The TOGA XBT Programme: The Use of Upper Ocean Water Thermal Data for Analysis and Prediction of Climate Variability

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INTRODUCTION One of the goals of the TOGA program was to gain a description of the tropical oceans and the global atmosphere as a time dependent system in order to determine the extent to which this system is predictable on time scales of months to years, and to understand the processes underlying its predictability. The primary source of upper-ocean thermal data globally for such studies has been the TOGA XBT Network. These observations from a multi-national data collection effort have contributed to the documentation and understanding of upper-ocean thermal variability on inter-decadal, inter-annual, and seasonal time scales.

DATA SET During TOGA (1985-94) more than 250,000 temperature profiles were collect in the Tropical Pacific, Atlantic, and Indian Oceans (30N-30S). These data available from the TOGA Subsurface Data Centre provide an important component to monitoring the El Niño/Southern Oscillation (ENSO) and understanding the ocean processes involved in climate variability. Some examples of this are presented. Prior to TOGA a reduced XBT network was primarily confinded to the Pacific and Atlantic Oceans. During TOGA the XBT network expanded in all three oceans with real-time satellite transmission of data insuring timely inclusion of the data in experimental El Niño forecasts.

PACIFIC OCEAN On a decadal time scale, how representative is the TOGA Decade? Does the TOGA 1985-95 climatology in the Pacific compare well with the pre-TOGA Levitus Climatology (1982)? Shown in Figure 1 are the ocean thermal field in the Tropical Pacific at the 100 metre depth for the TOGA climatology and Levitus pre-TOGA climatology. The temperature difference between the two climatologies suggest the Levitus (pre-TOGA) climatology is significantly warmer in the Western Equatorial Pacific than that observed during the TOGA period. This is most likely due to a shallower thermocline in the Western Pacific during the 1986-87 El Niño and the 1991-93 warm events.

Figure 2, the Warm Pool thickness at 165° E, shows a poleward movement in the tropical regions with a seasonal variability modulated by the interannual ENSO variability. The Warm Pool is drained during the El Niño (70m deep only at the end of the event), while it is over-filled at the end of La Niña (200m deep instead of 150-170m during a "normal" period). The depth of the 25 °C isotherm shows the variability of the mixed layer thickness along the Pacific Equator. The warm pool, in the Western Pacific, with a thick warm layer, whose thickness and longitudinal extension varies interannually is shallow but extended to the Central Pacific during the 1986-87 and 1991-92 El Niños. During the 1988-89 La Niña the 25 °C isotherm was deepened (160m) and was confined to the Western Pacific The Eastern Pacific has a shallow warm layer with a seasonal up welling modulated by interannual events (50m deep during El Niños, at the surface during La Niña).

A dynamical model-based operational ocean analysis system has been implemented at NMC (M. Ji, 1995). This system consists of an ocean general circulation model (modified GFDL) run jointly with upper ocean thermal data assimilation. Assimilation is done continuously during model integration. The model temperature field computed at the previous time step serves as the first guess field. Error estimates are assigned to each observations and to the first guess. A horizontal temperature correction field is obtained by

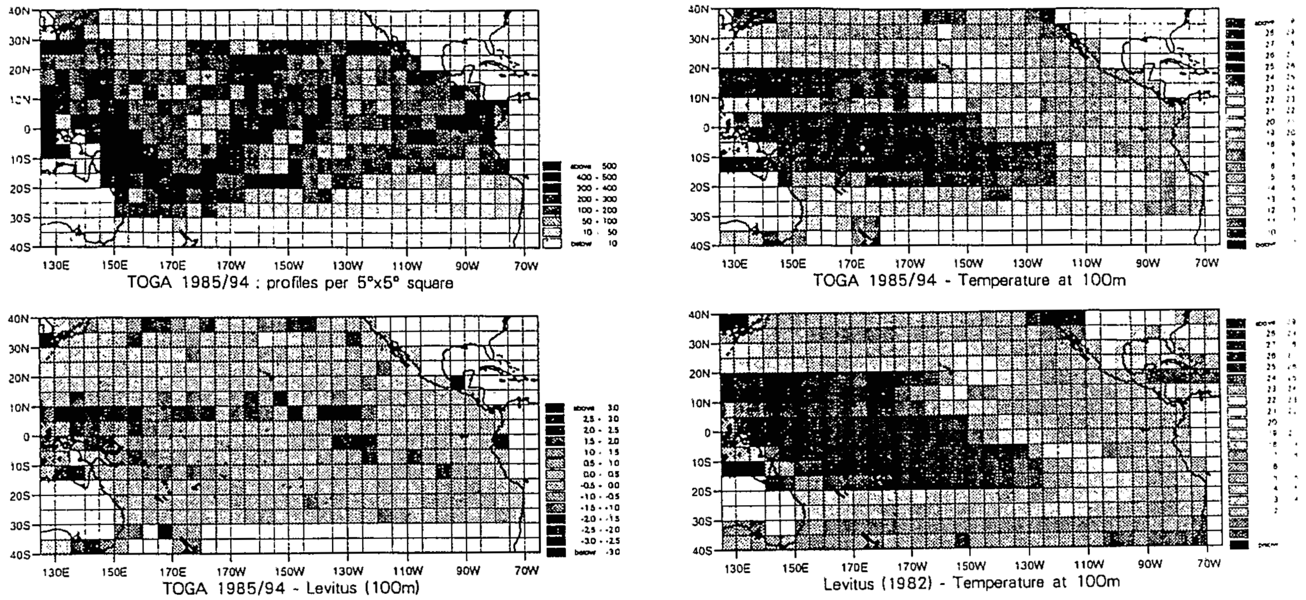

Figure 1 Climatology: Number of XBT profiles for Pacific TOGA Region (1985-1994) received at TOGA Subsurface Data Centre (upper left panel), temperature at 100 m depth from TOGA climatology (upper right panel), temperature at 100 m depth from Levitus (1982) climatology (lower left panel), temperature difference TOGA 1985/94 - Levitus (1982) at 100m. Temperature in °C.

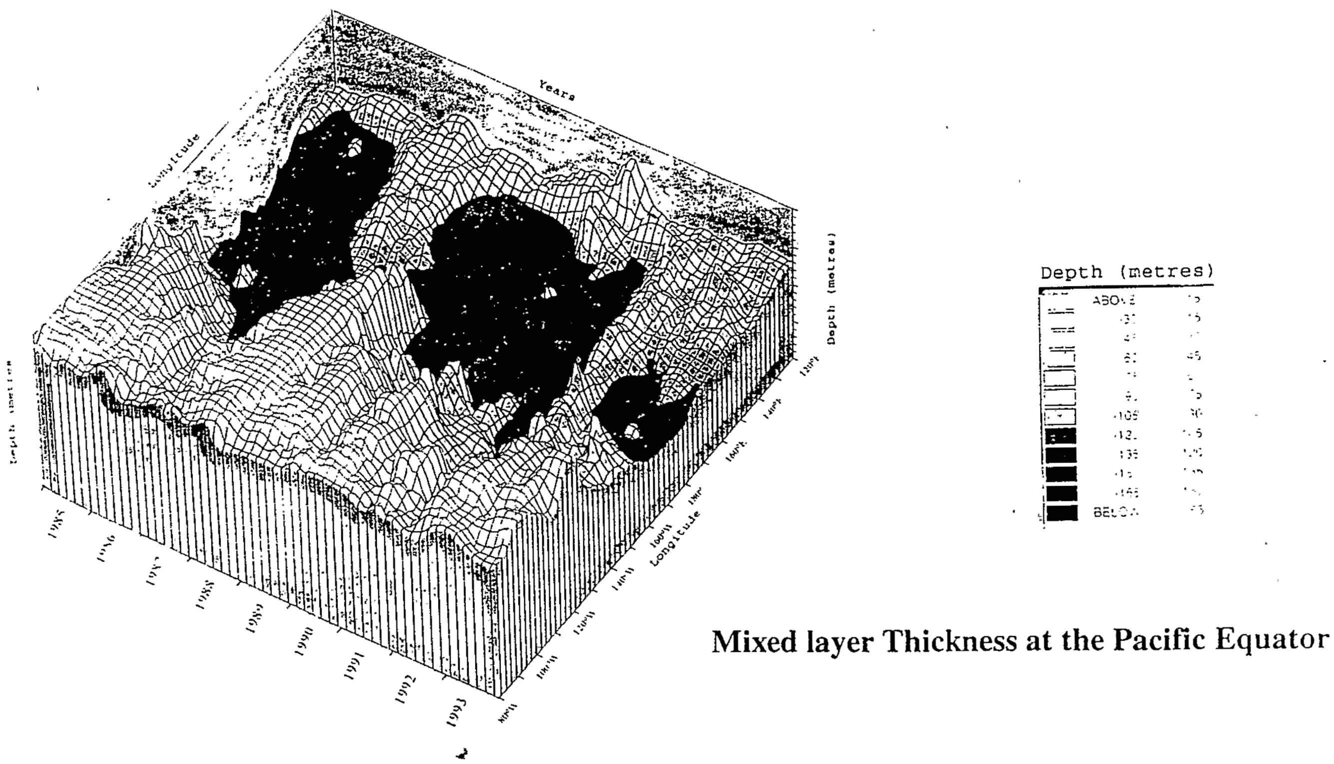

Figure-2 Depth of the 25°C isotherm (1985-93, from the TOGA subsurface data centre). Two main regions:

- **Warm Pool**, in the Western Pacific, with a thick warm layer, whose thickness and longitudinal extension **varies interannually** (shallow, **80m**, but extended to the Central Pacific during the **86-87** and **91-92 El Niños**, deep, **160m**, and confined to the Western Pacific during the **88-89 La Nina**).
- **Eastern Pacific** with a shallow warm layer with **a seasonal up welling modulated by interannual events** (**50m** deep during **El Niños**, at the **surface** during **La Nina**).

optimal interpolation. An Eleven-year retrospective Pacific Ocean Analysis (RA3) for the period 1982 to 1993 has been produced at NMC using the ocean data assimilation system. The forcing for this consisted of the mean annual cycle surface stresses of Hellerman and Rosenstein (1983) on which was superimposed the forcing from the FSU monthly analyses. Figure 3, the time history of the 20° C isotherm from the RA3 (right panel) since February 1982 along the equator shows strong interannual fluctuations with a suggestion of eastward propagation of the main signals. Strongest amplitudes are located in the central and eastern Pacific. The left panel (FHSU) without data simulation does not capture the structure or amplitude of the fluctuation as well as the analyses from RA3. The model also computes surface pressure variations on its rigid lid, which can be related to sea level variations. The model-based estimates of sea level variability are improved by the upper ocean thermal data assimilation.

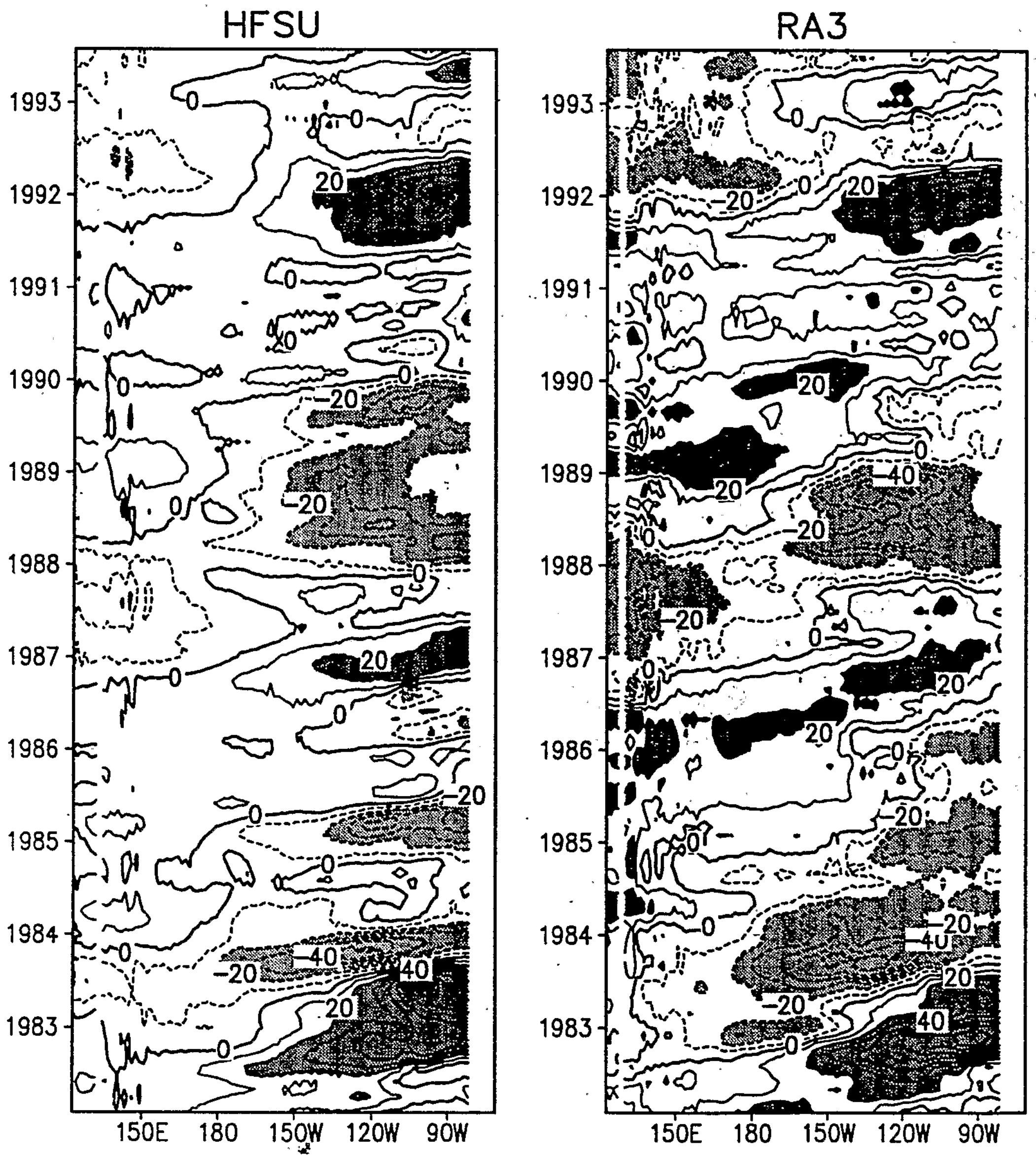

Figure-3 Interannual fluctuations of the 20^o C isotherm along the Equator: Time history for the anomalous depth of the 20^o C isotherm (H_{20}) along the Pacific Equator for the period 1982 to 1993 (from a dynamical model-based operational ocean analysis system implemented at NMC). The RA3 ocean analysis (right panel) is with upper ocean thermal data assimilation. The HFSU simulation (left panel) uses the same wind forcing without upper ocean thermal data assimilation. The contour interval is 10m. Dark shading is for anomalies greater than 20 m, light shading is for anomalies below -20 m.

ATLANTIC OCEAN While the Pacific Ocean has been the most widely studied mainly due to the strength and importance of the ENSO phenomenon, an example of the Tropical Atlantic variability suggest teleconnections with ENSO, in addition to local effects. The 14-year (1980-1994) 12 month running mean of the 20 °C isotherm depth at the equator and 10° W (Figure 4) shows an increase in the depth of the 20 °C isotherm in the Eastern Tropical Atlantic in relation to the 1982-83 and 1986-87 El-Niño events in the Pacific, however with different time lags. During the strong 1988-89 La Niña the depth of the 20 °C isotherm decreased in the Eastern Tropical Atlantic as in 1985-86 when there was a mild cooling event in the Pacific suggesting that local effects in the Atlantic may be at least as important as ENSO.

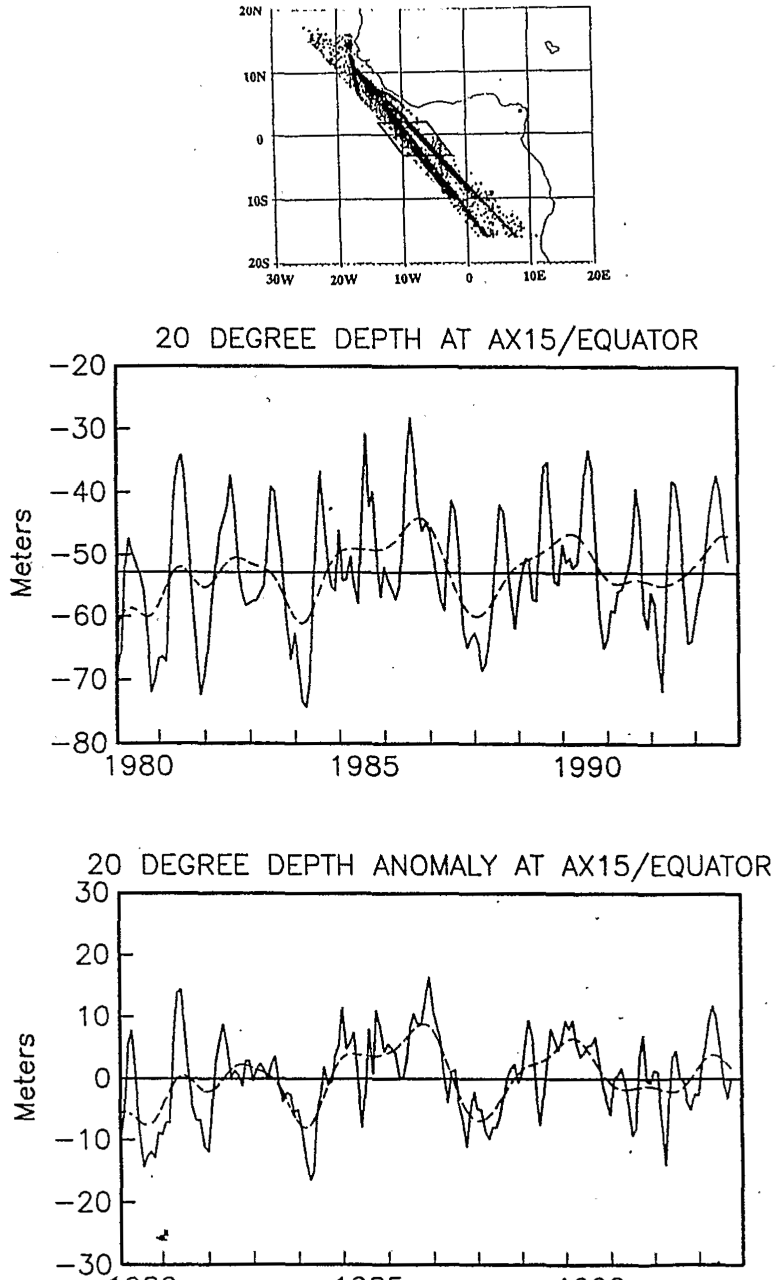

Figure-4 Depth of the 20°C isotherm in the Eastern Tropical Atlantic Ocean (AX-15/Equator) and depth of the 20°C isotherm anomaly from 1980-1994 (dashed line is 12 month running mean).

INDIAN OCEAN Another example of teleconnection can be found in the Eastern Indian Ocean by studying the tropical geostrophic circulation. Figure 5, Long-term annual mean transports in Sv calculated from TOGA frequently repeated XBT lines using climatological T/S relationship show strong annual and semi-annual variation of all the currents. Understanding the dynamics of the Indonesian throughflow in this region is vital for model development as it is a crucial branch in the global network of currents responsible for ocean heat transport. In particular, the throughflow transfers a significant fraction of the heat gained by the tropical Pacific to the Indian Ocean (Meyers et al., 1994).

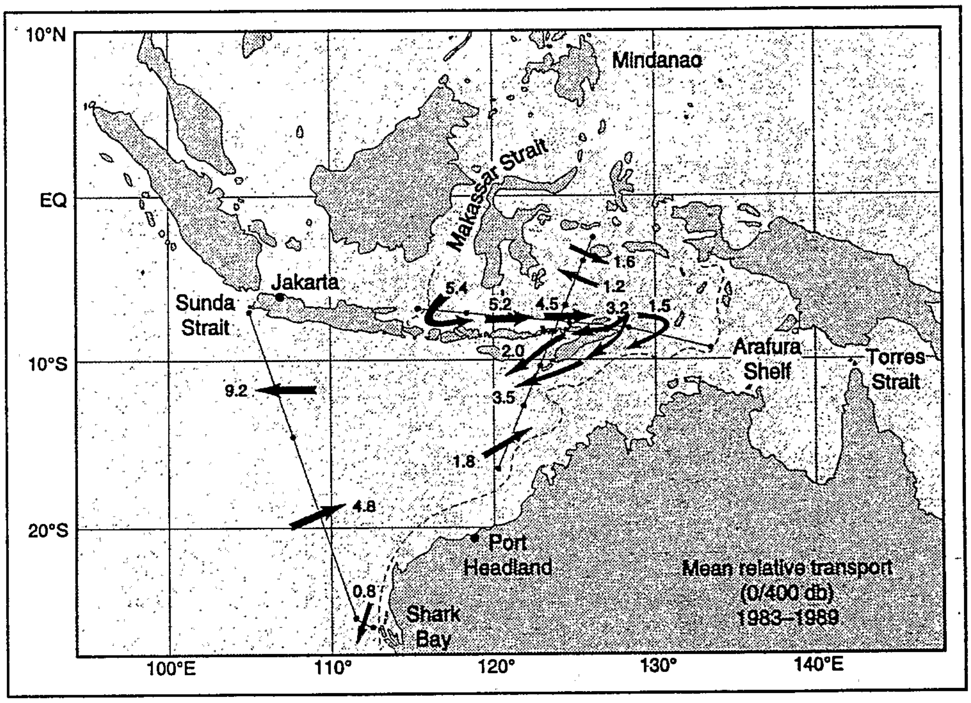

Figure-5 Long-term annual mean transports in Sv calculated from TOGA frequently related XBT lines using Climatological T/S relationship (Meyers et al., 1994).

CONCLUSION High frequency signals like the Manden-Julian oscillation can not be resolved do to the low temporal sampling of the Network. However, the XBT Network is fundamental for seasonal to decadal climate analysis on a global scale. It has been demonstrated by a number of dynamic models that assimilation of upper ocean thermal data is necessary to increase the forecasting skill of the models. In consequence it has been recommended by the Panel on Near-Term Development of Operational Ocean Observations (Nnox, 1994) that the TOGA XBT Network continue and expand as an operational component of GOOS/GCOS for CLIVAR.

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