Episodic Wind Forcing of a Tropical Warming Event

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The availability of coincident observations from four spaceborne sensors and simulation from an ocean general circulation model provided an opportunity for a comprehensive examination of a recent anomalous warming event in the tropical Pacific. The event was revealed as the aggregation of a series of intraseasonal episodes. During the second half of 1994, four distinct groups of equatorial westerly wind anomalies were observed by the scatterometer to occur near the date line. Each group of wind anomalies initiated an eastward-propagating, downwelling Kelvin wave that was exhibited as anomalous sea-level rise observed by an altimeter. Corresponding to the passage of Kelvin waves are surface-warming episodes observed by a visible-infrared radiometer, The westerly wind and warming episodes are also associated with enhanced atmospheric convection represented by anomalous integrated water vapor; the water vapor anomaly was observed by a microwave radiometer. The anomalous sea level and sea-surface temperature were closely simulated by an ocean general circulation model when it was forced by realistic winds

Recently, the evolvement of a warming phenomenon in the eastern tropical Pacific, El Niño, was inferred on the basis of a few months of sea-level rise observed by the microwave altimeter on the Topex/Poseidon spacecraft*. Traditionally, El Niño has been viewed as a low frequency warming of the tropical ocean, based on temporally averaged observations [Rasmussen and Carpenter, 1982]. The recent increased observations have revealed critical intraseasonal phenomena occurring before and during an El Niño event. The phenomena include propagation of sea-level variation across the equatorial Pacific [e.g., Lukas et al., 1984]. The sea-level changes have been interpreted as the manifestation of equatorial Kelvin waves which are the eastward-propagating disturbances in the ocean that are confined to a narrow waveguide by the Coriolis force. These Kelvin waves have been related to anomalous westerly wind bursts near the date

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line by theoretical studies and numerical models [e.g., Giese and Harrison, 1990]. The episodic wind anomalies are found to increase in intensity preceding an El Niño event, as shown by data taken at island stations and at moored buoys [e.g., Luther et al., 1983]. The precise way by which the synoptic west-wind episodes extend their influence to what has been viewed as low-frequency changes in surface temperatures is still not clear. Documentation on forcing and response has not been sufficiently comprehensive.

To compute the interannual anomalies, the climatological annual cycle (compiled from measurements made over a long period of time) is usually removed from the data. Since we do not have a period of data long enough to compute such a cycle for most of the spacebased observations, the deviation of the 1994 value of a parameter from its corresponding 1993 value is, hereafter, referred to as an “anomaly”. In the equatorial eastern Pacific, the Trade Winds generally blow from the east to the west, and their zonal component is generally negative. The zonal component of surface wind measured by the scatterometer (Fig. 1a) clearly shows four groups of westerly (positive) anomalies that extend to the east of the date line. The first group occurs in July, the second extends from mid-September to the first week of October, the third covers the first half of November, and the fourth takes place in December. The first two groups are located further to the east but are weaker in magnitude than the last two. Each group of these wind episodes is followed by eastward propagation of anomalous sea-level, as observed by the altimeter (Fig. lb), and as apparently caused by a downwelling Kelvin waves traveling at roughly 200 km/day. The first two groups of Kelvin waves fade at longitude 125°W, while the third one appears to reach longitude 90°W. As for the fourth group, the beginning is visible at the end of December. Starting in mid-August and just west of the date line, an east ward propagation of negative anomalies is visible between the first and second groups of positive sea level anomalies. It is likely to have been caused by an upwelling Kelvin wave, following from a strong anomalous easterly wind (Fig. 1a).

Anomalous surface-warming episodes are also found at approximately the same time and in the areas as sea-level rise. The second group of positive anomalies which starts in October is almost continuous with the warming events in November and December. At the time of the warming episodes, there are also anomalous increases in atmospheric water vapor, signifying enhanced atmospheric convection. The relationship between a westerly wind event and enhanced convection is most obvious in November and December which is toward the mature phase of the El Niño. The respective centers of the water vapor anomalies are located slightly to east of the wind anomalies (i.e., where the surface winds converge), and slightly to the west of sea surface temperature anomalies. Similar spatial relation have been observed from satellite data [Liu, 1989] and simulated by a simple numerical model [Gill and Rasmussen, 1983] for the 1982-1983 El Niño event. A series of seasonal tropical instability waves [Legeckis, 1977] are clearly visible in the eastern Pacific in both Figs. 1 b and lc, traveling westward at a typical speed of roughly 50 km/day.

The observed sea level and sea surface anomalies agree with simulation by an ocean general circulation model when forced by realistic winds, both in time and location but with slightly different magnitudes (Fig. 1e and 1f). The simulation provides a theoretic link between the observed forcing and responses. Unlike the El Niño events in the eighties, the equatorial warming events in the nineties are more frequent, last for shorter periods, and are less intense. Whether the 1994 warming can be classified as an El Niño event is being debated. The observations and model simulations indicate that the 1994 warming is largely an aggregation of episodic events. The interaction between the episodic temperature changes associated with Kelvin waves and the low-frequency thermal changes of El Niño will be examined in future studies.

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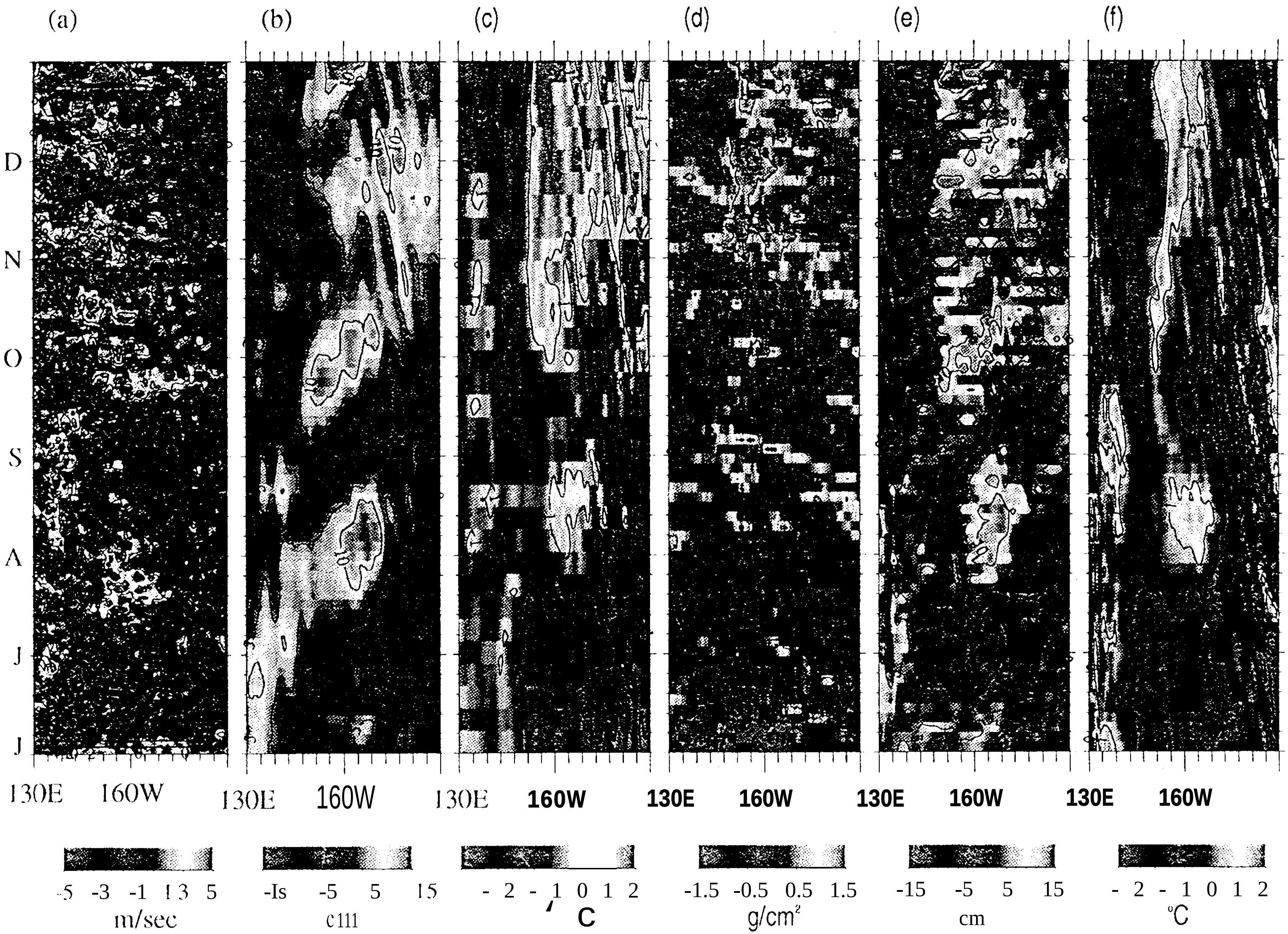
Figure legends

Fig. 1 Time-longitude variation, along the equator, of the 1994-1993 difference in (a) zonal wind component, (b) sea level, (c) sea surface temperature, and (d) atmospheric water-vapor, as derived from spacebased observations and corresponding simulation of sea level (e) and sea surface temperature (f) by the Modular Ocean Model (MOM) developed at the Geophysical Fluid Dynamics Laboratory [Bryan and Cox, 1972] when forced by realistic wind. The vertical axis represents the calendar months from June to December. The horizontal axis represents longitude, running from Indonesia, across the Pacific, to the Galapagos Islands. The zonal wind component is derived from observations by the microwave scatterometer on the European spacecraft ERS- 1 [Freilich and Dunbar, 1993. The sea-surface height is derived from the observations by the microwave altimeter on the joint U.S.-French Topex/Poseidon Mission [Fu et al., 1995]. The sea-surface temperature is produced through optimal interpolation of data from the Advanced Very High Resolution Radiometer blended with in situ data [Reynolds and Smith, 1994]. The atmospheric integrated water vapor is derived from observations by the Special Sensor Microwave Imager [Alishouse et al., 1990].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