Interannual variability of the ocean carbon cycle

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The worldwide collaborative Joint Global Ocean Flux Study has recently concluded[4]. Analysis of the formidable dataset of ocean biogeochemical properties has shown that the ocean is not in steady state[1,3]. From year to year the biogeochemical properties exhibit substantial variability, due to both internal variations and climatic variability.[6,7]

SOLAS has undertaken the difficult task of understanding and quantifying interannual variability (IAV) in air-sea CO_2 fluxes. The JGOFS dataset, along with that of previous initiatives (such as GEOSECS and WOCE), and other information such as SeaWiFS ocean colour, provide an extraordinary starting point. Nevertheless, the global ocean is still considered undersampled and in order to expand our understanding and move forward, progress needs to be made to fill the gap between modelling and observations.

The IAV in air-sea CO_2 fluxes is driven by interannual variations of the physical properties of the ocean due to climatic phenomena such as the North Atlantic Oscillation (NAO), El Niño/Southern Oscillation (ENSO) and the Southern Annular Mode (SAM). The use of Ocean General Circulation Models (OGCMs) coupled to state-of-the-art Ocean Biogeochemistry Models (OBMs) is a valuable way to quantify the impact of these natural oscillations on air-sea CO_2 fluxes. Although OGCMs succeed in reproducing global patterns in physical properties, they show large deficiencies in capturing some features of ocean physics that are critical for assessing IAV such as reasonable depths of the upper mixed layer and eddy-induced mixing processes. These deficiencies are highlighted when OGCMs attempt to reproduce some climatic phenomena. For instance, OBMs capture fairly well the impact of ENSO on air-sea CO_2 fluxes in the Equatorial Pacific Ocean, because the physical changes caused by ENSO are realistically represented by OGCMs[7,8] (Figure 1). On the other hand, biogeochemical changes induced by the NAO and SAM occurring at high latitudes are underestimated by OBMs[6]. This is due to the inability of current OGCMs to simulate the impact of such large scale variability in the upper ocean physical properties at high latitudes. Thus, the lack of realism in the physics also reflects on the impact of important climatic events on the biogeochemical processes and air-sea gas fluxes[2].

Some of the problems of the OGCMs could potentially be solved by the assimilation of remote sensing data both for the physics (sea surface temperature and height) and for the biogeochemistry (ocean colour). Although data assimilation would overcome some negative aspects of OGCMs, moving from available observations (ocean colour, SSH, pCO_2) to air-sea CO_2 fluxes is not straightforward.

Data collection also needs improvement, especially in spatial and temporal frequencies. For instance, the lack of a robust dataset for winter air-sea CO_2 fluxes in the Southern Ocean is a critical barrier to understanding if this region is a net source or sink of CO_2. This implies that model predictions for future global warming scenarios, although already possible, may suffer from biases if they can not be properly constrained for the present. Upcoming new techniques have to be implemented to improve the coverage and quality of observations. For

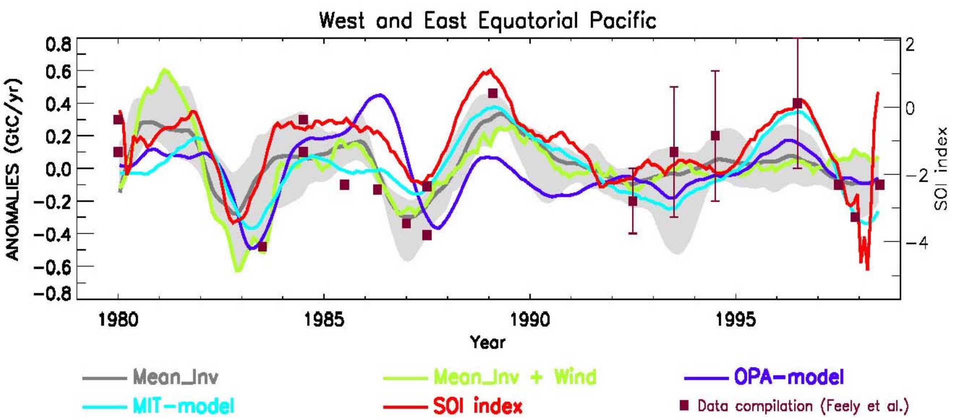

Figure 1: Anomalies of air-sea CO_2 fluxes in the Equatorial Pacific Ocean shown by data (boxes), ocean biogeochemical models (pale and dark blue lines) and atmospheric inversions (grey and green lines), and (red line) the Southern Oscillation Index from [7]. © AGU.

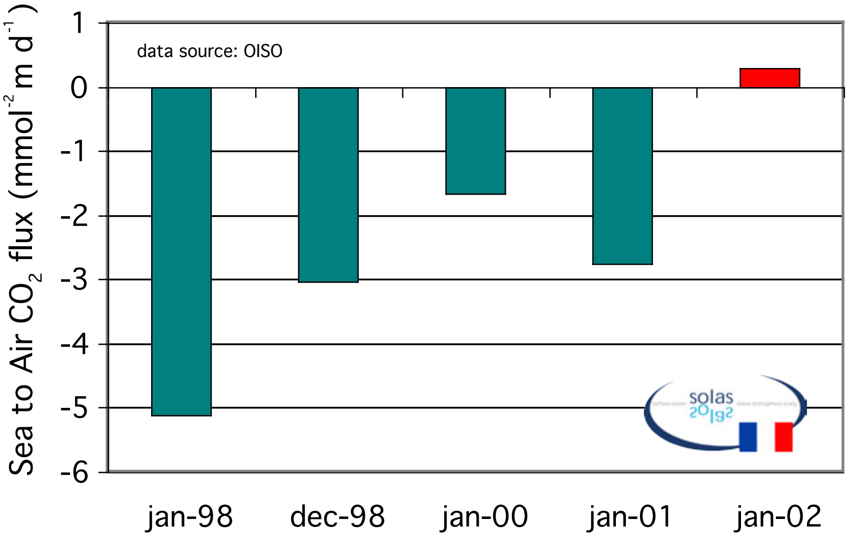

Figure 2: Observed air-sea CO_2 fluxes in the Indian sector of the Southern Ocean during the austral summer from 1998 to 2002 (Unpublished OISO data averaged between 50° and 56° S, negative values are into the ocean).

instance the implementation of dissolved oxygen sensors mounted on profiling floats (ARGO) already measuring temperature and salinity would provide complementary information about processes such as ocean ventilation, stratification and air-sea fluxes[5]. Time-series are particularly valuable for the study of IAV and the underlying processes. Observing IAV offers important information on both stability and variability of biogeochemical cycles; in addition, repeated observations often highlight unexpected changes such as in the Southern Ocean (Figure 2) and feedback processes[3] to explain these variations. A good understanding of the mechanisms which drive IAV in the ocean would give us a solid basis for making future predictions and interpreting the variations that occurred in the recent past such as the Holocene.

The required effort, both for modelling and data collection, necessitates new scientists contributing to improving understanding of processes whose surface has only been scratched so far. This calls for investing resources in high level education to form the next generation of scientists to work on the SOLAS project.

Acknowledgments

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Microlayer: μystery and μagic!

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The standing room only discussion began with three presentations of new research on the sea-surface microlayer

Professor Robert Upstill-Goddard (University of Newcastle-upon-Tyne, UK) presented some recent work on the difference in species composition between the bacterioneuston (the bacterially-enriched layer at the ocean surface) and bulk seawater in the North Sea. Whether or not the bacteria in the neuston actively 'choose' to populate the microlayer was a source of some discussion. He went on to show that, in tank experiments, there is evidence to suggest that bacterial uptake of biogenic trace gases such as methane in the microlayer may have a significant effect on magnitude of air-sea flux (interpreted as modification of the apparent transfer velocity).

Dr. Alastair Jenkins (Bjerknes Centre for Climate Research, Bergen, Norway) presented a mathematical model of the physics of the viscous surface layer of the ocean. This highlighted that there are in fact a number of 'microlayers', defined by vertical discontinuities in different parameters: a biological microlayer (bacterioneuston), a physical (viscous) microlayer - defined by the layer through which diffusion dominates over turbulence; and a chemical microlayer (composed of organic substances which are of lower density than seawater and/or hydrophobic) which may or may not form a coherent surface film.

The third presentation was made by Dr. K. Magnus Eek (University of Victoria, Canada), on his novel, semi-autonomous 'rotating disk' sampler for the sea-surface microlayer. Previously samples of the microlayer have been taken using rotating drums, or mesh 'screens'. The problem with all physical sampling of the micro-

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