Meridional circulation and equatorial instability waves in the Central Equatorial Pacific Ocean

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Abstract

An acoustic tomography experiment using seven 200 Hz tomography transceivers was carried out in the Central Equatorial Pacific Ocean from December 1999 to December 2000. The purpose of the reciprocal transmission network was to observe the north-south volume transport related to the shallow meridional circulation and the temperature and current fields associated with equatorial instability waves. The time-series of areal averaged barotropic vorticity determined from the measured barotropic circulation clearly shows that the mean vorticity was positive during La Niña and negative during the normal state. The time-series of temperature along the 3 °N zonal section showed that cold and warm waters moved westward interchangeably during La Niña. These results suggest that oceanic phenomena related to La Niña were not confined to the tropics but also extended to the extratropical area.

1. Introduction

Gu and Philander [1] and others have suggested that the tropical and subtropical Pacific Ocean is connected via a shallow meridional circulation cell (STC: the Subtropical Cell). This cell has been hypothesized to be the means by which variability in extratropical subduction produces a delayed, decadal modulation of the El Niño-Southern Oscillation (ENSO) phenomenon in the tropics. This in turn can affect the subtropical ocean via rapid atmospheric forcing. In the northern hemisphere, hydrographic data and models both indicate that approximately 14 Sv of subducted subtropical water in the upper thermocline first goes to the western boundary, enters the Equatorial Undercurrent, and then upwells along the equator. Another 5 Sv of flow follows a more direct interior route from the eastern Pacific southwestward to the Equator. While the interior appears to be the weaker pathway, previous descriptions of the STC are only suggestive because they are based on smoothed, multidecadal hydrographic data and simplified models. A better dynamical understanding of the STC may lead to improved ENSO, decadal, and interdecadal climate forecasts.

The highly accurate, averaging nature of acoustic tomography is well suited to observing the weak but large-scale currents of the STC. The inherent averaging along the acoustic paths provides a far better signal-to-noise ratio for detecting weak meridional flow than conventional point measurements. JAMSTEC carried out the fieldwork by deploying seven acoustic transceivers in the central equatorial region for the two years 1999-2000; only data from the second year are reported here. Much of the data were available in near real time permitting timely data analysis.

During the tomographic observation period, La Niña was dominant in the equatorial region. A preliminary result of this central equatorial Pacific tomography experiment is a qualitative understanding of the behavior of equatorial phenomena related to La Niña as described below.

2. Observation

Seven 200 Hz tomography transceivers were deployed to monitor the rectangular region from 178°E to 172°W and from 0.5°N to 13.5°N (Figure 1). The zonal distance was about 1200 km, and the meridional distance about 1500 km. There were 21 acoustic paths connecting the various transceivers. The transmission schedule had a four-day cycle consisting of one sing-around transmission day, one non-transmission day, one simultaneous transmission day, and one non-transmission day. The cycle of transmissions began on January 5, 2000. Each of the transceivers sequentially transmitted the 200 Hz acoustic signals, modulated by a tenth-degree m-sequence every four hours on the sing-around transmission day. On the other transmission day in the cycle, all of the transceivers transmitted the signal at the same time every four hours; lower internal wave travel time noise is expected for these reciprocal transmissions. The measured data for sing-around transmissions were available via satellite telemetry and analyzed in near-real time; these are the data reported here.

The reference sound speed profile was determined from CTD casts and the NODC database. The sound channel was at a depth of about 1000 m with a steep thermocline above. The travel times of eigenrays for each acoustic path were calculated according to the reference profile. The ray identification of multipaths was carried out by comparing calculated values with observed data. There were 232 eigenrays identified for all acoustic paths. The sum and difference travel times for each eigenray were obtained using this identification.

The stochastic inverse method was used for reconstructing the temperature (sound speed) fields. The sound speed anomaly was vertically expanded using the first four empirical orthogonal functions (EOFs) and horizontally by a Fourier series. The three-dimensional temperature fields were reconstructed using the sum travel times. The travel time differences along the acoustic paths from the reciprocal transmissions were averaged over a day and directly converted to barotropic velocity using the simple relation, $u = (C^2/R)\delta t$, where u is velocity, C is a nominal sound speed, R is range between transceivers, and δt the measured differential travel time.

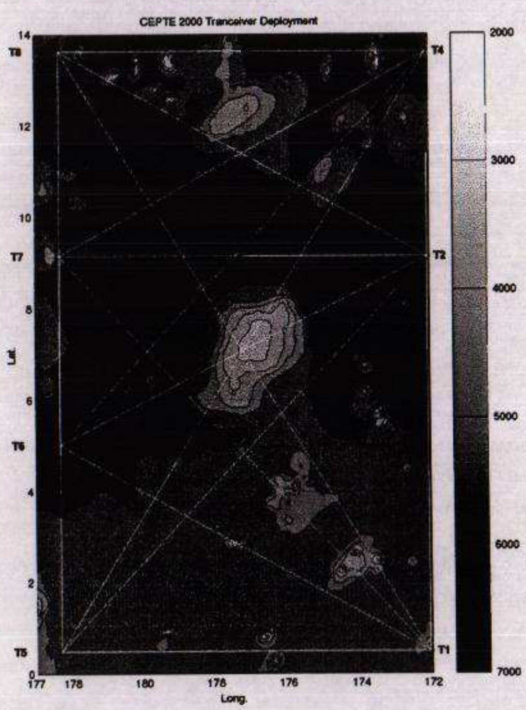
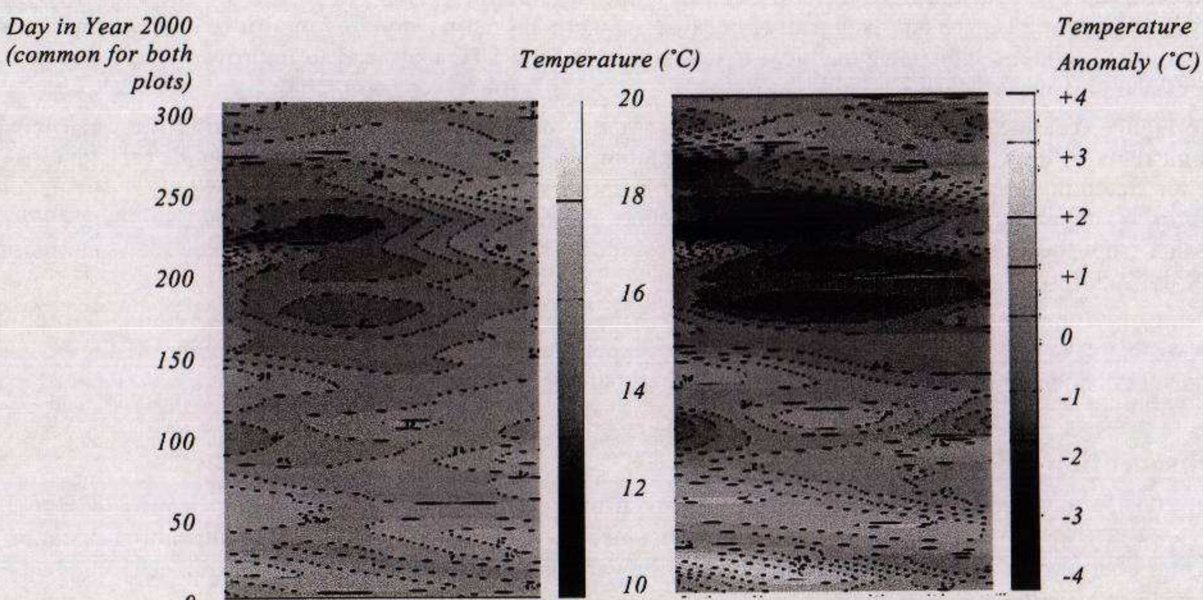


Figure 1. The Central Equatorial Pacific Tomography Experiment (CEPTE). The locations of the seven transceivers are shown, with the paths connecting them. The color scale denotes bathymetry from 0-7000 m. Longitude extends from 177°E to 172°W.

3. Temperature Field

The three-dimensional temperature field over the observing area was reconstructed every four days. From these fields, zonal water temperature along 3°N was depth-averaged from 100 m to 400 m (Figure 2).



Longitude extends from 177°E to 172°W (for both plots)

Figure 2. Estimated temperature along the zonal section at 3°N versus time (year days 2000): (left) total temperature, (right) temperature anomaly. Note the different gray scales for temperature (left, from 10 to 20°C; right –4 to +4°C). The La Niña extended from day 0 (start of this record) to day 150 and from day 270 to 310 (end of this record), with the "normal" period from day 100 to day 240. The Legeckis wave signals are seen during the La Niña periods, with a phase velocity of 0.5 m s^{-1}.

This figure shows that warm and cold waters interchangeably moved westward during La Niña and disappeared during the normal state. The phase velocity of these waters is about 0.5 m s^{-1}, which is the same as that reported by Legeckis [2] for equatorial instability waves. Tropical Atmosphere Ocean (TAO) array data shows that La Niña began in summer of 1999 and was interrupted in early spring (~ yearday 100) of 2000. In late summer (~ yearday 240) 2000, La Niña became active again (Figure 3). The zonal water temperature along 3°N is consistent with the TAO array data. A comparison of Figure 2 and 3 clearly indicates that the Legeckis waves were active during La Niña, but inactive during the normal state.

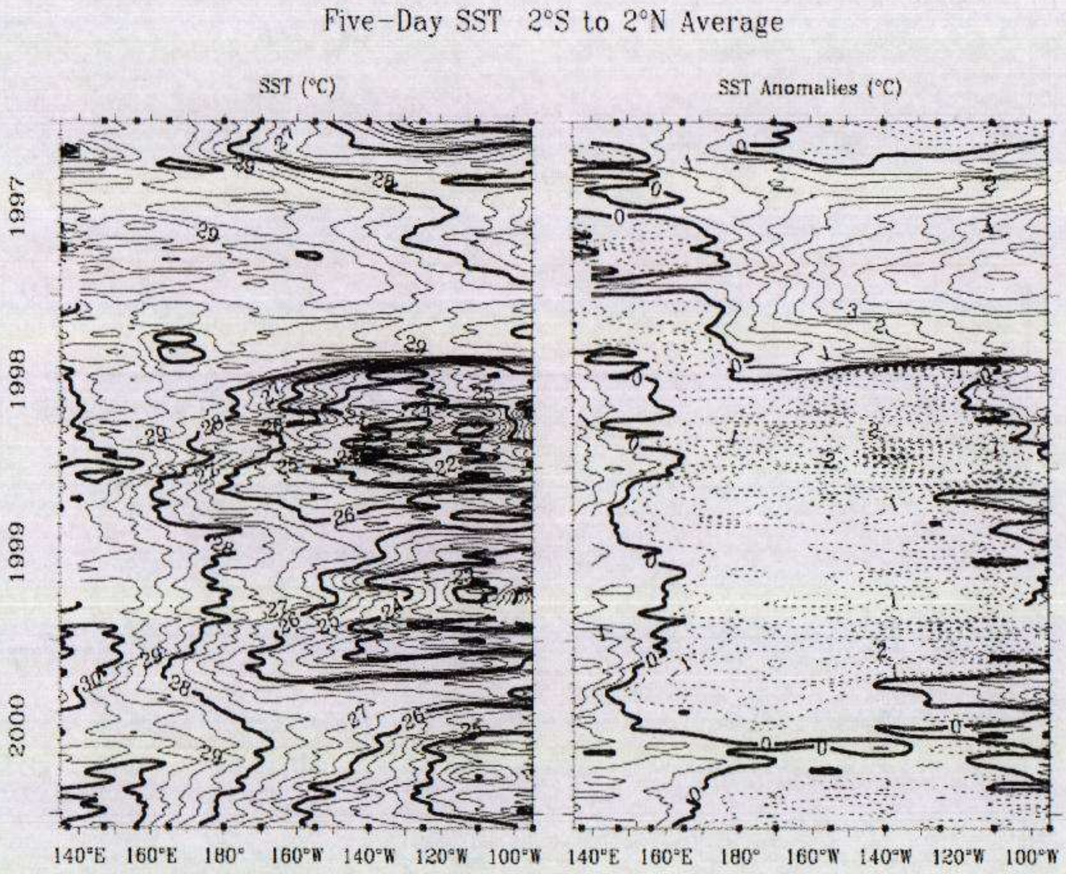


Figure 3. Sea surface temperature (SST) data from the TAO array. The time-space area of interest here is in the lower left of each panel.

4. Barotropic Flows

The barotropic velocity along several of the acoustic paths is shown in Figure 4. The flow along the 172°W meridian from 9°N to 13.5°N changed during La Niña and during the normal state (Figure 4a; [3]). The flow along the 178°E meridian did not change in the same way during these periods, (Figure 4d). The phase appears to be delayed by about 50 days (the second peak in Figure 4a relative to the first peak in Figure 4d). The flow along the 9°N zonal line from 178°E to 172°W was eastward during La Niña and reversed during the normal state (Figure 4c). The flow along the 13.5°N zonal line from 178°E to 172°W was westward during La Niña and eastward during the normal state (Figure 4b).

Tomographic current velocity observations also allowed us to calculate the circulation [4] over a region enclosed by acoustic paths. The barotropic flow along the acoustic paths was combined to calculate the circulation (instrument clock errors cancel in this case). The time-series of the circulation over the northern rectangle enclosed by the 9°N and 13.5°N zonal lines and the 178°E and 172°W meridians (i.e., path T2-T4-T8-T7-T2) is shown in Figure 5. This figure clearly shows that the circulation changed sign from positive during La Niña to negative during the normal state. This result was in a good agreement with the time series of TAO array data.

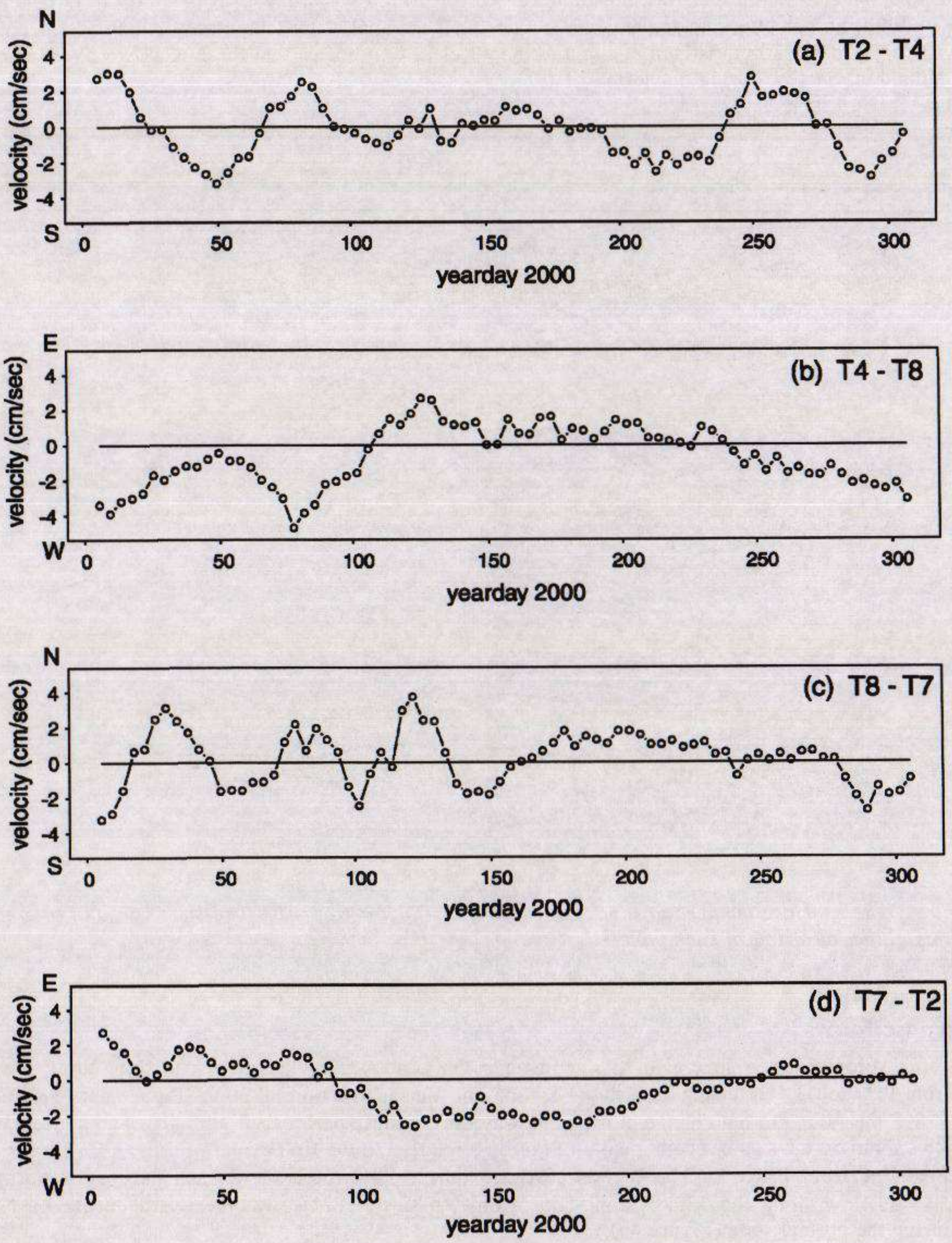


Figure 4. Barotropic velocity along the indicated paths versus time. The path orientation and sign convention is indicated on the left side of each panel (E-W, N-S).

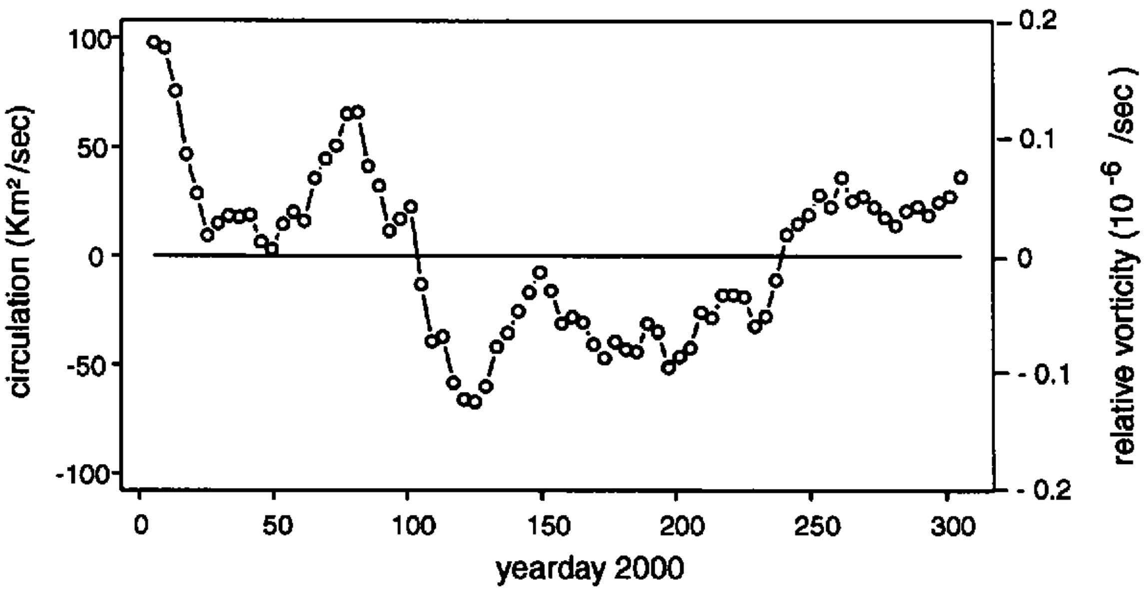


Figure 5. Circulation (left axis, $10^3\ m^2\ s^{-1}$) and vorticity (right axis) measured along the closed path T2-T4-T8-T7-T2, versus time.

5. Summary

This tomography experiment revealed that the Legeckis wave was only active during La Niña and that the circulation (i.e., mean vorticity) of the northern region, changed sign, from positive during La Niña to negative during the normal state. These preliminary results suggest that the mean vorticity may be a good indicator of La Niña conditions. Subsequent work will address the depth-dependent velocity and temperature.

References

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