Highlights on the Marine Carbon Pump (*from JGOFS Science*)

The oceanic ecosystem and carbon cycles are based on the phytoplanktonic capacity to assimilate natural and anthropogenic CO_2 into biogenic (organic and calcareous) carbon within the photic (i.e., illuminated) layer and on the ability of the whole marine foodweb and biogeochemical or physical processes within the aphotic layer to transform or to transfer part of the newly formed organic carbon to deeper waters and ultimately to bottom sediments, where it can be sequestered on geological time-scales. The following five figures summarise many new insights from JGOFS research into the function of the marine carbon pump.

One of the most important achievements of the JGOFS global CO_2 survey is the establishment of a clear picture of the temporal and spatial variability of air-sea CO_2 exchanges. Figure 1 shows the mean annual exchange of CO_2 across the sea surface (red-yellow areas are regions where large amounts of CO_2 are released into the atmosphere while blue-purple areas are regions where the ocean takes up large amounts of CO_2 from the atmosphere). The global map reveals that the warm equatorial Pacific Ocean is the largest continuous, natural source of CO_2 to atmosphere. In contrast, the cold North Atlantic, North Pacific and the Southern Ocean are important CO_2 sinks, i.e., the ocean regions where large amounts of CO_2 is physically absorbed and biologically assimilated.

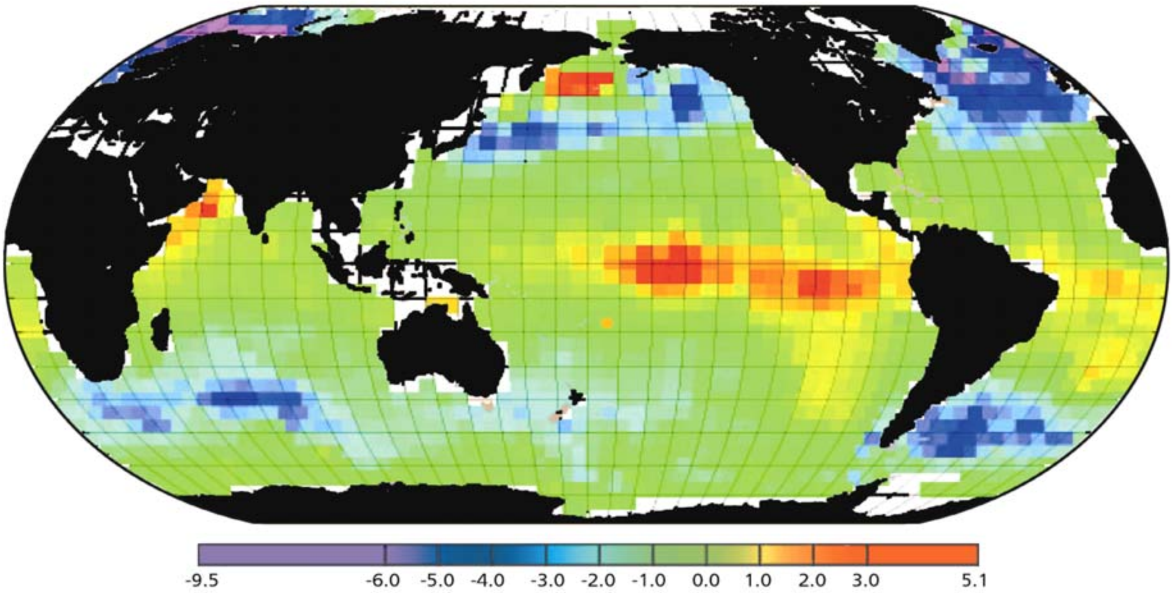

Figure 1: Global map of the average annual exchange CO_2 flux (mol-C m^{-2} a^{-1}) across the sea surface. Reprinted from: Takahashi T. et al., Net sea-air CO_2 flux over the global oceans, Proceedings 2^{nd} International Symposium CO_2 in the Oceans. CGER-I037-'99, p. 9-15 © 1999 CGER/NIES/EAJ.

Large regional and seasonal variations in ocean's state and dynamics make it a challenge to accurately and synoptically estimate phytoplankton distribution and activity from ships, buoys and discrete in situ observations. Recent improvements in remote sensing capability, simultaneous to the JGOFS fieldwork phase, have made it possible to measure surface phytoplanktonic pigment concentrations within few days or hours, in every part of the global ocean. This figure shows a global composite SeaWiFS image of Chlorophyll a for 1998. The particular importance of the polar areas, the coastal and equatorial upwellings and the large river estuaries is clearly shown.

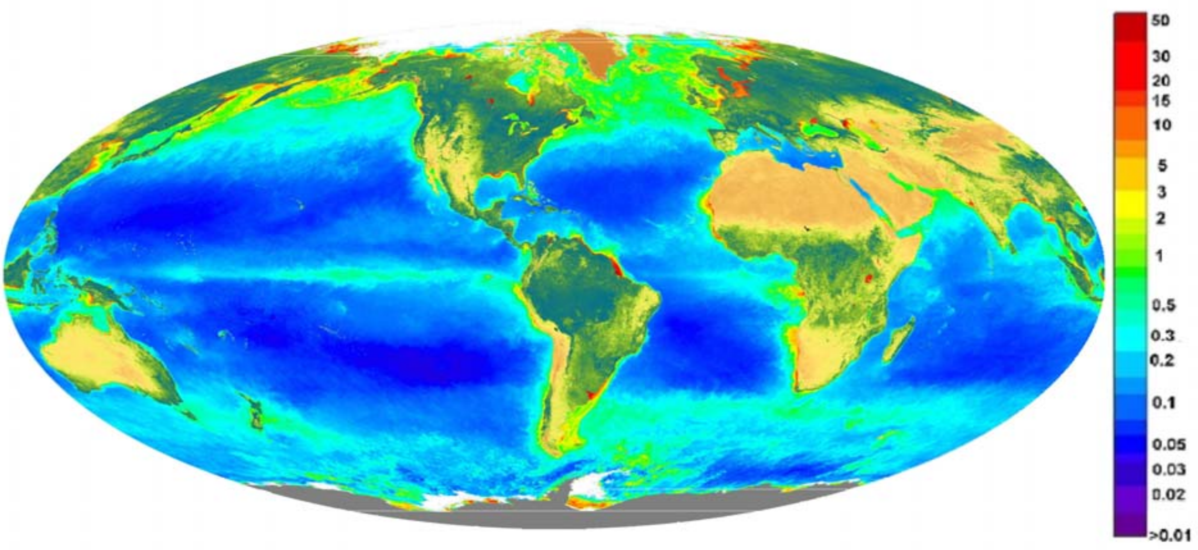

Figure 2: Estimate of phytoplankton distribution in the surface ocean: global composite image of surface chlorophyll a concentration (mg m^{-3}) estimated from SeaWiFS data (Source: NASA Goddard Space Flight Center, Maryland, USA and ORBIMAGE, Virginia, USA).

With SeaWiFS Chlorophyll a data (Figure 2) and JGOFS in situ observations, it is now possible to estimate the temporal and spatial patterns of primary production (i.e., production of biogenic matter by phytoplankton) over the global surface ocean. This model output shows that the distribution of the global ocean primary production is quite similar to that of the surface chlorophyll seen from space (red-yellow areas are regions where primary production is high while blue-purple areas are regions where surface production is low). Yet, some regional discrepancies in the distribution patterns of chlorophyll concentration and primary production emphasize the importance of other oceanographic or biogeochemical processes, such as physical stability, biological community structure, or macro- (e.g., nitrogen or phosphorus) and or micronutrient (e.g., iron) availability. [Models of PP are for the whole photic layer, not only the surface layer seen by the satellite sensors]

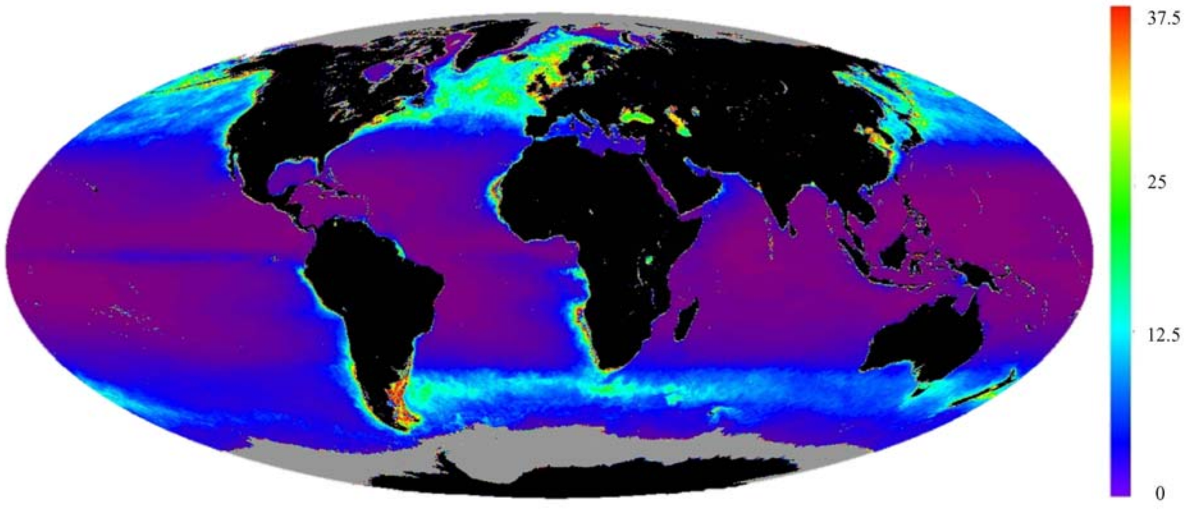

Figure 3: Annual primary production (mol-C m^{-2} a^{-1}) estimated using SeaWiFS data and model. Courtesy of P. Falkowski and D. Kolber, Environmental Biophysics and Molecular Ecology Laboratory, Institute of Marine and Coastal Sciences, Rutgers University, USA.

Over the past decade, ocean modelling techniques have advanced greatly to reshape our ability to understand better, reproduce and predict the dynamics of the ocean carbon cycle. One technique, inverse modelling, using ocean nutrient and oxygen data to constrain organic carbon production in the surface ocean and respiration below the photic layer, has provided oceanographers with a vastly different perspective of ocean carbon dynamics. This figure shows that organic carbon export from the euphotic zone occurs predominantly in tropical and subtropical upwelling areas and in the Southern Ocean. The comparison of the inverse modelling output on export production with the modelled primary production (Figure 3) exhibits some similarities as well as some strong discrepancies that emphasize the importance of recycling and mineralization processes, not well understood yet within the ocean interior or "twilight zone", which will be a focus of the future ocean biogeochemistry and ecosystem project.

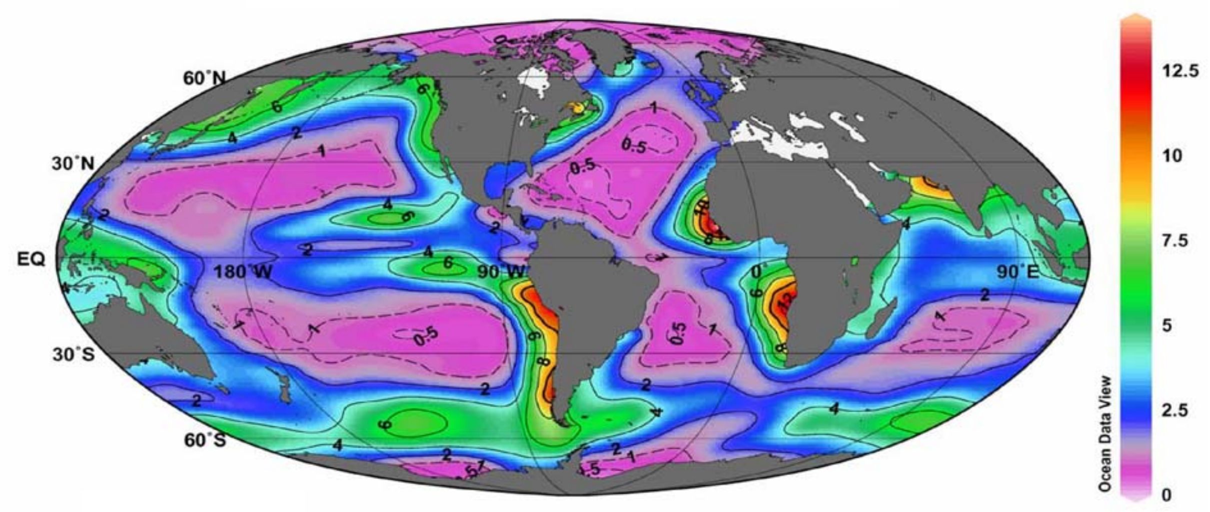

Figure 4: Modelled distribution of organic carbon production (mol-C m^{-2} a^{-1}) exported from the euphotic zone. The modelled export of organic carbon is larger than estimates based on primary productivity maps published before the start of JGOFS activities. Reprinted from: Schlitzer R., 2000. Applying the adjoint method for global biogeochemical modeling in: "Inverse Methods in Global Biogeochemical Cycles" by P. Kasibhatla et al. (eds.), AGU Geophysical Monograph Series, 114, 107-124. © 2000 American Geophysical Union.

Flux data from sediment traps in the water column and on the ocean floor and radioisotope data indicate that the organic carbon export through the ocean interior and to deep-sea sediment represents a few percent of the primary production in the photic layer in the central zones of main basins. Respiration (i.e., remineralisation of biogenic matter) of benthic organisms (i.e., living in the surface ocean sediments) provide a great deal of information about the, transfer, transformation, and recycling in the overlying waters. This figure shows a model output based on direct measurements of benthic respiration, which is mostly dominant along the eastern and western oceanic boundaries, near the major rivers and estuaries, and to some extent at the apex of the equatorial upwellings.

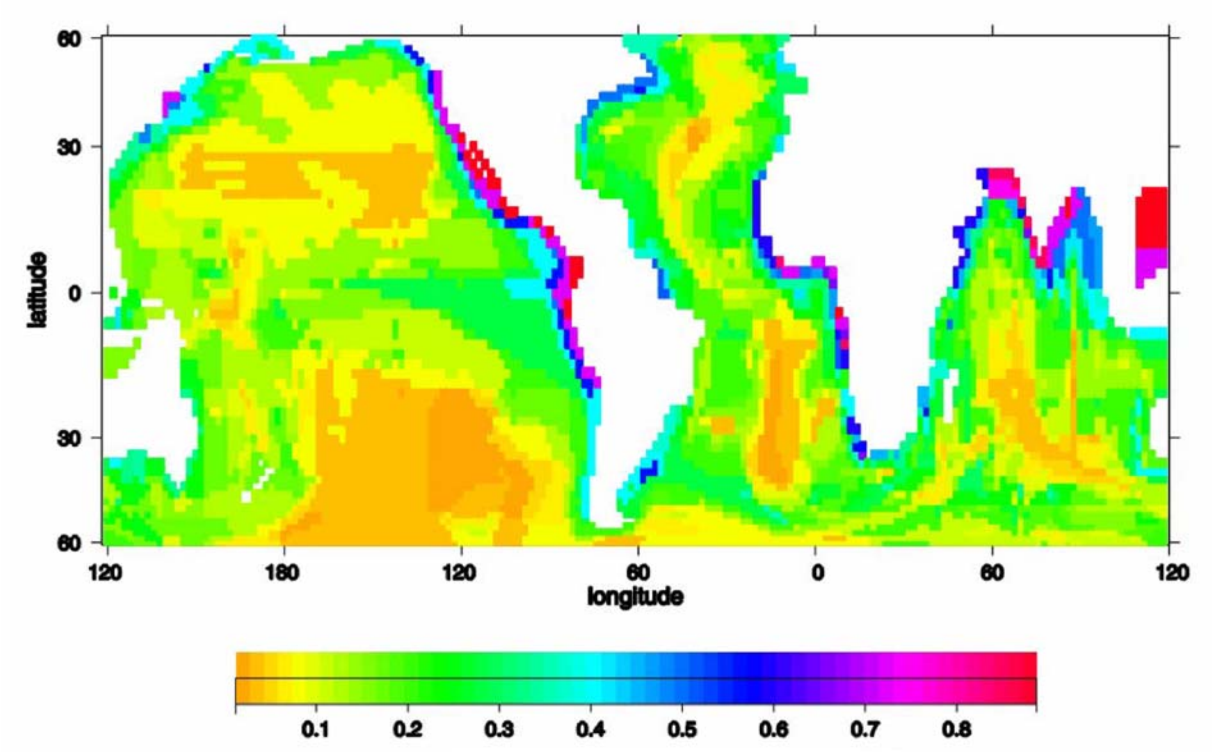

Figure 5: Global map of seafloor respiration based on direct measurements of benthic O_2 fluxes (mol-O m^{-2} a^{-1}). Reprinted from: Jahnke R.A., 1996. The global ocean flux of particulate organic carbon: Areal distribution and magnitude. Global Biogeochemical Cycles, 10(1), 71-88. © 1996 American Geophysical Union.

Conclusion

Thanks to the international collaborative efforts undertaken within JGOFS, the complete oceanic carbon cycle is now understood better. Yet the challenges ahead of the oceanographic, biogeochemical and ecological community are still significant if they are to reconcile the various snapshots of information already acquired into a fully coherent and quantified picture, and to help forecast future responses of the oceanic carbon cycle to the current anthropogenic alterations of the global carbon cycle.

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