Changes in the 20°C Isotherm Depth Along the Equator During Three ENSO Events

Exceptionally good monitoring of the winds, sea level, and upper ocean thermal fields over the Pacific Ocean during the 1982-83 warm event has allowed, for the first time, a description of the simultaneous evolution of several dynamic parameters along the equator. In particular, the patterns of anomalous monthly mean sea level and wind fluctuations moved eastward across the Pacific at about 1 m s^{-1} (Figure 1). Because of the France-U.S. XBT ship-of-opportunity program, it is also possible to follow the evolution of the thermocline response along the equator. Consequently, the 1982-83 El Niño Southern Oscillation (ENSO) is the first event in which the wind, sea level, and upper ocean thermal structure have been more or less adequately monitored.

The eastward movement of the wind anomaly across the Pacific Ocean during the 1982-83 ENSO raises two distinct questions.

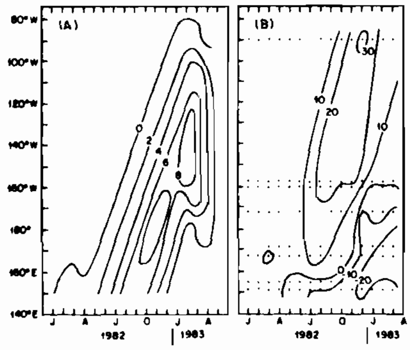

FIGURE 1 (*Donguy et al.*)
Time-longitude contour plot of (A) zonal wind anomaly at the 850 mb level along the equator (data from the Climate Analysis Center) and (B) monthly sea level anomalies at several near-equatorial stations across the Pacific (from Wyrtki and Lukas, 1983).

(1) What is the response of the equatorial ocean to a moving wind perturbation? Because previous analytic models considered a wind relaxation or a wind forcing confined to a part of the Pacific Ocean, it is difficult to compare such responses to the 1982-83 phenomenon. (2) Did similar changes exist during previous events, or is eastward movement unique to 1982-83? The poor quality of wind data during previous events does not allow a reliable answer, although according to Wyrtki (1977) an eastward movement of the wind relaxation as far as 160°W had been observed in 1972.

This study of several ENSOs points out an eastward progression of the thermal structure anomaly and also notes significant differences between the velocities of progression. The ENSO events examined are those of 1969, 1972, and 1982, but not the 1976 event due to a lack of data. We considered the 20°C isotherm depth averaged from 2°N to 2°S to be representative of the upper equatorial thermal structure. The 1982-83 temperature data were recorded at 160°E, 160°W, and 100°W by the France-U.S. XBT program, at 138°W by Toole (1983), and at 85°W by Leetmaa *et al.* (1983). Temperature data for the 1972-73 and 1968-69 events consisted of XBT casts obtained from NOAA's National Oceanographic Data Center, hydrographic casts from ORSTOM Noumea files, and observations made by the Japanese Fisheries Fleet.

In 1982-83, an increase in the depth of the 20°C isotherm seems to move from 160°E in July 1982 to 85°W in January 1983 (Figure 2A). The propagation speed of this anomaly is 0.7 m s^{-1} and is consistent with the movement of the sea level anomaly (Figure 1B), which was observed in July 1982 at Nauru (170°E) and then in December at the Galápagos Islands (90°W). This same eastward movement appeared during the strong 1972 El Niño (Figure 2B) and during the weak 1969 El Niño (Figure 2C). In each case, an eastward propagation occurs in the deepening of the 20°C isotherm.

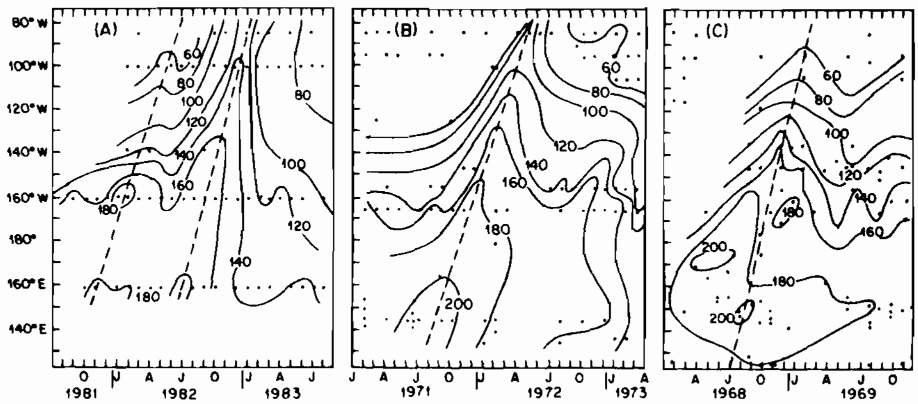

FIGURE 2 (*Donguy et al.*)
Depth of the 20°C isotherm along the equator (averaged from 2°N to 2°S) in (A) 1982-83, (B) 1971-72, and (C) 1968-69.

A comparison of the characteristics (Table 1) of these El Niños shows interesting differences between them. The equatorial zonal slope of the thermocline is smaller than usual during El Niño, and a greater relaxation occurs for more intense events. In 1982-83 this slope, as well as the zonal slope of sea level, practically disappeared in January 1983. In 1972-73 the thermocline slope was at its minimum in May, five months later in the year than during the 1982-83 event. In 1968-69 the thermocline slope was at its minimum in March, more similar in phase to the 1982-83 event. It is possible to distinguish (Figure 2A) another propagation of a thermocline fluctuation from 160°E in November 1981 to 100°W in June 1982, which has a phase similar to that of the two earlier events. The eastward speed of propagation for each El Niño was 0.5 m s^{-1} in 1971-72, 0.7 m s^{-1} in 1982-83 and in 1968-69.

Eastward propagation speeds of 0.5-0.7 m s^{-1} associated with free equatorially trapped waves imply that only baroclinic modes of order higher than 2 would be dominant. Generation of higher vertical modes in the approximated two-layered tropical ocean does not seem likely. Moreover, the duration of the anomaly of the thermocline depth at a given longitude in the western Pacific lasts several months, in contrast to the fairly rapid passage of the signature of free Kelvin waves (Lukas *et al.*, 1983). Therefore, we reject the idea of free waves to explain the eastward movement of upper thermocline anomalies at 1 m s^{-1} or less. Rather, we think that the eastward propagation of isotherm depth anomalies has the characteristics of a forced wave. However, this forced wave would have more complex dynamics than a pure hydrostatic balance, because the changes in isotherm depth precede the wind reversal. While a forced wave seems to be an appropriate description of the gradual eastward progression at 1 m s^{-1} or less, note that the features of the higher frequency components suggest a free wave (Lukas *et al.*, 1983).

The Busalacchi *et al.* (1983) model of pycnocline changes during El Niño episodes of the 1960s and 1970s contains forced equatorially trapped waves induced by wind changes occuring mostly in the western and central Pacific. A statistical representation of the isotherm depth variations observed from 1979 to 1982 can be compared with the varia-

TABLE 1 (*Donguy et al.*)

Depths of the 20°C isotherm in the western and eastern equatorial (2°N-2°S) Pacific during El Niño in 1982-83, 1972-73, and 1968-69. The zonal slope of the thermocline is proportional to the west-east difference of the 20°C isotherm depths. Onset times of the wind and sea level anomalies and of the thermocline depression in the western Pacific (West Pac) and their arrival times in the eastern Pacific (East Pac) are given. The velocity is the eastward propagation speed of the thermocline depression.

	West Pac 20°C Isotherm	East Pac Depth	West Pac Onset	East Pac Arrival	Velocity
Wind 1982-83			Jul 82	Feb 83	0.6 m s^{-1}
Sea level 1982-83			Jul 82	Jan 83	0.7 m s^{-1}
Isotherms 1982-83	180 m	150 m	Jul 82	Jan 83	0.7 m s^{-1}
Isotherms 1971-72	200 r	100 m	Sep 71	May 72	0.5 m s^{-1}
Isotherms 1968-69	200 m	60 m	Sep 68	Mar 69	0.7 m s^{-1}

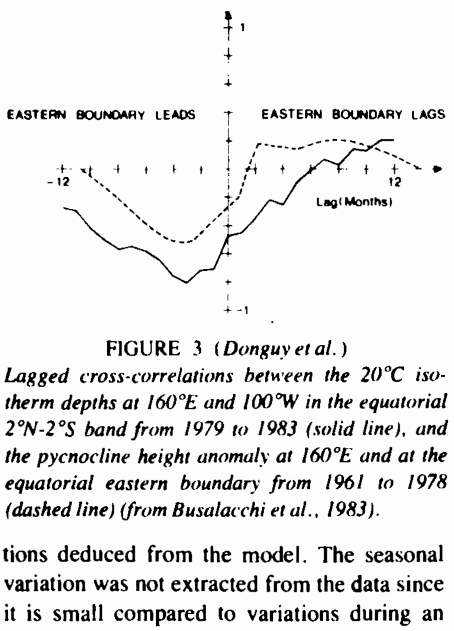

FIGURE 3 (*Donguy et al.*)

Lagged cross-correlations between the 20°C isotherm depths at 160°E and 100°W in the equatorial 2°N-2°S band from 1979 to 1983 (solid line), and the pycnocline height anomaly at 160°E and at the equatorial eastern boundary from 1961 to 1978 (dashed line) (from Busalacchi et al., 1983).

tions deduced from the model. The seasonal variation was not extracted from the data since it is small compared to variations during an ENSO event. A cross-correlation of the 20°C isotherm depth at 160°E and 100°W is presented in Figure 3. The correlations of the modeled pycnocline height anomaly between the eastern boundary of the Pacific Ocean and 160°E are also shown in Figure 3. Both correlation curves are very similar in shape, indicating that the eastward propagation speed observed in 1982-83 is in agreement with the model and also with previous El Niños during 1961-78. The negative correlations observed in 1982-83 are clearly stronger than the ones predicted by the model. This feature is caused by the exceptional amplitude of the 1982-83 event. The observed and predicted peaks of negative correlation are in good agreement. The negative lag indicates that the time of maximum thermocline depth in the eastern Pacific occurs three months before the minimum thermocline depth in the western Pacific, a feature probably attributable to the westward propagating Rossby waves. While the Busalacchi *et al.* (1983) model contained two peaks of positive correlation (0.2) at about 2 months (induced by eastward propagating Kelvin wave) and 7 months, the 1979-83 data did not have these features.

In conclusion, we have shown that during El Niño episodes anomalies in the depth of the thermocline and in sea level progress eastward along the equator as a wind-forced wave at a speed of 0.5 to 1.0 m s^{-1}.

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