm[2] in winter and only 4 Mkm[2] in summer. Research about sea ice is conducted at various scales, from satellite views to microscopy. Epontic algae and other microorganims live within its different layers, particularly in first-year ice (courtesy of G. Dieckmann, AWI).



The seasonal waxing and waning of sea ice around Antartica (***Figure 1***) is one of the largest seasonal signal on planet Earth. With the help of satellite remote sensing a lot of attention has been put on the specific role of ice on the CO_2 fluxes : on the one hand the large extent of sea ice in winter clearly precludes gas exchanges (including CO_2), but on the other hand the sea ice (in its various kinds) can support intense biotic activity especially in the coastal and continental shelf zone, with much implications for the biological CO_2 fluxes. Moreover, the ice edge interacts with the various frontal boundaries in the Southern Ocean, these interactions of these fronts and the ice edge may have significant physical biogeochemical impacts.

The sea ice has definitely to be approached as a unique system (***Figure 1***) which supports a complex trophic network. The sea ice primary production by epontic algae (***Figure 2***) has been estimated to be 0.04 GT C yr^{-1} i.e. 10% of the SiZ production (Arrigo et al., 1997). Interannual variability of primary production in the seasonal ice zone (SIZ) may be linked to ENSO. In the SIZ, in addition to the classical export pathway based on diatoms, the carbon export flux associated with *P. antarctica* represents another important pathway for carbon sequestration (e.g. Di Tullio, 2000). Because blooms of *P. antarctica* cause intense DMS emissions (e.g. DiTullio et al., 2000) the role of *P. antarctica* may be more important than previoulsy thought with respect to the biological pump. Care should be taken that the export of *P. antarctica* cell carbon and associated mucilageneous biomass is quantified. Large deviations from the classical Redfield ratios have been reported (e.g. Arrigo et al., 1999 ; Saggiomo et al., 2002), which has much implications for modellers. We still have to fill in the gap of the linkage between the ice and the adjacent water column ecosystem to better understand the dynamics of the Seasonal Ice Zone.



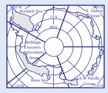


__Figure 2 :__ Maps of sea ice primary production for the 15[th] day of each month during the simulation (October is not shown). Gray areas on the inset map denote multiyear ice. (Arrigo et al., 1997).

Question 5 : How has the role of the Southern Ocean changed in the past ?

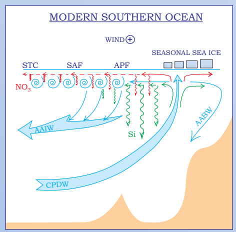


__Figure 3 :__ In the modern Southern Ocean the biological pump of carbon is typified with high export of siliceous biogenic material south of the Polar Front , PF (Anderson et al., 2002).

The biogeochemistry of the Southern Ocean is very sensitive to climate change, but depending of the proxies, much disagreement is remaining about what happened to the biological pump of CO_2 during the past, and especially during the Last Glacial Maximum (LGM). To reconcile contradictory interpretations multiproxies studies that take into account the glacial boundary conditions of wind stress, ocean circulation, sea ice extension and temperature are encouraged.

One major debate (e.g. Anderson et al., 2002) is about the variations in the location of the fronts in the Antarctic Circumpolar Current. Because this location appears to be constrained by the seafloor topography (***Figure 3***) the northward shift of the Polar Front during the LGM is now questioned (Anderson et al., 2002). One scenario (Anderson et al., 2002) considers that during the LGM, compared to the modern ocean, the primary productivity increased north of the PF due the northward penetration of nutrients (especially of silicic acid) and to enhanced aeolian inputs of iron (***Figure 4***). But south of the PF less production of diatoms is envisaged, the change in nitrate utilization being explainable by enhanced production of *Phaeocystis* which left no record in sediments. To get better paleoreconstructions a convergent focus of modern ocean scientists and of paleoceanographers is needed, especially on the variations of opal/Corg, N/P, N/C, and on the role of *Phaeocystis* for C export flux.

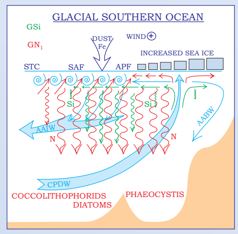


__Figure 4 :__ LGM possible scenario: aeolian Fe inputs north of PF determined a drastic change, with increased export of siliceous material north of PF and large export of carbon south of it due to P. antarctica (Anderson et al., 2002).

Question 6 : How might the role of the Southern Ocean change in the future ?

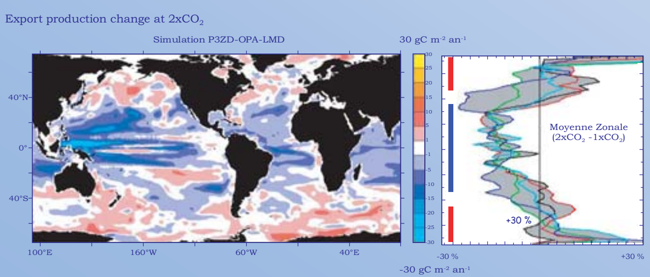


__Figure 5 :__ : Modelled impacts of doubling the atmospheric CO_2 compared to present on the export production of organic carbon in the world ocean (Bopp et al., 2001). Note that the model predicts a global diminution of 5-10% of the export of organic carbon but an increase of about 20% in the Southern Ocean.

We already have some indications the biogeochemistry of the modern Southern Ocean is changing. Global physical-biogeochemical coupled models are now available (***Figure 5***, Bopp et al., 2001) indicating the Antarctic Ocean might become the main oceanic sink for atmospheric CO_2 if atmospheric CO_2 concentration continues to increase exponentially. Nevertheless this capacity could be counteracted by an induced stratification of Southern Ocean in a warming climate. To improve our predictive capacity however coupling models with observations is a high priority. We first need to identify the key parameters (time + space) showing maximum sensitivity to change in models (considering both regional and global response) ; this goes through designing observational strategies to test model predictions, detect the global climate change, and understand the linkages. Second we need improved understanding and parametrizations for accurate model predictions, especially to better know : (1) how do ecosystems structures (taxonomic groups) respond to changing physical and chemical boundary conditions associated with Antarctic Circumpolar Waves (Le Quéré et al., 2001) and global warming, and (2) how do ecosystems responses influence climate through " feedbacks " associated with altered carbon fluxes and altered sources and sinks of other climate-sensitive substances (e.g. DMS).

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