CONTRASTING THE EVOLUTION OF THE 1986-1989 AND 1992-1993 ENSO EVENTS

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INTRODUCTION

During the TOGA decade, two radar altimeters provided basin-scale sea-level observations. GEOSAT was launched in March 1985 and its exact repeat mission (ERM), from November 1986 to September 1989, provided a synoptic sea-level data set well suited for dynamical studies of the tropical Pacific Ocean. TOPEX/POSEIDON was launched in August 1992 and is still observing the ocean with greater accuracy than GEOSAT. Fortuitously, the GEOSAT ERM mission encompassed the 1986-1989 ENSO event while the TOPEX/POSEIDON mission observed the second warming of the 1991-1993 El Niño. Therefore, together with sea surface temperature (SST) and surface wind fields, we now possess unprecedented large scale sources of observations with which to study two consecutive El Niño and thereby gain information on the similarities and differences between the evolution of the 1986-1987 and the 1992-1993 warm events and their further developments.

Toward that end, we first contrast the zonal evolution, at the equator, of SST and FSU zonal wind stress for 1986-1989, 1992-1994 and the seasonal cycle. Then, we project sea-level data from GEOSAT, TOPEX/POSEIDON and from an XBT-derived dynamic height climatology onto the long equatorial wave meridional structures. Finally, we contrast SST anomalies (SSTA), zonal geostrophic current anomalies and SSTA tendencies, at the equator, during the GEOSAT and TOPEX/POSEIDON periods.

SEA SURFACE TEMPERATURE, ZONAL WIND STRESS AND SEA-LEVEL

Sea surface temperatures

In September 1986, isotherms are 10°C to the east of their seasonal position (Figure 1a, 1c) observed in September 1992 (Figure 1b, 1c). Then isotherm displacements follow the seasonal displacements; i.e. the ENSO warmings, in 1987 and 1993, are coincident with the seasonal warming in spring. In spring 1987, SST is 2°C warmer than seasonally and 1°C warmer than in spring 1993. For about 10 months after the warm peak, the 27°C isotherm retreats west and reaches 170°W in March (Figure 1a, 1b). This does not occur seasonally. In 1988 isotherms stayed shifted to the west, whereas in 1994, there is an eastward migration of isotherms similar to that observed in the seasonal cycle. The cooling in 94 is seasonal-like whereas it is much higher in 88. Finally, in September 1994, isotherm positions are much like that in September 1986 (Figure 1a, 1b)

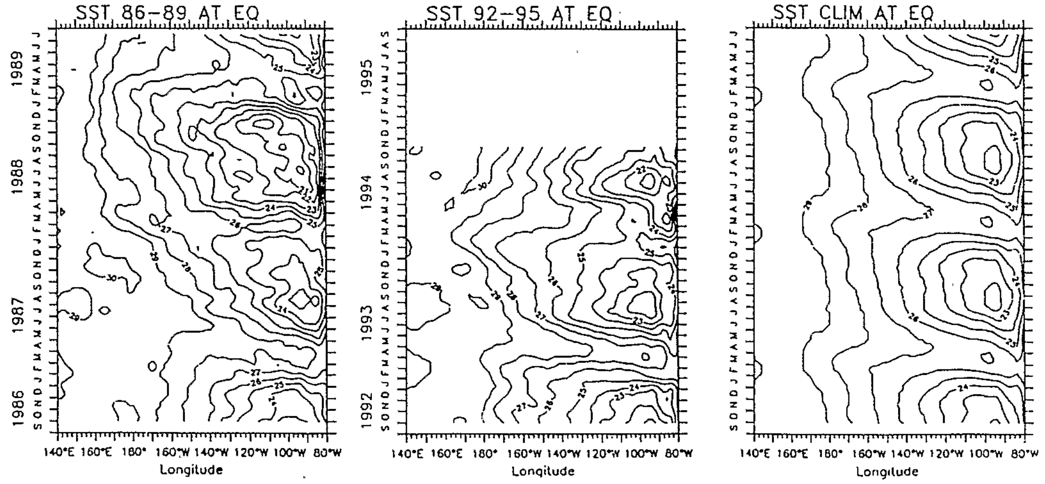
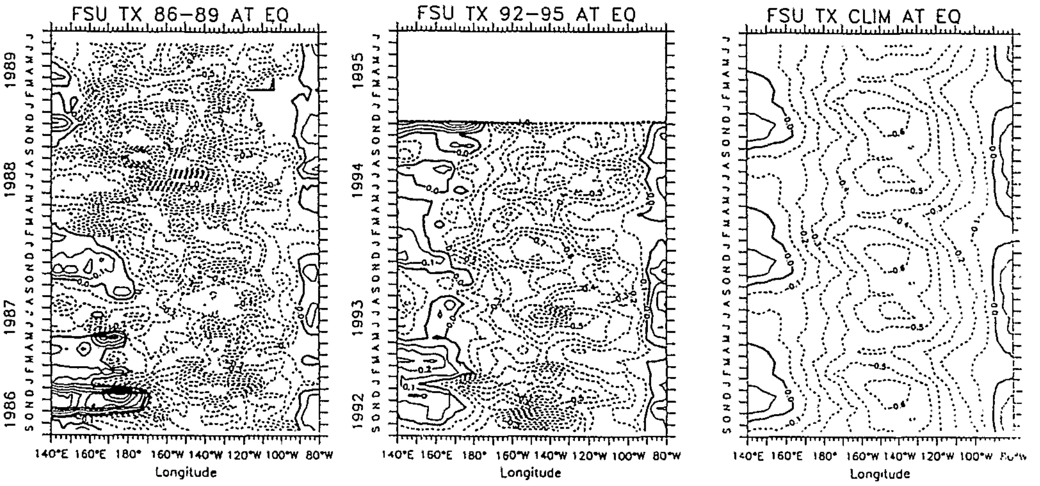


Figure 1 - Zonal sections, at the equator, of Reynold's SST for the GEOSAT period (a-left), TOPEX/POSEIDON period (b-middle) and the 1982-1994 climatology (c-right)

Winds

In late 1986, westerly wind bursts are observed in the western Pacific (Figure 2a). They are much stronger than in late 1992 (Figure 2b) and occur seasonally (Figure 2c). In 1987 and 1993-1994, the strongest equatorial easterlies, located between 120°W-160°W, have features similar to the climatology but in 1988-1989, during La Niña, there is a westward shift of easterlies located west of the coldest SSTs (Figure 1a, 2a). The springtime weakening of the trades is consistent with the seasonal weakening. Finally, in November-December 1994, the structure of the winds resembles that of November-December 1986.



Figures 2 - Zonal sections, at the equator, of FSU zonal stress (Cd = 1.2×10^{-3}) for the GEOSAT (a-left) period, TOPEX/POSEIDON (b-middle) period and the 1961-1994 FSU climatology (c-right)

Sea-level

GEOSAT sea-level anomalies (Delcroix et al., 1994), TOPEX sea-level anomalies (Menkes et al., 1995) and XBT-derived dynamic height climatology (courtesy of Billy Kessler) are projected onto long equatorial waves following Boulanger and Menkes (1995) and the resulting coefficients are presented in Figure 3-4. Anomalies are computed relative to the year 1987 for GEOSAT, 1993 for TOPEX and the annual mean for the XBTs. Only the Kelvin and the first Rossby meridional modes are considered here. The sum of these two modes represents roughly 70% of the variance of the total signal for each data set.

Kelvin wave activity : Consistent with equatorial winds (Figures 2a, 2b), downwelling Kelvin waves, much stronger in late 1986 than in late 1992, are forced with similar timings (Figures 3a, 3b) in the western Pacific. Consistent with the enhanced easterlies in the central Pacific, there are more upwelling Kelvin waves in 88 than in 94. The downwelling Kelvin wave activity in late 94 is similar to that observed in late 86.

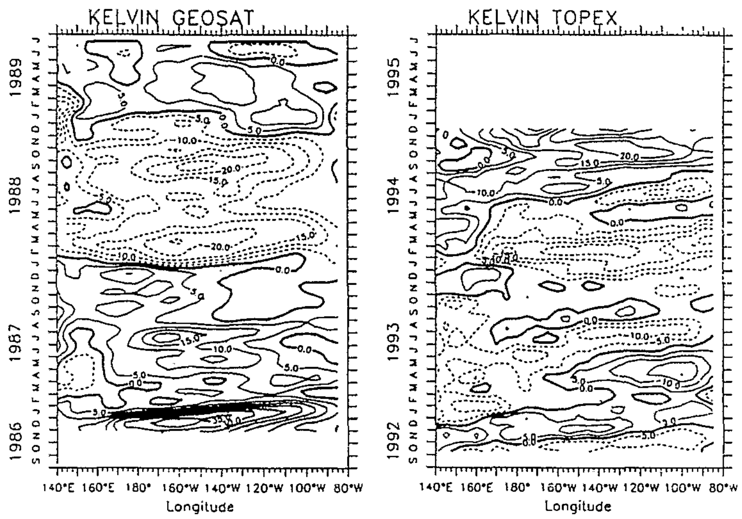


Figure 3 - Kelvin coefficients for GEOSAT (a-left) and TOPEX (b-right) sea-level anomalies. At the equator, a coefficient of 1 represents 0.9 cm. Positive coefficients represent downwelling Kelvin waves

First Rossby meridional mode : During El Niño years, in 87 and 93, the Rossby wave evolutio strong seasonal features (Figures 4b-c) and the corresponding forcing is similar to the seasonal R wave forcing (not shown here). From March onward, the 88-89 Rossby wave activity diverges fro seasonal Rossby waves whereas the 94 Rossby wave activity is clearly linked to the seasonal (Figure 4b, 4c). Consistent with the decrease of easterlies in the east (Figure 2a), there is an enh upwelling Rossby wave activity in 88. Finally, The late 94 Rossby waves features are similar to th 86 Rossby wave features.

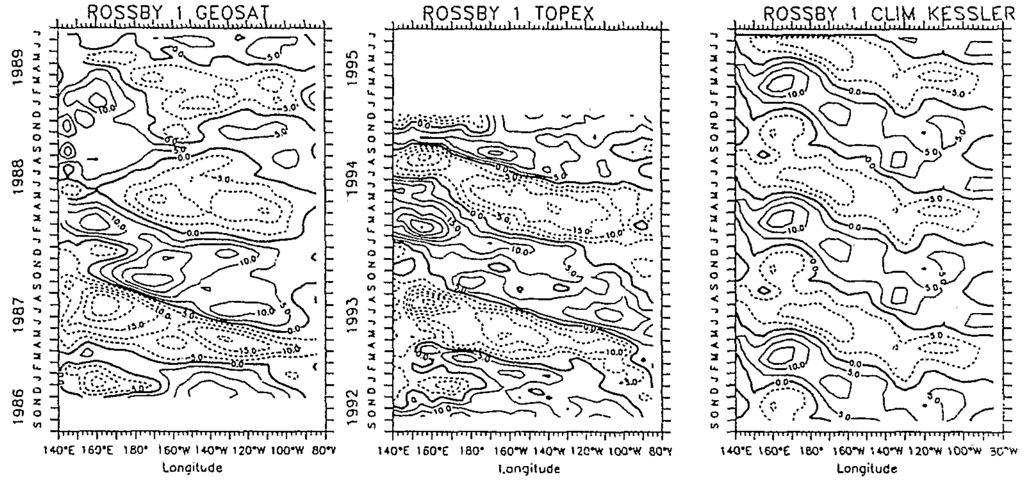


Figure 4 - first meridional Rossby mode coefficients for GEOSAT (a-left), TOPEX (b-middle) sea-le anomalies and XBT-derived dynamic height climatology (c-right). Positive coefficients represent downw Rossby waves

In spring 88 as in spring 94, the seasonal weakening of the easterly trades in the eastern half basin (Figure 2) generates upwelling Rossby waves that propagate to the central-western Pacific (Fi 4a-b). But in 88, at that time, contrary to 94, there are stronger than normal easterlies west o dateline (Figure 2a) (which may be due to the warm pool displacement to the west, Picaut and Del 1995) which generate strong upwelling Kelvin waves propagating to the central-eastern Pacific (Fi 3a). Therefore, the 88 La Niña is characterized by a divergence of the zonal wind stress anom (relative to a long term mean) which is centered at 150°W (not shown here) the spatial structu which generated both upwelling Kelvin waves and upwelling Rossby waves.

SST AND ZONAL CURRENT ANOMALIES

In order to study the possible role of zonal advection on the evolution of sea-surface tempera anomalies (computed with respect to the 1981-1994 SST climatology), zonal geostrophic cur anomalies are computed as follows: zonal geostrophic currents are computed as in Menkes et al., (1 from GEOSAT, TOPEX/POSEIDON sea-level and the XBT-derived dynamic height climatol Anomalies for GEOSAT and TOPEX/POSEIDON-derived currents are then computed with resp the XBT-derived geostrophic zonal currents. Equatorial sections of SST anomalies (SSTA), cur anomalies and SSTA tendencies (∂SSTA/∂t) are presented in Figures 5-6.

The 86-89 ENSO is characterized by positive SSTA (1-2°C) that persisted during 14 mo (10/86-11/87), east of 160°E, and were sharply followed by negative SSTA (1-2°C) that pers during 14 months (4/88-5/89), east of 160°E (Figure 5a). In contrast, the 1993 El Niño is character by a brief and weak warming (1°C), in phase with the seasonal warming, in spring 1993 and loc east of 160°W (Figure 6a). However, in August 94, a strong warming occurs, east of 160°E with patt similar to these observed in late 86.

Zonal geostrophic current anomalies at the equator (Figures 5b, 6b) show eastward propaga patterns at speeds indicating the predominance of Kelvin waves. In 87, prior to the SSTA peak (Fi 5a), zonal current anomalies were mainly eastward (Figure 5b) and may have advected warmer wa from the west. From November 86 through August 87, these eastward current anomalies are globall phase with the SSTA tendencies (Figures 5b, 5c). Therefore, advection by these anomalous currents have contributed to the warm SSTA developments. Then current anomalies reversed prior to the SSTA peak in 88 and contributed to the warm pool displacement to the west during the 88-89 La (Picaut and Delcroix, 1995). From September 87 through January 89, westward current anomalies globally in phase with the SSTA tendencies, east of 160°E which may indicate that zonal advection again an important factor for cold SSTA developments during La Niña. During the second cold S peak, in November-December 88, SSTA tendencies and current anomalies ceased to be in phase. Contrary to 86-87, the weaker 92-93 currents (Figure 6b), tend to counteract the SSTA tendencies (Figure 6c) and the 93 warming is weak and spatially limited (Figure 6a). But, from spring 94 onward, the eastward currents are again in phase with the SSTA tendencies (Figure 6b, 6c) and the late 94 warming starts. This again may be an indication that zonal advection is important for the development of the 94-95 El Niño. Note that the amplitude and spatial extension of the late 94 warming are similar to that in late 86.

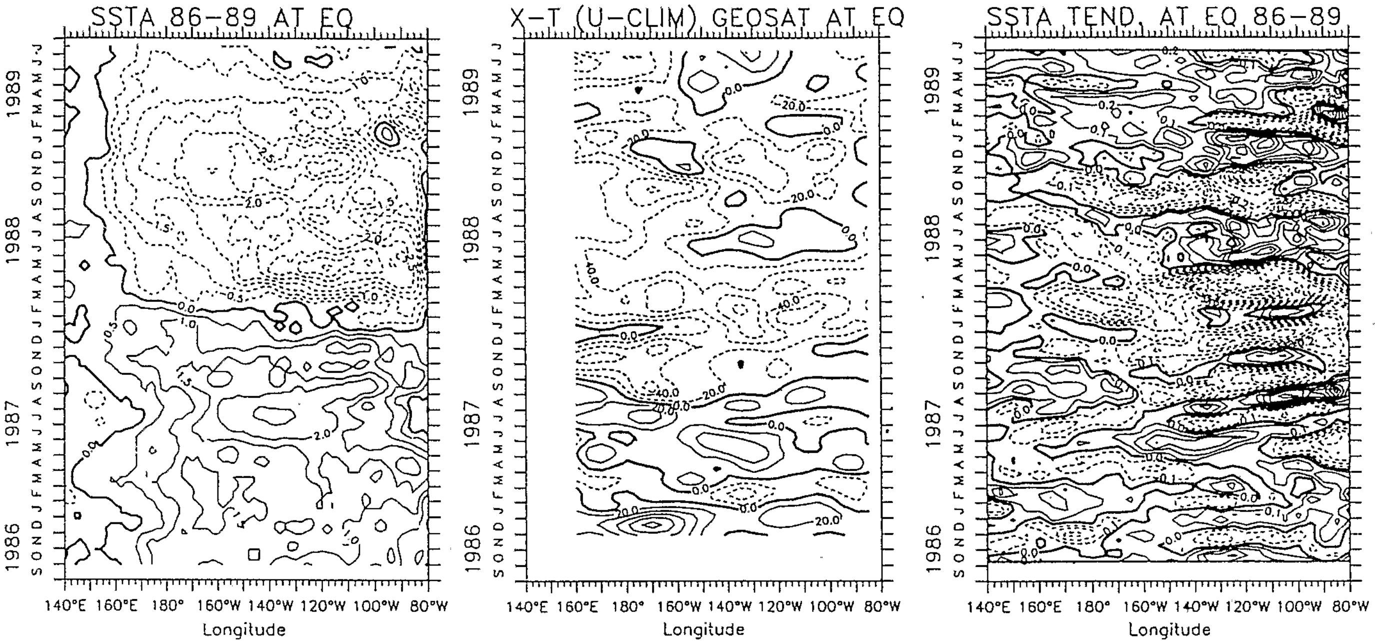
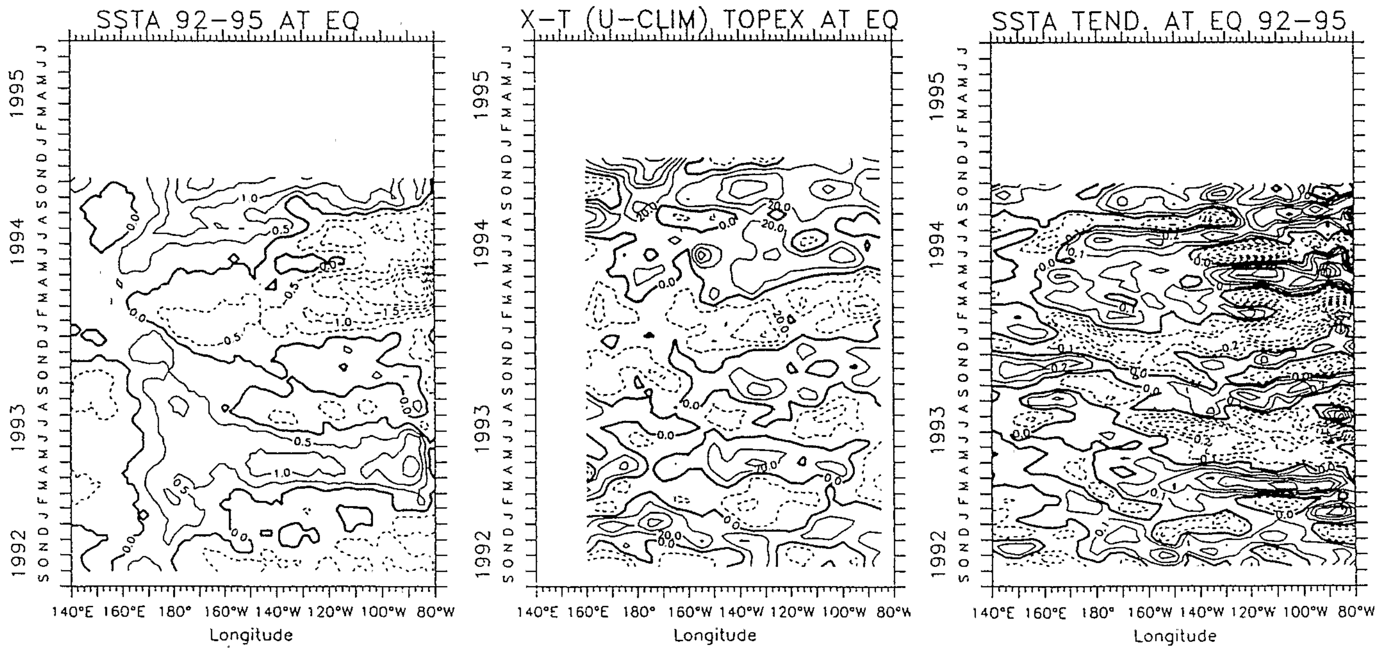


Figure 5 - Zonal sections, at the equator, of SSTA (a-left), zonal geostrophic current anomalies (b-middle) and SSTA tendencies (c-right) during the GEOSAT period. Positive contours in b indicate eastward currents.



Figures 6 - Zonal sections, at the equator, of SSTA (a-left), zonal geostrophic current anomalies (b-middle) and SSTA tendencies (c-left) during the TOPEX/POSEIDON period. Positive contours in b indicate eastward currents.

SUMMARY AND CONCLUSIONS

Two radar altimeter have provided a basin-scale perspective of the 2 ENSO events (86-89 and 92-93). During both El Niño, the Kelvin wave activity is somewhat similar although the late 86 downwelling Kelvin wave activity is much larger than in late 92. The Rossby wave activity is very similar in 86-87 and 92-93 and is phase-locked to the seasonal Rossby wave. The 88 La Niña is characterized by a divergence of zonal winds centered at 150°W. This divergence results from the seasonal weakening of the trades in the east and unsually strong easterlies west of the dateline. This particular structure generates both upwelling Kelvin and upwelling Rossby waves moving toward the central Pacific.

During 86-89, zonal geostrophic current anomalies at the equator are globally in phase with the SSTA tendencies. This is not the case during the brief 93 warming but, from mid-94 onward, the agreement between current anomalies and SSTA tendencies reappears. This suggests that zonal advection may be important for both El Niño and La Niña.

Unlike the 86-87 El Niño, the second warming in 1993 seems to be a slight amplification of the seasonal cycle.

Lastly, the onset of the 87 and 95 El Niño are very similar but their further evolutions has proved to be quite different. To understand the processes that govern the previous similarities and differences and estimate all the terms in the heat equation, numerical model simulations will be required.

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PROCEEDINGS OF THE

International Scientific Conference on

TROPICAL OCEAN GLOBAL ATMOSPHERE (TOGA) Programme

(2-7 April 1995, Melbourne, Australia)

WCRP-91 - WMO/TD No. 717

VOLUME I

December 1995