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Sea Level and Dynamic Topography in the Western Pacific During 1982-83 El Niño

During the strong 1982-83 El Niño, two oceanographic networks gathered continuous data in the tropical Pacific: the sea-level network established and operated by the University of Hawaii, and the XBT network using ships of opportunity established and operated by the Groupe SURTROPAC of the Centre ORSTOM de Nouméa. The latter is a joint France-U.S. program and covers three main routes: Nouméa-Japan, Nouméa-California, and Nouméa-Tahiti-Panamá.

Surface circulation derived from sea level in the western Pacific

Monthly maps of sea-level anomaly in the Pacific for 1982-83 (Wyrtki, 1985a) show abundant data in the western Pacific (Figure 1), particularly in the vicinity of the Nouméa-Japan shipping route. Sea-level deviations from the long—term mean at each station have been plotted along this route in the form of a space-time diagram for the years 1979 to 1983 (Figure 2). From 1979 to May 1982, deviations of sea level are small and exceed 10 cm only on a few occasions, indicating that the mean topography of the sea surface was relatively undisturbed during this period. In June 1982 a strong negative anomaly developed near 10°N at the location of the Countercurrent trough. The anomaly reached a peak value of -30 cm in January 1983 and lasted until June 1983. South of the equator, sea level also dropped in late 1982, but the lowest deviation was reached near 10°S in July 1983. Sea level returned to normal in June in the Northern Hemisphere and not before the end of 1983 in the Southern Hemisphere.

The rapid drop of sea level near 10°N in 1982 indicates an intensification of the North Equatorial Countercurrent. In 1983, in the Southern Hemisphere, the depression of sea level also indicates an anomalous circulation. North of the minimum, between the equator and 10°S, surface eastward flow moved warm waters to the eastern Pacific. Sea-level anomalies during the 1982-83 warm event showed a southward displacement of the subtropical gyre in the southwestern Pacific and consequently a strong slope in sea level between 10° and 20°S, inducing a strong geostrophic flow from east to west (Wyrtki, 1984). The westward flow south of the minimum would be identified as the South Equatorial Current.

Surface circulation from XBT in the western Pacific

Variations of the sea surface can also be monitored by means of dynamic topography computed with data from the XBT network. Monthly dynamic topography relative to 400 decibars has been computed along the Nouméa-Japan route (20°S — 20°N, 150°E — 165°E) between 1980 and 1984 (Figure 3), using actual T-S relationships, to emphasize interannual anomalies.

Average T-S relationships have been computed for the Pacific Ocean (Emery and Dewar, 1982). These T-S relationships must be improved — particularly in the southwestern Pacific for several reasons: they are limited to 27°C, although surface temperature can pass 30°C and they do not extend south of 10°S. Moreover, these T-S relationships are long—term averages and they do not represent interannual fluctuations, which are important in the western tropical Pacific as shown by surface salinity data (Donguy and Dessier, 1983). Consequently, the T-S curves have been modified by the following method.

In the western tropical Pacific, all salinity profiles exhibit a similar shape — an increase from the surface to a more or less well-defined salinity maximum in the thermocline and a decrease downward. Below the salinity maximum, T-S curves of cruises carried out during the period of El Niño show only weak deviations of salinity from the mean and regular T-S relationships can be used (Morlière and Rébert, 1985). From the salinity maximum up to the surface, sea-surface salinity and temperature gathered by ships of opportunity in the SURTROPAC program are used to complete the curves. In order to specify salinity within the surface layer, a linear relationship is taken between the monthly averaged surface temperature-salinity and the salinity maximum on the T-S curve (Figure 4). Although the actual relation is not always linear, the exact choice of the relation affects the results only slightly, as long as it describes a continuous increase in salinity. Monthly T-S curves are obtained for the period 1980-84 and used for dynamic calculations. Results show up to eight dynamic centimeters difference in dynamic height relative to 400 decibars compared to calculations performed with a constant T-S relationship.

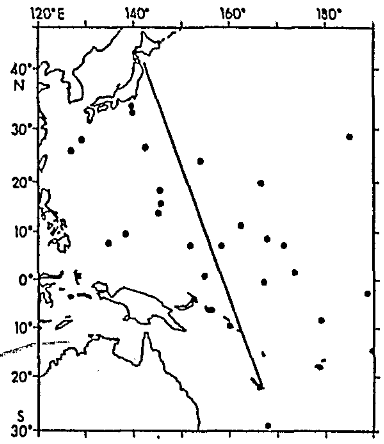

FIGURE 1 *(Donguy, Eldin, and Wyrtki) Sea-level network and Nouméa-Japan XBT route.*

From 1980 to 1981, the usual pattern occurs (Figure 3) as earlier described by Wyrtki (1974): a maximum of dynamic height at 5°S (South Equatorial Ridge) and a minimum at 8°N (North Equatorial Countercurrent Trough). There was no appearance of seasonal variations during this time. From August 1981

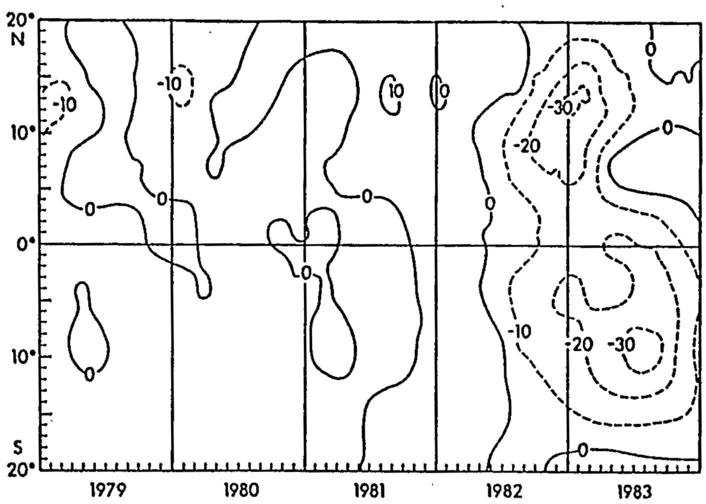

FIGURE 2 *(Donguy, Eldin, and Wyrtki)*
Sea–level deviations from the long–term mean in centimeters, 1979-83, along the shipping route from New Caledonia to Japan.

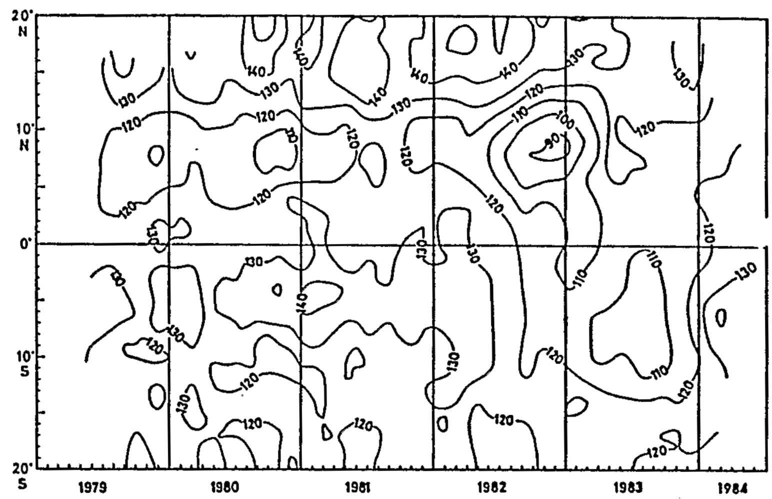

FIGURE 3 *(Donguy, Eldin, and Wyrtki)*
Dynamic topography in dynamic centimeters, 1979-1984, relative to 400 db, along the shipping route from New Caledonia to Japan.

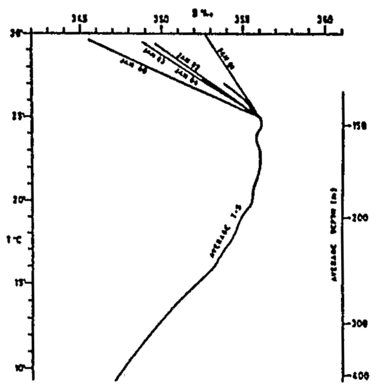

FIGURE 4 *(Donguy, Eldin, and Wyrtki)*
Example of T-S relationship (4°S — 2°S, 160°E — 164°E) modified using monthly surface data.

to February 1982, the South Equatorial Ridge expanded from the equator to 15°S, implying that this area was occupied by low-density water due to a great heat content. At that time easterly winds prevailed and surface salinity was high (Donguy and Dessier, 1983). These features could be interpreted as the existence of a build-up in the western Pacific associated with a westward current from at least 5°N to 5°S. They are also consistent with the calculation made by Wyrtki (1985b) who found a positive heat anomaly in 1981 by integration of sea level between 15°N and 15°S.

Starting in June 1982, dynamic heights decreased between 15°N and 15°S, but especially in the vicinity of 8°N. The decrease seems to propagate southward, reaching 10°S in March 1983. This feature is very similar to the sea-level anomaly observed at the same time (Figure 2) and can be interpreted in the same way. Between September 1982 and April 1983, during the mature phase of the warm event both the North Equatorial Countercurrent and the North Equatorial Current were strengthened. In the vicinity of the equator, flat dynamic topography indicates the presence of a weak eastward current.

In the Southern Hemisphere a dynamic trough develops during 1983, instead of the usual South Equatorial Ridge, and induces a strong westward South Equatorial Current between 10°S and 15°S (Wyrtki, 1985a). This feature seems characteristic of El Niño conditions as noticed by Donguy *et al.* (1985). The end of the warm event is apparent in the beginning of 1984 by a return to conditions observed prior to 1981.

Conclusions

The excellent agreement of the time-space patterns of variations of both sea level and dynamic height indicates that the two parameters can be used jointly to monitor the variability of ocean circulation. Rébert *et al.* (1985) have already shown that sea level can be used to monitor both dynamic height and heat content at individual stations. The next important step will be to combine the coverage of XBT lines and of sea-level stations for the preparation of maps of dynamic height and heat content for the equatorial Pacific. The data from the two networks are complementary in other aspects as well. They combine the spatial coverage of XBT lines sampled at a particular time with the continuous record of sea level at discrete stations. These two networks will probably constitute the basic large-scale monitoring effort of the TOGA program.

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A Global Sea-Level Network: How Many Gauges are Enough?

For the past two centuries, tide gauges have provided the only means of measuring mean sea level (MSL) and have usually been installed for specific local purposes (*e.g.*, harbor navigation, storm surge, or tsunami warning) unconnected with global circulation interests. In recent times, however, MSL has come to be regarded as an essential oceanographic parameter for use in the tropics as a proxy for heat content and as a measure worldwide of geostrophic surface currents. The first attempt to weld strategically placed gauges into a global network is the proposal, now called "GLOSS" (Global Sea-Level Observing System), designed for the TOGA program as well as for the WOCE period and beyond. This plan (IOC, 1986), which can be taken as a first model for a continuing global network, envisages a total of approximately 250 gauges (150 of which already exist), the main selection criteria for which are: (1) the allocation of a gauge to each island or each island-group at intervals not closer than 500 km; and (2) the allocation of gauges along continental coasts at intervals not less than 1000 km. The authors of the proposal (primarily Prof. K. Wyrtki and Dr. D.T. Pugh) stress that these initial criteria are somewhat arbitrary, make no allowance for different sea-level variability in different regions, and will require modification in the light of experience. In fact, the results of the investigation described below show that these are quite reasonable initial criteria, although for full global coverage the MSL data-set will need expansion by means of precise satellite altimetry.

It is possible to evaluate the suitability of the suggested spacings of criteria (1) and (2) from the existing worldwide tide-gauge records stored by the Permanent Service for Mean Sea Level (PSMSL). While preference in the choice of gauges for the purposes of a global network must be given to those gauges with maximum exposure to the open ocean, all records will contain a contribution from local forcing (*i.e.*, local air-pressure fluctuations, wind setup, and runoff) which has to be understood and removed from the sea-level time series from each station. Usually the local effects are larger along coastlines with a wider continental shelf. If local effects dominate, then the gauges become unsuitable for global monitoring as a much denser regional network is required to provide interconnection of information across the network. Figure 1(a-n) shows the average (zero-lag) correlation between pairs of stations along the coastlines and in island groups for which sufficient data exist. Annual values of MSL have been used to provide an estimate of the average correlation over time scales from two years to decades. In addition, each station record has been de-trended so the correlations should not include a contribution from the secular changes in sea level due to land movements or low-frequency climatic change. The requirement for the optimum spacing for a global network in this frequency range can be expressed as an average correlation of 0.5 between stations, *i.e.*, at a distance apart at which half the variance of the sea-level variability at two stations is correlated. With such a requirement, then the variability in common between different elements of the network, which will be representative of the regional variability, should certainly be extractable by statistical techniques such as Principal Components Analysis.

In general, Figure 1(a-n) supports the hitherto arbitrary design spacing (motivated primarily by cost and other practicalities) between sea-level measuring stations as specified in criteria (1) and (2) of IOC (1986). The American Pacific data (Figure 1 [b-n]), which contain strong contributions from El Niño events, suggest that a spacing wider than 1000 km could be sufficient in that area, although there are in fact very few operational gauges along the southern parts of the coastline (Figure 1[d]). Enclosed seas (Figure 1[j and m]) also show a high degree of coherence between gauges and may, for global studies purposes, be represented by relatively few tide gauges. The weakest average correlation between stations for distances up to 1000 km is shown in the data from the European Atlantic coastline (Denmark to Spain, including the British Isles (Figure 1[k]). However, this figure includes gauges around the North and Irish seas which will not necessarily be representative of ocean conditions and which contain a large amount of "local" variability as discussed above; two gauges, Newlyn and La Coruña, 780 km apart and closer than most to the open ocean show an adequate correlation of 0.73. For criterion (1), Figure 1 (e-f) shows data from the central Pacific and Philippines, respectively, and supports the use of a 500– to 1000–km spacing in these areas. More detailed discussion of