Reports

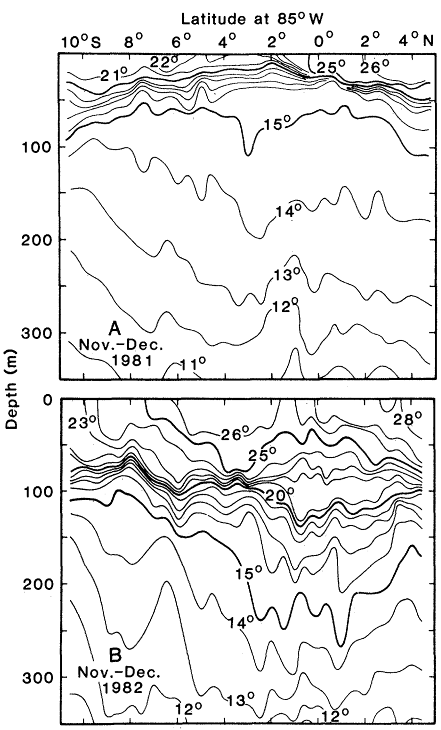
Oceanographic Observations of the 1982 Warming of the Tropical Eastern Pacific

Abstract. *Moored current meter, sea level, hydrographic, and surface drifter measurements show the large changes that took place in the eastern tropical Pacific during the onset of the warm episode of 1982. In August the near-surface flow at 0°, 110°W reversed direction to eastward. By October the sea surface temperature in the equatorial zone increased by 5 degrees Celsius above the long-term monthly mean value, sea level rose by 22 centimeters at the Galápagos Islands, and the thermocline was displaced downward by 50 to 70 meters along the equator and the South American coast.*

The interannual appearance of exceptionally warm surface waters in the central and eastern tropical Pacific Ocean and along South America is referred to as El Niño (*1*). Such an event began in 1982 and, as of April 1983, is still in progress. The socioeconomic effects on the coastal regions of Ecuador and Peru have been disastrous: a tremendous increase in rainfall, flooding and landslides, damage to transportation facilities, huge agricultural losses, disturbance of many coastal fisheries, and loss of life (*2*). Such episodes of anomalously warm water may be associated with abnormal weather over the mid-latitude regions of the Northern Hemisphere—for instance, lower atmospheric pressure in the vicinity of the Aleutian Low and large perturbations in the seasonal position of the jet stream over North America (*3*).

In 1982 El Niño started in the western and central Pacific Ocean, where strongly anomalous trade winds first appeared in July 1982. Sea surface temperature anomalies subsequently expanded until, by October and November 1982, sea surface temperatures in the eastern Pacific were approximately 5°C warmer than the 20-year monthly mean value (*4*). [Most Niños, those of 1972 and 1976 for example, have evolved quite differently because warm sea surface temperatures usually first appear off the coasts of Ecuador and Peru during the early months of the year and then expand westward until the entire Pacific is affected 6 months later (*5*).] The current Niño, which is considered to be one of the largest events during the past 100 years, is the best documented one yet, in large measure because the Equatorial Pacific Ocean Climate Studies (EPOCS) program of the National Oceanic and Atmospheric Administration started in 1979. The EPOCS program includes a variety of oceanic measurements with current and temperature recorders placed beneath moored surface buoys, with satellite-tracked drifting buoys, with sea level recorders located on islands, and with temperature, salinity, and velocity profiling instruments lowered from research vessels. This report describes some of these measurements and contrasts conditions during the 1982 El Niño with normal conditions.

The unusual oceanographic conditions during El Niño are not confined to the surface of the ocean but are observed to depths of hundreds of meters. This is evident in Fig. 1, for example. In November–December 1981 the thermocline (defined as the region between the 25° and 15°C isotherms) at the equator was about 40 m thick and the depth of its center (defined by the 20°C isotherm) was about 40 m. A year later, in November–December 1982, the equatorial thermocline was nearly twice as thick and twice as deep. In fact, the entire thermocline along 85°W from 4°N to 10°S (the boundaries of our measurements) was 50 m deeper. Sections normal to the South American coast at 5°S and 10°S also showed an anomalous deepening of the thermocline. Clearly, by November–De-



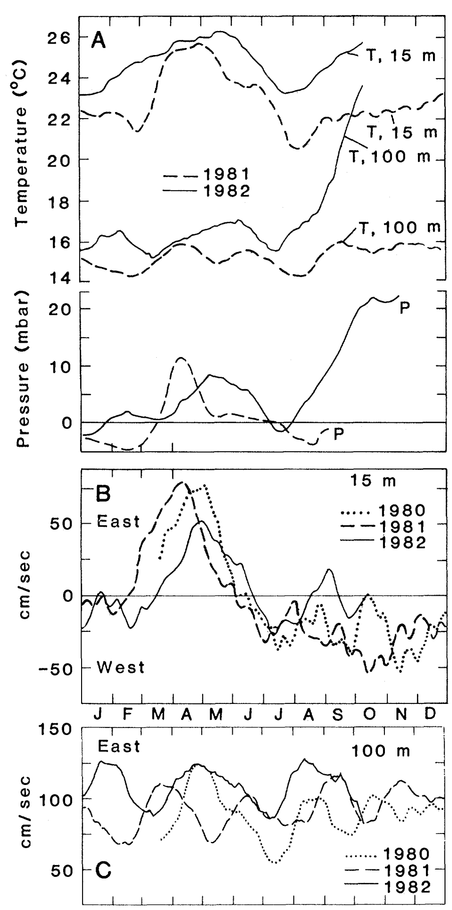


Fig. 1 (left). Temperature sections along 85°W in November–December in (A) 1981 and (B) 1982. Station spacing was 0.5°. Fig. 2 (right). (A) Low-pass filtered time series (31-day running averages) of temperature (*T*) at 15- and 100-m depths and 0°, 110°W, and pressure (*P*) at 20-m depths at the Galápagos Islands. The pressure fluctuation in millibars is equivalent to sea level variation in centimeters. Pressure and temperature data are shown for 1981 and 1982. (B and C) Low-pass filtered time series (31-day running averages) of east-west current component at 15- and 100-m depths and 0°, 110°W; nearly 2.5 years of data are shown.

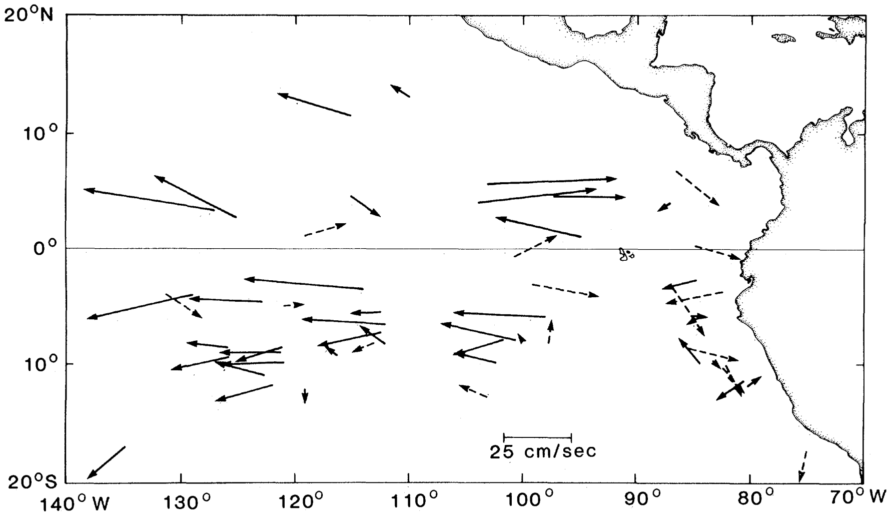


Fig. 3. Net movements of drogued surface buoys during December. Solid arrows show displacements from beginning to end of December 1979, 1980, 1981. Broken arrows show those for December 1982.

cember 1982 there was a large accumulation of unusually warm water in the eastern tropical Pacific Ocean. This accumulation of warm water produced an increase in sea level primarily because of the temperature-dependent steric effect. The difference in the dynamic height anomaly between the surface and 1000 decibars was nearly 30 dynamic centimeters between November 1981 and November 1982—comparable to the sea level change observed at the Galápagos Islands (Fig. 2). The rise in sea level at the Galápagos Islands started toward the end of July 1982. By October the sea level was 22 cm higher than the long-term mean for that month and was as high as it had been in November 1972 during El Niño of that year (*6*). The increase in sea level at the Galápagos Islands was accompanied by a sharp increase in the temperature at a depth of 100 m and a less pronounced increase near the surface at 110°W on the equator (Fig. 2). Between mid-July and mid-October the monthly average increase in heat storage of the upper 100 m of the ocean at 0°, 110°W was about 250 W/m^2. This change is more than 2½ times greater than the climatological mean surface heating for that season (*7*) and was caused by changes in the flow field.

Surface currents in the eastern tropical Pacific have been measured with satellite-tracked drifter buoys since 1979 (*8*). Normally these buoys are carried away from the equator by the wind-driven equatorial divergence and upwelling. Beginning in August 1982, several buoys were carried toward or even across the equator. The monthly displacements during December for the years 1979–1981 and those for December 1982 are shown in Fig. 3. The vectors for 1979–1981 show a predominance of westward flow except in the region where the North Equatorial Countercurrent is found between about 5° and 8°N. To the east of 90°W the magnitude of the westward flow decreases; at about 10°S there has been some suggestion of southwestward flow outward from the coast. In contrast, the December 1982 vectors indicate a predominance of eastward flow within about 5° of the equator and also some southward flow along the coast of Peru and Chile, opposite to the local wind. The westward flow that occurred south of about 5°S and west of 90°W was weaker and more disorganized than during prior years. These observations suggest that warmer equatorial water was being transported into the eastern Pacific instead of the normal offshore transport of cooler coastally upwelled waters. In January 1983 the near-equatorial surface currents again turned westward, and exceptionally large speeds, up to 80 cm/sec, have been observed.

Measurements that describe the current and temperature fluctuations on the equator near 110°W have been made at several depths between 15 and 250 m since March 1980 (*9*). The striking features in these records are the strong seasonal variations in the surface layers and the near absence of such a variation at depths of 100 m and more (Fig. 2). For example, in 1981, which was a normal year, the near-surface currents at 15-m depth were eastward and the sea surface temperatures were high in March through May, when the intensity of the westward trade winds was at a minimum. In September and October 1981, when the trades were intense, the near-surface flow was westward and near-surface temperatures were low (Fig. 2). In 1982 the currents followed the seasonal cycle during the early part of the year, but in July 1982 (when the sea level and sea surface temperature at the Galápagos Islands started to increase) the westward surface flow decelerated and by late August the surface flow was eastward. The surface currents subsequently fluctuated while the temperature and sea level continued to increase monotonically.

Our measurements seem to confirm theoretical results (*10*) concerning the variability of upper ocean equatorial circulation. The 1982–1983 warm event is the best documented one yet. Further analysis of measurements from other locations is necessary to determine exactly how the eastward transport of unusually warm surface waters occurred. The measurements made during the current El Niño are likely to provide answers to many questions concerning its initiation, growth, and final decay.

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References and Notes

1. According to the definition of the Scientific Committee on Oceanic Research (Working Group 55), El Niño occurs when the monthly mean departures of sea surface temperature from the 25-year long-term monthly mean values exceed 1 standard deviation for four consecutive months at three of five coastal stations of Peru. These stations are at Talara, Puerto Chicama, Chimbote, Isla Don Martin, and Callao. At the end of 1982, surface temperatures exceeded the long-term means by five or more standard deviations at most of these stations.
2. *New York Daily News*, 20 March 1983; *Wall Street Journal*, 24 March 1983; *Time*, 11 April 1983.
3. J. D. Horel and J. M. Wallace, *Mon. Weather Rev.* **109**, 813 (1981).
4. Two widely used monthly averaged sea surface temperature maps are F. Miller's hand-drawn charts (available from NOAA NMFS, P.O. Box 271, La Jolla, Calif. 92038) of ship observations and the National Meteorological Center's computer-generated chart (available from *Oceanic Monthly Summary*, NOAA W/NMC21, Washington, D.C. 20233) of ship and satellite data.
5. E. M. Rasmusson and T. H. Carpenter, *Mon. Weather Rev.* **110**, 354 (1982).
6. K. Wyrtki, *J. Phys. Oceanogr.* **7**, 779 (1977).
7. B. C. Weare, P. T. Strub, M. D. Samuel, *Contributions to Atmospheric Sciences No. 20* (Department of Land, Air and Water Resources, University of California, Davis, 1980).
8. Lagrangian current measurements were made from successive displacements at 4- to 8-hour intervals of satellite-tracked surface buoys drogued at 15-m depth.

9. Current and temperature measurements were made at several (up to seven) depths between 15 and 250 m with vector-averaging current meters (VACM) suspended beneath surface buoys tautly moored at 0°, 109°30'W from March 1980 until April 1982 and at 0°, 108°W from April to October 1982. The 108°W data are used to extend to 109°30'W time series beyond April 1982. Previous current measurements recorded simultaneously at 0°, 109°30'W and 0°, 110°30'W for 100 days in 1979 showed that there is little amplitude or phase difference in the currents for short zonal separations at these longitudes for frequencies less than 0.25 cycle per day. Vector-averaging wind recorder measurements at 3.5-m height were also recorded routinely. All data were recorded at 15-minute intervals and water depth was about 3.4 km. Deployment intervals were about 6 months. Previous studies [D. Halpern *et al.*, *J. Geophys. Res.* **86**, 419 (1981)] of upper ocean VACM measurements in deep water regions showed that at frequencies below 0.3 cycle per hour the amplitudes of current fluctuations recorded by VACM suspended within the upper 100 m beneath a surface-following buoy were only 5 to 10 percent larger than corresponding measurements made beneath a spar buoy or subsurface buoy.
10. S. G. H. Philander and R. C. Pacanowski, *J. Geophys. Res.* **86**, 1903 (1981).
11. Contribution No. 618 from the NOAA/ERL Pacific Marine Environmental Laboratory.

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Siphonodictidine, a Metabolite of the Burrowing Sponge *Siphonodictyon* sp. That Inhibits Coral Growth

Abstract. *Siphonodictidine is the major secondary metabolite of an undescribed Indo-Pacific sponge* Siphonodictyon *sp. that burrows into living coral heads. The structure of siphonodictidine was determined from spectral data. Laboratory bioassays suggest that siphonodictidine and, by analogy, the siphonodictyals from* S. coralliphagum *are responsible for maintaining zones of dead coral polyps around the oscular chimneys of these sponges.*

Most burrowing sponges, like the relatively common *Cliona* species, burrow into shells, rocks, or dead corals. A few sponges, such as *Siphonodictyon coralliphagum* (*1*) from the Caribbean and the undescribed *Siphonodictyon* species (*2*) burrow deep into living coral heads, leaving only the oscular chimneys exposed. In order to survive, these sponges must be able to prevent overgrowth by the coral polyps and are observed to have a 1- to 2-cm zone of dead coral polyps around the base of each oscular chimney. Rützler (*1*) suggested that the dead zone was maintained by the production of mucus that flowed down the oscular chimney and spread around the base. We contend that the mucus acts as a carrier for secondary metabolites that are toxic to coral polyps. We now report the structure of a toxic secondary metabolite, siphonodictidine (**1**) from the Indo-Pacific *Siphonodictyon* species and present evidence to support the hypothesis that **1** is responsible for inhibiting coral growth around the base of the oscular chimney.

While collecting marine organisms at Palau, Western Caroline Islands (*3*), we encountered a sponge that was similar in appearance and habitat to the burrowing sponge *S. coralliphagum*, except that the protruding oscular chimneys were an off-white color in contrast to the familiar yellow oscular chimneys of *S. coralliphagum*. Only the oscular chimneys of the undescribed *Siphonodictyon* sp. could be collected, but even after collection the sponge material exuded a sticky mucus. The ethyl acetate soluble material from a methanol extract of the sponge was chromatographed on a Sephadex LH-20 column with methanol as eluant. Fractions that showed antimicrobial activity against *Staphylococcus aureus* and *Bacillus subtilis* were combined and chromatographed again on Sephadex LH-20 with a mixture of dichloromethane and methanol (1:1) as eluant, and obtained siphonodictidine (**1**, 1.06 percent, dry weight) as the major metabolite (*4*).

Table 1. Hydrogen nuclear magnetic resonance (NMR) data for siphonodictidine (**1**), marislin (**3**) and hydroquinone **4**; recorded in $CDCl_3$ solution at 360 MHz (except at 100 MHz for **4**) with internal tetramethylsilane as standard ($\delta = 0$). Abbreviations: s, singlet; t, triplet; m, multiplet; and J, coupling constant.

H at	1	3	4
C-1	3.78 (t, 2 H, J = 7 Hz)		3.35
C-2	5.21 (t, 1 H, J = 7 Hz)	5.73	5.3
C-4	2.05 (m, 2 H)	~ 2.2	~ 2.15
C-5	2.12 (m, 2 H)	~ 2.2	~ 2.15
C-6	5.18 (t, 1 H, J = 7 Hz)	5.18	5.3
C-8	3.22 (s, 2 H)	3.22	3.3
C-10	5.86 (s, 1 H)	5.86	5.95
C-12	7.06 (s, 1 H)	7.06	7.1
C-13	1.97 (s, 3 H)	1.98	2.0
C-14	1.58 (s, 3 H)	1.60	1.65
C-15	1.68 (s, 3 H)	2.20	1.75

Siphonodictidine (**1**) had the molecular formula $C_{16}H_{25}N_3O$. A positive Sakaguchi test (*5*) and a signal at δ 157.4 in the ^{13}C nuclear magnetic resonance (NMR) spectrum indicated the presence of a guanidine group. Condensation of **1** with 2,4-pentanedione yielded the corresponding 4,6-dimethylpyrimidine derivative **2**, confirming the presence of the guanidine group (*6*).

The sesquiterpenoid portion of **1** was identified by interpretation of the spectral data. Comparison of the ^1H NMR data (Table 1) and ^{13}C NMR data (Table 2) of **1** with those of the model compounds marislin (**3**) from *Chromodoris marislae* (*7*) and the hydroquinone **4** from *Sinularia lochmodes* (*8*), indicated that the molecules were identical in the C-4 to C-14 region. In the ^1H NMR spectrum ($CDCl_3$) the signal at δ 3.76 (t, 1 H, J = 7 Hz), coupled to a NH proton signal at 7.80 (br t, 1 H) and an olefinic proton signal at 5.21 (br t, 1 H, J = 7 Hz), was assigned to the C-1 methylene group attached to the guanidine group. Addition of methanol-d_4 to the sample resulted in exchange of the -NH protons causing the signal at δ 3.78 to appear as a sharp doublet. The major mass spectral fragmentation peaks at m/z of 126 (100 percent, $C_6H_{12}N_3$), 148 (7.6 percent, $C_{10}H_{12}O$), and 149 (5 percent, $C_{10}H_{13}O$) result from cleavage of the bond between C-4 and C-5.

In laboratory assays measuring rates of photosynthesis and respiration in the hard coral *Acropora formosa* (*9*), respiration was stimulated by **1** at concentrations of 10^{-2} to 10^{-1} ppm in seawater. The rate of photosynthesis was unaffected at these concentrations but was slightly depressed at concentrations over 10 ppm. At a concentration of 100 ppm acute toxicity was observed with cell lysis occurring as the tissue was stripped from the skeleton. At the higher concentration, **1** was a quick-acting toxin, showing an effect in 5 to 30 minutes. However, its effects on photosynthesis and particularly respiration in *A. formo-*

Table 2. Carbon-13 nuclear magnetic resonance data for siphonodictidine (**1**), marislin (**3**), and hydroquinone (**4**); recorded in $CDCl_3$ solution (C_6D_6 for **3**) at 20 MHz with internal tetramethylsilane as standard ($\delta = 0$).

Atom	1	3	4
C-1	39.6*	188.8	28.8
C-2	117.8	115.4	122.9†
C-3	141.2	162.3	137.6†
C-4	39.0*	40.7	39.6
C-5	26.2	26.0	26.5
C-6	125.5	125.4	126.2†
C-7	132.2	133.0	132.3†
C-8	38.2*	38.7	38.4
C-9	153.9	154.5	154.3
C-10	108.6	109.2	108.8
C-11	120.3	120.7	120.5
C-12	137.4	138.2	137.6
C-13	9.6	9.8	9.7
C-14	15.9*	15.9	16.0
C-15	16.3*	19.0	16.0

*Signals may be interchanged. †We have reassigned these signals.