TROPICAL OCEAN ATMOSPHERE NEWSLETTERS, vol 29, 5-6, 1985

(DELCROIX T. et C. GAUTIER)

Seasonal Variations of Heat Content and Sea Level in the Tropical Pacific

It is now well established that the variability of the oceanic heat storage is one of the main factors influencing the climate system. Monitoring this variability is a considerable task since it requires the knowledge of the temporal evolution of temperature profiles on a global basis. Ship-of-opportunity programs have been designed in several crucial regions of the globe (Meyers and Donguy, 1980), and have provided new insights into the variability of the heat content in these regions. Nevertheless, these programs are difficult to maintain and a method based on satellite data, which would provide a global coverage, at least on some time scale, would be more appealing and would represent the necessary complement to these *in-situ* programs.

As the sea level has been shown to contain major information of integrated quantities, such as dynamic height or heat content (Patullo *et al.*, 1955; Wunsch, 1972; Wyrtki, 1974, 1980, and Verstraete, 1982) and can be easily recorded from island gages and obtained from altimetry in the future, we have investigated relationships between variations in heat content and those in sea level. In this paper we examine these relationships in the tropical Pacific (30°N-30°S) using the seasonal cycle of these two parameters.

The seasonal means of heat content Hc given by:

$$Hc = \int_0^{1000} \rho \quad CpTDz \qquad (1)$$

are calculated from the surface to 1000 m, in boxes of 1° square, using National Oceanographic Data Center (NODC) temperature profiles compiled by Levitus, 1982 (all the variables have their traditional meaning).

Since sea-level (SL) measurements are not available with adequate coverage on a global basis from island data, we need to use a surrogate variable, if it exists. According to Gill and Niiler, 1972, the changes in SL at one point can be expressed as the sum of three terms:

$$SL = ST + SA + SB, \qquad (2)$$

where ST is the steric level representing the effect of expansion or contraction of the water column, SA is the barometric term and SB is a term that is proportional to the changes in bottom pressure.

On a seasonal time scale, it has been shown that the two last terms on the right-hand side of (2) are negligible and that SL and ST agree relatively well in this frequency band, at least within the accuracy of the measurements (Pattulo *et al.*, 1955; Wunsch, 1972; and Gill and Niiler, 1973).

We verify this assumption in our area of interest by comparing the computed ST and the observed SL in the vicinity of locations where the sea level was measured. The steric level has been calculated for the four seasons in boxes of 1° square, using the termperature profiles described and seasonal salinity profiles obtained from the same NODC data set (Levitus, 1982).

These computations were performed for 20 locations for which we had long-time records (more than 10 years) of sea-level observations (Wyrtki and Leslie, 1980) for best comparisons.

The results thus obtained displayed a good one-to-one correspondence for the stations west of the date line, north of 15°S and on the eastern coast of the Americas. In the central Pacific it was difficult to conclude, since the amplitude of the seasonal signal of sea level and steric level is within the noise of the measurements (*i.e.*, respectively 1 and 3 cm). The results for three stations representative of the western part (Legaspi), the central part (Canton) and the eastern part (Chimbote) are presented in Figure 1. There is a remarkable correspondence between the two parameters on the seasonal time scale, and the difference between the two curves on each plot is well within the error of the measurements.

Assuming, now, that steric-level changes are representative of sea-level changes, on a seasonal time scale, we studied the relationship between the seasonal variations in heat content (Hc) and those of sea level, using the steric level as a surrogate variable for the sea level.

Computed seasonal variations of ST and Hc have been analyzed and correlations

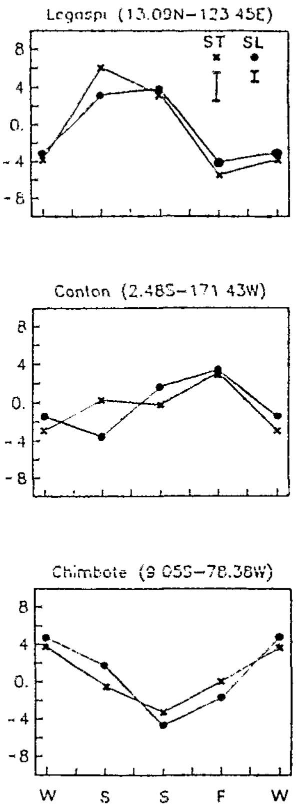

FIGURE 1 *(Delcroix and Gautier)*
Seasonal variations of the steric level (ST=x) and of the sea level (SL=o) in three locations. Units are in centimeters.

Winter = Feb/Mar/Apr	*Spring = May/Jun/Jul*
Summer = Aug/Sep/Oct	*Fall = Nov/Dec/Jan*

varying from .78 to .86 have been found for the four seasons. The worst case is presented in Figure 2 for the winter season, for which the root mean square deviation (σ) from the mean regression line is 2.3 cm and departures from this line superior to 2σ occur for 4% of the cases only. It is clear that, even in this case, there is a tight relationship, if one considers that the accuracies on heat content and steric level are, respectively, 0.3 x 10^9 J m^{-2} and 3 cm.

Most of the points with large departures from the mean regression line correspond to stations within the 0°-15°N latitude band in the central part of the basin. This is the region of the Intertropical Convergence Zone (ITCZ) and, therefore, a region of maximum rainfall (Dorman and Bourke, 1979), where the seasonal variation of the salinity profiles could induce large changes in the seasonal variation of the steric. (Changes in steric level are due to changes in density profiles, whereas changes in heat content are due to changes in temperature profiles.)

If we assume that the steric level is representative of the sea level and use the correlation established and shown in Figure 2, three simple conclusions can be drawn:

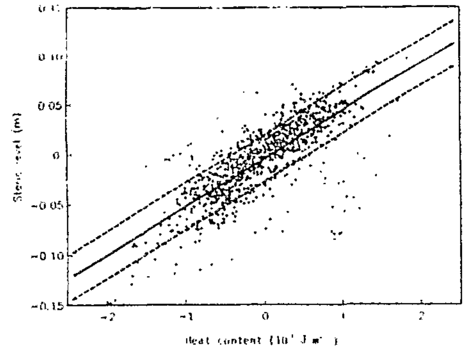

FIGURE 2 *(Delcroix and Gautier)*
Regression of the seasonal variations of the steric level in meters and of the heat content (abscissa) in 10^9 J m^{-2} during the winter season. The regression line and lines of one standard deviation (2.3 cm) are shown.

1) Seasonal variations in heat content can be derived from sea-level measurements, such as those obtained from altimetry, only if the seasonal signal is >5 cm. This 5 cm value has been obtained by allowing the noise level to be 25% of the computed seasonal heat content signal.

2) Monitoring seasonal variations of heat content from sea-level measurements is restricted to locations where sea-level variations are >5 cm. The spatial distribution of these locations, mainly situated between 5°S and 10°N and in the northwest part of the basin, will be presented and discussed in a future paper. A worse accuracy in the sea-level signal will reduce the number of such locations (and the total corresponding area). Table 1 gives an idea of the percentage of boxes of 1° square for which the seasonal variability of the heat content could be deduced as a function of various accuracies in the sea level. (The total area investigated is covered by 8090 boxes.)

TABLE 1 *(Delcroix and Gautier)*

SL in cm	Hc in 10^9 J m^{-2}	Percentage of boxes
5	1.1	17
6	1.3	11
7	1.5	6
8	1.7	3.5
9	1.9	2
10	2.1	1
11	2.3	.6
12	2.5	.3
13	2.7	.1
14	3.0	.1
15	3.2	.01

3) The effects of the seasonal variations in the salinity profiles on the seasonal variations in sea level should be further analyzed, particularly in the 0°-15°N band, where sea-level changes as large as 10 cm can occur without heat content changes. This suggests that a better knowledge of the seasonal ability in salinity and of its relationship precipitation and evaporation will be ne sary to correctly interpret future altim measurements in terms of heat cont changes in the tropical Pacific regions.

These results only apply over seaso frequencies and, therefore, should not interpreted out of this context. It cannot expected that heat content, steric level a sea level will agree on all time and spa scales. Studies of possible relationships other frequency bands will be conducted understand how they might affect t present conclusions.

References

Dorman, C. E. and R. H. Bourke (197 Precipitation over the Pacific Ocea 30°S to 60°N. *Monthly Weather Rev. 107*, 896-910.

Gill, A. E. and P. P. Niiler (1972) The theo of the seasonal variability in the ocea *Deep-Sea Research, 20*, 141-177.

Levitus, S. (1982) *Climatological Atlas of t World Ocean*. NOAA Profession Paper 13, U.S. Department of Co merce, Rockville, MD. 173 pp.

Meyers, G. and J. R. Donguy (1980) An XB network with merchant ships. *Tropi Ocean-Atmosphere Newsletter*, No. 6-7.

Pattulo, J., W. Munk, R. Revelle and Strong (1955) The seasonal oscillati in sea level. *Journal of Marine Resear 14*, 88-155.

Verstraete, J. M. (1982) Sea level variatio in the Gulf of Guinea. *Tropical Ocea Atmosphere Newsletter*, No. 9, 5-6.

Wunsch, C. (1982) Bermuda sea level relation to tides, weather, and barocli fluctuations. *Reviews of Geophysi and Space Physics, 10*, 1-49.

Wyrtki, K. (1974) Sea level and the season fluctuations of the equatorial currents the western Pacific Ocean. *Journal Physical Oceanography, 4*, 91-103.

Wyrtki, K. (1980) Sea level during tl NORPAX shuttle experiment. Repo HIG-80-6, Hawaii Institute of Ge physics, University of Hawaii, 27 pp.

___ and Leslie (1980) The mean annu variation of sea level in the Pacifi Ocean. Report HIG-80-5, Hawaii Inst tute of Geophysics, University Hawaii, 160 pp.

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