Reports

The Possible Link Between Net Surface Heating and El Niño

Abstract. *Three diagnostic analyses are described which strongly suggest the importance of local net surface heating in the life history of the large-scale, air-sea phenomenon centered in the eastern tropical Pacific Ocean, commonly called El Niño. These analyses rely upon monthly marine weather summaries for the period 1957 to 1976. In the first, correlations and coherence spectra were calculated which show a strong link between the net surface heat flux and sea-surface temperature variations over the eastern equatorial Pacific. The second analysis, also based upon the use of coherence spectra, indicates a sea temperature precursor in the eastern ocean near 25°S which precedes sea temperature changes near the El Niño focus near 5°S. Since the link between the two regions would require ocean advective velocities that appear to be unreasonably large, this analysis also suggests the importance of atmospheric forcing through the surface heat flux. In the third analysis a proxy variable is described that seems to be a reasonable indicator of the overall effect of ocean dynamics on the temperature of the El Niño core region. A composite analysis of the four El Niño events of 1957, 1965, 1972, and 1976 suggests that local surface heating is important during the early part of an event, whereas dynamical factors dominate later.*

Oceanographers and meteorologists have recently been devoting considerable effort to discerning the underlying causes and consequences of the large-scale, ocean-atmosphere phenomenon commonly called El Niño. This is the name given to a period during which unusually warm surface water prevails in the eastern tropical Pacific Ocean; such an event seems to occur approximately every 2 to 6 years, with a duration of a year or longer. The most respected hypothesis describing the development of an El Niño is that first postulated by Wyrtki (*1*). A number of aspects of this hypothesis have been corroborated observationally by Wyrtki (*2*) and others (*3*) and theoretically by a variety of modeling efforts (*4*). Simply put, this hypothesis states that El Niño is preceded by stronger than average easterlies throughout much of the equatorial Pacific region, which results in raised sea level in the western ocean and lowered sea level in the eastern ocean. For as yet unexplained reasons, these winds weaken considerably for a month or more; as a result, there is an eastward-moving equatorially trapped wave in the ocean mixed layer which in the eastern ocean results in higher sea level, a deepened thermocline, and the increased surface temperatures indicative of an El Niño. Furthermore, other waves tend to propagate the higher sea levels and surface temperatures back westward along the equator and poleward along the American coasts.

I discuss here three sets of evidence which strongly suggest that variations in net surface heating in the eastern tropical Pacific also play an important role in the development and demise of El Niño events. The evidence has been derived from an archive of marine weather observations covering the entire tropical Pacific for the period 1957 to 1976 (*5, 6*), from which monthly averages of sea-surface temperature and net surface heating have been derived.

One way of describing the surface-ocean heat balance for a large region is the budget equation for a mixed layer with depth h

$$Q_N = \rho C_p h \frac{\partial \bar{T}}{\partial t} - \rho C_p \left(\frac{\partial \bar{T}}{\partial x} \int_{-h}^{0} u\,dz + \frac{\partial \bar{T}}{\partial y} \int_{-h}^{0} v\,dz + \frac{W_h \Delta T}{2} \right) \tag{1}$$

where Q_N is the net surface heating given as the absorbed solar radiation minus the losses from evaporation, net infrared radiation, and sensible heat (*7*); $\partial \bar{T}/\partial t$ is the rate of change of the average temperature (taken as the surface temperature) of the region to depth h; the terms in parentheses describe the cumulative effects of advection and upwelling.

Figure 1 illustrates the monthly departures from long-term (20-year) monthly

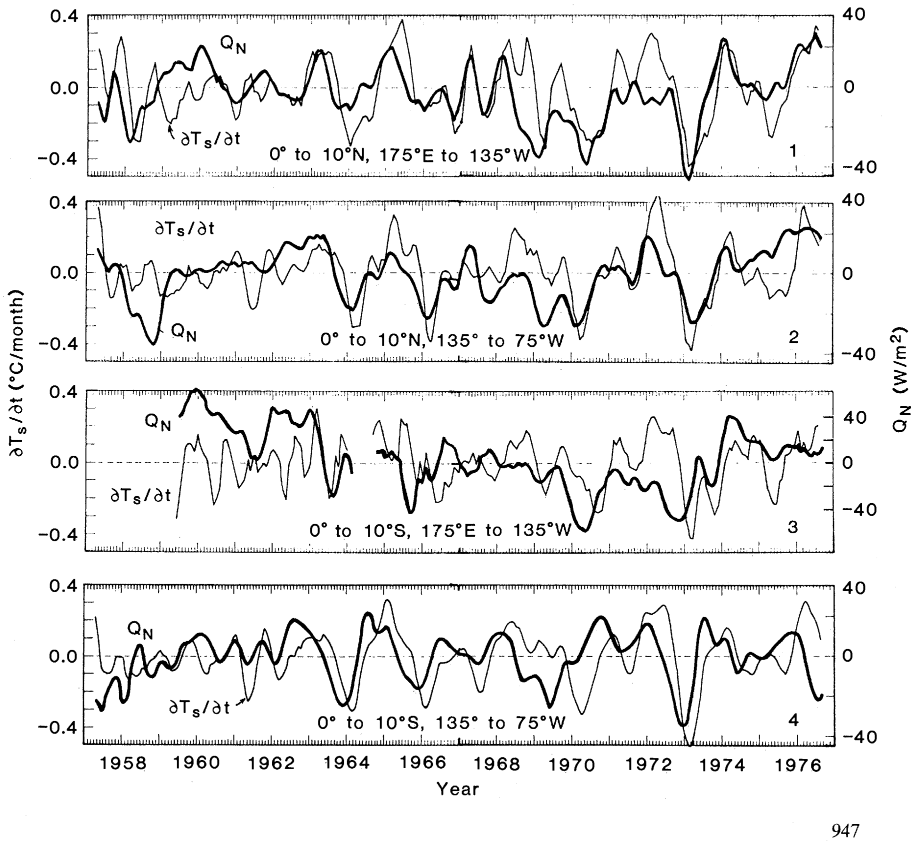

Fig. 1. Monthly departures of net surface heating (Q_N) and the rate of change of sea-surface temperature ($\partial T_s/\partial t$) for regions 1 through 4. The plots have been smoothed with a seven-point binomial filter.

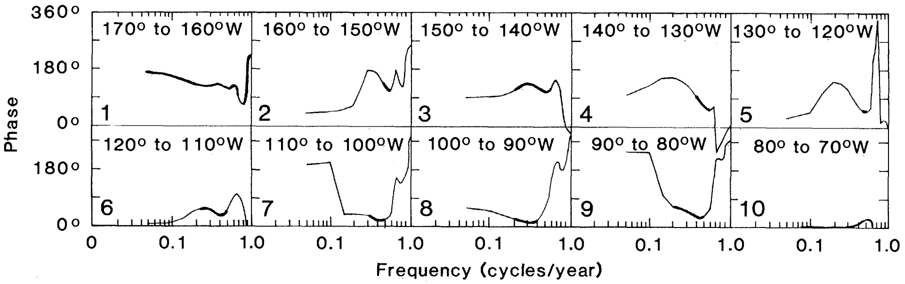

Fig. 2. Phases of the coherence spectra of the sea-surface temperatures in the region 0° to 10°S, 90° to 80°W, and those for 10° regions between 20°S and 30°S. Positive phases indicate that the temperatures near 25°S lead those nearer the equator. The heavier lines show those spectral intervals that have coherence squares of greater than 0.3. The 95 percent confidence intervals about the phases are approximately 20° to 30°.

means of the rate of change of sea-surface temperature ($\partial T_s/\partial t$) and the net surface heat flux (Q_N) for four broad regions in the eastern equatorial Pacific: region 1, 0° to 10°N, 175°E to 135°W; region 2, 0° to 10°N, 135° to 75°W; region 3, 0° to 10°S, 175°E to 135°W; and region 4, 0° to 10°S, 135° to 75°W. The regional average heat flux departures were derived from the departures of 5° subunits. The rate of change of temperature was defined as

$$\left(\frac{\partial T}{\partial t}\right)_i = T_{i+1} - T_i \qquad (2)$$

where T_i and T_{i+1} are the regional surface temperatures for months i and $i + 1$, respectively. Figure 1 indicates moderate to strong relationships between $\partial T_s/\partial t$ and Q_N, especially for regions 1 and 4. There is also a suggestion that variations in Q_N lead those of $\partial T_s/\partial t$ by an average of one or more months.

The inference of a link is confirmed by correlation analyses between Q_N and $\partial T_s/\partial t$ for each of the four regions. The zero lag correlations in all cases are about 0.39. The relationship for the interannual periodicities associated with El Niño is better illustrated by the results of coherence spectra analyses. For spectral periods in the range of 2 to 5 years, Q_N is strongly related to ΔT_s with maximum coherence squares of 0.90, 0.65, 0.55, and 0.90 for regions 1 through 4, respectively. Furthermore, the associated phase spectra indicate that, for the periods of the maxima, Q_N tends to lead $\partial T_s/\partial t$ by approximately 2 to 6 months (*8*).

In a second analysis, which also seems to point out the importance of net surface heat fluxes in El Niño, I considered the variation in sea temperature departures near 25°S and those near 5°S, 85°W. Rasmusson and Carpenter presented evidence suggesting (*6*) that temperature variations east of the date line near 25°S lead by several months those at 5°S near the South American coast. This would seem to be contradictory to the basic Wyrtki hypothesis of variations propagating away from the equator along the South American coast. To better establish this relation statistically, I calculated coherence spectra between sea temperature departures for the 10° grid, 0° to 10°S, 90° to 80°W, and for ten 10° grids between 20°S and 30°S from 70°W to 170°W. Despite the fact that the latter grids have between only 1,500 and 12,900 observations in the entire 20 years of available data, all show coherence squares with the near equatorial region significant at the 95 percent level (*8*). Figure 2 shows the associated phase spectra for each of the coherence pairs. The portions of the plots with heavier lines correspond to those frequencies with significant coherence squares. Although in some cases the regions of significance are quite small, the phases indicate that the variations near 25°S lead those near 5°S by about 0 to 10 months. In addition, there is some suggestion that the phase differences increase as one proceeds westward from the South American coast.

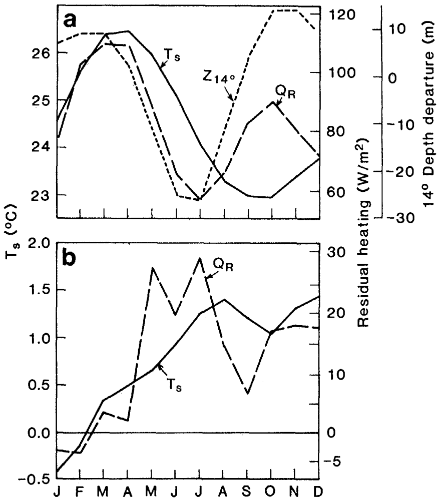

Fig. 3. "Heating residual" for region 4 (0° to 10°S, 135° to 75°W): (a) 20-year monthly mean heating residual (Q_R), 20-year monthly mean sea-surface temperature (T_s), and long-term monthly mean variation in the depth of the 14°C isotherm ($Z_{14°}$); (b) average monthly departures of Q_R and T_s from the 20-year means for the El Niño years of 1957, 1965, 1972, and 1976.

These results are indicative of the importance of surface heating because the currents in the region near 25°S would not seem to be of the proper magnitude and direction (*9*) to account for the phase differences by oceanic advection. In this case, one seems forced to elicit a mechanism involving atmospheric forcing by the surface fluxes resulting in variations near 25°S and the date line followed by those near 25°S and 100°W followed further by those near the South American coast. One might speculate that these changes are associated with the weakening of the South Pacific High, which has been strongly linked to El Niño (*10*).

The third evidence of the importance of surface heating to interannual variations of sea temperatures in the eastern equatorial Pacific may be derived from a reanalysis of Eq. 1. If

$$\rho C_p h \frac{\partial \overline{T}}{\partial t}$$

is subtracted from each side of the equation, then the expression

$$Q_N - \rho C_p h \frac{\partial \overline{T}}{\partial t}$$

is balanced by the three dynamical terms in parentheses. Unfortunately, these dynamical terms have not been directly observed through an El Niño cycle. However, if one assumes that h is a constant mixed-layer depth and $\overline{T} = T_s$, then one may derive a "heating residual" which may be a useful proxy of the sum of the dynamical contributions to the heat budget. Figure 3a shows the 20-year monthly mean values of this residual quantity (Q_R) for region 4, based upon an assumed h of 25 m. This is plotted together with the 20-year monthly mean surface temperature (T_s) and the long-term seasonal variations in the depth of the 14° isotherm ($Z_{14°}$), which Meyers (*11*) has indicated are strongly related to variations in upwelling and thus to the dynamical influences on the surface layer in this region. Both Q_R and the $Z_{14°}$ departures have semiannual cycles (Fig. 3a), despite the lack of such in T_s or Q_N (not shown). Choices of h in the calculation of Q_R that are much larger than 25 m remove the semiannual nature of this term.

Figure 3b shows the departures of Q_R from the 20-year mean for region 4 averaged for each calendar month of the four moderate and strong El Niño years (*12*) in the period 1957 to 1976. This compositing is similar to that recently carried out by Weare (*5*) and Rasmusson and Carpenter (*6*). Figure 3b also shows the corresponding average T_s. During January through April, Q_R stays quite near zero despite the fact that T_s is steadily increasing. Between April and May there is a dramatic increase in Q_R; this result suggests the dominance of the dynamical influences from May onward. One implication that may be drawn from Fig. 3b is that variations in Q_N may explain sea temperature changes in this region in the early phases of an El Niño, but dynamical influences dominate during the subsequent period. If, as suggested by the Wyrtki (*1*) hypothesis, h (in Eq. 1) is increased during El Niño, then Q_R would rise less steeply.

Further confirmation of these results is hampered by the general lack of data for the eastern Pacific, including ship reports, island surface observations, rawinsondes, and oceanic temperature and salinity data at depth. In addition, even if net surface heating is important or even dominant, the more difficult question remains as to the ultimate cause of the heating changes and their relation to the other known variations in the tropical Pacific, especially those related to the Wyrtki hypothesis. One might speculate that the heating and dynamical changes are both necessary for El Niño and that a full-fledged event occurs only when both processes are in proper phase. This might help to explain the apparent collapse of the early stages of an El Niño event in 1975 (*13*).

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Single Gene Mutations in Tomato Plants Regenerated from Tissue Culture

Abstract. *Plants were regenerated from cultured leaf explants of an inbred variety of* Lycopersicon esculentum. *Seeds were collected from the regenerated plants and sown in the greenhouse. The resultant plants were then evaluated in the field. Several monogenic mutations segregated in the progeny of regenerated plants. The recovery of single gene mutations is evidence that plant tissue culture can be mutagenic. Complementation tests revealed that one mutation was located on the long arm of chromosome 10.*

Tissue culture techniques, particularly shoot tip culture and somatic embryogenesis, have been advocated as methods for regenerating large numbers of genetically identical clones (*1*). However, extended culture periods can result in cell lines and regenerated plants with chromosomal abnormalities (*2*). Aneuploid and polyploid regenerated plants have been reported in many species, including tobacco, *Crepis*, and sugarcane (*3*). Larkin and Scowcroft (*4*) suggested that this variation among regenerated plants could be useful for the development of new cultivars. A component of the culture medium that is capable of inducing chromosomal variation could also cause nuclear gene mutation. If most of the nonchromosomal variation in regenerated plants has a genetic basis, plant regeneration in vitro could be used to introduce genetic variability rapidly into sexually propagated crop varieties. We have examined the variability in self-fertilized progeny of a large number of plants regenerated from leaf explants of a cultivar of a typical diploid seed–propagated species, the tomato *Lycopersicon esculentum* Mill., to ascertain to what extent the variation is sexually transmitted. We report on 13 morphological traits observed among regenerated plants, their sexual transmission, and their genetic characterization as controlled by single nuclear genes.

Seeds of a standard inbred tomato cultivar, UC82B (*5*), were used as a source of ten donor plants that were identified morphologically as typical of this cultivar. Young, fully expanded tomato leaves, after being sterilized at their surfaces, were placed on a culture medium (*6*). No known mutagens or extraneous chemicals were added to the culture medium. A callus mass developed shortly after inoculation and the first shoots were regenerated in 3 to 4 weeks. All regenerated shoots were transferred to a rooting medium (*7*) that was modified by adding $2\ \mu M$ 1-naphthalene acetic acid. One to three plants were recovered from each explant that regenerated shoots.

Regenerated plants (*R*) were transferred to a greenhouse where observations were made on the morphological variation (*8*). The regenerated plants were self-fertilized, and seed was collected from each regenerated plant to evaluate the next (R_1) generation. Seed collected from 230 regenerated UC82B plants were sown in greenhouse flats to screen for seedling characters before transplanting the seedlings into the field. Progeny of each of the 230 plants (a total of at least 11,040 tissue culture–derived plants) were evaluated in replicated plots in the field in 1980 or 1981. Additional data were collected on self-fertilized R_1 and R_2 plants and on segregating populations of specific crosses (*9*).

As expected, chromosomal variation (particularly 4n = 48 autotetraploidy) was frequently observed among the regenerated plants, but attention was directed instead to fertile variants whose R_1 progenies segregated for distinct morphological characters. Although some progenies appeared to segregate for new phenotypes, several were identified as being phenotypically similar to mutants reported previously. By examining the R_1 seedlings in the greenhouse and the R_1 plants in field plots, we identified 13 putative nuclear gene mutations arising from the 230 regenerated plants. No mutants were observed among more than 2000 plants from the seed of UC82B used as donor material. An examination of R_1 segregation data suggested that most of the variants originated by simple Mendelian mutation (Table 1). Each variant was regenerated from a separate leaf explant and, as far as we can determine, was a separate mutational event. A detailed analysis of single plant selections of generation R_2 was completed in the greenhouse for 9 of the 13 plants. The expression of two traits, *ms-tc1* and *G-tc1*, was highly variable in the greenhouse and could not be classified adequately, suggesting temperature sensitivity. An evaluation of R_2 seed of plants expressing *ms-tc1*, however, was completed in the field, where phenotypes were distinct. All of the remaining characters (Table 1) could be equally easily classified in field or greenhouse conditions. For all the