Abnormal Bloom of Phytoplankton around 10°N in the Western Pacific during the 1982-83 ENSO.

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ABSTRACT

The chlorophyll concentration at the surface of the tropical Pacific has been monitored through the 1982-83 ENSO, owing to the SURTROPAC ships of opportunity network. The event was characterized by a decrease in chlorophyll concentrations at the equator, where a belt of relatively rich water however persisted. The most striking anomaly was observed in the western Pacific between 5°N and 15°N. In this region, chlorophyll at the surface is generally less than 0.07 mg m^{-3}, caused by a mixed layer exhausted in nutrients and by strong density gradient in the thermocline. From October 1982 to March 1983, higher concentrations up to 0.70 mg m^{-3} have been recorded by the network. This is consistent with the shallowing of the thermocline which characterizes all ENSO events and was especially well marked in 1982-83. This bloom can be explained by nutrients supplied to the surface mixed layer through the thermocline. Turbulent vertical mixing was indeed made easier during this ENSO event by shallow thermocline, abnormally strong winds, and mixed layer cooler than usual by 2°C. NO_3 data from this region show that 0.07 moles m^{-2} of nitrates have been consumed between January 1982 and January 1983; this value which does not take horizontal advection into account is probably underestimated.

1. Introduction

It is generally considered that ENSO events cause a pronounced decrease in the primary production of the equatorial Pacific Ocean, where upwelling conditions which usually prevail are favourable to the growth of phytoplankton. This is shown by lower than normal direct measurements of primary production (Barber and Chavez, 1986) and by low nutrients concentration at the equator (Feely, et al., 1987). For logistic reasons however (i.e. existing observational networks, availability of research vessels, distance from oceanographic institutes), the Galapagos region and the Peruvian coast have received much more attention than the Central and Western Equatorial Pacific Ocean (Cowles, et al., 1977 ; Barber and Chavez, 1983 ; Feldman, 1986). Furthermore, oceanographic research was focused on the Peruvian anchovies fishery problems (Walsh, 1981), and interest for large scale open ocean primary production has grown up only since a few years, in relation with ocean - climate interactions studies (Chavez et al., 1984 ; Chavez and Barber, 1987). In this scope, a major challenge for oceanographers is to routinely estimate (for instance : on a monthly basis) how much carbon is globally fixed by photosynthesis and buried into the deep sediments. This task is out of reach if undertaken using time consuming *in situ* fourteen carbon experiments, and even if undertaken using proxies such as precise laboratory chlorophyll determinations. Only satellites equipped with sea color sensors today would permit a global survey of a parameter in close relation with photosynthesis (Smith, 1984). The Coastal Zone Color Scanner (CZCS) onboard of Nimbus 6 was still active during the 1982-83 El Nino (Feldman, 1986), but intense cloudiness during most of this warm episode in the equatorial region (Gill and Rasmusson, 1983) prevented teledetection of the sea color most of the time. The only, while rudimentary, global view of the phytoplankton biomass in the

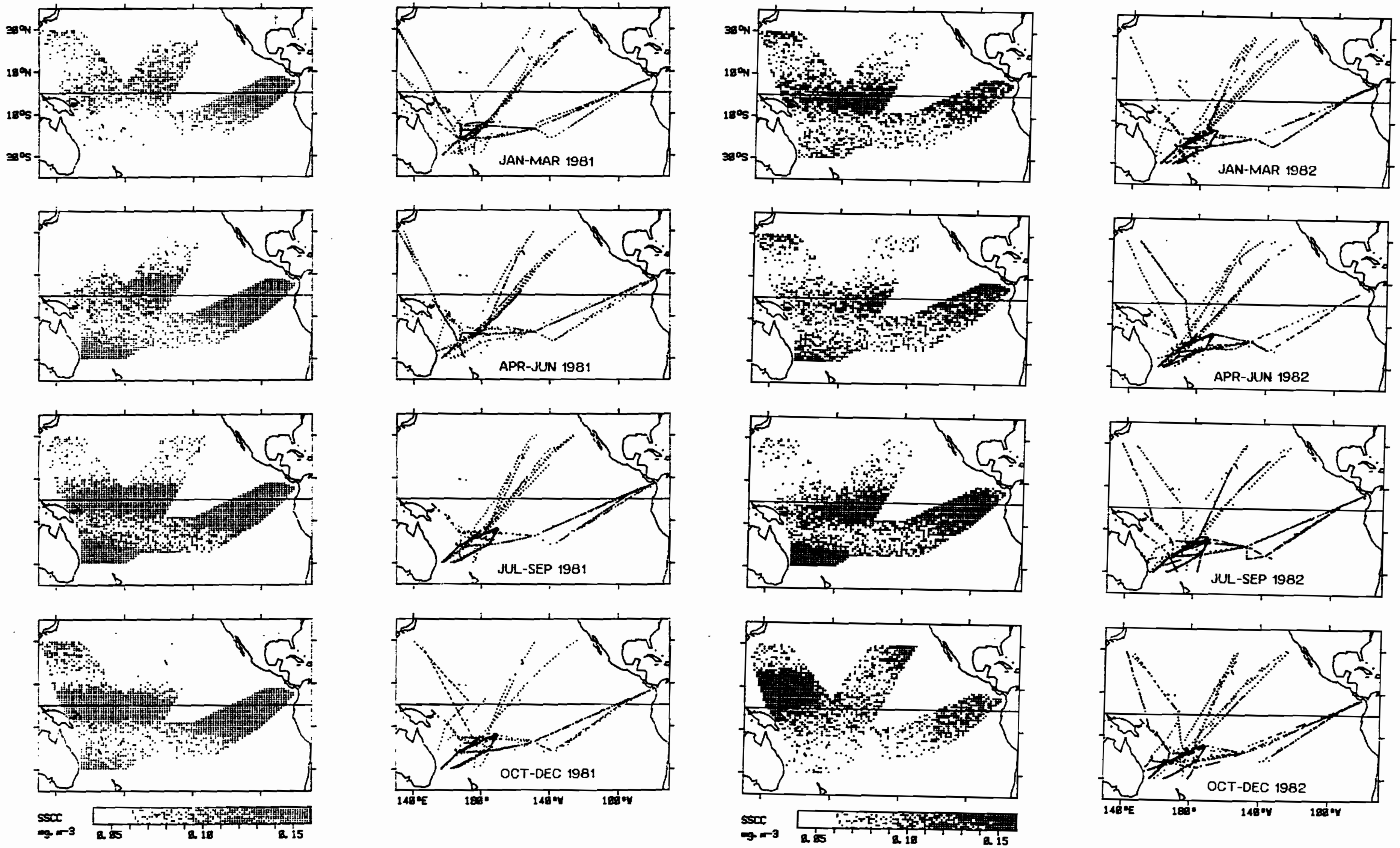

FIG.1.Odd columns : quarterly charts of sea surface chlorophyll concentration (SSCC) in the tropical Pacific (shaded), from 1981 to 1984. Even columns: position of the data collected by the SURTROPAC merchant ships network during each quarter.

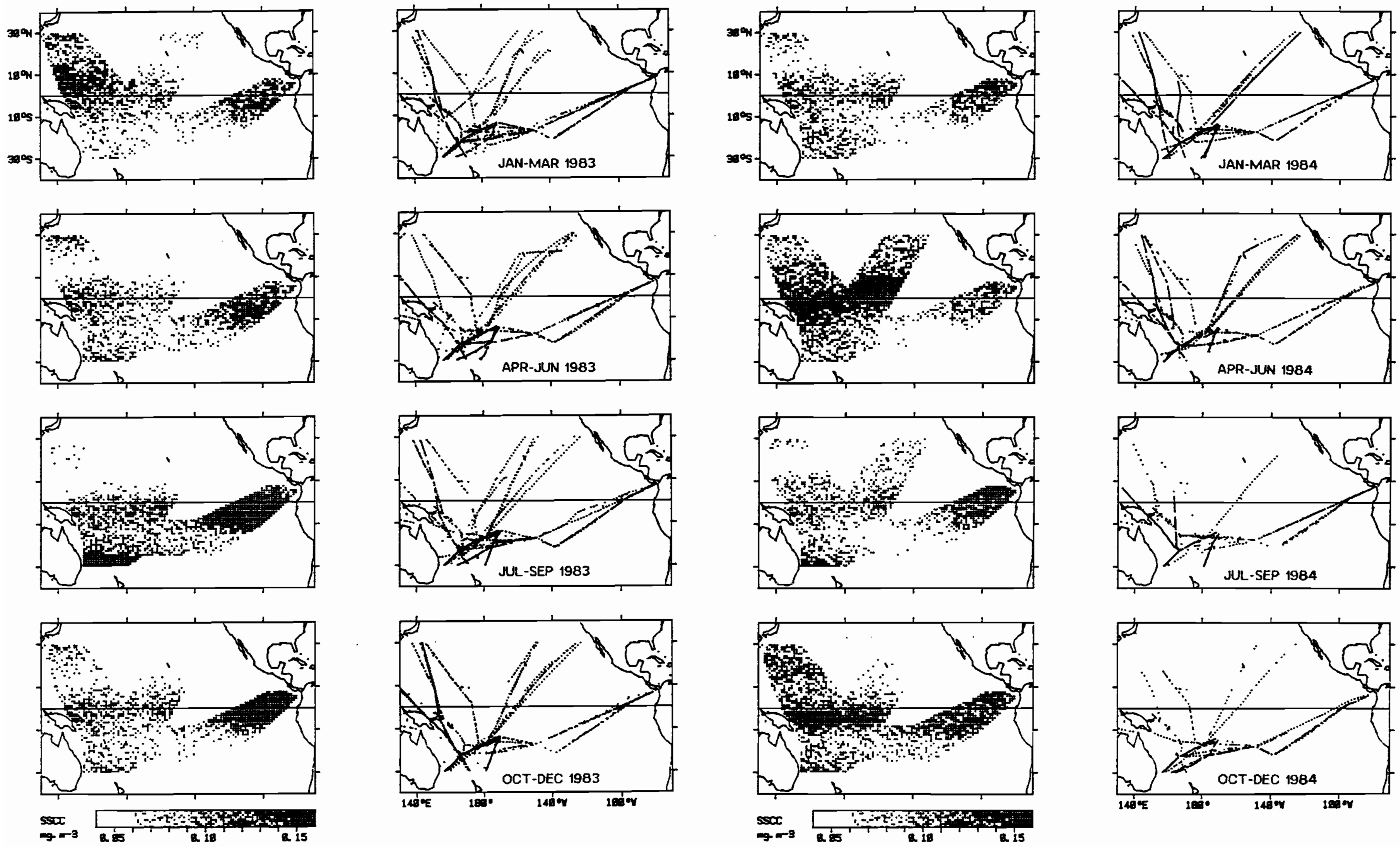

FIG.1. (Continue)

Tropical Pacific Ocean has thus been provided by the SURTROPAC network of merchant ships (ORSTOM, New Caledonia) : chlorophyll measurements are included in the routine observations made from these ships, and the period from 1982 to 1983 was an especially well sampled one (Dandonneau, 1986). The variations of the phytoplankton biomass at the surface of the Pacific Ocean during this exceptional warm event are described using the chlorophyll data from the merchant ships network. Attention is called on a phytoplankton bloom which developed in the western Pacific between the equator and 15°N, and which had never been detected in the past. Quality of the data, and possible mechanisms, are examined in order to establish the reality of this bloom.

2. Methods

Chlorophyll measurements are made according to a specially adapted technique (Dandonneau, 1982), which was developed in order to face the difficulties inherent in sampling, filtration, and filter storage made by voluntary observers. The main constraint arises from the volume of filtered water, which must be small, so that filtration does not take too much time. Filtration is made with a syringe on 13 mm in diameter Millipore HA type filters (porosity : 0.46µ). Filtered volume has been reduced to 10 cm^3, entailing a second constraint : measurement technique must be very sensitive (usual techniques based on the fluorescence of chlorophyll in acetone or methanol require 100 to 500 cm^3 of sea water). Fluorescence is thus measured directly on the surface of the filters, without extraction of the chlorophyll by a solvent. This procedure multiplies the sensitivity by a factor 10. The instrumental error, and causes of chlorophyll data rejection, have been discussed in previous papers (Dandonneau, 1986 ; Dandonneau and Eldin, 1987).

3. Results

The observations collected by the SURTROPAC merchant ships network are distributed along three main shipping tracks : from New Caledonia to Japan, from Australia to North America, and from New Caledonia to Panama. All three tracks were regularly sampled from 1981 to 1984 (at least two or three voyages at each quarter, except in July to September 1981 for the New Caledonia to Japan track), ensuring a reasonably good coverage during the 1982-83 El Nino (Fig. 1). Large scale chlorophyll concentration patterns in the Pacific are dominated by the equatorial belt of rich waters which corresponds to the equatorial upwelling.

Chlorophyll concentrations greater than 0.15 mg m^{-3} spread along the equator westwards to 180° (Fig. 1) during the first half of 1981, and across the entire Pacific ocean until March 1982. Such a large spreading of chlorophyll concentrations greater than 0.15 mg m^{-3} along the equator from America to New Guinea will not be seen until march 1984; only from april to june 1984, and from october to december 1984 does the equatorial enrichment appear again like a long even stripe through the entire Pacific Ocean. Most of the time, the equatorial enrichment is weak in the western Pacific.

From October 1982 to June 1983, the equatorial enrichment is still weaker, with lowest values in April-June 1983, but persists through the El Nino event, with chlorophyll concentrations lesser than 0.10 mg m^{-3} in the central Pacific, and lesser than 0.13 mg m^{-3} in the eastern Pacific. During the northern hemisphere 1982-83 winter, a large bloom of phytoplankton develops west of the dateline, between the equator and 15°N. The position of this bloom, centered at about 10°N, makes it different from a consequence of equatorial upwelling. Furthermore, westerly winds which prevailed in this region during the 1982-83 El Nino did not favour equatorial upwelling. This bloom is very uncommon in this area, as shown on Figure 2 : the mean conditions from October to March (derived from the data collected from 1979 to June 1982, and from July 1983 to 1985) show low chlorophyll

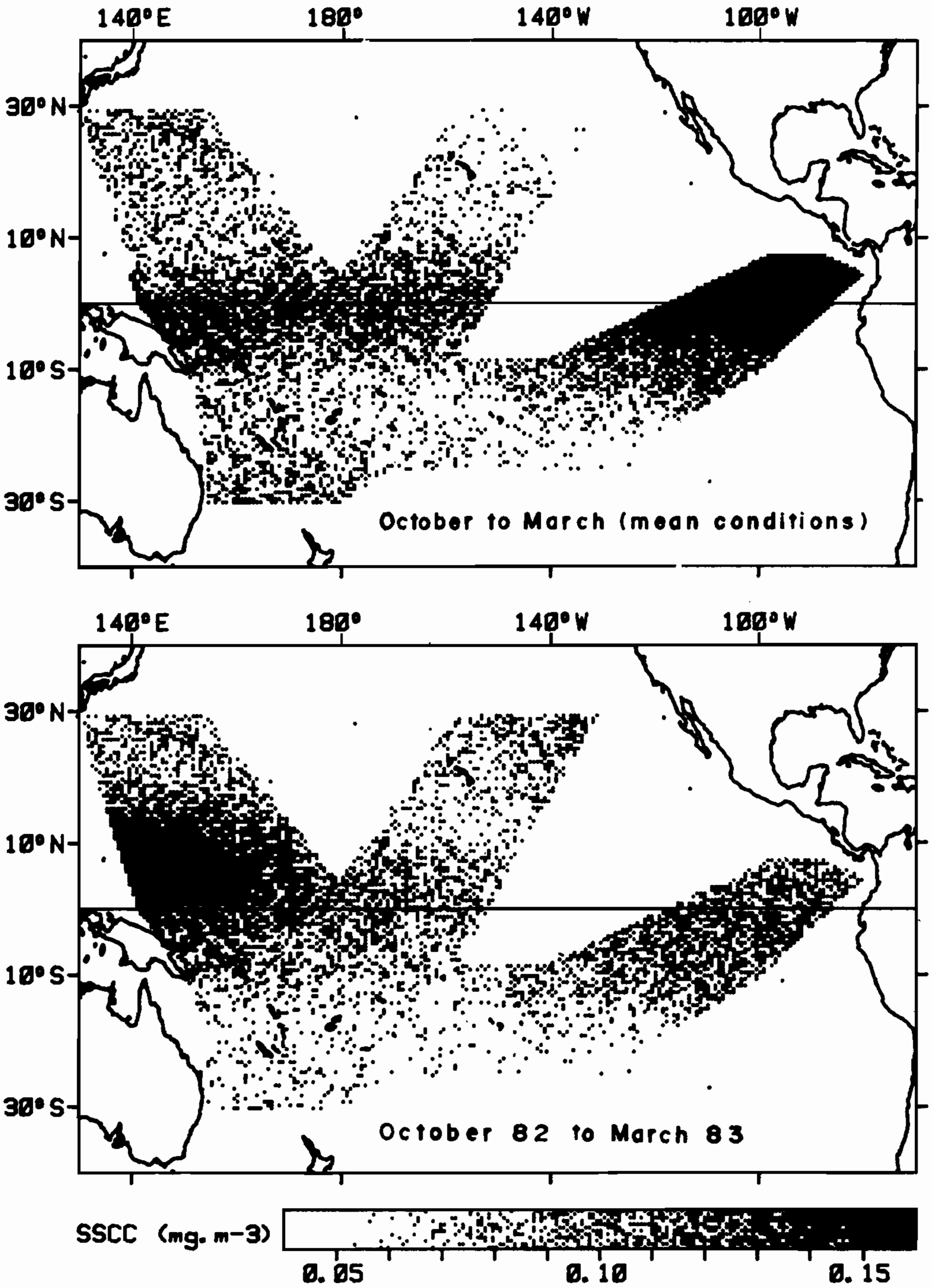

FIG.2. Top : mean chlorophyll concentration at the surface of the tropical Pacific in northern winter (October to March) from 1979 to 1985 (1982-83 winter excluded). Bottom : mean chlorophyll concentration during the 1982-83 northern winter.

concentrations at 10°N, which are typical of tropical waters with a nutrient-exhausted mixed layer (Figure 2, top). The patterns shown for the same months during the 1982-83 El Nino are strikingly different (Fig. 2, bottom), the main difference being the very large bloom which occurred in the northwestern tropical Pacific.

These equatorial or near equatorial large scale features account for most of the variance shown on the quarterly charts from 1981 to 1984 (Fig. 1). A winter increase in chlorophyll concentrations south of about 20°S (austral winter : April to September) can also be seen on these charts. This winter enrichment has been explained as the result of a cooling of the surface mixed layer which thickens and incorporates deep nutrients from the thermocline (Dandonneau and Gohin, 1984). It is much more pronounced in the southern hemisphere near Australia than at the same latitude in the northern hemisphere near Japan.

4. Discussion

Consequences of El Nino on the marine primary production have only been described in the eastern and equatorial Pacific (Walsh, 1981 ; Barber and Chavez, 1983, among other papers cited here). The bloom which developed in the western Pacific at about 10°N during the 1982-83 El Nino (Fig. 1: October 1982 to March 1983) had never been observed on previous El Ninos, nor has it been observed by the Coastal Zone Color Scanner which was still active in 1982-83. The SURTROPAC merchant ships network furthermore did not detect any chlorophyll enrichment in this region before nor after the 1982-83 El Nino. The observation reported here thus has the character of an exceptional one. Low precision and risk of bias inherent to this chlorophyll measurement technique (Dandonneau, 1982, 1986) call for prudence, and arguments must be presented showing that the observed enrichment does not result from measurements errors.

The chlorophyll data from the northwestern tropical Pacific during the 1982-83 El Nino have been collected by two merchant ships : M.S. Pacific Islander, and M.S. Mosel; the first one is part of the SURTROPAC network of merchant ships since 1981, and is still continuing; the second one has been sampling from February 1983 to December 1984. Both were careful observers, and ensured the monitoring of the sea surface chlorophyll in this region after the 1982-83 warm event. The chlorophyll enrichment was detected by both ships from November 1982 to February 1983 (Figure 3). Later, the highest chlorophyll concentrations at each voyage shifted toward the equator. Mean chlorophyll concentrations in the northwestern tropical Pacific never exceeded 0.10 mg m^{-3} during the period from January 1981 to December 1983 (Fig. 1), as well as during the entire monitoring experiment (Fig. 2, bottom), except during the 1982-83 ENSO; higher chlorophyll values were then detected at each voyage between November 1982 and February 1983 by two different merchant ships. Such a coincidence being the result of measurements errors is very unlikely.

Under normal conditions, the western tropical Pacific is generally characterized by high chlorophyll values at the equator, and low ones on the northern and southern sides (Fig. 1; Fig. 2, bottom). At the end of 1982 and the beginning of 1983, the highest chlorophyll concentrations were centered at about 10°N, instead of the equator. This can be seen at each ship's voyage from November 1982 to February 1983 (Fig. 3) ; the chlorophyll data collected during these voyages all show the highest values neatly shifted to the north of the equator, and embedded between lower values to the south and to the north. The most frequent measurement errors in this experiment are systematic errors (overestimates, or, more frequently, underestimates) ; when these errors are obvious, the data from the entire voyage are rejected (Dandonneau, 1986). But even in such cases, the spatial structure of the chlorophyll distribution is still visible. An extra equatorial enrichment in the western tropical Pacific is then an exceptional feature which can hardly result from measurement errors. The chlorophyll-latitude plots from individual voyages shown in Fig. 3 reveal a high, undersampled spatial variability. It cannot be said here if this variability, which throws some uncertainty on our conclusions, results from the measurement errors, or reflects the intrinsic variability of the chlorophyll field, which can be high too, as shown by precise shipboard measurements made during an oceanographic cruise (Fig. 4).

The shift of the western tropical Pacific enriched area from the equator to about 10°N implies that the physical processes which maintained the enrichment are distinct from equatorial upwelling. The western Pacific between 5°N and 15°N is characterized by a thick mixed layer, exhausted in nutrients, and corresponds thus to the "typical tropical structure" described by Herbland and Voituriez (1979); such tropical waters have a low chlorophyll content. In 1982, after the onset of El Nino, the mean depth of the thermocline decreased by 50 meters at 6 - 8°N (Meyers and Donguy, 1984). Furthermore, the sea surface temperature cooled by 2°C in this region, which Meyers et al. (1986) related to intense evaporation caused by anomalous strong winds. Cooling of the surface mixed layer causes the water immediately below the thermocline to have a lesser density than the mixed layer, and so, to be entrained into the mixed layer. Nutrients from below the thermocline can thus be transferred to the surface and be available to photosynthesis. The data from the Ryofu Maru cruises at 137°E (Masuzawa and Nagazaka, 1975) indicate that the nitrate - temperature relationship is a straight line which intercepts $[NO_3]=0.0$ at T | 24 to 26°C (Dandonneau, 1986). The upper layer temperature decreased to below 26°C north of 15°N in January 1983 (Meyers and Donguy, 1984) so that a small quantity of nitrates could have been injected into the mixed layer. Furthermore, the rise of the thermocline, and the cooling of the mixed layer both are likely to favour turbulent vertical mixing. The typical tropical structure which usually prevails in the western Pacific Ocean between 5°N and 15°N could thus have been replaced by a regime of nitrates pulses, causing the observed phytoplankton bloom. The data from the Ryofu Maru indeed show a shift in the nitrate - temperature relationship between January 1982 and January 1983, corresponding to a 2 μmole l^{-1} drop of $[NO_3]$ at a given temperature (Dandonneau, 1986). This shift was observed on a 35 m thick layer, and if horizontal advection is neglected, the upward flux of nitrates through the thermocline can be estimated to 70 mmoles m^{-2}, i.e. 980 mg m^{-2}. A C/N ratio in the phytoplankton equal to 9.01 (Sharp et al. 1980) gives 8.83 g m^{-2} of new organic carbon production from January 1982 to January 1983, most of which probably occurred after the onset of El Nino. If this result is applied to the area limited by 5°N-15°N, 130°E-170°E (i.e. about 4.8 10^6 km^2), carbon fixation by new production is 0.04 Gt. Advection however cannot be neglected in this region, especially during the 1982-83 El Nino, when the North Equatorial Countercurrent was intensified (Tournier and Picaut, this volume). An error can thus be made when assuming that the January 1982 to January 1983 nitrate decrease was caused only by photosynthetic production. It has been shown indeed that the phosphate - temperature relationship in this region undergoes interannual variations which are not completely explained by the ENSO cycle (Dandonneau, 1988).

No positive anomaly of the chlorophyll concentration at the sea surface was observed in the northwestern tropical Pacific during the 1986-87 El Nino (unpublished data from the SURTROPAC network). Previous warm events, in 1957, 1965, 1972 and 1976 have occurred while no observing network or satellite existed for the sea surface chlorophyll, so that possible phytoplankton blooms could not be detected. The global compilation of data made by Koblentz-Mishke et al. (1970) does not show any sign of such blooms in the western tropical Pacific. The 1982-83 El Nino was a very strong one (Quinn et al. 1987). During this event, the sea surface temperature between 5°N and 15°N was the coldest recorded since 1969 (unpublished data from the SURTROPAC network). The anomaly of the 20°C isotherm depth (observation minus mean annual cycle) at 13°N in the western Pacific reached a peak value, which was only surpassed in 1957 and 1972 (Kessler, this volume). The sea level at Truk Island (7°27'N, 151°51'E) in January 1983 was 25 cm below the mean value (Wyrtki, 1985), which was only (and briefly) surpassed in January 1977

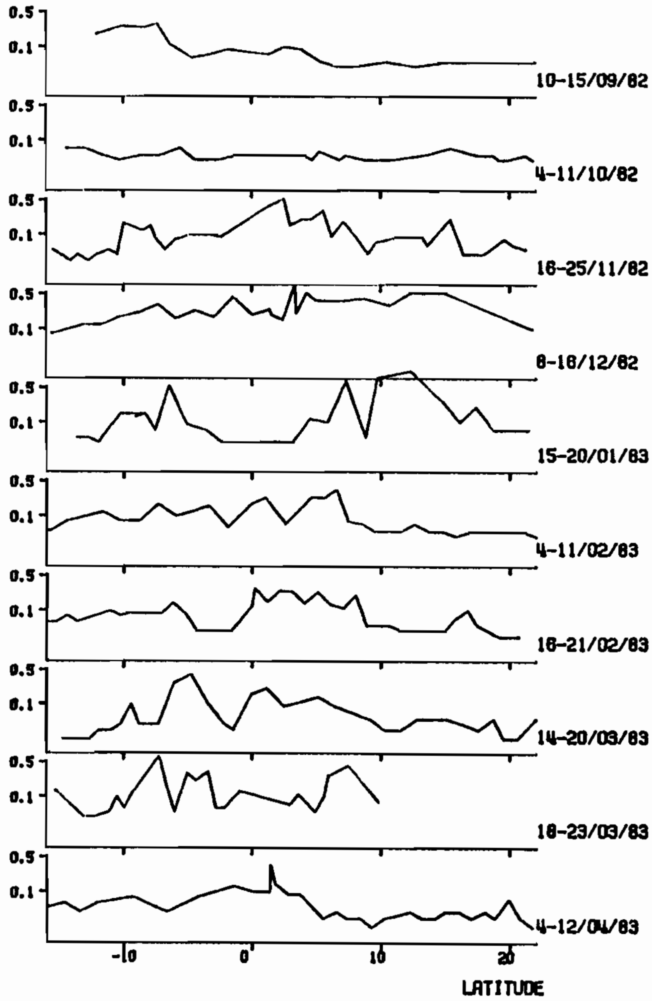

FIG.3. Surface chlorophyll on the New Caledonia to Japan shipping track (logarithmic scale). All the merchant ships voyages from September 1982 to April 1983 are represented here.

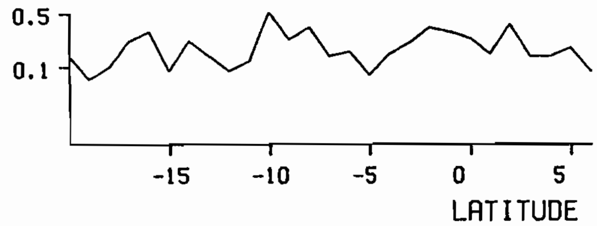

FIG. 4. Chlorophyll concentration (logarithmic scale) at the surface along 165°E, from precise shipboard laboratory measurements during cruise PROPPAC 2 in April 1988 (ORSTOM, Nouméa, courtesy of Aubert Le Bouteiller). Mesoscale variability is as high as shown by the data collected by merchant ships (Figure 3).

(Meyers, 1982). Wyrtki (1985) indeed found that the upper layer volume of the tropical Pacific was much smaller in 1983 than in previous years. Such a low sea level is indicative of low heat content (low sea surface temperature, and/or shallow thermocline) in the upper oceanic layers (Rébert et al., 1985 ; Delcroix and Gautier, 1987) and is favourable to vertical mixing of nutrients and to enhanced photosynthesis. The phytoplankton bloom which we have observed between November 1982 and February 1983 then could be an abnormal feature, which only occurs during very strong El Ninos, when threshold conditions are surpassed.

The equatorial upwelling did not completely vanish during the 1982-83 El Nino. A slightly enriched zone persists at the equator through the warm event, east of the dateline, even in April-June 1983 when chlorophyll concentrations were remarkably weak over most of the Pacific (Fig. 1). Most papers dealing with the consequences of El Nino indeed mention a decrease in productivity rather than a complete pause of the equatorial upwelling (Barber and Chavez, 1986). Existing information on nitrates concentration at the equator in the central Pacific during El Ninos generally shows concentrations significantly different from zero : 6.47 μmole l^{-1} at 150°W in February 1965 (Hisard, 1985); 2 μmole l^{-1} at 160°W in May, 1987 (Wong, personal communication); but | 0 μmole l^{-1} at 158°W in April, 1983 (Feely et al., 1987). The map of chlorophyll distribution in April-June, 1983 (Fig. 1) indeed shows a quasi null influence of the equatorial upwelling in the central Pacific. Permanence of an equatorial enrichment during El Ninos at the equator in the eastern Pacific has been shown on a time series of observing merchant ships voyages from 1979 to 1985 (Dandonneau and Eldin, 1987) : in spite of a decrease of the chlorophyll concentration in the equatorial zone, the limit between enriched equatorial waters and oligotrophic waters in the south only shifted from about 15°S to about 12°S during the 1982-83 El Nino. This limit could be located for each voyage, except on two occasions, in December 1982 and in April 1983.

5. Conclusions

The network of observing merchant ships managed by the SURTROPAC Group in Nouméa has allowed to gather chlorophyll data which provide a unique view of the tropical Pacific Ocean before, during and after the 1982-83 El Nino. It has thus been possible to draw quarterly charts of the chlorophyll distribution at the surface of the Pacific ; in spite of the limited number of available data (about 1000 for each chart), of the high variability which generally characterizes the biological fields, and of the coarseness of the measurement technique, these charts agree reasonably well with current knowledge of the consequences of El Nino. Furthermore, they reveal the occurrence of a large phytoplankton bloom which occurred between 5°N and 15°N from November 1982 to February 1983. Such a bloom in this region had never been detected on previous El Ninos, and has no more been detected during the 1986-87 event. This bloom can however be explained by the extreme conditions (abnormally low sea surface temperature, shallow thermocline) which occurred during the 82-83 warm event, and would thus be a characteristic feature of very strong El Ninos.

Acknowledgments : The officers who carefully sample the surface of the Pacific Ocean and make the filtrations for the chlorophyll measurements took a very large part in this work. I wish to pay homage to their benevolent contribution.

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