

## **The major role of the Southern Ocean in climate change**

by Paul Tréguer and Robert F. Anderson

Following the 2002 Ocean Science Meeting, which included a special session on the cycle of carbon in the Southern Ocean, the Southern Ocean – Synthesis Group (SOSG) organised a workshop on the biological pump of CO<sub>2</sub> and its responses to climate change. Thirty-two scientists from Australia, France, Germany, New Zealand, the United Kingdom and the USA attended this workshop, held in Honolulu (16-17 February 2002). The major aim of this workshop was to contribute to the synthesis phase of JGOFS and especially to identify synthesis contributions to the [Final JGOFS Open Science Conference](#) (5-8 May 2003, Washington DC, USA). The meeting was introduced by Paul Tréguer ([IUEM, Brest](#), France), Chair of the SOSG, who: (1) recalled the answers to the 6 major questions SO-JGOFS addressed since the beginning of the last decade, as given during the SO-JGOFS Symposium held in Brest in July 2000 (<http://www.univ-brest.fr/IUEM/sojgofs/sojgofs.htm>), and (2) identified the synthesis works already published as well as the gaps. Reiner Schlitzer ([AWI, Bremerhaven](#), Germany), Chair of the Global Synthesis and Modelling Working Group (GSWG) appointed by the JGOFS SSC, then introduced the plans for the next GSWG meeting, to be held in Ispra (Italy), 24-27 June 2002 (see, <http://me-www.jrc.it/jgofs/>).

Two plenary talks set the stage for later discussions of synthesis topics. Patrick Monfray ([LSCE, Gif-sur-Yvette](#), France) gave a very provocative talk on possible responses of the Southern Ocean as well as of the world ocean to combined climate and external forcings. This talk was based on outputs of a 3D coupled ocean – atmosphere complex model that includes a relatively complex ocean biogeochemistry ([Pelagic Interaction Scheme for Carbon and Ecological Studies, PISCES](#)). Increased stratification of the ocean with global warming is expected to play a major role on biogeochemical fluxes as the mixed layer decreases and the productive season lengthens. The model predicts a significant increase both in primary and export production in the high latitudes, but a decrease of biogenic fluxes in low latitudes. Iron from below also seems to play a role that has been underestimated; most present studies focus on iron from above. To validate model predictions for the near future, in addition to microscale and/or mesoscale experiments (*e.g.*, iron fertilisation experiments), Patrick Monfray suggested we should take into account of the natural variability of biogeochemical fluxes and ecosystem structures due to the Antarctic Circumpolar Waves (ACW). Indeed the ACW affects the mean SST by  $\sim 1^{\circ}\text{C}$ , and the mixed layer depth by  $\sim 50$  m, which is comparable to predicted changes of the ocean features as a response of doubling the present atmospheric CO<sub>2</sub> concentration. Of course, initiatives to continue present, or to establish new time-series are of major interest in this perspective and will receive strong support from the SOSG. Excerpts of this talk are available on the web site: <http://univ-brest.fr/IUEM/so-jgofs/>.

Tilla Roy ([ACRC, Hobart](#), Australia) presented a talk on the inconsistencies still remaining between the outputs of atmospheric inversion models and the global synthesis of air-sea  $\Delta p\text{CO}_2$  data. Present estimates of the Austral annual sink of atmospheric  $\text{CO}_2$  are still poorly constrained, varying between  $-0.1$  (Metzl *et al.* 2001; Gruber *et al.* 2001) to  $-0.6$   $\text{GTC yr}^{-1}$  (Takahashi *et al.* 2002) for the part of the Southern Ocean south of  $50^\circ\text{S}$ . Negative air-sea  $\Delta p\text{CO}_2$  fluxes such as these are not reconcilable with outputs of atmospheric inversion models validated from the few  $\text{CO}_2$  land stations located in the Southern Hemisphere. Increasing the number of land stations is requested, especially for South Africa and South America. New approaches for a better integration of ocean and atmospheric data of  $\text{CO}_2$  and  $\text{O}_2$  are also strongly recommended.

Following a discussion on the plenary talks, workshop participants divided into working groups (WG) to assess and promote synthesis of recent findings concerning three topics of particular importance to research on the carbon cycle of the Southern Ocean:

- WG1 (Chair: Uli Bathmann, [AWI, Bremerhaven](#), Germany): What physical (*e.g.*, light, ice, mixed layer depth, mixing rate) and chemical (*e.g.*, Fe, Si) conditions regulate phytoplankton growth and species composition?

- WG2 (Chair: Tom Trull, [ACRC, Hobart](#), Australia): What is the « fate » of biogenic material (*e.g.*, regeneration *in situ*; sinking without being grazed; grazing and export as fecal material), and can the « fate » be correlated with environmental conditions?

- WG3 (Chair: Greg Mitchell, [UCSD, San Diego](#), USA): Is the satellite view of phytoplankton biomass in the Southern Ocean consistent with the results from (1) to (2) above?

In reporting on the deliberations of WG1, Uli Bathmann noted that the huge international effort undertaken during the last decade has drastically changed our simplistic vision of the Southern Ocean that prevailed at the beginning of the 1990s. To better account for the complexity of the Southern Ocean ecosystems and for the impact of climate change on primary production (cf. Patrick Monfray's introductory talk), WG1 suggests that, on the one hand, biogeochemical models should take account of a « polygonal » approach of the primary production limitations, including the role of light, nitrate, phosphate, silicic acid, iron, and grazing for the major players (diatoms, Phaeocystis, cryptophyceans, and other small phytoplankters). On the second hand, complementary approaches are also encouraged to include (1) the building up of a hierarchy of limiting factors and bifurcations models, (2) the design of the appropriate physical background (*e.g.*, importance of mesoscale features in the frontal zones), (3) the measurements of the initial (winter) values, (4) and the coupling between atmosphere and sea ice. New experiments in Lagrangian mode are recommended including mesocosms, *in situ* and model experiments.

Tom Trull reported on what we learnt from the outputs of the SO-JGOFS field and modelling work about the « fate » of biogenic material in the Southern Ocean and on the links with

environmental conditions. Among the participants of Working Group 2, there is a consensus that the export production of organic carbon out of the photic layer is high, however it also seems that the export flux of carbon deeper than 2000 m is almost comparable to that in the rest of the world ocean; if this is indeed so, the mineralisation of organic carbon in the “twilight zone” should be high, of which we already have some indications. But WG2 also pointed out the present gaps: we know neither which pathway (sinking, subduction, bio-entrainment) is the most effective nor which region/subsystem of the Southern Ocean is the most important for organic carbon export below the ventilation depth. New areas of research are to be initiated to better understand and model the aggregation/disaggregation mechanisms at microscales.

Greg Mitchell reported on the accuracy of the satellite view of the Southern Ocean (Working Group 3). SeaWiFS data now allow realistic estimates of the seasonal and interannual variability of chlorophyll concentrations in Antarctic surface waters from sea colour, although persistent cloud coverage makes it difficult to get continuous determinations. Improved algorithms will soon be available for accurate determinations of chlorophyll in the offshore waters of the Southern Ocean. The participants also debated on the degree of confidence for primary production and export production derived from satellite-based estimates of phytoplankton biomass. WG3 recommended that future campaigns in the Southern Ocean conducts systematic *in situ* optics (for a detailed list of parameters and methods available, please contact: [gmitchell@ucsd.edu](mailto:gmitchell@ucsd.edu)) in parallel with classical primary production measurements.

Bob Anderson (LDEO, Palisades, USA) gave preliminary information on the agenda of the [Final JGOFS Open Science Conference](#) (5-8 May 2003, Washington DC, USA). Oral communications will focus on scientific themes and not on regions, although regional reports are possible by posters. The SOSG meeting has already identified possible poster communications on synthesis answers to the six SO-JGOFS major questions, as well as contributions to thematic oral presentations.

#### References:

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