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Subsurface Temperature Variability Along the West Coast of North and South America

The anomaly of temperature at 100 m along the coast of North and South America was computed from subsurface temperature profiles from the "Master Oceanographic Observation Data Set" (MOODS) at Fleet Numerical Oceanography Center in Monterey, California. These files include all available bottle casts, MBT, XBT, and CTD profiles, and real-time radio reports of subsurface temperature. For 1951-84, the anomaly of temperature at 100 m was computed each month relative to the long-term mean for that period. Data for all years before 1951 were combined into a single composite year, labeled 1951. The computations were made for 27 areas, each spanning 3 degrees of latitude from British Columbia to Chile (50°N to 30°S, Figure 1). The zonal extent of each area was chosen so that each area would extend

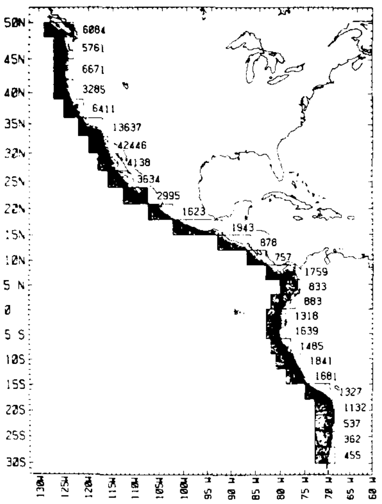

FIGURE 1 (*Brainard and McLain*) *Locations of 27 areas along the eastern Pacific from 50°N to 30°S and the distribution of observations of temperature at 100 m within the areas. The number of observations is printed to the right of each area. Note the scarcity of observations off Chile, southern Peru, and Central America.*

roughly the same distance offshore, and varied from 4 degrees of longitude in regions having a meridional coast to a maximum of 10 degrees of longitude off southern Mexico and Guatemala where the coastline is nearly zonal. There were a total of 115,515 temperature profiles available for the 27 areas, with almost 85% from north of 15°N. Observations are sparse for the areas off southern Peru, Chile, and Central America, particularly in the early 1950's and also in recent years due to delays in data assembly. The computed anomalies were smoothed to remove small variations in time and space by first passing the array through a nonlinear median filter in which the central value of each 3 x 3 subarray was replaced by the median of the 9 values in the subarray. This was followed by a triple pass through a linear smoother for subarrays of 3 months by 5 areas. The subarrays were extended farther in space than in time to emphasize the strong coastwise coherence of the data. In this smoothing, the central value of each 3 x 5 subarray was replaced by one-half of the original value plus one-half of the mean of the 14 surrounding values

A time-latitude contour plot of the smoothed anomaly field (Figure 2) shows each of the major anomalous warm and cold events of the past three decades. Each of the well-documented El Niño events—1957-58, 1965, 1969, 1972-73, 1976-77, and 1982-83 (Quinn *et al.*, 1978)—are clearly evident and show strong coherence along the coast. The extreme spatial extent and magnitude of the 1982-83 event distinguish it as the most significant warm event of the period. It was the only event having an anomaly greater than 1°C north of Pt. Conception. Norton *et al.* (1984) attribute the extreme character of the 1982-83 event in the California Current system to the synchronous occurrence of warming processes associated with equatorial warming and midlatitude atmospheric perturbations. The 1954-56 cold event is comparable in extent and duration with the 1982-83 warm event. Only these two events retain their anomalous character for the entire distance from British Columbia to Chile. Following the 1954-56 cold event, the monthly mean temperature of coastal waters from the equator to Baja California rose from 1°-2°C below the mean (1956) to 1°-3°C above the mean (1957) in 5-10 months. This represents the highest rate of temperature change during the 33 year period and was associated with changes in atmospheric circulation (Huang, 1972).

The leading edges of the warm anomalies tend to lag in time with distance poleward from the equator, suggesting poleward propagation of anomalies. (Insufficient data are available to track the leading edge of the 1954-56 cold event.) The approximate speeds of propagation along the coast for the 1957-58, 1972-73, 1976-77, and 1982-83 warm events are summarized as follows:

Dates	Initial latitude	Final latitude	Approximate speed of propagation (km/day)
Oct '56-Jun '57	14°S	22°N	23
Feb '72-Jan '73	1°S	25°S	9
-Aug '72	1°S	30°N	26
May '76-May '77	4°S	19°S	6
-Sep '76	4°S	34°N	56
Apr '82-Apr '83	1°S	22°S	7
-Jul '82	1°S	28°N	45
-Nov '82	1°S	46°N	32

In contrast with the general poleward propagation, the 1957-58 warm event appeared to originate off southern Peru (about 14°S) and propagate north across the equator to Baja California. Each of the other three events originated near the equator and propagated poleward. In the four cases, the propagation to the north was several times faster than the propagation to the south. All of the propagation speeds were slower than the theoretical speeds of coastal Kelvin waves or coastally trapped waves, suggesting changes in advection as well as the passage of propagating waves.

The data suggest the existence of a long-term warming trend of the coastal waters, particularly off western North America. Extreme cold conditions occurred in the early 1950's, followed by warming in 1957-58, moderate conditions from 1960 to 1975, warm conditions since 1976, and extreme warm conditions in 1982-83. Such a trend can also be seen in sea-level observations, which are related to the vertical integral of the density structure and thus temperature, dating to the 1920's (McLain *et al.*, in press). Plots of anomaly of temperature at the surface and at 200 m reveal the same characteristics as at 100 m, but generally with lower magnitudes. The warming trend thus represents a general deepening of the thermal structure along the coast. Such a deepening would cause a change in the slope of the thermal structure normal to the coast and a tendency to increase transport of warm water and associated organisms poleward along the coast. Also, deepening the thermal structure would reduce the biological productivity of the surface waters by reducing the ability of upwelling-favorable winds to upwell deeper than normal nutrient-rich water (McLain *et al.*, in press).

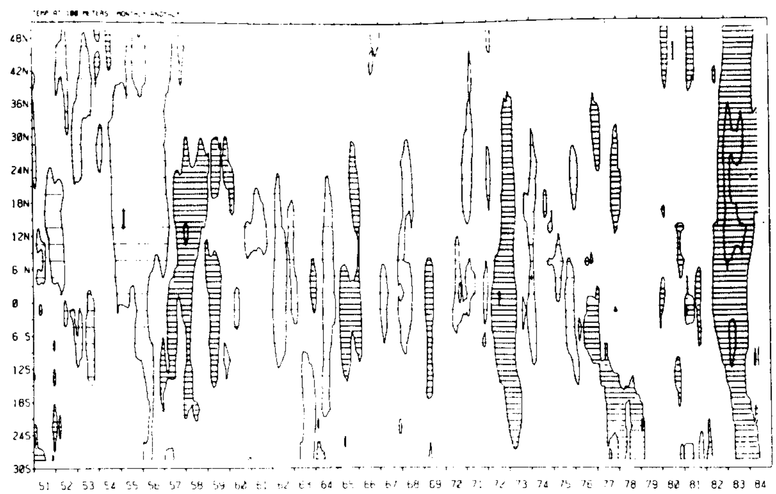

FIGURE 2 (*Brainard and McLain*)

Time-latitude contour plot of anomaly of temperature at 100 m along the coast from 50°N to 30°S for 1951 to 1984. Positive anomalies >0.5°C are indicated by cross-hatching (overlapping plus signs) and negative anomalies < −0.5°C by widely spaced horizontal lines (overlapping minus signs). The heavier contour lines represent positive anomalies >1.5°C and <2.5°C. Blank areas on the plot represent anomalies between +0.5°C and −0.5°C or nonavailability of data.

References

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