Proceedings of the Third SPREP Meeting on Climate Change and Sea Level Rise in the South Pacific Region.
Noumea, New Caledonia, 18–22 August 1997.

CARBON FLUXES AND CLIMATE IN THE EQUATORIAL PACIFIC

Robert Le Borgne

FLUPAC programme
Centre ORSTOM de Nouméa
New Caledonia

ABSTRACT

In the tropical Pacific, carbon fluxes within the ocean and between the sea and the atmosphere are closely linked to the geographical extension of the equatorial upwelling. This oceanographic pheno-enon is due to the divergence of equatorial surface currents which generates vertical transport of deep and cold waters, with rather high carbon dioxide (CO_2) and nutrient (e.g. nitrate, phosphate, silicate) concentrations to the surface. It yields a double effect on the superficial and lighted surface layer: (1) export of CO_2 from the sea to the atmosphere because of differences in partial pressures between the two, the ocean being considered as a "source"; (2) increase of CO_2 uptake by oceanic primary production (i.e. plant photosynthesis), thanks to the presence of nutrients in the lighted layer, a process known as the "biological pump" and the ocean being considered as a carbon "sink". From present carbon budget estimates, it appears the equatorial upwelling is a "source" of CO_2, in spite of its enhanced primary production.

On a global scale, the Pacific equatorial upwelling covers most of the total "source" area on earth, but it varies interannually in association with the El Niño–Southern Oscillation (ENSO) events. Thus, during El Niño periods, geographical extension of the upwelling is minimum; so is CO_2 export from the ocean. This case has been observed during the 1991–1995 period on atmospheric records. On the contrary, during La Niña periods (e.g. the 1996 year), extension of the upwelling is maximum, leading to a greater CO_2 export flux to the atmosphere.

An important international research effort has been made in the 1990–1996 period in the frame of JGOFS (Joint Global Ocean Flux Study). Its purpose was to determine the main processes taking place in the biological pump and air–sea exchanges. However, the geographical extension of the upwelling, which can be tracked by pigment concentrations, has been poorly surveyed, mainly because of the lack of satellite devoted to oceanic primary production. The NASA SeaWifs satellite, which is just about to be launched, should fill this gap.

CARBON DIOXIDE IN THE OCEANS

Global warming, which is observed nowadays, may be ascribed to an enhancement of the greenhouse effect, a process which lowers the amount of radiations reemitted towards the high layers of the atmosphere. Actually, life on earth would be impossible without the greenhouse effect, which is due mainly to the water vapour. Other gases, however, also take part in such an effect, the major one being carbon dioxide (CO_2), which contributes 50% of all other greenhouse gases, the rest being achieved by methane (18%), CFCs (14%), ozone (12%) and nitrous oxides (6%).

Carbon dioxide, which is generated by human activities, is exchanged between the ocean and the atmosphere and within the different layers of the ocean (figure 1). Thus, oceans are able to absorb a significant part of the CO_2 production thanks to their physico-chemical properties, by what is called the "physical pump" and by the "biological pump". The latter is made of a succession of processes in which carbon dioxide is taken up by photosynthesis, transformed into organic matter and exported towards the deep oceanic layers, either by sinking or by migrations of pelagic animals. Still, the CO_2 budget is not uniform on a global scale so that some areas of the world ocean are considered as "sources" (i.e. they export CO_2 to the atmosphere) whereas others are called "sinks" (i.e. they trap atmospheric CO_2).

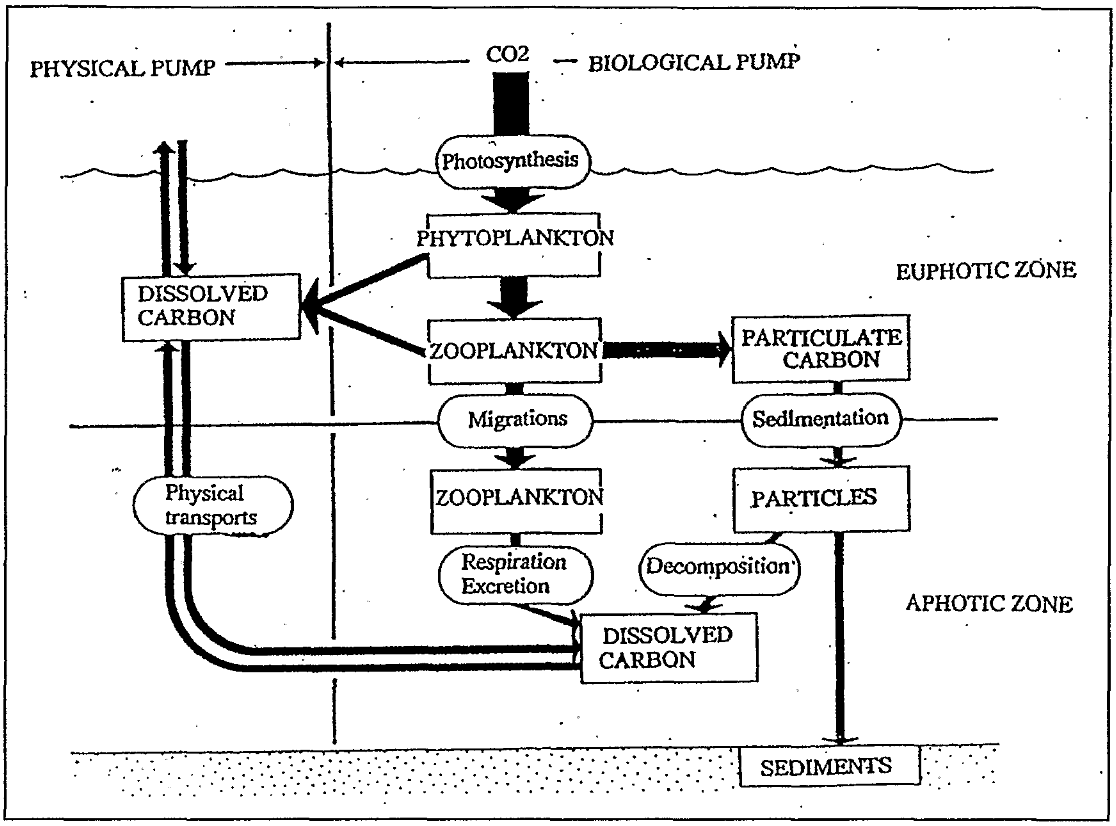


Figure 1. Pathways of the carbon cycle within the ocean and exchanges with the atmosphere and the deep ocean.

STUDY OF THE EQUATORIAL PACIFIC BY THE JGOFS PROGRAMME

The equatorial belt represents a particular case because it acts simultaneously as a "sink" and as a "source", thanks to an upwelling which is due to the divergence of equatorial currents. In such an upwelling process, deep nutrients are brought up to the lighted surface layer, leading to an increased primary productivity and a subsequent utilisation of CO_2. Such an increase in oceanic vegetal biomass at the equator can be seen on images of ocean colour as provided by the NASA CZCS satellite between 1978 and 1984 (figure 2). However, at the same time, upwelling waters bring CO_2 from the deep layers and export it to the atmosphere thanks to a differential in partial pressures (pCO_2). Actually the "source" effect overpasses the "sink" effect in the equatorial Pacific, which is considered as being the main CO_2 export zone on earth because of its size (half the total equatorial belt). These elements led the international JGOFS (Joint Global Ocean Flux Study) programme to launch a study of the equatorial Pacific in 1989. The main goals were: (1) to establish a carbon budget for this oceanic area; and (2) to study its time variations in relation to ENSO events.

JGOFS ACTIVITIES IN THE EQUATORIAL PACIFIC BETWEEN 1990 AND 1996

Oceanic cruises allowed process studies to be made, but not temporal surveys, the latter activity being carried out along ship of opportunity lines (figure 3). Unfortunately, no ocean colour satellite was on operation during the 1990–1996 period, the NASA SeaWifs satellite being launched only at the beginning of August 1997.

THE MAIN RESULTS OF THE JGOFS PROGRAMME IN THE EQUATORIAL PACIFIC

A scientific meeting on the "Carbon cycle in the equatorial Pacific" was held at ORSTOM/Noumea in June 1995, sponsored by NATO, NSF and ORSTOM. Taking also more recent results into account, the following conclusions may be presented about our present knowledge of the carbon cycle in the equatorial Pacific:

1. *Two contrasted areas characterise the equatorial Pacific*: one is the upwelling zone and the other, located west of the upwelling, is the oligotrophic ("poor") area. Transects made during the FLUPAC cruise of ORSTOM and

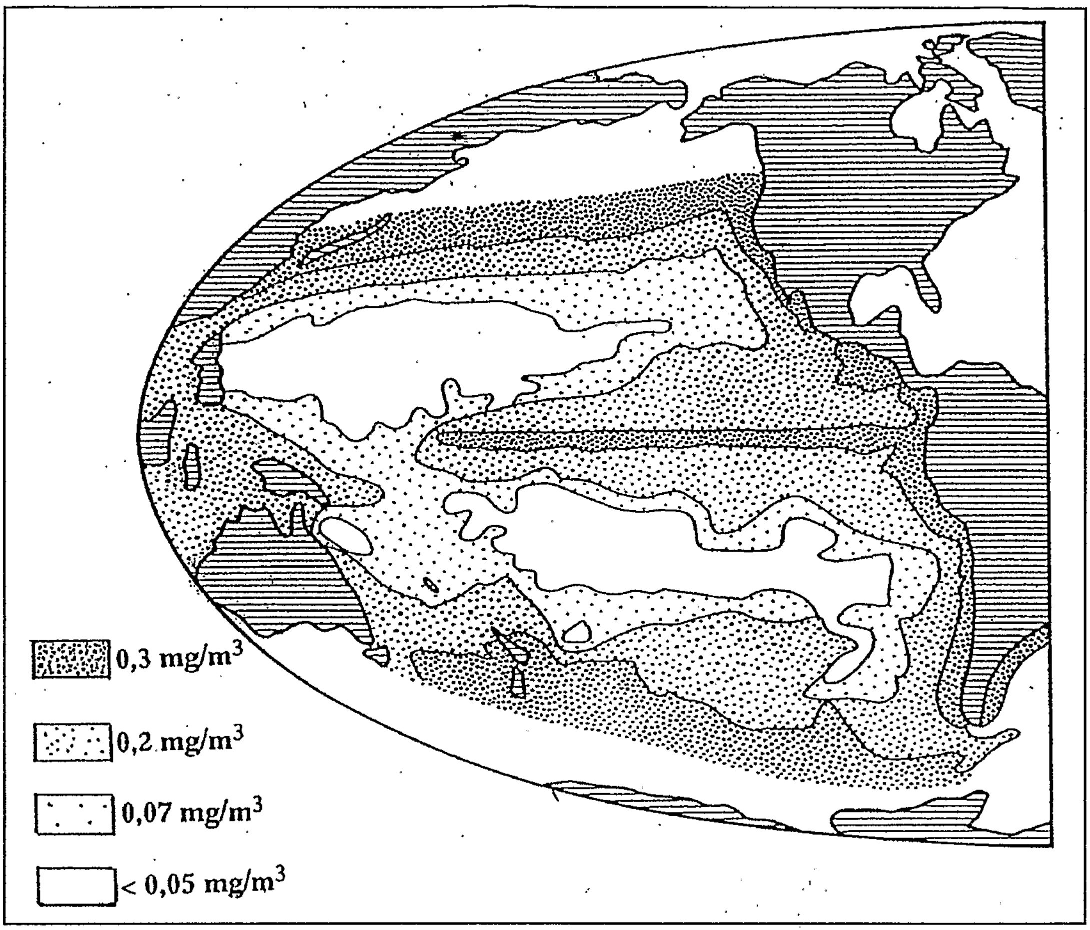


Figure 2. Phytoplankton abundance (as chlorophyll "a" concentrations) as seen from CZCS satellite observations (from Feldman, NASA).

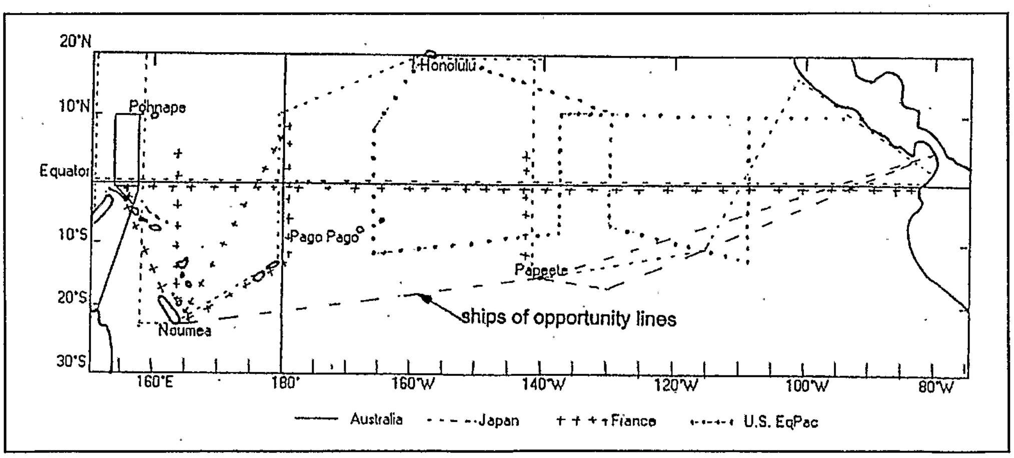


Figure 3. Cruises of Equatorial Pacific JGOFS.

EqPac expeditions of US JGOFS, evidence the difference between the two areas (figure 4a-c). On the EqPac transect in the central Pacific (140°W), lifting of the isotherms and cooling of the surface layer show the upwelling. Similar features are observed also for other parameters and lead to relatively high surface salinity, total CO_2 and nutrients. A resulting superficial increase in chlorophyll concentration (a proxy of the vegetal biomass) may be seen. A different scheme appears on the FLUPAC transect along 165°E: no surface cooling, low surface salinity and total CO_2 concentration, no nutrient and deep chlorophyll. So the western part of the equatorial Pacific presents a low CO_2 partial pressure difference with the atmosphere and low planktonic biomasses. It may be concluded the CO_2 export flux and biological pump are low in this area. The contrary is true in the upwelling: active CO_2 export fluxes and biological pump. Another conclusion can be drawn: since all parameters are linked, boundaries of the upwelling zone can be followed by salinity measurements made along the ship of opportunities lines or TAO moorings, or by the colour of the sea as monitored by satellites.

2. *CO_2 export is maximum in the upwelling area in spite of the biological pump.* Thus, from measurements of CO_2 exchanges made during the FLUPAC and OLIPAC cruises (figure 5) of France–JGOFS, it appears the whole equatorial area, lying between 10°S or 15°S and 5°N exports carbon dioxide, maximum values being seen in the upwelling, located east of the dateline in October 1994. So, in spite of the biological pump, the equatorial area appears to be a source. According to Murray *et al.* (1995), an average of 1 gigaton of carbon would be exported from the ocean to the atmosphere each year as carbon dioxide in the equatorial Pacific. Without the biological pump, another 0.8 to 1.8 gigatons of carbon would be added to the atmosphere.

3. *Important time variations of the CO_2 export are linked to the ENSO variations.* Considering the distribution of nitrate along two equatorial transects (figure 6) in order to locate the position of the upwelling area, two different situations appear in October 1994 (FLUPAC cruise of R/V l'Atalante), during an El Niño (negative SOI) and in April 1996 (ZONAL FLUX cruise of R/V Thompson) during a La Niña event (positive SOI): the western border of the upwelling was at 172°W in October 1994 and west of 165°E in April 1996 repectively, corresponding to a more than 2500km shift between the two periods. A correlation between the western border of the equatorial upwelling (as defined by a sharp increase in pCO_2 values) and the SOI (averaged on 5-month periods) has been presented by Inoue *et al.* (1996), using data collected during Japanese oceanographic cruises of JAMSTEC and the Ocean Research

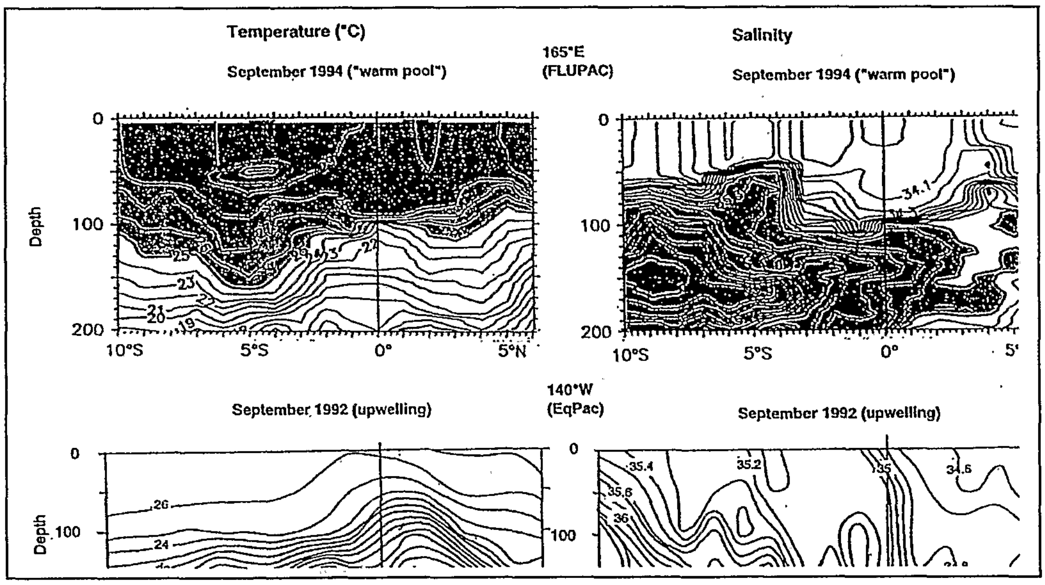


Figure 4a. Temperature (in °C) and salinity (psu) equatorial transects in the western oligotrophic area (165°E) and in the upwelling (140°W)

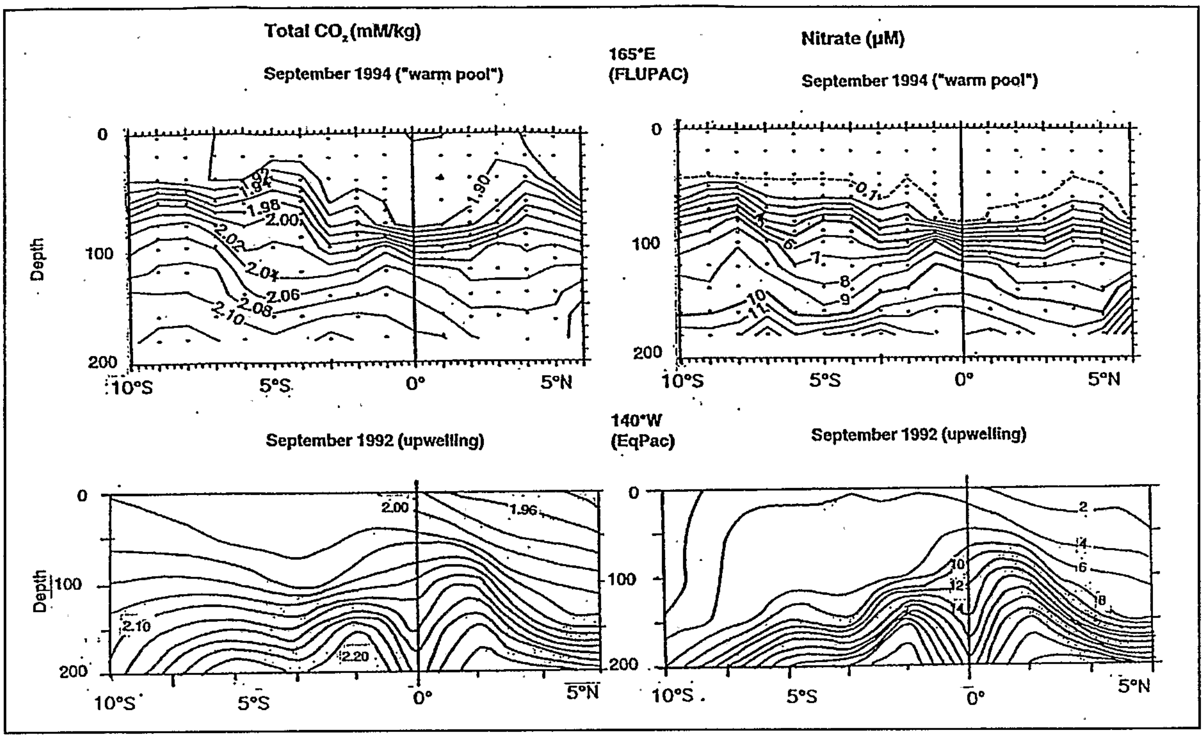


Figure 4b. Total CO_2 and nitrate (in µM) equatorial transects in the western oligotrophic area (165°E) and in the upwelling (140°W)

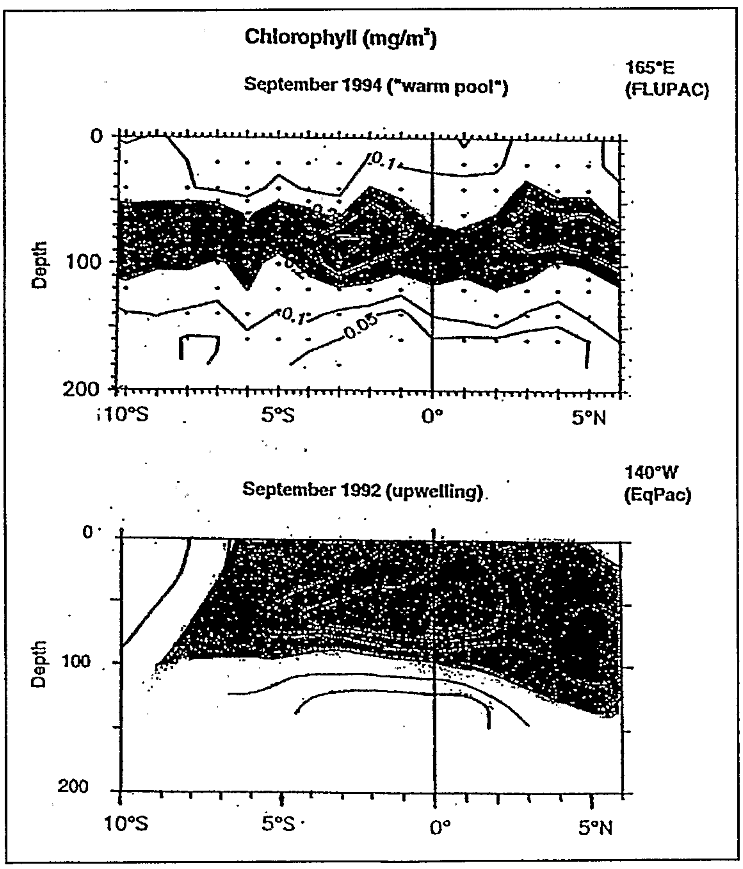


Figure 4c. Chlorophyll (µg/l) equatorial transects in the western oligotrophic area (165°E) and in the upwelling (140°W).

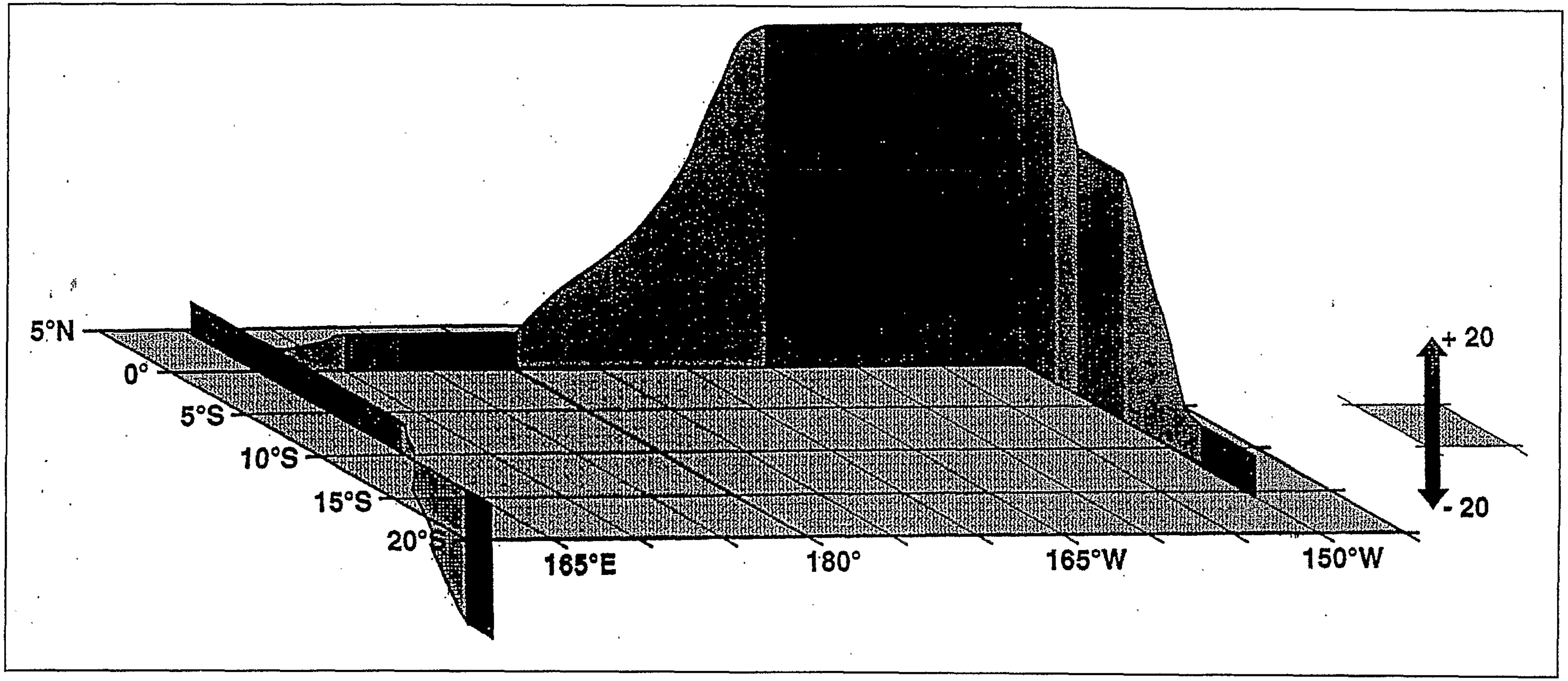
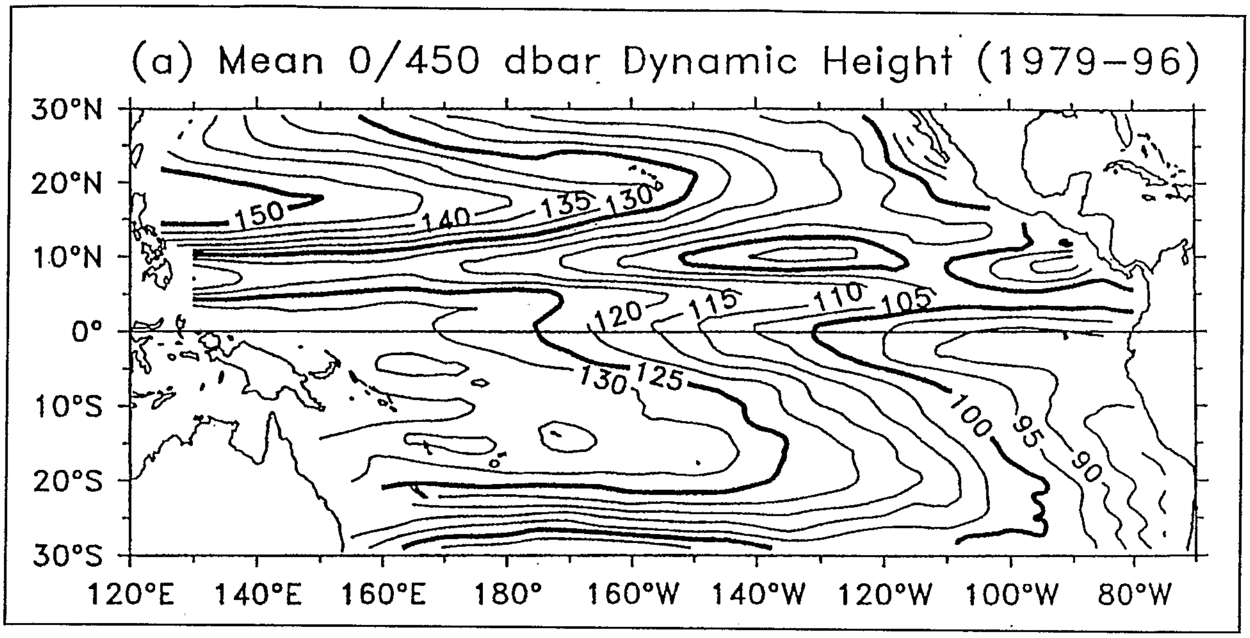


Figure 5. CO_2 fluxes (as Δ fugacity of CO_2) in the equatorial Pacific (Metzl *et al.*, 1996)



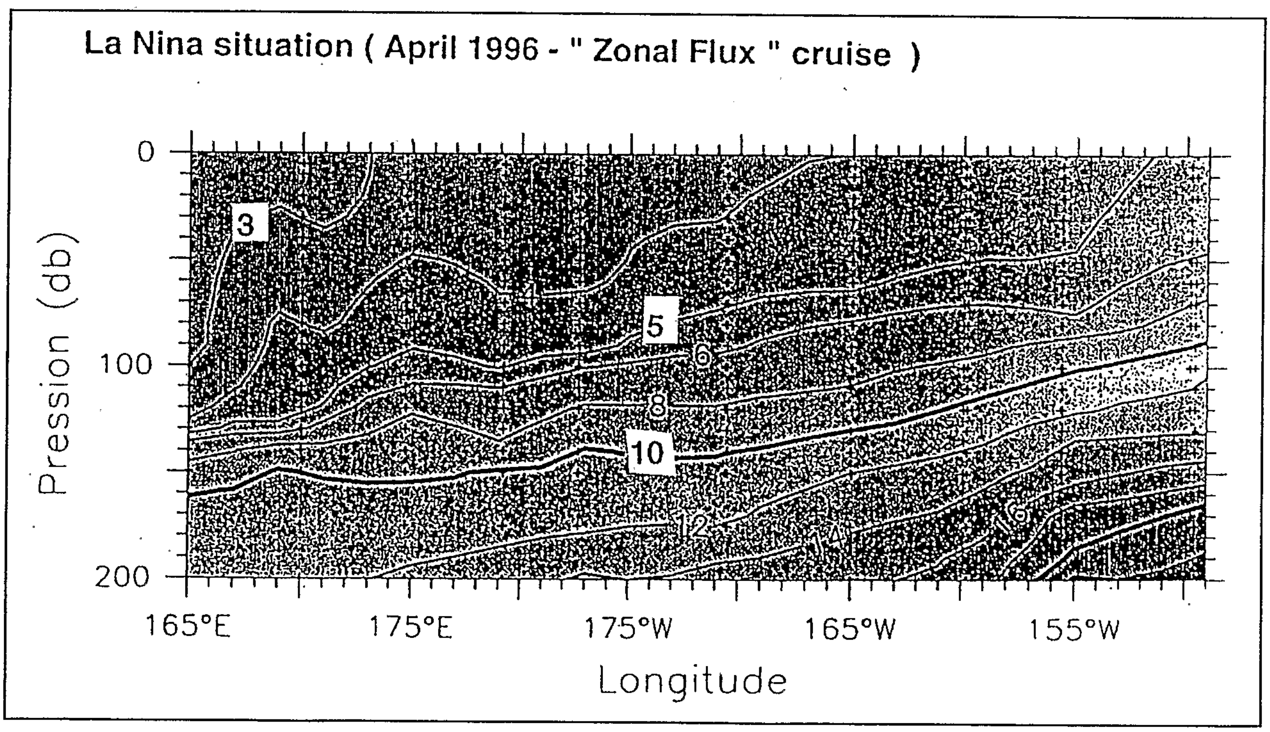


Figure 6. East–west temporal variations of the upwelling as monitored by nitrate concentrations in October 1994 and April 1996.

Institute of Tokyo, between 1987 and 1994 (figure 7). During this period, the upwelling western border would move between 160°W and 150°E, representing a distance of 5500km. Therefore, it can be infered from such spatial variations that export of carbon, which is associated with the surface of the upwelling area, undergoes very significant time variations related to ENSO. In other words, climate changes act on the CO_2 export on a rather short term basis. Inversely, CO_2 increase acts on the climate on a long term scale, increasing the average temperature by greenhouse effect.

Such ENSO-related variations of CO_2 export by the equatorial area may be seen on atmospheric records of the CO_2 partial pressure, such as those made at Cape Matatula in American Samoa or at Mauna Laua in Hawaii (Thoning *et al.*, 1994). In the latter case, when values are corrected for seasonal and long term variations, El Niño events (as defined by negative SOI) are characterised by slower pCO_2 increases, wheras the opposite is true for La Niña's (Figure 8). Actually, the relationship between pCO_2 increases and the SOI is rather loose, due to the influence of other effects such as the terrestrial vegetation photosynthesis and volcanic erruptions.

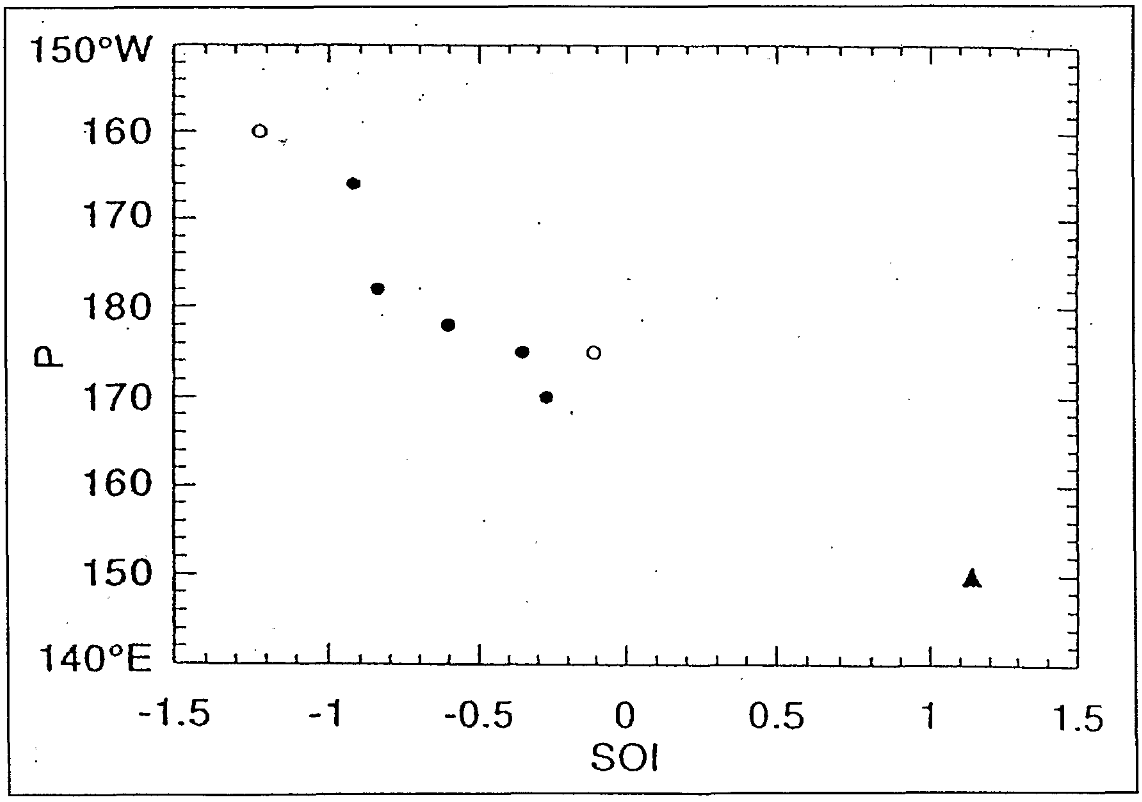


Figure 7. The relationship between the position (P) of the western boundary of the equatorial upwelling, where a sharp pCO_2 change occurs, and the SOI (Inoue *et al.*, 1996)

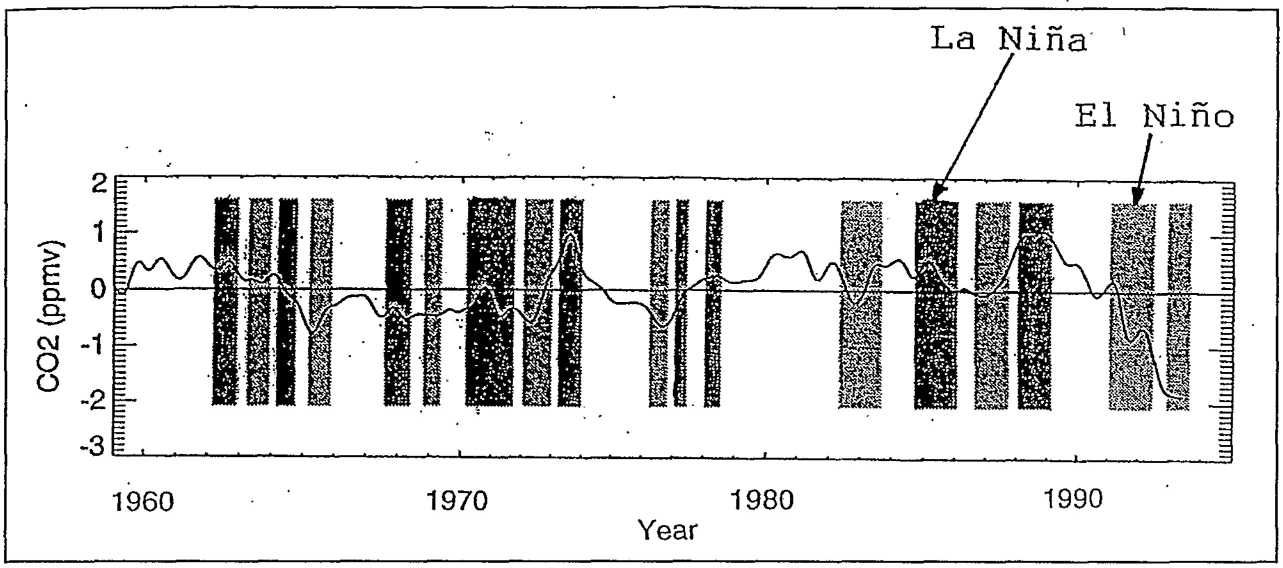


Figure 8. The atmospheric carbon dioxide concentration anomaly (ppmv) from Mauna Loa (Hawaii) after removing the long term increase and seasonal signal (Meyers and O'Brien, 1995)

On Figure 8 it may be seen that the 1991–1995 period which was an El Niño one was also a period of particularly slow increase in atmospheric pCO_2 because of the reduction of the equatorial upwelling area.

CONCLUSIONS

During the last 10 years, because of an important international research effort, knowledge of the carbon cycle in the ocean and CO_2 exchanges with the atmosphere progressed: the association between ENSO variations and the location of the western border of the equatorial upwelling could be shown and a description of chemical and biological features was made in order to be able to monitor temporal variations of the upwelling by remote sensing or ships of opportunities, and to assess the role of the biological pump. Most of the present scientific effort tends to predict the effect of the physics on CO_2 thus complementing the remote sensing observations.

REFERENCES

Feldman, G. C. *CZCS Images*. Space Data and Computing Division, NASA, Goddard Space Flight Division, USA.

Inoue, H. Y., Ishii, M., Matsueda, H. and Ahoyama M. (1996). Changes in longitudinal distribution of the partial pressure of CO_2 (pCO_2) in the central and western equatorial Pacific, west of 160°W. *Geophysical Research Letters, Vol. 23,* 1781–1784.

Metzl, N., Louanchi, F. and Poisson, A. (1996). Variations interannuelles du CO_2 océanique. In Atelier JGOFS-modélisation/PNEDC- , Paris, juin 1996, N. Metzl (ed) *Rapport JGOFS-France No. 24.* 87–93.

Meyers, S. D. and O'Brien, J. O. (1995). Pacific ocean influences atmospheric carbon dioxide. *EOS,* Dec. 5, 1995, 536–537.

Murray, J. W., Johnson, E. and Garside, C. (1995). A US JGOFS Process Study in the equatorial Pacific (EqPac): Introduction. *Deep-Sea Research, Part II*, Vol. 42, 275–293.

Thoning, K. W., Tans, P. P. and Waterman, L. S. (1994). Atmospheric CO_2 records from sites in the NOAA/CMDL continuous monitoring network. In Boden, T. A., Kaiser, D. P., Sepanski, R. J. and Stoss, F. W. (eds) *Trends 93: a compendium of data on global change.* ORNL/CDIAC-65. Carbon dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., USA.