Equatorial upwellings in the Atlantic and Pacific oceans: a comparative study

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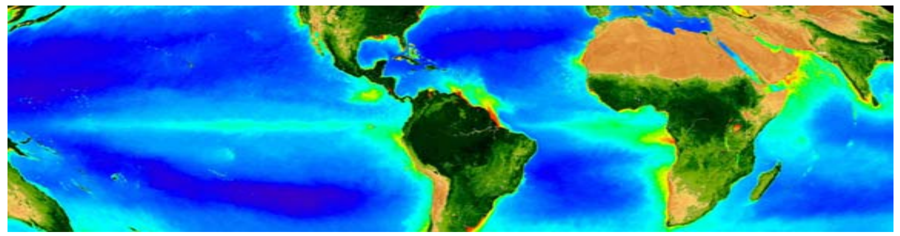
1. Introduction

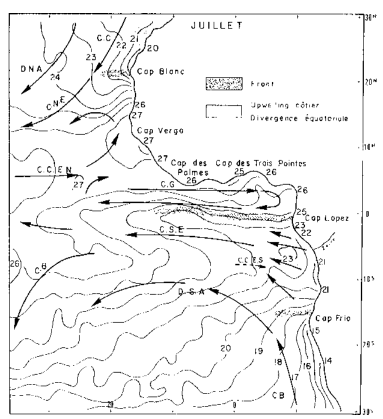
Due to the Coriolis force, westward surface currents diverge on the equator, generating upwelling of deep waters. The result is the occurrence of surface waters with higher concentrations of dissolved gases and nutrients and a higher primary production. Such an increase in phytoplankton biomass is indeed clear on Sea color images of the equatorial Atlantic and Pacific. But the two upwellings present very different features as far as the seasonality and pelagic ecosystem structure and functioning are concerned.
A comparison between the two systems is possible, thanks to existing data which were collected in the two regions with the same methodologies by ORSTOM (now IRD) oceanographers. Data collection took place in the Atlantic along 4°W (south of Ivory Coast) between 1975 and 1980. In the Pacific, data are those of the 1994-1996 period and of the longitudes between 165°E (north of New Caledonia) and 150°W (north of Tahiti).



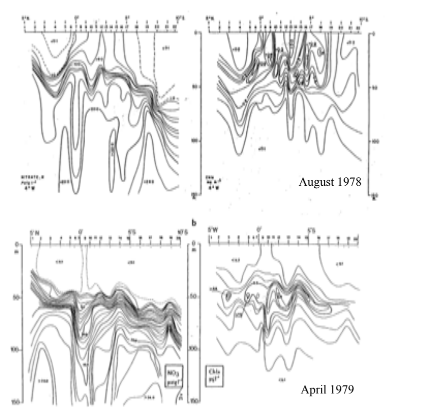
Mean chlorophyll *a* for the summer period (June 21 1998 - Sep 20, 2001) (courtesy of the SeaWiFS project: http:// seawifs.gsfc.nasa.gov). At this time of year, the equatorial Atlantic upwelling occurs and generates an increase in phytoplankton biomass as in the Pacific.

2. Wind and current regimes: the role of Africa in the Atlantic

The pattern observed in the equatorial Pacific is altered in the eastern Atlantic by Africa, which limits the northern part of the equatorial surface current system to about 5°N, and influences the latitude of the ITCZ and, therefore, the wind regime. As a result, the upwelling is centered on 2°30S in the Atlantic, while it is on the equator in the Pacific. But the major difference between the two oceans is the seasonal occurrence of the upwelling in the Atlantic, while its occurrence is not season dependent in the Pacific. In the Atlantic, surface cooling and nitrate happen during summer of the northern hemisphere (end of June till beginning of October) and there is no upwelling during the rest of the year.



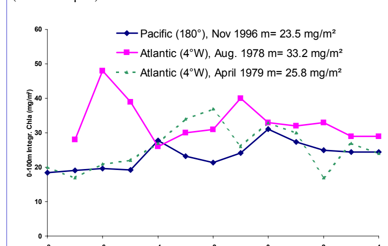
Sea surface temperature (SST) and circulation in the eastern equatorial Atlantic in July (in Wauthy, 1983).
CG (Guinea Current), a branch of the CCEN (North Equatorial Counter Current), is limited to the North by Africa.
CSE: South Equatorial Current



Sections in the Atlantic (4°W) showing NO_3 and Chl*a* profiles between 5°N (left) and 10°S (right) (in Herbland *et al*., 1983).
August 1998 (upwelling season): surface nitrate occurs between 0°30N and 7°S with a maximum of 6µM at 2°30S. Highest Chla concentrations are above 0.9µg/l vs. 0.5 in the Pacific.
April 1979 (warm season): No upwelling, the nitracline is 40-50m deep and there is a deep chlorophyll maximum.The situation is a "Typical tropical system" (TTS).

3. Planktonic biomass and production

The above two transects in the Atlantic are compared to a transect made in the HNLC (High Nutrient-Low Chlorophyll) area of the Pacific along 180°. Higher values are observed in the eastern equatorial Atlantic, the difference between the two oceans being marked for the mesozooplankton (i.e. >200µm).



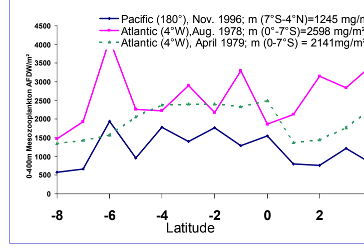
In the Atlantic,integrated Chlorophyll *a* values are higher in summer (upwelling season), quite variable and still high north of the upwelling area.During the "warm" season (April 1979), the enrichment area extends from 4°S to 0°(data from Herbland *et al*., 1983).
Almost all values of the Pacific (Le Bouteiller *et al*., in press) are lower than those of the Atlantic.

Comparison of ^{14}C uptake values (mg C/m²/day) in the equatorial Atlantic and Pacific

Ocean	Cruise	season	Longitude	Latitude	^{14}C uptake	References
Atlantic	CIPREA 1	cold	4°W	1°30S-4°30S	1069	Minas *et al.* (1983)
	CIPREA 2	warm	4°W	1°30S-4°30S	1094	Voituriez *et al.* (1982)
Pacific	EqPac	annual mean	140°W	1°S-1°N	1140	Barber *et al.* (1996)
	EqPac		140°W	5°S-5°N	888	id.
	NOAA	Spring-Fall	95°W-170°W	5°S-5°N	625-936	Chavez *et al.* (1996)
	FLUPAC	October	150°W	0°	1100	Le Borgne *et al.* (1999)
	ZONAL FLUX	April	165°E-150°W	0°	1051	id.
	EBENE	November	180°	4°S-5°N	749	Le Bouteiller *et al.* (in press)

In the Atlantic, ^{14}C uptake was measured in situ, during 12h-long incubations. 125 ml flasks and Sartorius filters of 0.45µm porosity were used. Values are close for the two seasons. Provided results from the two equatorial regions can be compared, ^{14}C uptake values are quite similar to EqPac annual mean and Zonal Flux on the equator. On a wider band (5°S-5°N), values are lower in the Pacific.

3. Planktonic biomass and production (ctd.)



Integrated mesozooplankton ash-free dry weight (AFDW) values for the 0-400m water column (data are those of Le Borgne *et al*., 1983, for the Atlantic and of Le Borgne *et al*., in press, for the Pacific). Almost all values of the Pacific are under those of the eastern Atlantic and the mean value of the Atlantic upwelling (August 1978) is twofold the Pacific value.Note that the latter values are higher than White *et al.* (1995)'s for the two EqPac surveys made in 1992.

4. Discussion

Can we assume a steady-state in the equatorial Atlantic?
During the whole upwelling season, surface nitrate concentrations are significant in the equatorial Atlantic as they are in the Pacific, indicating that inputs by advection are balanced by phytoplankton uptake. So, we may conclude that the latter is limited or controlled in both oceans. In the Atlantic, the grazing control hypothesis was the explanation 20 years ago and was based on the good relationship between mesozooplankton AFDW and integrated chlorophyll (Le Borgne, 1981). However, blooms of Salps and Pyrosomids were observed frequently in the Atlantic (Le Borgne, 1983) which contrasts with the equatorial Pacific where no such observation has been made west of the Galapagos islands. Such blooms and the higher variability of integrated chlorophyll in the Atlantic, would indicate a poor steady state. One possible explanation for this, is the transition from a typical tropical system, which prevails during the "warm" season, into the upwelling system. Since the upwelling season only lasts for three months in the Atlantic, it is likely that the steady state is not well settled. Comparatively, the same explanation could apply to the equatorial Pacific when it shifted from a typical tropical situation prevailing during the strong 1997-1998 El Niño, into the upwelling when it restarted in June-July 1998. This led to unusually high chlorophyll values (Chavez *et al.*, 1999) for several months before reaching lower and steadier concentrations..

Why is the equatorial Atlantic richer in chlorophyll and mesozooplankton?
Possibly, a greater part of the grazing pressure in the Atlantic is achieved by the mesozooplankton, while microzooplankton contributes to most of it (80-90%) in the Pacific. This would mean that large cells make a greater contribution to the total in the Atlantic, which is a reasonable explanation if we consider the chlorophyll size structure in the two equatorial areas (see below).

Chlorophyll « a » size structure (in % of the total) in the equatorial Atlantic and Pacific HNLC areas (from Le Bouteiller *et al*., 1992, for : FOCAL at 4, 23 and 35°W , PIRAL at 20-22°W and PROPPAC at 165°E) . Data of Le Bouteiller presented by Rodier and Le Borgne, 1997, for FLUPAC at 150°W.

Programme	>1µm	>3µm
FOCAL	71	33
PIRAL	73	63
PROPPAC	62	31
FLUPAC	60	30

Larger cells make a greater contribution in the Atlantic equatorial upwelling. 2 possible reasons:
(1) More silicate in the Atlantic. On 4°W, 2-3 µM of Si $(OH)_4$ in the photic zone (0-50m), and > 5µM underneath.
(2) Iron concentrations might be higher in the Atlantic (dust from the nearby Sahara, outflows from the Congo and Amazon rivers).

Summary

1. Seasonal upwelling (July-September), centred at 2°30 S in the Atlantic vs. quasi permanent in the Pacific (except during strong El Niños), centered on the equator.
2. HNLC situation with a weaker steady state, due to the temporary occurrence of the upwelling in the Atlantic.
3. Higher Chla concentrations and integrated Chla in the Atlantic.
3. More large sizes in the total Chla and more mesozooplankton in the Atlantic.
4. More iron in the Atlantic

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