Climate Change and Sea Level Rise in the South Pacific Region
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ON SEA LEVEL CHANGES IN THE TROPICAL PACIFIC AT SEASONAL AND INTERANNUAL TIME SCALES

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INTRODUCTION

Probable global warming related to human activities call for a precise monitoring of sea level, specially for low-level islands and atolls. In the tropical Pacific, such a monitoring is possible from the network of tide gauges maintained at islands by the TOGA (Tropical Ocean and Global Atmosphere) Sea Level Centre in Honolulu, Hawaii. Aside from this network, this note presents the actual ORSTOM-Noumea approach for observing and understanding sea level changes in the tropical Pacific, at seasonal and interannual time scales. This relies on various types of TOGA-related observational networks, including ships-of-opportunity, oceanographic cruises, deep-sea moorings, and satellite altimetry, together with modelling studies.

METHODS

Ship-of-opportunity programmes have operated out of NoumÄa, New Caledonia since 1969. Various parameters, including subsurface temperatures from 0 to 400 m, have been collected along trans-Pacific shipping routes since 1979, using eXpendable BathyThermograph (XBT) instruments. By way of background, the spatial distribution of XBT data obtained in 1991 is presented in Fig.1. In this representative example the temperature profiles are roughly concentrated along four mean ship routes, from New-Caledonia to Japan, California, and French Polynesia, and from French Polynesia to Panama. As usual, temperature profiles and mean Temperature-Salinity (TS) relationships could be used to derive 0/400 dbar dynamic height. Variations of 0/400 dbar dynamic height, which measure expansion or contraction of the water column, will be used hereafter as an alias for sea level.

INFERRED SEA LEVELS

During the 1979-85 period, distribution of XBT data was particularly dense in the south-western tropical Pacific (24°S-10°S; 160°E-140°W; area I in Fig.1), making it possible to adequately describe the time-space variations of 0/400 dbar dynamic height. Figure 2 presents the "sea level" anomaly measured in this last region in May 1983, during the peak phase of the 1982-83 El Nino Southern Oscillation (ENSO) event. It indicates that a very strong ENSO event only induces a sea level anomaly north of about 18°S, with amplitudes ranging from 0 to -25 cm. Details about the corresponding mechanisms can be found in Delcroix and Henin (1989).

Impacts of ENSO phenomenon upon sea level changes were also quantified through XBT data in the western equatorial Pacific, during the 1984-1989 period. This period is of principal interest because it includes the 1986-87 ENSO as well as the 1988-89 cold phase of ENSO - generally referred to as La Nina. Figure 3 presents monthly 0/400 dbar dynamic height anomalies averaged over 10°N-10°S and 130°E-160°E (area II in Fig.1). "Sea level" is lower in 1984 than in 1985; the change is of the order of 15 cm between early 1984 and a pair of positive extrema in May 1985 and April 1986. Thereafter, "sea level" drops sharply by 26 cm to a minimum in August-September 1987, about 3 months after the minimum Southern Oscillation Index (SOI; not shown here). Then, "sea level" rises to a positive anomaly of 12 cm in March 1989, several months after the peak in SOI. By the

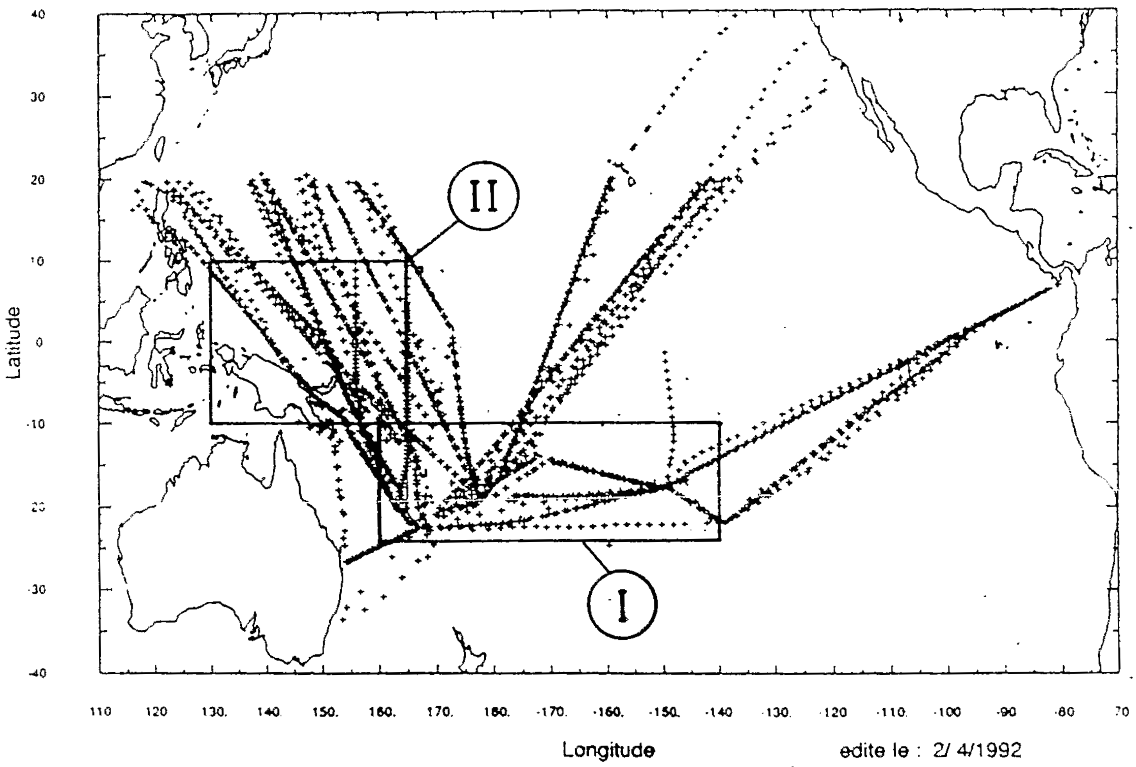

Figure 1. Spatial distribution of eXpendable BathyThermograph (XBT) data collected in 1991, out of ORSTOM-Noumea, New Caledonia. The significance of areas I and II is identified in the text.

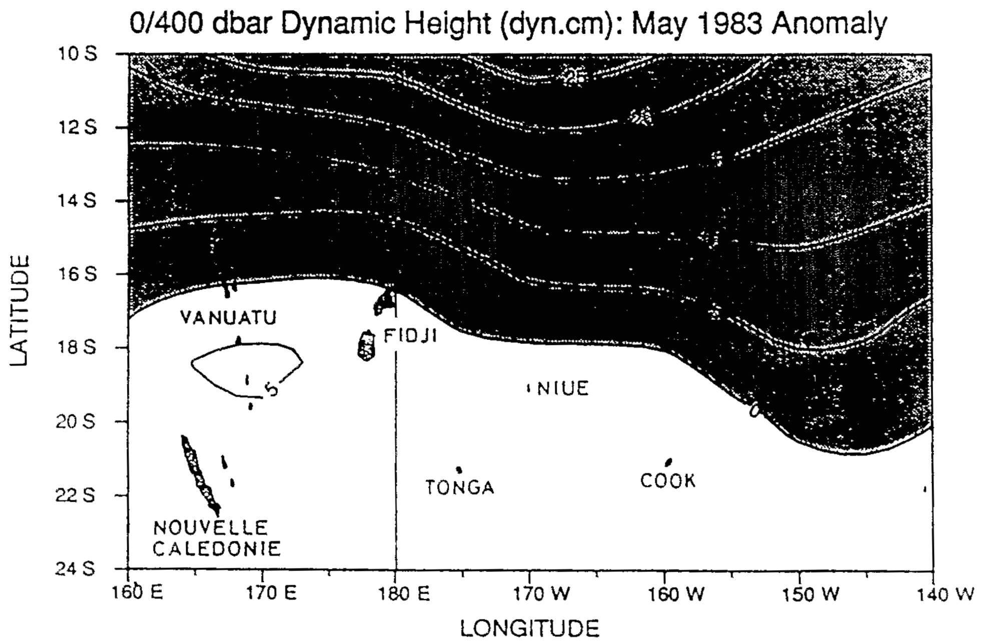

Figure 2. 0/400 dbar dynamic height anomalies (re. 1984-86) in area I of Fig.1, during May 1983. Shaded area denotes negative anomalies. Units are dyn.cm.

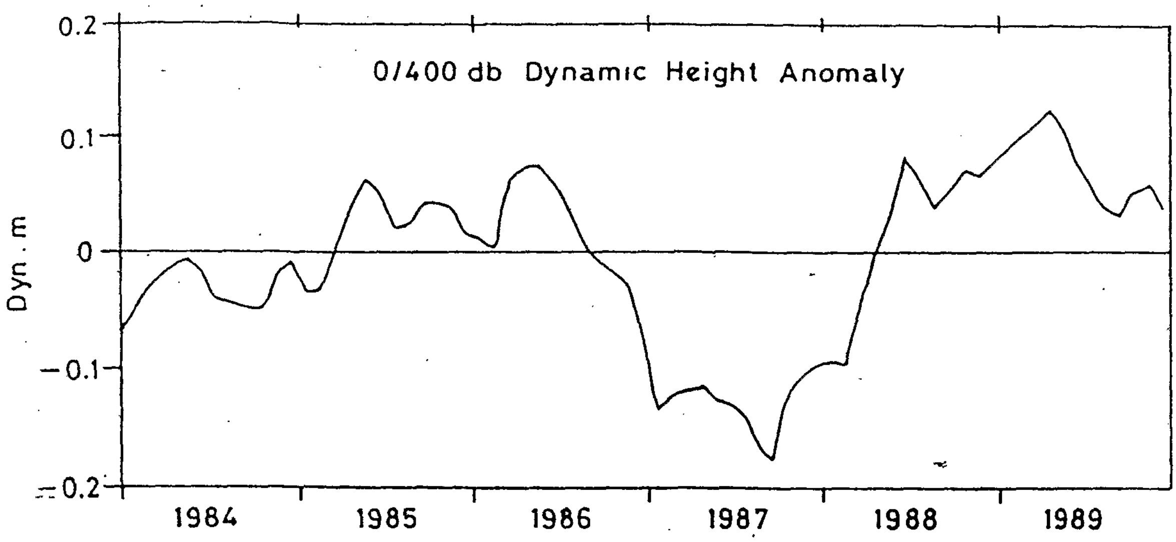

Figure 3. Monthly variations of 0/400 dbar dynamic height anomalies over the western equatorial Pacific (10°N-10°S; 130°E-165°E; area II in Fig.1). Units are dyn.m. Note the strong depression (rise) associated with the 1986-87 El Nino (1988-89 La Nina) period.

end of 1989, "sea level" anomalies return to near zero. In the western equatorial Pacific, peak to peak "sea level" anomalies related to ENSO phenomenon are thus of the order of 30 cm. Further information appears in Delcroix et al. (1992).

ORIGINS OF "SEA LEVEL" CHANGES

Oceanographic cruises provide information on the mechanistic origins of the aforementioned "sea level" changes. Repeated oceanographic cruises were carried out during 1986-88 along 165°E (Fig.4), thanks to independent major research programmes, namely the ORSTOM-SURTROPAC (Survey of the Tropical Pacific) programme, the ORSTOM-PROPPAC (Production Pelagique dans le Pacifique) programme, and the U.S.A.-People's Republic of China (US-PRC) joint programme on air-sea interaction studies. Each expedition obtained vertical profiles of temperature, salinity and horizontal velocity at selected sites ranging from 20°S to 10°N. The time integral of upper ocean transport across 165°E, 10°N-10°S, was computed from discrete horizontal velocity measurements. Derived variations of the upper ocean volume were converted into "sea level" anomalies. These are presented in Fig.5 and compared with the aforementioned XBT-derived "sea level" anomalies. This comparison strongly suggests that, except for the early beginning of the ENSO event (July 1986), sea level variations of the western equatorial Pacific during 1986-88 reflect closely the surface layer zonal transport across 165°E. Specifics are discussed in Delcroix et al. (1992).

Large-scale measurements of temperature (and, sometimes salinity) are available in near real time through the TOGA-TAO (Tropical Ocean Global Atmosphere - Tropical Atmosphere Ocean) array of moorings (Fig.6). These moorings, originally developed at the Pacific Marine Environmental Laboratory (PMEL-NOAA) in 1984, constitute another element of interest for sea level monitoring. As an example, Fig.7 presents time series of daily 0/300 dbar dynamic height anomalies along 165°E, during the 1985-89 period. In agreement with Fig.3, "sea level" anomalies clearly reflect the influence of El Nino and la Nina, with peak to peak variations up to 50 cm between the two

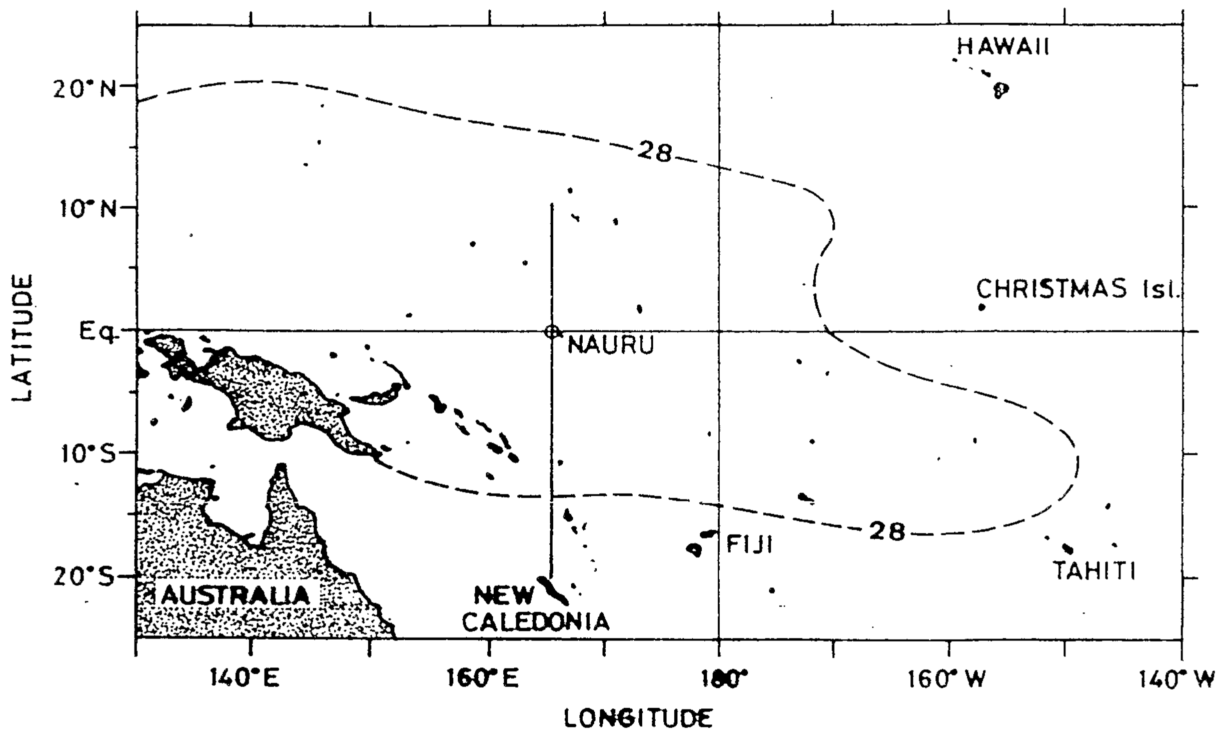

Figure 4. Location of temperature, salinity and velocity sections at 165°E. Also shown is the climatological mean position of the 28°C surface isotherm (broken line), as derived from Levitus (1982).

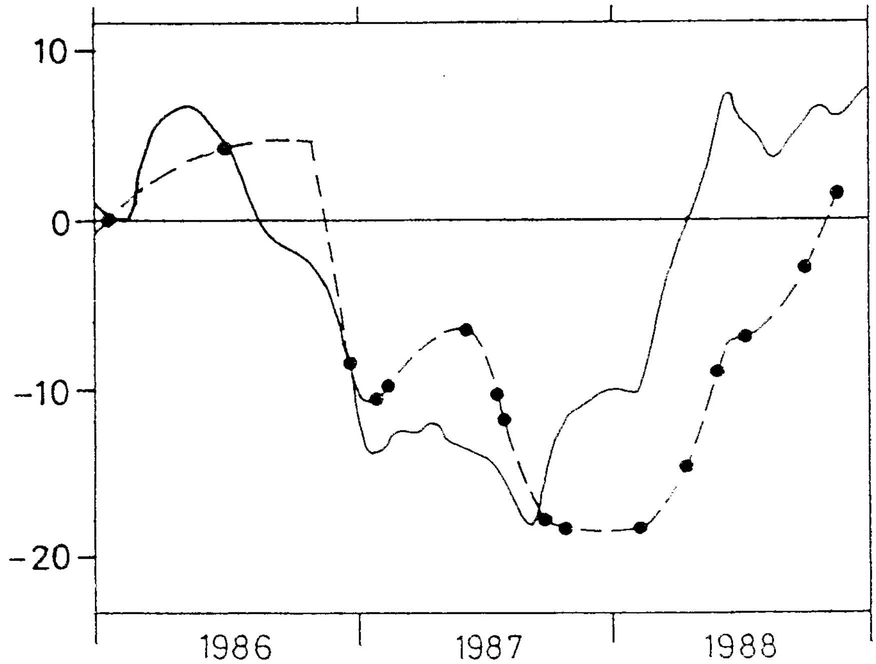

Figure 5. Changes in "sea level" in the (10°N-10°S, 130°E-165°E) region (area II in Fig.1), as estimated from XBT data (solid curve), and from the time integral of upper ocean transport across 165°E (dashed curve, with dots showing the times of the cruises along 165°E from which the transport was estimated). Adapted from Delcroix et al. (1992).

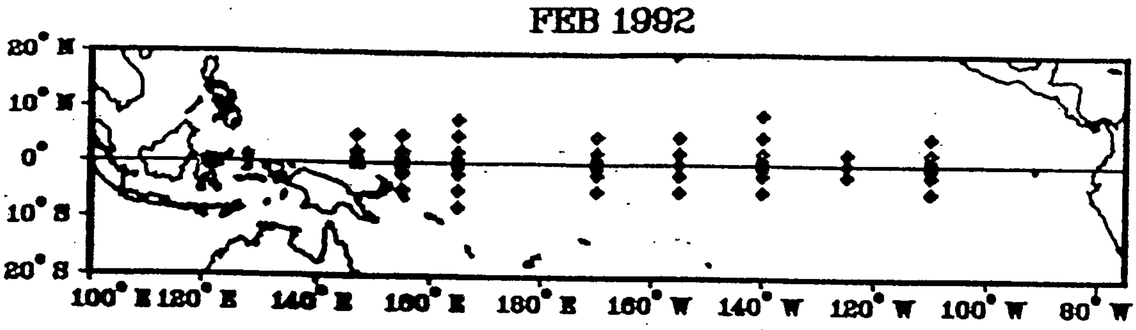

Figure 6. Spatial distribution of TOGA-TAO mooring array in February 1992.

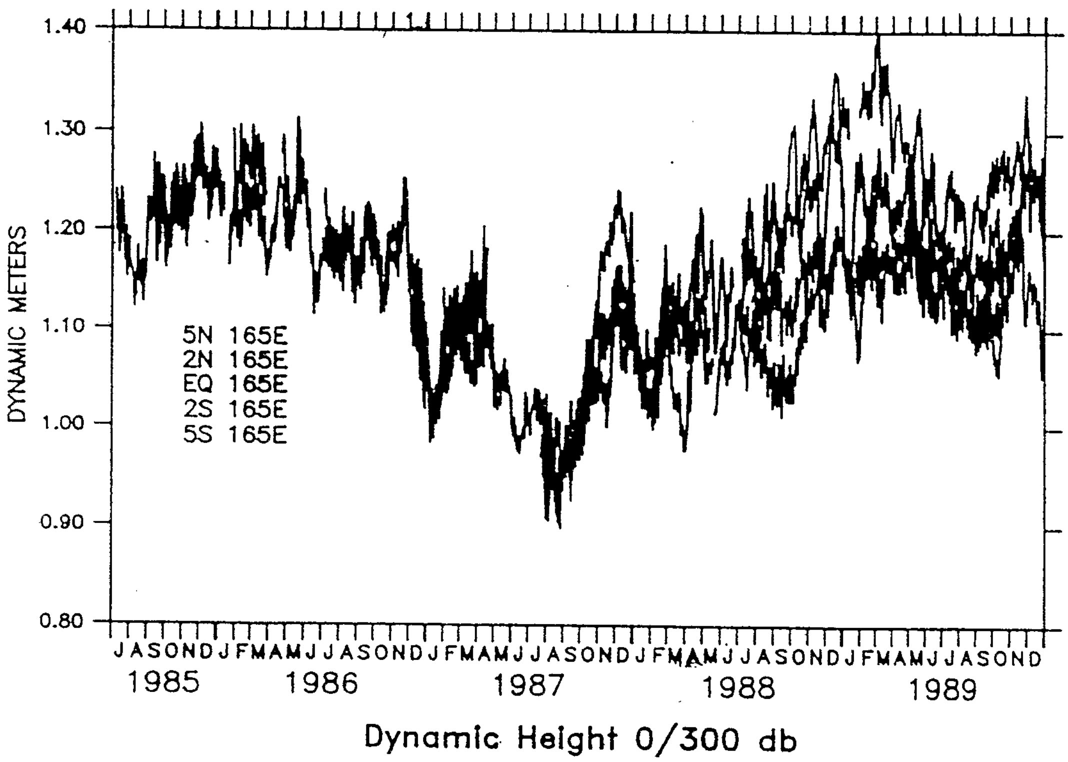

Fig.7. Daily variations of 0/300 dbar dynamic height along 165°E.

extreme ENSO phases. Details about the TOGA-TAO array and its scientific use can be obtained in Hayes et al. (1991).

Despite the relative quality of the previously reported sea-level-related observations, satellite measuring provides the only way of obtaining basin-wide sea level observations over a long time period. This can be fully appreciated by looking at Figure 8 which presents the ground-tracks of the US Navy GEOSAT 17-day repeat orbit over the tropical Pacific ocean. Analysis of GEOSAT data during the 1986-87 El Nino (e.g. Delcroix et al., 1991) has revealed basin-wide eastward and westward propagations of sea level anomalies, characterising long equatorial waves. For example, Figure 9 reveals an eastward propagation of a 10-18 cm sea level anomalies along the equator at the early stage of the 1986-87 El Nino. This propagation characterises a downwelling Kelvin wave propagating at about 10 km/h, thus crossing the entire equatorial Pacific on a monthly time scale. Modelling studies (e.g., duPenhoat et al., 1992) demonstrate that the observed GEOSAT sea level anomalies can be adequately hindcasted, meaning that the main responsible mechanisms are identified. The future TOPEX/POSEIDON mission (starting August 1992), with unprecedented high-quality sea-level coverage over several years, will undoubtedly provide fruitfull information about basin-wide sea level changes.

CONCLUSIONS

In conclusion, we have presented independent and complementary observations enabling detection of sea level variations at seasonal and Interannual time scales. We have shown that the tropical Pacific experiences sea level anomalies of the order of -30 to + 30 cm during ENSO phenomenon. Although ENSO-related variability may obscure any long-term slow sea-level rise possibly associated to global warming, ENSO does provide real scenarios for investigating regional impacts and response strategies to an eventual warming.

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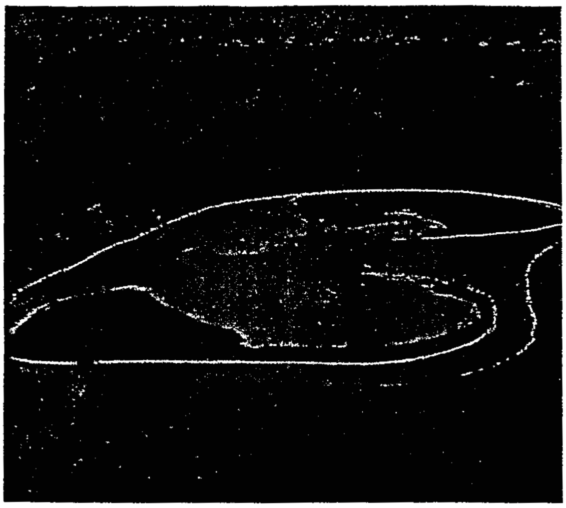

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