EL NIÑO[1]

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One of the most celebrated of oceanic disturbances is that known as *El Niño*, an occurrence of the first half of the year which is reported at irregular intervals from the coast of Northern Peru. Conspicuous outbreaks were reported in 1891 (Schott, 1931) and 1925 (Murphy, 1926) and more recently in 1941 (Lobell, 1942), 1953 (Posner, 1957) and 1957-1958. Similarities between this phenomenon and conditions observed off the California Coast and in other coastal upwelling zones suggest that the underlying causes of the observed abnormalities are the same in such regions.

Unfortunately it is not easy to discuss the Peruvian *Niño* in quantitative terms. The lack of a long record of systematic observations throughout the year makes it difficult to determine satisfactory averages with which to compare observations believed to be abnormal. Although it has been possible to establish a crude picture of the seasonal march of surface temperature along the Peruvian Coast (see later), little is known about changes in surface salinity; subsurface conditions are even less well known. In order to look for meteorological changes which might produce *El Niño* one would like a set of average pressure charts such as Dr. Namias has prepared for the Northern Hemisphere—but no such information is readily available.

With such a paucity of quantitative information it is not surprising that the characteristics of *El Niño* have never been well defined. One symptom is common to all reports—the presence of unusually high sea surface temperatures. Other frequently mentioned features include a southward coastal current, heavy rainfall, red tide *(aguaje)*, invasion by tropical nekton, and mass mortality of various marine organisms including guano birds, sometimes with subsequent decomposition and release of hydrogen sulfide (known as *El Pintor*).

Before attempting to define *El Niño* or to hypothesize as to its origin, it is of interest to examine some of the conditions observed during the events of 1957 and 1958.

As early as December 1956 unusually high sea temperatures were observed off Northern Peru. The summers (Southern Hemisphere) of both 1957 and 1958 were marked by heavier than usual rainfall in the north, and as far south as Lima (12°S) the winter of 1957 was warmer and less overcast than usual, this condition lasting until early September. There were, to my knowledge, no reports of a southward coastal current, but there were some indications that the northward flow of the Peru Current was much reduced. The guano birds, which were nesting on the northern islands in December 1956, abandoned their fledglings as they did again during the summer of 1957-1958. During the winter of 1957 large numbers of guanay *(Phalacrocorax bougainvillii,* the principal producer of commercial guano) died along the beaches, apparently from starvation. This did not happen in 1958, but adult birds were uncommonly scarce. Anchoveta *(Engraulis ringens)*, the main food of the guano birds, although caught by fishermen, were unavailable to the birds. There was no evidence of excessive mortality of these fish, but rather indications that they were no longer present at the shallow depths where they are usually abundant. Coastal waters were invaded by tropical forms, the yellowfin tuna fishery extending farther southward than usual, and hammerhead sharks, manta rays, and dolphin fish were common at least as far south as Lima.

Evidence for the conditions described above, although credible, is difficult to document. However, early in 1958 it was possible to make some measurements from *Bondy,* a Peruvian naval vessel attached to the Servicio Hidrográfico. The scientific work was carried out by scientists of the Consejo de Investigaciones Hidrobiológicas. During the period 24 February to 9 March a systematic survey was made of the region between 12°S and 4°S, extending offshore about 60 miles. Observations included 78 bathythermograph and surface-salinity measurements, and hourly surface-temperature readings were made along the track of the vessel.

As is usual along the Peruvian Coast, lowest temperatures (21.5-23.0°C) were found just offshore. However, the areas of cold water were small and isolated, and most of the region was covered with water whose temperature was greater than 25°C. When these values are averaged by one-degree squares they can be compared with the February average latitudinal variation of surface temperature in the same squares, as computed from data in the period 1939-1956 published in the *Mapas Mensuales* of the Compañia Administradora del Guano (Fig. 11). During this period lowest February temperatures were observed in 1950, highest in 1941. Averages from the 1958 *Bondy* cruise are similar to those of 1941, or from 2°C to 4°C higher than the long term mean.

Off upwelling coasts, such as that of Peru, subsurface temperature measurements usually show a moderately strong and deep thermocline offshore, which becomes shallower and less intense as it approaches the coast (Wooster and Cromwell, 1958). Weakening of the thermocline near the coast is associated with the enhanced vertical-mixing characteristic of upwelling. During the February *Bondy* cruise, most of the region was covered by a shallow (less than 30 meters) layer of warm (greater than 25°C) water underlain by a strong thermocline lying offshore a

[1] Contribution from the Scripps Institution of Oceanography.

distance of 20 to 60 miles, and only in a few places were the ascending isotherms and weak thermoclines of upwelling encountered.

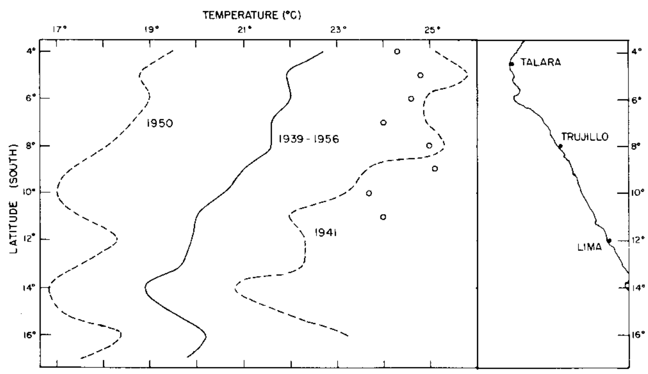

FIGURE 11. February values of average sea surface temperature along the coast of Peru. Curves are based on one-degree square averages from *Mapas Mensuales*. Circles are values for the same squares computed from *Bondy* data of February-March 1958.

Surface salinities in most of the region were $35^0/_{00}$ or greater, with lower values (to $34.92^0/_{00}$) only off Talara (4°30′S) and Paita (5°S). South of 7°S, there was a general increase of salinity with increasing temperature (Fig. 12), and also with increasing distance

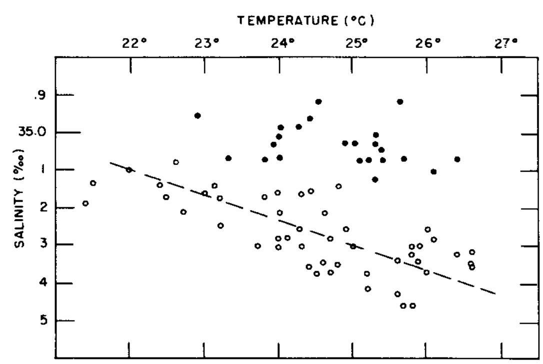

FIGURE 12. Surface temperature-salinity diagram for *Bondy* cruise of February-March 1958. Observations north of 7°S shown by filled circles, south of 7°S by open circles.

offshore. Only north of 7°S, and especially off Talara, were low salinities associated with high temperatures. Therefore it appears that the warm waters observed off northernmost Peru were of different origin than those present south of 7°S.

I would like to propose the following hypothesis concerning the cause of *El Niño*. Usually a southerly wind blows parallel to the Peruvian Coast, causing a net transport of surface water away from the coast, with replenishment from greater depths. For some reason, as yet unknown, the Peru Current swings westward a few degrees south of the equator. To the north are found the warm and relatively low saline waters of Panama Bight (Wooster, 1959).

Each year during southern summer highest temperatures are found along the Peruvian Coast from

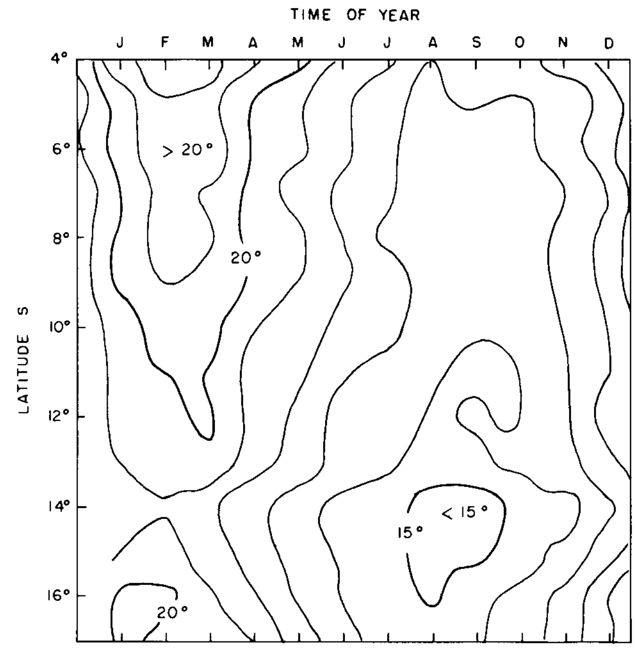

FIGURE 13. Average sea surface temperature along the coast of Peru, based on one-degree square averages for the period 1939-1956 from *Mapas Mensuales*.

4° to 17°S (Fig. 13). During *Niño* years, there is a general weakening of the atmospheric circulation, and reduction of the wind-stress component parallel to the coast is responsible for a weakening or cessation of upwelling. Higher than normal temperatures then result from *in situ* heating (as suggested by Sears, 1954) and from a coastward drift of open-ocean surface waters. In Northern Peru, the northern boundary of the Peru Current lies farther south than usual, and the tropical waters usually found north of this boundary may reach as far south as 7°S.

It has been suggested that red tides *(aguaje)* are more frequent during *Niño* periods (Schweigger, 1958). This would be consistent with the model if one accepted the theory that red tides are associated with reduced horizontal and vertical circulation, and thus with reduced dispersal of rapidly growing flagellate populations. This theory is implicit in the discussion of Kierstead and Slobodkin (1953).

In the light of this hypothesis, *El Niño* can be defined as the set of conditions developing off an upwelling coast when reduction of the wind stress causing upwelling during an extended period of time leads to weakening or cessation of vertical mixing. The resulting conditions include an increase in surface temperatures, the development of a thin layer of light water offshore, a modification of the surface circulation depending on the nature of the variation in the wind stress, and the biological changes associated with the altered environment. At the same time, in a region such as the Peruvian offing, where a cold coastal current turns away from the coast at low latitudes, the well-defined zone of transition to warmer waters may be at higher latitudes than usual.

El Niño as thus defined is a generic term applicable not only to Peruvian coastal waters but also to similar regions off California, Southwest Africa, Western Australia, and the coast of Vietnam.[1] In the last two regions the monsoonal changes in wind stress lead to annual *Niños.*

Testing of the proposed hypothesis requires a much better set of oceanographic and meteorological observations than are presently available from Peru. Although the *Niño* phenomenon is less well developed in California waters, the extensive body of data from that region might make it possible to examine the hypothesis during years such as 1957 and 1958.

DISCUSSION

Stommel: What I have to say is only to offer some more or less obvious remarks based on Schott's charts of mean summer and winter winds and sea surface temperatures in the *Geographie des Indischen und Stillen Ozeans* (February and August). First we note that there is a considerably greater variation in the winds over the California Current than over the Peru Current. In February the high pressure area over the California Current is weaker than in August; whereas over the Peru Current the high pressure region is strong in both seasons. Looking now at the corresponding charts of the surface temperature, we see that the isotherms are bent toward the Equator on the eastern side of the Pacific in both seasons off Peru, but off California, they are bent toward the Equator only during August. In February, when the atmospheric high is not strong, they extend almost parallel to latitude circles much of the way to the California Coast. If we can assert that the distortion of the isotherms is produced by the winds, then we can see that there is a powerful "thermostatic" action off California, which reduces the seasonal variability of temperature but that this is not so developed off Peru, because there the winds distort the temperature field throughout the whole year. Depending upon how we like to talk of things, therefore, we might say that there is normally an *El Niño* off California every winter, when the winds die down as a rule each winter, whereas in the Peru Current, the *El Niño* is by definition, an abnormal event, because there the winds do not normally change much with season. Of course, this is only a playing with words, but it does point up, I think, a rather important difference between the two current systems. I wonder if more recent studies of oceanic climatological data substantiate the general features of Schott's Charts?

Namias: Although I am not ready to propose anything deserving the designation of a theory, I believe that there are interactions between the North Pacific Anticyclone on the one hand and its Southern Hemisphere counterpart, the South Pacific Anticyclone, whose air circulation affects Peru and its coastal waters. We recognize interrelationships of this sort (called teleconnections) between the semi-permanent high pressure areas of the Northern Hemisphere, and it is quite conceivable that there are similar coupling mechanisms operating between the Northern and Southern Hemisphere cells. In the present case, especially during winter of 1958, the dislocation of the North Pacific High and the westerlies as well (both far south of normal over the eastern North Pacific) was so great it would surprise me if the doldrum belt as well as the position and strength of the South Pacific High were not influenced. In fact, if the southward displacement of wind systems observed in the North Pacific carried into the South Pacific one could account for the weakened (or absent) prevailing southerly winds off the Peruvian Coast which appear to be responsible for *El Niño.*

[1] Some readers of this manuscript have objected to the use of the name *El Niño* to identify the general phenomenon, feeling that previous usage restricts the term to the Peruvian Coast. If a more appropriate generic term can be found, I would recommend its use. I have used *El Niño* in a broad sense to emphasize that the Peruvian *Niño* is *not* a unique phenomenon, but is rather merely a striking example of a wide-spread occurrence.

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