EQUATORIAL WAVES AND WARM POOL DISPLACEMENT IN 1992-1996

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Zonal displacement of warm and fresh water in the equatorial Pacific, varying in phase with the Southern Oscillation Index are thought to be caused by horizontal advection by zonal current anomaly. This mechanism has been tested for the 1992-1996 period, with an analysis of the contribution of equatorial Kelvin and Rossby waves to these anomalies.

Introduction

In the Pacific equatorial band, the zonal displacement of the eastern edge of the warm, "fresh" pool is dominated by strong interannual variations in phase with the Southern Oscillation Index. Previous authors suggested or demonstrated that the displacement was caused solely by horizontal advection by zonal current anomaly, and was significant for ENSO mechanisms [Gill, 1983; McPhaden and Picaut, 1990; Picaut and Delcroix, 1995; Picaut et al., 1996, 1997, Delcroix and Picaut, 1997]. This note aims to:

1. test the relevance of this advective mechanism over the 1992-1996 period, using the surface geostrophic current derived from TOPEX/POSEIDON (T/P) measurements,
2. analyse the contribution of equatorial Kelvin and Rossby waves to surface zonal equatorial current anomalies.

Results

To analyse the role of oceanic advection in the zonal displacements of the warm pool, surface zonal geostrophic current anomalies (relative to the 1993-1994 period) were derived from T/P sea level data in the tropical Pacific, following the method presented in Menkes et al. [1996]. The T/P derived current anomalies were validated against in situ near-surface TAO current measurements [McPhaden, 1993]; they compare extremely well (figures not shown) over the 1992-96 period, with a mean correlation of 0.77 and a mean ratio of standard deviations of 1.06 at the equator and 156°E, 165°E, 140°W and 110°W.

The longitude-time variations of zonal current anomalies averaged within 2°N-2°S are shown in figure 1a. Two hypothetical drifters were launched into this current anomaly field in October 1992, and were displaced eastward or westward depending on the sense of the current anomaly. The drifters reached their easternmost positions in June 1993 and in December 1994, at times of the El Niño mature phases when we observed maximum SST anomaly in the NIÑO3 region (5°N-5°S-150°W-90°W). Conversely, the drifters were westernmost in 1996 when the tropical Pacific was under the influence of a weak La Niña event.

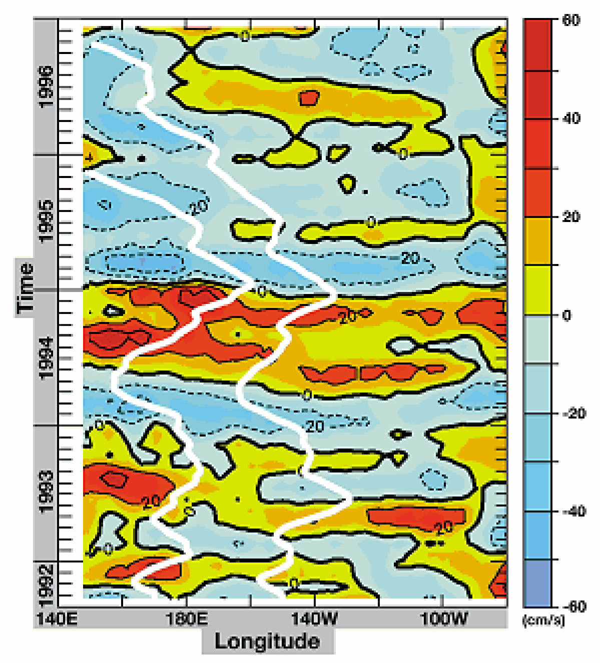

Figure 1a
Longitude-time distribution of 2°N-2°S averaged surface geostrophic current anomaly (ref. 1993-1994) derived from T/P. Positive (negative) values denote eastward (westward) current anomalies; units are cm/s. Superimposed as thick white lines are the trajectories of two hypothetical drifters moved by the surface current anomalies.

When superimposed on the observed SST [Reynolds and Smith, 1994], the drifter trajectories bracket the eastern edge of the warm pool reasonably well (figure 1b), say the 28.5°C isotherm, indicating that migrations of this eastern edge are chiefly due to zonal current anomalies. Adding the 1993-94 averaged zonal near-surface current, derived from TAO measurements, to the T/P derived zonal current anomaly does not notably change the drifter trajectories which still follow the eastern edge of the warm pool (figure 1c). However, the parallelism in position does not apply in 1996, as was observed in early 1989 [Picaut et al., 1996], minimising the role of zonal advection in the warm pool displacement during these two La Niña periods. Also, using the total current (mean + anomaly) in figure 1c results in a convergence of the hypothetical drifter trajectories into a single trajectory; this important feature is discussed at length in Picaut et al. [1996, 1997].

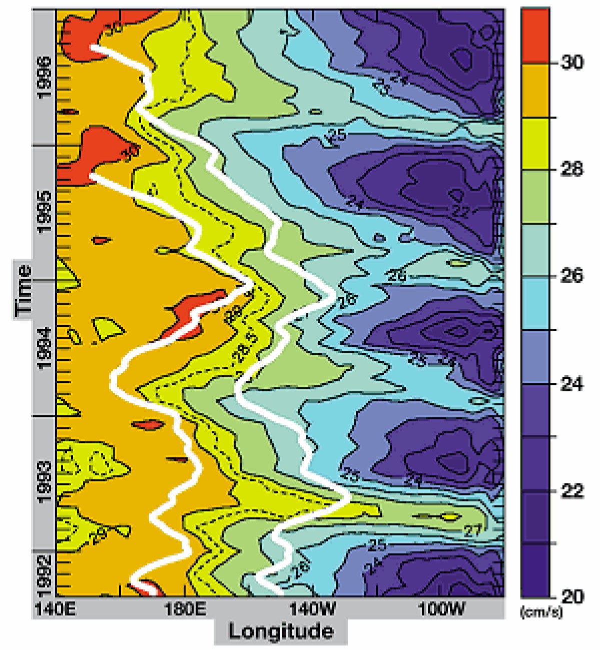

Figure 1b
Longitude-time distribution of 2°N-2°S averaged sea-surface temperature. Contour interval is 1°C, except for the 28.5°C. Superimposed as thick white lines are the trajectories of the two hypothetical drifters moved by the surface current anomalies depicted in figure 1a.

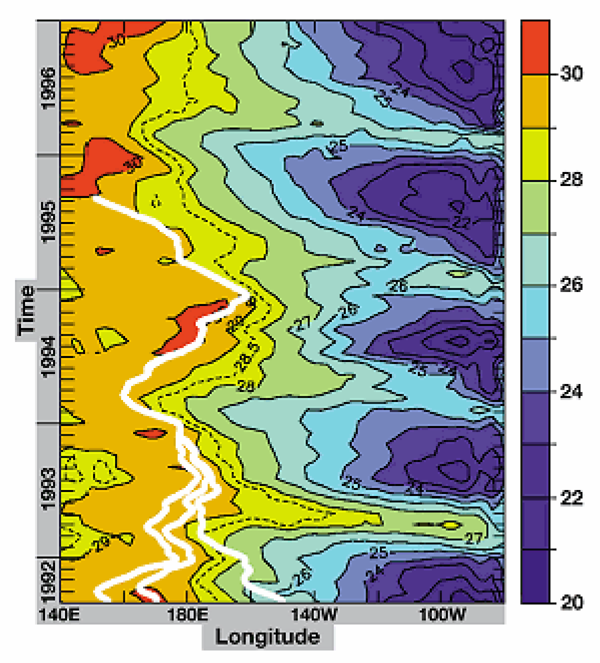

Figure 1c
Longitude-time distribution of 2°N-2°S averaged sea-surface temperature. Contour interval is 1°C, except for 28.5°C. Superimposed as thick white lines are the trajectories of three hypothetical drifters moved by the total surface current (mean + anomaly), illustrating the convergence of drifters into a single, main trajectory.

Based on T/P sea level and derived current anomalies, the contribution of the first baroclinic Kelvin and first-meridional Rossby modes to current anomalies was computed as in Delcroix et al. [1994]. As demonstrated by these authors, these two modes account for most of the variance of the current anomalies in the equatorial band. The 2°N-2°S averaged Kelvin and Rossby contributions are depicted in figure 1d-e, together with the drifter trajectories. Without going into detail in this short note, it appears that the Kelvin and Rossby wave sequence is responsible for the displacements of the eastern edge of the warm pool. Some examples are given below.

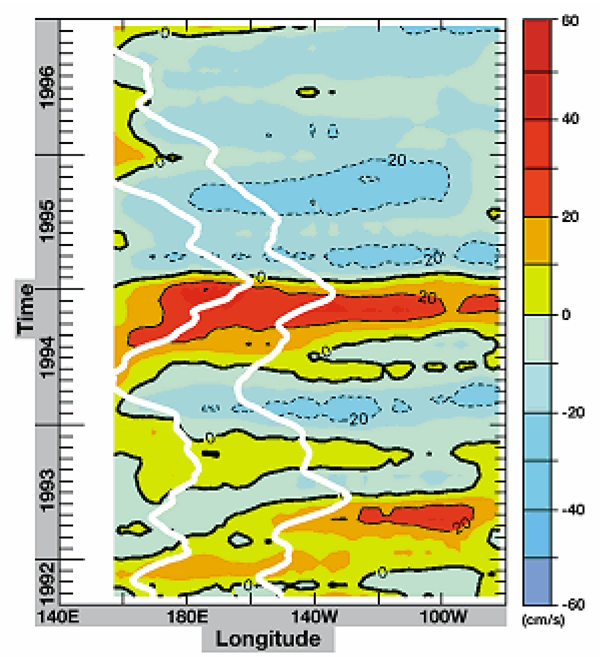

Figure 1d
Longitude-time distribution of 2°N-2°S averaged first-baroclinic Kelvin mode contribution to the surface geostrophic current anomaly (ref. 1993-1994) derived from T/P. Positive (negative) values denote eastward (westward) current anomalies, and units are cm/s. Superimposed as thick white lines are the trajectories of the two hypothetical drifters moved by the surface current anomalies depicted in figure 1a.

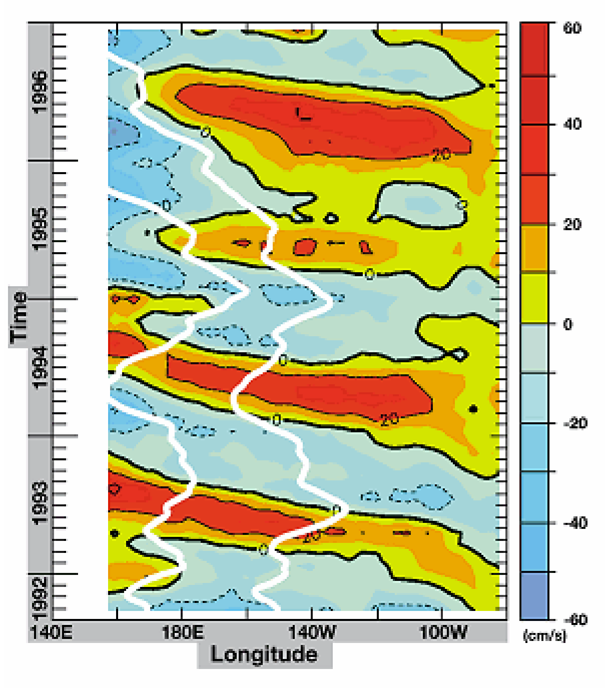

Figure 1e
Longitude-time distribution of 2°N-2°S averaged first meridional mode Rossby contribution to the surface geostrophic current anomaly (ref. 1993-1994) derived from T/P. Positive (negative) values denote eastward (westward) current anomalies, and units are cm/s. Superimposed as thick white lines are the trajectories of the two hypothetical drifters moved by the surface current anomalies depicted in figure 1a.

As noted above, the drifters reached their easternmost positions in June 1993 and December 1994. In June 1993, their positions clearly resulted from a packet of downwelling Kelvin waves (U>0) appearing from the beginning of the time series, and from an upwelling Rossby wave (U>0) propagating from the eastern basin in early 1993 to the western basin by mid-1993. In December 1994, the drifter positions resulted chiefly from a packet of downwelling Kelvin waves present almost right through the second half of 1994, and from Rossby wave contributions which were either favourable (March-June 1994) or unfavourable (July-December 1994) to the eastward drifter displacements.

After June 1993 and December 1994, the trajectories shifted from eastward to westward, which may have terminated the 1993 and 1994-95 El Niño events. The June 1993 shift was mainly due to a downwelling Rossby wave (U<0), as observed in July 1987 when the 1986-87 El Niño gave way to the 1988-89 La Niña [Picaut and Delcroix, 1995]. The December 1994 shift also resulted from a downwelling Rossby wave, later reinforced by well-marked upwelling Kelvin waves (U<0) present over most of the remaining analysed time period.

In conclusion, the 1992-96 period somewhat resembles 1987-89 as far as equatorial waves are concerned, in particular the major role of downwelling Kelvin waves during a growing El Niño event, and the likely role of downwelling Rossby waves in terminating an El Niño. The role of local wind forcing and eastern/western boundary reflections in the generation of such equatorial waves should therefore be thoroughly investigated.

This was partly done by Boulanger and Menkes [1997] who pointed out that most of the Rossby waves reaching the central basin in 1992-96 were wind-forced and did not originate in an eastern boundary reflection. Their observational results conflict to some extent with the need for eastern boundary reflections in the Picaut et al. [1997] ENSO conceptual model run over a non-specific period. Such a conflict interestingly stresses the important question of whether equatorial wave behaviour in 1992-96 should be considered typical. Here it is worth noting that the 1990-94 period is described either as the longest El Niño event on record [Trenberth and Hoar, 1996] or as a succession of three El Niño events [Goddard and Graham, 1997]. The latter team indicates that other mechanisms than those usually attributed to ENSO were involved in the 90s. Also, the low skill of previously-successful dynamical models in predicting the 1990-94 anomalies [Goddard and Graham, 1997] consistently suggests that the mechanisms leading to ENSO-related variations in the 90s were unusual. As such, the actual mechanisms need to be clearly identified: this is an on-going investigation with T/P, in situ and model-derived data.

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