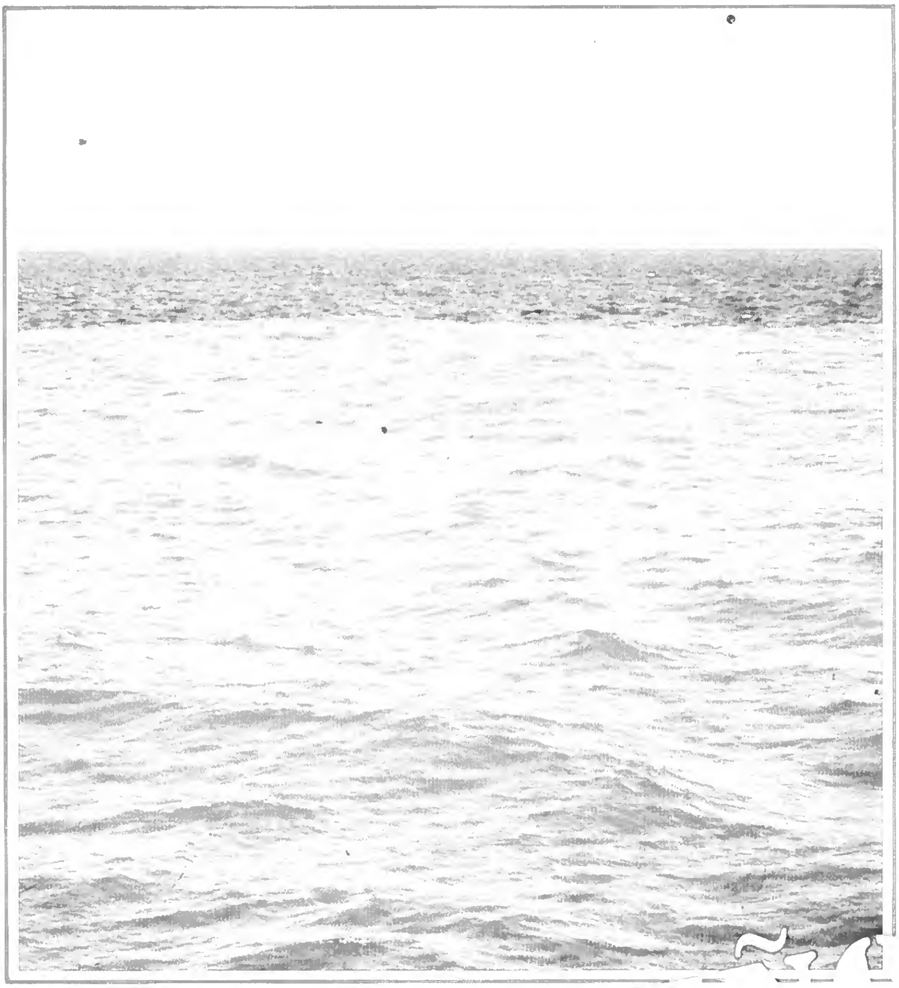

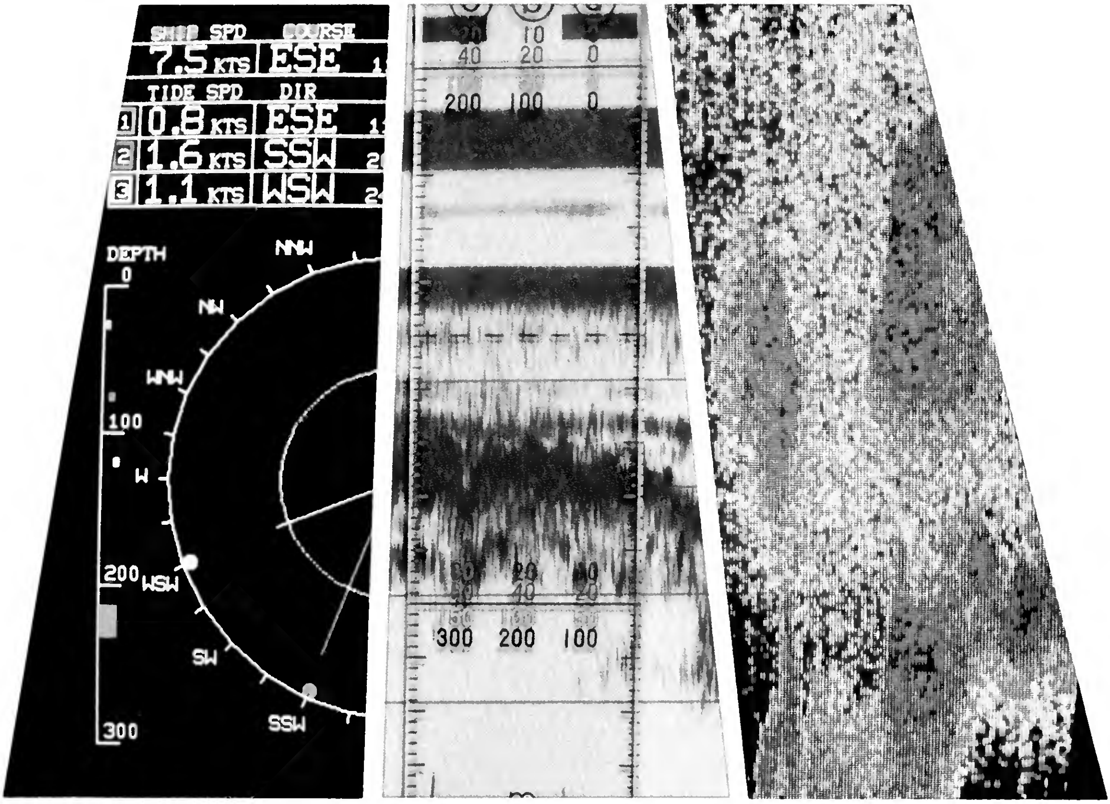

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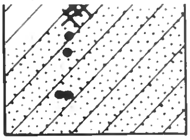

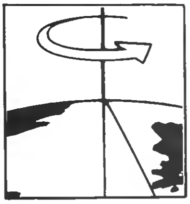

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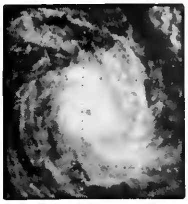

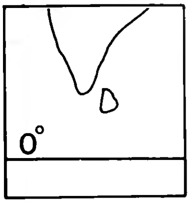

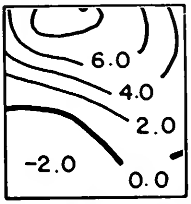

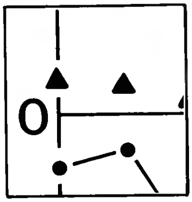

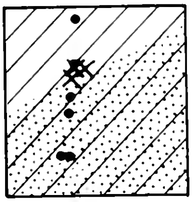

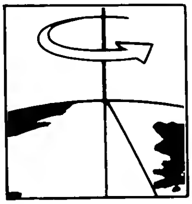

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The Cover: El Niño waters two miles off Huacho, Peru, in January, 1983. The light blue indicates upwelling, the darker blue, warm waters. Photo by Wolf Arntz. Concept by E. Kevin King.

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Introduction: The 1982–83 El Niño

Oceanographers talk about ocean climate, partly as an analogy to our atmospheric climate, but mainly in terms of the close relation of atmosphere and ocean. The analogy is relevant to what we need to know. Certainly we must try to understand the regular cycles of ocean climate—diurnal or seasonal—but it is the departures from average patterns that are crucial to our social systems. We have learned to make some predictions—as far as about 10 days. Thus, we can separate weather from climate, and realize that for the latter we shall need different concepts—concepts that include the ocean as a central element.

Our historical records reveal not only year-to-year weather variability, but longer term trends in climate: little ice ages, and the recent slight temperature maximum in the Northern Hemisphere. There is general agreement about some atmospheric temperature increase due to the increasing carbon dioxide in the atmosphere and resulting potential greenhouse effect. However, there is less agreement about the magnitude of this effect and, especially, the time scale on which it may occur. The critical factor is the role of the oceans. Ocean circulation is influenced by atmospheric temperature and winds, so we can expect changes in the ocean following changes in the atmosphere. How, in turn, will changes in ocean circulation affect the atmosphere? The ocean, because of its great heat capacity, absorbs much of the short-term diurnal or seasonal temperature cycles and so not only ameliorates local coastal climates, but moderates the global system. This damping effect of the ocean is essential for short-term smoothing through long-term trends. How does the feedback between ocean and atmosphere work? Is it responsible for the geologically sudden (less than 100 years), very large changes in atmospheric carbon dioxide that we are discovering by sampling air in glacial ice cores? These questions stress the need for a comprehensive view of the world's oceans as a dynamic system, subject to change, particularly at decadal time scales; changes which in turn can perturb the chemical and biological cycles on Earth. Where are we now? We have a static description of the distribution of certain major nutrients. We have detailed studies of the dynamics of particular features, such as Gulf Stream meanders. We are rapidly developing insight into the processes transferring carbon and nutrients between the upper water layers and the deep ocean. We are developing theories about the ocean's physical and chemical systems. But, even more important, we have a suite of new techniques—satellite sensing, for studying the physics and biology of the upper ocean layers; acoustic tomography and floats, for describing internal structure and movements; computer simulations of ocean dynamics, for comparing theory and observation. Can all these elements be put together in a coherent scheme? This is possibly the single most important question facing the oceanographic community today, comparable to the start of the Ocean Drilling Program more than a decade ago.

As scientists, we would like to conduct an experiment, but in the strict sense this is impossible. However, natural systems occasionally have very large fluctuations that occur as highly significant, short-lived departures from the average state of the system. Such natural "experiments" allow us to study the response of the system in a semi-experimental way. At the same time, these large perturbations can have significant social consequences, creating a context for an examination of human issues as well as scientific priorities. El Niño, an event in the tropical Pacific, is such an experiment, focusing scientists' attention on air/sea interactions on the global scale and, on the human scale, on events of social significance that extend to the middle of the continents. We are still in the process of analyzing and interpreting the data gathered from recent events. Thus, it is appropriate to ask oceanographic and atmospheric scientists involved in these studies to report on their results.

The 1982–83 El Niño was a unique event in the oceans and atmosphere. As the articles in this issue disclose, no two El Niños are alike; but if the underlying physics and dynamics can be determined, a theory may be forthcoming that embraces the significant features of climate change. As the lead article by Dr. Rasmusson explains, this is a fascinating tale of scientific progress, revealing "an elegant system of physical and ecological interactions."

John H. Steele,
Director,
Woods Hole
Oceanographic Institution

El Niño: The Ocean/Atmosphere Connection

by Eugene M. Rasmusson

El Niño, a striking example of large-scale interannual ocean variability, is even more significant when viewed in the grander context of global climate variability. This oceanic event, once thought to be of limited interest, is in reality a key part of the complex system of climate fluctuations now referred to as the El Niño/Southern Oscillation (ENSO) phenomenon. ENSO is the dominant global climate signal on time scales of a few months to a few years. It is associated with major dislocations of the rainfall regimes in the tropics, which bring drought to productive agricultural areas and torrential rains to otherwise arid regions. ENSO circulation anomalies also extend deep into the extratropics, bringing unusual wintertime conditions to mid-latitude locations as far apart as the United States and New Zealand.

The intense interest in ENSO is of fairly recent origin. Even as late as the middle 1960s, El Niño was viewed primarily as a regional phenomenon, while the atmospheric Southern Oscillation, discovered more than 40 years earlier, was still dismissed by most meteorologists as no more than an interesting curiosity. This state of affairs was noted by A. J. Troup, a well-known Australian meteorologist, when he complained in 1965 that "at present the phenomenon known as the 'Southern Oscillation' receives little attention." The linking of the Southern Oscillation and El Niño in the late 1960s generated a surge of interest and a general recognition of the potential importance of ENSO to seasonal-interannual climate prediction. This story of how diverse lines of oceanographic and meteorological research finally converged to reveal an elegant system of physical and ecological interactions is a fascinating tale of scientific progress.

Walker and the Southern Oscillation

The story of the Southern Oscillation begins 80 years ago with the appointment of a Cambridge University mathematician named Gilbert Walker to the post of Director-General of Observatories in India. Walker was a man of broad interests, having published papers on such diverse topics as electromagnetism, games and sports, and the flight of birds. His interest in primitive projectiles, particularly the boomerang, resulted in his being nicknamed "Boomerang Walker" by his Cambridge friends. Ever the Renaissance man, his interest in music as well as science led him to develop improvements in the design of the flute after his retirement.

Life in India was and still is largely at the mercy of a notoriously fickle feature of the climate system, the summer monsoon. During June through September of most years the monsoon provides the life-giving moisture needed for the socioeconomic well-being of the nation. All too often, however, rains are excessive or, even worse, inadequate, leading to drought, crop failure, and—in the more extreme monsoon failures—to widespread famine and starvation.

Walker arrived in India in 1904, shortly after the great famine of 1899–1900. From the beginning, he set his mind to finding sound methods for forecasting the year-to-year fluctuations in the monsoon. His predecessors had begun this effort following the catastrophic monsoon failure of 1877; their approach, which centered mostly on the search for predictors in the immediate neighborhood of the subcontinent, had produced little in the way of practical results. Walker was aware of recent evidence that indicated a tendency of the surface pressure in the Indian-Australian and South American regions to swing like a giant seesaw over periods of a few years. This reinforced his view that the monsoon was a global-scale phenomenon, and he set out to document large-scale fluctuations in the hope that they held the key to monsoon forecasting. To accomplish this, he set a small army of statisticians and clerks to work computing hundreds of correlations between surface pressure, temperature, and rainfall data from meteorological stations around the world. Even such unlikely parameters as sunspots and the magnitude of the annual flood of the Nile were fed into his statistical black box.

An early synthesis of results was published in 1923 and 1924. The correlations, Walker said, demonstrated the existence of three large atmospheric oscillations: Two "Northern Oscillations," centered in the North Atlantic and the North Pacific, and a larger, more pervasive "Southern Oscillation" (SO), whose centers of action were in the tropics. In a later paper he characterized the SO in the following terms: "When pressure is high in the Pacific Ocean it tends to be low in the Indian Ocean from Africa to Australia; these conditions are associated with low temperatures in both these areas, and rainfall varies in the opposite direction to pressure" (Figure 1).

In the wake of El Niño: charred blackboys (grass trees) and treetrunks, all that remain where bushfires swept the coastline of Victoria, Australia, in February 1983. (Photo by Bill Bachman, Photo Researchers)

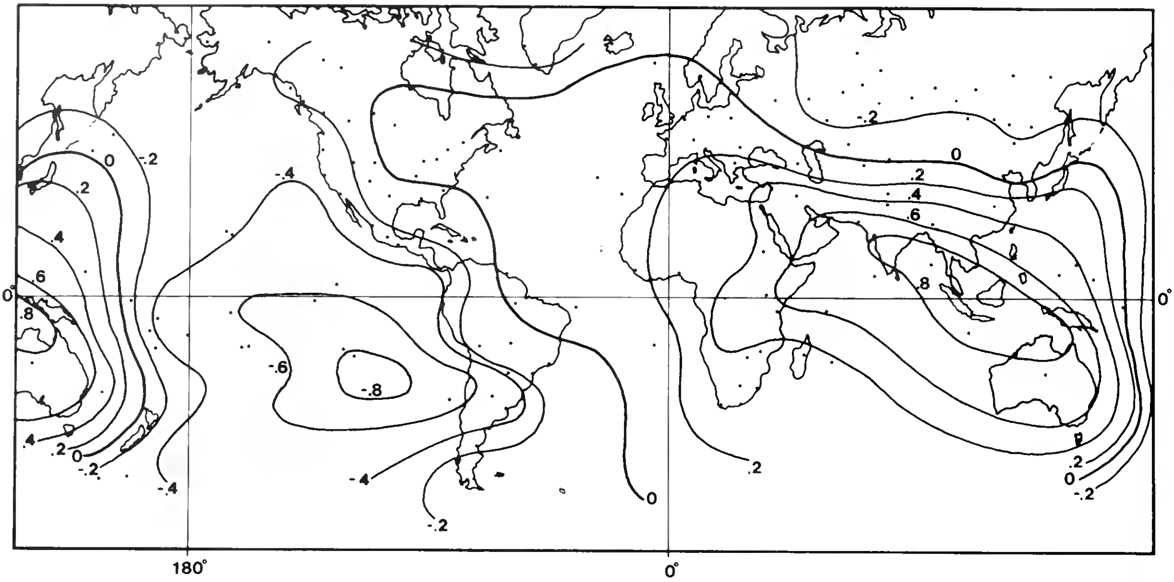

Figure 1. Walker's Southern Oscillation as presented by Berlage in 1957. The map shows the worldwide distribution of correlations of annual pressure anomalies with simultaneous anomalies at Djakarta, Indonesia.

From the beginning, Walker's results were controversial. The long-term stability of the oscillations was questioned, largely because his conclusions were drawn entirely from a mass of correlation coefficients derived from relatively short time series, with no *a priori* hypotheses or theoretical support. After all, it was pointed out, these relationships might change with time, for with so many correlations a few will appear significant simply by chance, even if the data consist of nothing more than series of random numbers. Walker countered by pointing out that he drew conclusions only when the correlations showed a homogenous pattern over a large region.

Questions were raised concerning the more remote mid-latitude connections as, for example, the correlation between the SO and the pressure at Charleston, South Carolina. In answer to this criticism he wrote prophetically:

> *I think the relationships of world weather are so complex that our only chance of explaining them is to accumulate the facts empirically. . .there is a strong presumption that when we have data of the pressure and temperature at 10 and 20 kilometers, [Walker had only surface data], we shall find a number of new relations that are of vital importance.*

Although Walker continued his studies of the SO after his return to England in 1924, his efforts to translate these findings into a skillful predictive relationship for the Indian monsoon were largely unsuccessful. He was knighted for his work in India, and, according to his biographer, "this and other honors he wore lightly and ever remained modest, kindly, liberal minded, wide of interest and a very perfect gentleman." He died in 1958, at the age of 90, with the El Niño/Southern Oscillation link still unknown, but on the verge of being revealed.

The Ocean Connection

Walker recognized the likelihood of an ocean role in the memory mechanism of the SO, but the sea-surface temperature and subsurface data available to him were hardly adequate for quantifying such a relationship. It took a combination of better data and an act of nature, which coincidentally occurred during the last two years of Walker's life, to set investigators on the trail that led to the linking of El Niño and the SO.

The key climate event was the occurrence in 1957–58 (during the International Geophysical Year) of a remarkably strong pattern of anomalies over the Pacific Basin in both ocean and atmosphere. These fluctuations caught the attention of a small group of scientists interested in relating large-scale sea/air interactions to short-term climate variability. Among this group was Jacob Bjerknes, a distinguished meteorologist in the golden years of his career, who had been transplanted from Norway to the University of California at Los Angeles (UCLA) during World War II. As a young scientist, Bjerknes made landmark contributions to the theory of airmass analysis, fronts, and extratropical cyclones, after which he spent many years studying the general circulation of the atmosphere. His studies of ocean/atmosphere interaction were first focused on the North Atlantic, but, after the events of 1957–58, he shifted his attention to the tropical Pacific.

The initial analysis of the 1957–58 ocean/atmosphere data revealed some intriguing facts.

> 1) The strongest El Niño since 1940–41 occurred in 1957 (Figure 2), but the ocean warming, instead of being limited to the eastern Pacific,

extended westward along the equator all the way to the dateline, one quarter of the distance around the world. Was the occurrence of this large-scale warming and the El Niño merely coincidental?

2) Easterly trade winds were relatively weak, and rainfall was excessive in the central equatorial Pacific. A relationship between weak tradewinds and the infrequent wet periods that punctuate this otherwise arid region had been noted in 1921, before Walker's first paper on the SO was published. However, this was the first evidence that the wind and rainfall anomalies might be linked to above-normal sea-surface temperature.

3) Pronounced 1957–58 wintertime circulation anomalies were observed in the atmosphere over the eastern North Pacific, in the form of stronger-than-normal westerlies and an unusually intense Aleutian low-pressure center. Were these anomalies related to tropical conditions?

In 1966, Bjerknes suggested that the 1957–58 pattern of equatorial anomalies was not unique, but had occurred with earlier El Niños. Furthermore, he hypothesized a causal relationship between the equatorial warming and the atmosphere-circulation anomalies in the North Pacific, but cautioned that "studies of further analogous happenings are of course needed to verify (or disprove) the admittedly somewhat tenuous reasoning."

The 1963 and 1965 ENSO episodes provided Bjerknes with two more "analogous happenings." These studies were among the first in which satellite imagery was used to define the region of anomalously heavy rainfall over the central equatorial Pacific. In 1969 Bjerknes published a comprehensive synthesis in which he demonstrated an intimate link between the events in the Pacific and the SO. Basically, Bjerknes hypothesized that the normal sea-surface-temperature gradient between the relatively cold eastern equatorial Pacific and the huge pool of warm water in the western Pacific-Indonesian region gives rise to a great east/west circulation cell in the plane of the equator. Dry air gently sinks over the cold waters of the eastern Pacific, flows westward along the equator as part of the Southeast Tradewind system, driven by the westward "push" arising from higher surface pressure in the east and lower pressure in the west. The air is warmed and moistened as it moves over the progressively warmer water, until, arriving in the western Pacific its moisture is condensed out as it rises in the towering rain clouds of the region. A return flow to the east occurs in the upper troposphere, thus closing the two-dimensional circulation pattern.

Bjerknes recognized this circulation cell as the basic link between the SO and the sea-surface-temperature variations in the equatorial Pacific and named it the Walker Circulation in honor of Sir Gilbert. Essentially, his reasoning was that when warming occurs in the eastern Pacific, the sea-surface-temperature gradient decreases, and the tradewind flow (that is, the lower branch of the Walker Circulation) weakens. But weaker tradewinds

Year	Event intensity		Key to source	Year	Event intensity		Key to source	Year	Event intensity	Key to source	Year	Event intensity	Key to source
1726		(3)	G	1852	2	(2)	B, PC	1896	(3)	PI, R	1943	(2)	G, T, R
1728		(4)	A, G	1854	2		B	1899	(4)	D, PI, R	1944	(2)	PI, T
1763		(4)	A	1855		(2)	PC	1900	(3)	PI, R	1946	(1)	PI, R
1770		(4)	A	1857	2	(2)	B, PC	1902	(3)	PI, R	1948	(1)	PI, T, R
1791	4	(4)	A, B	1862	2		B	1905	(3)	PI, R	1951	(2)	G, PI, T
1803	2		B	1864	4	(4)	A, B, PI	1911	(4)	F, E, PI	1953	(3)	G, E, T
1804	4	(4)	B	1866	2		B	1912	(3)	F, PI	1957	(4)	G, L, PI
1814	4	(4)	B	1868	1	(3)	B, C, PI	1914	(3)	G, PI, R	1958	(4)	G, L, PI
1817	3	(3)	B	1871	4	(3)	A, B, C	1917	(2)	H	1963	(1)	PI, R
1819	3	(3)	B	1873		(2)	PI	1918	(4)	C, D, PI	1965	(3)	M, PI, T
1821	3	(3)	B	1875	1	(1)	B, PC	1919	(3)	D, PI, R	1969	(2)	PI, T, R
1824	3	(3)	B	1877	4	(4)	A, B, PI	1923	(2)	H, PI	1972	(4)	N, O, PI
1828	4	(4)	A, B	1878	4	(4)	A, B, PI	1925	(4)	D, E, PI	1973	(4)	N, O, T
1829	1		B	1880	2	(3)	B, PI	1926	(4)	I, PI, T	1975	(1)	P, PI, T
1832	3	(3)	B	1884	4	(4)	A, B, PI	1929	(3)	G, I, PI	1976	(3)	Q, PI, T
1837	3	(3)	B	1885		(3)	PI	1930	(3)	G, PI, T	1982	(4)	S
1844	3	(2)	B, PC	1887	2	(3)	B, PI	1932	(2)	E, I, J	1983	(4)	S
1845	4	(4)	B, C, PC	1888	2	(3)	B, PI	1939	(3)	E, J, T			
1846	2	(3)	B, PC	1889	1	(1)	B, PI	1940	(2)	C, PI, T			
1850	2	(2)	B, PC	1891		(4)	D, E, PI	1941	(4)	E, K, T			

Key	Source	Key	Source	Key	Source
A	Frijlinck (1925)	H	Lavalle (1917, 1924)	O	Caviedes (1975)
B	Eguiguren (1894)	I	Shepard (1930, 1933)	P	Wyrtki et al. (1976)
C	Hutchinson (1950)	J	Mears (1944)	Q	Quinn (1976)
D	Murphy (1923, 1926)	K	Lobell (1942)	R	Rainfall (equatorial and/or Peruvian)
E	Sears (1954)	L	Wooster (1960)	T	Sea-surface temperature off Peru
F	Forbes (1914)	M	Guillén (1967)	PC	Pressure component of Southern Oscillation index
G	Schweigger (1961)	N	Idyll (1973)		
		S	Rasmusson (1982, 1983)	PI	Southern Oscillation pressure index

Year of onset of El Niño type events, 1726–1983, as classified according to event intensity by Eguiguren (1894), left, and the present authors, right (events below intensity 3 were not accepted prior to 1841 when pressure data became available). Numbers refer to event intensity: 1, very weak; 2, weak; 3, moderate; and 4, strong. (Adapted from W. H. Quinn and others, Fisheries Bulletin, Vol. 76, No. 3, 1978)

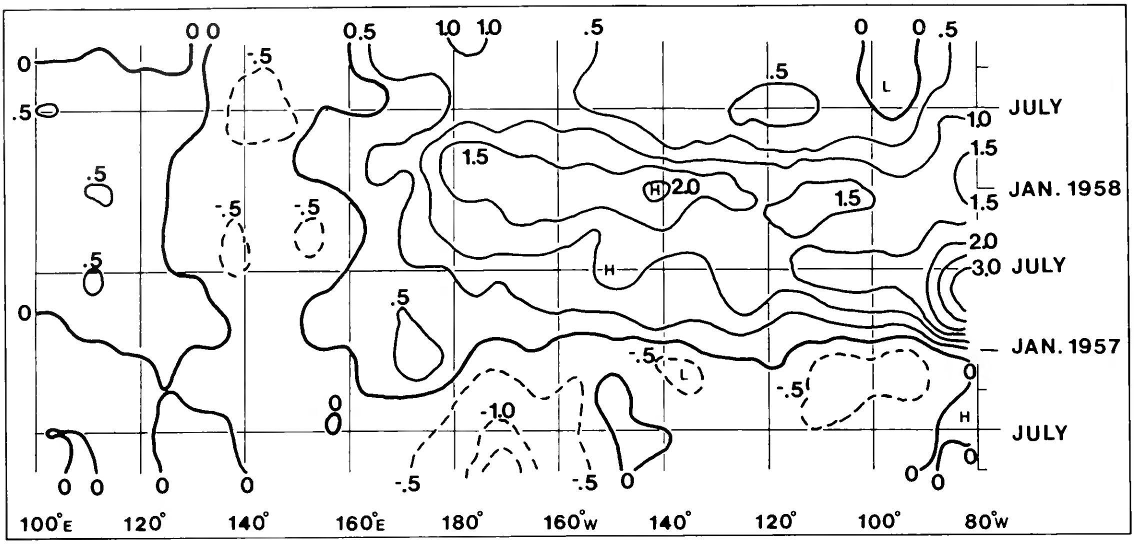

Figure 2. Time-longitude section along the equator from the South American coast (right) to Indonesia (left) showing the evolution of sea-surface-temperature anomalies (degrees Celsius) during the ENSO episode of 1957–58.

also must be accompanied by a weaker east/west pressure gradient. The required changes in pressure between the western and eastern equatorial Pacific are exactly what take place with swings in the SO seesaw (Figures 1 and 3). The final link in the ENSO chain had been forged!

The foregoing discussion covers only part of the complex of interactions described by Bjerknes in his 1969 paper, a view of events which came to be referred to as "Bjerknes' Hypothesis". No major element of this synthesis was entirely new; each had appeared in at least rudimentary form in his earlier publications or the publications of others. But Bjerknes organized and intertwined elements of the SO, global-scale teleconnections, and the large-scale sea/air interactions associated with the Pacific warmings into a new conceptual framework, supported by plausible dynamic and thermodynamic reasoning. In the words of a former student, Jule Charney, who himself became a renowned

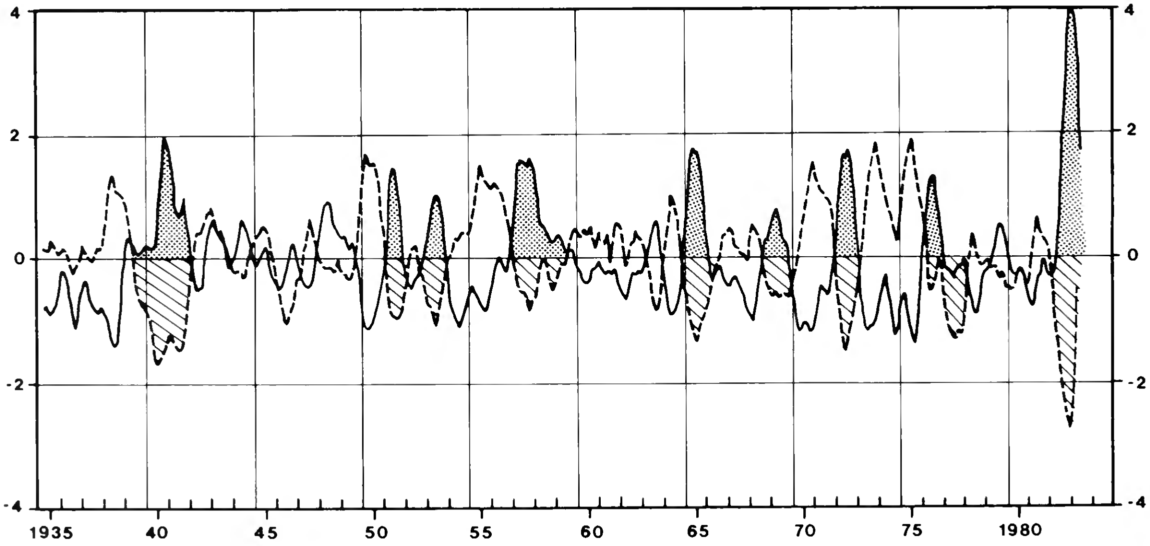

Figure 3. Curves for an index of El Niño (Puerto Chicama, Peru, sea-surface-temperature anomalies; solid line) and the Southern Oscillation (Tahiti-French Polynesia minus Darwin, Australia, surface-pressure-difference anomaly: dashed line). Values have been "standardized" by dividing the monthly anomaly values by their long-term standard deviation. Major ENSO events, which correspond to strong "negative" swings in the Southern Oscillation Index, and large positive sea-surface-temperature anomalies at Puerto Chicama are indicated by shading. Nine major episodes have occurred since 1935, with 1982-83 by far the most intense.

atmospheric scientist, "it is tangible, physical, securely based on observations and therefore eminently adaptable to theoretical and numerical analysis." Some of Bjerknes' reasoning has not withstood the test of time, but the conceptual framework he created is unusually robust; in a sense, his framework is malleable rather than brittle, able to bend and conform to new scientific evidence. Even today, it continues to serve as an important benchmark and point of departure for the ever increasing flood of ENSO studies.

The linking of El Niño and the Southern Oscillation was viewed as persuasive evidence that ocean circulation plays the role of flywheel in the ocean/atmosphere climate engine and is responsible for the extraordinary persistence of the SO from season to season. The host of studies since 1969 provides a much more complete description of the ENSO phenomenon, which emerges as the dominant global climate signal on time scales of a few months to a few years.

Northern Hemisphere Teleconnections

The teleconnection between equatorial Pacific sea-surface temperatures and the circulation over the North Pacific/North American sector initially described by Bjerknes in 1966 is but one of many ENSO teleconnections. It has, however, received the most theoretical attention, due in part to its association with wintertime climate anomalies over North America.

There is convincing evidence that this teleconnection is associated with the shift of the region of heavy rainfall from the western to the central equatorial Pacific during the "mature" stage of an ENSO episode. Upward motion in the region of enhanced rainfall, and associated spreading or divergence of the rising air as it reaches the upper troposphere, produces two large anticyclonic circulation anomalies at the jetstream level, a clockwise circulation to the north, and a counterclockwise circulation to the south of the equator (Figure 4a), which Bjerknes referred to as "Hadley Anticyclones" in 1972. On the equator, between the two cells, is an anomalous easterly flow, reminiscent of the weakening of the highly idealized Walker Circulation described by Bjerknes. On the poleward flanks of the cells are anomalous westerlies, associated with the enhancement of the eastern Pacific subtropical jetstream. Poleward and eastward of the North Pacific anticyclonic circulation anomaly is an apparent wave train with a negative anomaly center over the North Pacific, a positive center over western Canada and another negative center over the southwestern United States (Figure 4a).

Recent results from simple dynamic models of the atmosphere indicate that this pattern of anomalies, which is observed during an ENSO winter and generally referred to as the Pacific-North American (PNA) teleconnection, can be generated by the atmospheric heating associated with observed tropical rainfall. The "new relations of vital importance" that Walker prophesied would emerge from upper-air data have indeed been found.

The 1982-83 Episode

Each ENSO episode has a personality all its own. Nevertheless, most members of the species exhibit remarkable similarities in their development, maturation, and demise. However, conception and birth—when and where to start the clock on an ENSO episode—is still a mystery. Although ENSO may be born in the tropical Pacific, its conception may occur in some earlier climate event or conjunction of events in some other region of the world.

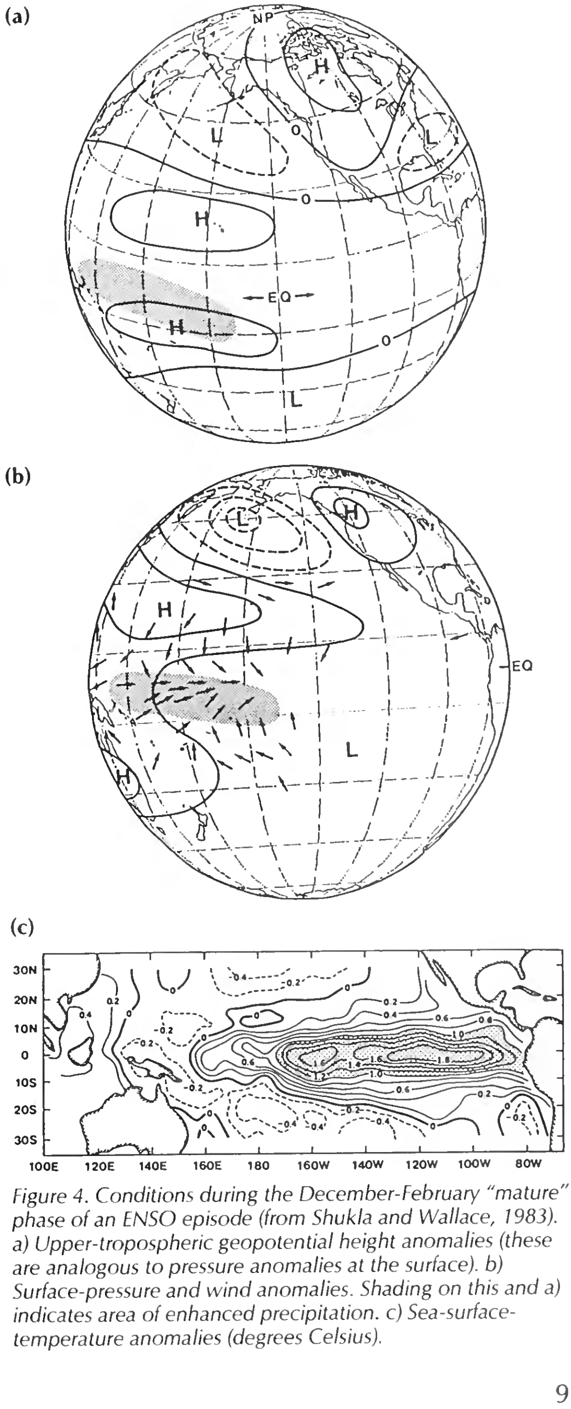

Figure 4. Conditions during the December-February "mature" phase of an ENSO episode (from Shukla and Wallace, 1983). a) Upper-tropospheric geopotential height anomalies (these are analogous to pressure anomalies at the surface). b) Surface-pressure and wind anomalies. Shading on this and a) indicates area of enhanced precipitation. c) Sea-surface-temperature anomalies (degrees Celsius).

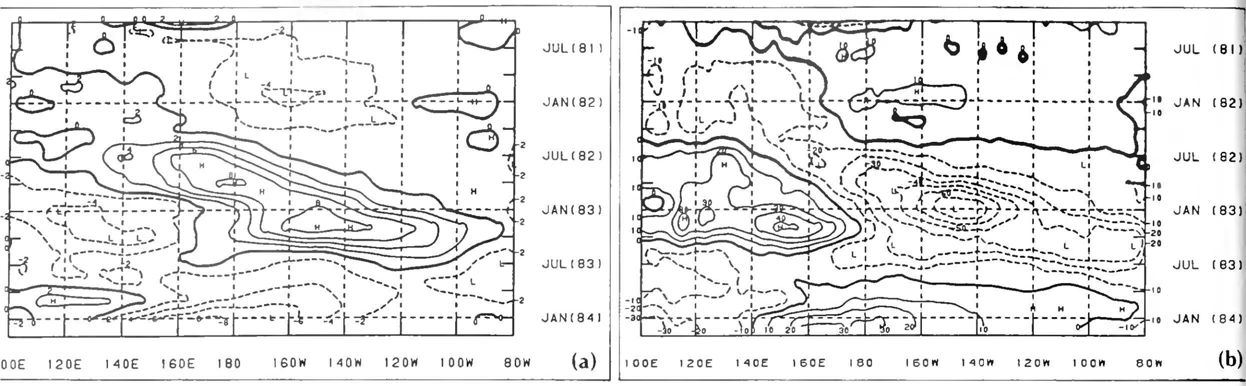

Figure 5. Time-longitude sections along the equator in the Pacific, showing the evolution of two parameters during the ENSO event of 1982–83. a) 850 millibar (about 1500 meters above the surface) westerly wind anomaly (meters per second). Positive values (solid lines) represent a reduction in the easterly component of the trade winds; negative values (dashed lines) indicate above-normal easterly winds. b) Outgoing longwave-radiation anomaly (watts per square meter) at the top of the atmosphere measured by polar-orbiting satellites. This parameter is frequently used as an index of precipitation variations in the tropics. Negative values (dashed lines) indicate above-normal; positive values, below-normal precipitation.

The anomalous warming at the ocean surface usually begins early in the year, with the appearance of positive sea-surface-temperature anomalies near the Ecuador/Peru Coast. However, the perverse ENSO of 1982–83 developed in a quite different manner. It did not clearly show its hand until June, 1982, when the Tahiti-minus-Darwin pressure difference, widely used to monitor swings in the SO pressure seesaw, began a precipitous fall that was to last for nine months and reach record low values (Figure 3). The sharp drop in this index signalled a relaxation of the pressure gradient that drives the lower branch of the Walker Circulation. The easterly flow in the western equatorial Pacific collapsed, and by July, the average wind on the equator between 135 and 170 degrees East was from the west, a

Figure 6. Parched bed of Lake Eildon in Victoria, Australia, during 1983 drought. (Photo by Bill Bachman/Photo Researchers [PR]).

Figure 7. Red, brown, and green algae at Lagumillar, Peru; animals that usually gnaw all growth were killed by flooding. (Photo by Wolf Arntz).

Figure 8. Geosynchronous satellite image, as seen on 19 April 1983, showing Hurricane William (lower center) passing through French Polynesia.

highly anomalous condition that was to persist until December. Viewed in a larger context, this region of westerly anomalies, which first appeared in the western Pacific, migrated steadily eastward reaching the far eastern equatorial Pacific almost 1 year later (Figure 5a).

The disruption of the rainfall regime of the tropical Pacific was of historic proportions. The heavy rainfall normally located over the North Australian-Indonesian "Maritime Continent" region, and along the South Pacific Convergence Zone that extends from near New Guinea southeastward across the dateline, shifted eastward (Figure 5b). The islands in the dry zone in the central equatorial Pacific month after month received record or near-record rainfall, while to the west, Indonesia, eastern Australia, and the Islands of Melanesia suffered severe and in some areas record drought, which did not break until the early months of 1983 (Figure 6).

October marked the onset of El Niño conditions on the Ecuador/Peru Coast. The rainy season began early and stayed late. During the nine-month period of October, 1982, through June, 1983, rainfall records were shattered at stations in southwest Ecuador and northwestern Peru (Figure 7). Without question, this period marked the most prolonged and catastrophic El Niño visitation ever recorded in that region, exceeding the great El Niños of 1925 and 1891.

By December, 1982, sea-surface-temperature anomalies exceeded 4 degrees Celsius over a vast area of the eastern and central tropical Pacific, and the region of equatorial westerlies extended eastward beyond the dateline (Figure 5a). This unusually large eastward shift of the tropical Pacific climatological regimes was associated with a corresponding eastward shift of the region of tropical-storm genesis.

The beautiful tropical islands of the south-central Pacific are noted for their benign climate; they rarely experience tropical storms. Between December, 1982, and April, 1983, French Polynesia was devastated by six tropical cyclones, five of which reached hurricane intensity (Figure 8). One of these, Veena, was described as the most severe hurricane to strike Tahiti in modern times. The Hawaiian Islands had been struck by an unusual northward-moving hurricane in late 1982, probably also ENSO related, since the last storm of similar characteristics had struck the islands almost 25 years earlier, in November, during the El Niño of 1957.

The seasonal evolution of drought conditions in the Pacific-Indian Ocean region, for the most part, was typical of ENSO episodes. Conditions eased over Australia and Indonesia early in 1983, as drought spread across the North Pacific Subtropics, enveloping the southern Philippines and the Hawaiian Islands. Dry conditions continued over Melanesia, Southern India, and Sri Lanka, while the drought in Southeast Africa was among the worst of the century.

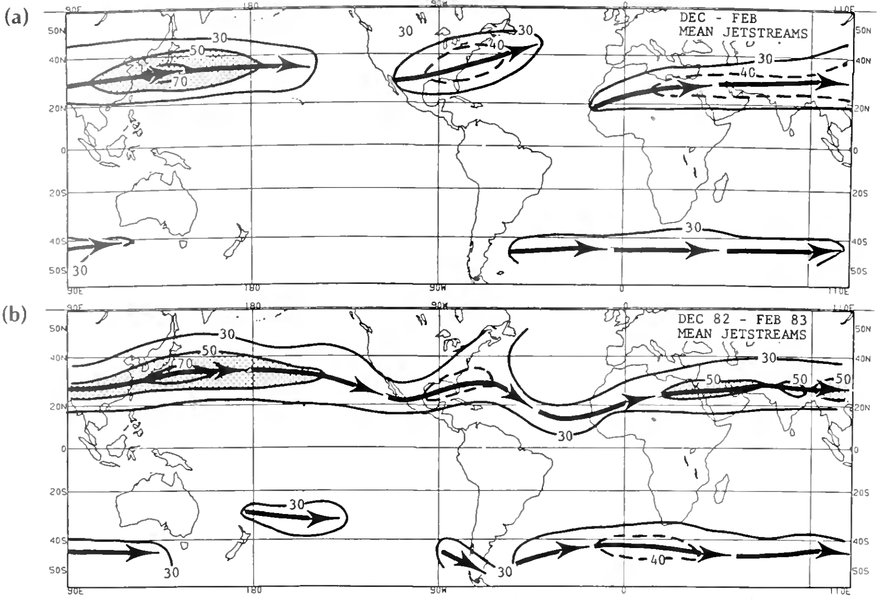

Figure 9. a) Typical December-February jet-stream pattern and b) the pattern during December, 1982–February, 1983. Units are given as meters per second.

More or less typical but extremely strong ENSO circulation anomalies developed over the central and eastern North Pacific extratropics during the 1982–83 winter and spring. The eastern Pacific subtropical jetstream intensified, as usual, but this time it reached record strength, and its extreme eastward extent was highly atypical (Figure 9). Mean monthly pressures in the region of the Aleutian Low also reached near-record low values, and the tracks of storms entering North America from the Pacific were at times displaced hundreds of miles southeastward, bringing destructive winds and tides to the California coast (see McGowan, page 48). In fact, the eastward extension and southward displacement of the jetstream over Baja California, and the Gulf of Mexico was associated with wet spells and storminess across the entire "sunbelt" from California to Florida and Cuba, a condition that persisted through much of the spring season. The disturbances moving along this track laid down a heavy snowpack over the Colorado River Basin, resulting in "delayed anomalies" in the form of widespread springtime snowmelt flooding.

By most measures, this ENSO episode was among the strongest of the past century. It also was noteworthy for the high degree of international cooperation in efforts to monitor the ENSO development and impacts (see Webster, p. 58). In the past, it has often taken months, even years, to assemble the types of data and information that were made available in a matter of days or weeks during the ENSO episode of 1982–83. Hopefully, the cooperation in reaching common goals exhibited during this episode has laid a firm foundation for the major program of international studies now being planned.

Eugene M. Rasmusson is Chief of the Diagnostics Branch of the Climate Analysis Center at the National Meteorological Center of the National Weather Service, part of the National Oceanic and Atmospheric Administration, Washington, D.C.

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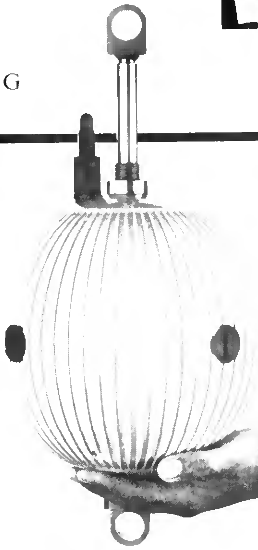

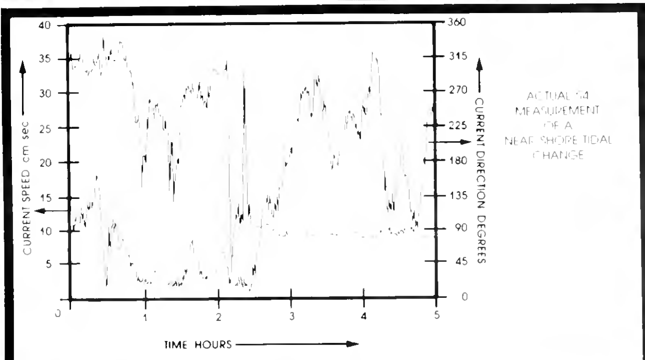

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THE LEADER IN OCEAN TECHNOLOGY

Downtown Mill Valley, California, during 1983 flood. (Photo by Steve Skloot/PR)

Floods, Fires, and Famine: Is El Niño to Blame?

by Michael H. Glantz

El Niño became a household word in America during the last year, capturing the interest of just about everyone, from policymakers to homemakers. This is probably because our world has been directly affected by the latest El Niño.

Scientists and media representatives refer to the El Niño that began in early 1982 and extended into the late summer of 1983 as the most potent in about a century, not only because of the large increase in the temperature of the surface waters in the central and eastern Pacific, but because of its alleged linkages to the devastating impacts on the economies of countries that border the Pacific Ocean in the Southern Hemisphere: droughts in Australia, Indonesia, Peru, and Hawaii; an increase in the number of destructive tropical typhoons in the southern Pacific region; the mysterious disappearance and subsequent reappearance of seabirds on Christmas Island; the destruction of Pacific coral reefs; the decimation of fish stocks that normally inhabit the coastal waters of Peru and Ecuador; and the list goes on.

Some scientists have compared it with the El Niño of 1877, while others have compared it to the less intense but better known 1925 event. Despite these and other comparisons, no two El Niños are alike. Consequently, no two El Niño events can be expected to produce the same impacts on societies around the world.

Some El Niño effects are local, affecting fish populations along the west coast of South America. Typically, they bring devastating rains and flooding to the usually arid coastal regions of northern Peru and Ecuador. Flora and fauna along the Peruvian and Ecuadorian coasts might be adversely affected by the increase in sea-surface temperatures; fishing off the Chilean coast may improve for the duration of a particular event.

During a severe El Niño, sea-surface temperatures are measurably higher than normal over large expanses of the South Pacific; these conditions can prevail for more than a year. Impacts on the atmosphere, and therefore on societies, appear to extend well beyond the southern part of the Pacific Great Basin. The Southern Oscillation, as it is called, is characterized by large-scale fluctuations of pressure and winds between Australasia and the central and eastern tropical Pacific. Thus, the implications of the El Niño phenomenon spread from the local to the global level. In a situation such as this, El Niño is linked to the devastating climatic impacts on societies—North America, Europe, West Africa, India—in addition to those in the southern Pacific region.

Teleconnections

Meteorologists have coined the phrase "teleconnection" to classify climatic anomalies that occur at great distances from each other but which appear to be related. Linkages among these anomalies are identified by either geophysical evidence, statistical correlation, or "wishful thinking." The idea is quite logical: Given that the atmosphere, biosphere, cryosphere, and oceans form a system, an event that disturbs one subsystem will likely have an impact that will ripple through related subsystems. Hypotheses concerning various teleconnections abound.

Using all of the hypothetical teleconnections, one could develop a scenario of linkages with El Niño that circle the globe, with proposed linkages from an El Niño event along the Peruvian coast to droughts in Northeast Brazil, droughts in West Africa, water levels in Lake Chad in Central Africa, droughts in India, Indonesia, and Australia, and back to El Niño off the coast of Peru.

"Discovering" El Niño

Why has El Niño recently become a major concern to scientists and policymakers around the globe? In the early part of this century, the main concern about El Niño related to guano birds. Guano is a substance composed chiefly of mineral-rich bird droppings and is used as fertilizer by Peruvians, domestically and as an export to foreign markets. In response to the uncontrolled mining of guano from the rock islands that dot the coastline, the Peruvian government established the Guano Administration Company in 1909. Its main task was to regulate commercial exploitation of guano.

During an El Niño event, the anchoveta population (the guano birds' main source of food) is greatly diminished. The impact of El Niño on the bird population is graphically portrayed in photographs taken earlier this century, in which Peruvian beaches are littered with millions of birds that died during their search for fish. El Niño meant that there would be a sharp decline in annual guano production.

Until the early 1950s, no commercial Peruvian anchoveta fishery developed because the Guano Administration and Peruvian farmers blocked all attempts to develop such an industry. Their political power diminished, however, in the face of changing factors in Peru and North America. The Peruvian government was overthrown in the late 1940s and the new President favored a policy of economic development based on the export of Peru's natural resources. Also at that time, the California Pacific sardine fishery collapsed and entrepreneurs identified Peru as a place to unload idle fishing fleets and processing plants.

In the post-war period, there was an increasing demand for meat products in North America, increasing the demand for anchoveta fishmeal, a feed supplement for poultry, hogs, and cattle. In addition, such technological innovations as the nylon net spurred a meteoric rise in fish landings by the Peruvian anchoveta fishery; landings doubled each year until 1960.

1957–58

When a major El Niño took place in 1957–58, there was little direct reference to it in the popular press outside Peru. The newly developed anchoveta fishing industry was in its early stages of growth and, in general, showed little concern. There were no measurable effects on the productivity of the fishery because their landings were well below the maximum sustainable, or optimal, yield.

Some scientists, however, considered it an

Chincha Norte Island off Peru was a pelican sanctuary during the 1960s, one of the guano islands. (Photo by S. Laurain/ United Nations) interesting focus of research, involving the atmospheric, oceanographic, and biological sciences. With this El Niño, the term's usage was deliberately broadened, suggesting that it was a phenomenon common among other major upwelling regions, especially the one off the coast of California.

The El Niño of 1957–58 also brought about a sharp decline in the anchoveta-consuming guano bird population to about 16 million birds from an estimated 30 million. The influence of the guano industry sharply declined. By the mid-1960s, a few international scientists, as well as some Peruvian industrialists, called for the deliberate destruction of the bird population for the sole purpose of "freeing up" a few million more tons of anchoveta for the rapidly increasing number of fishing boats and fishmeal-processing plants.

1972–73

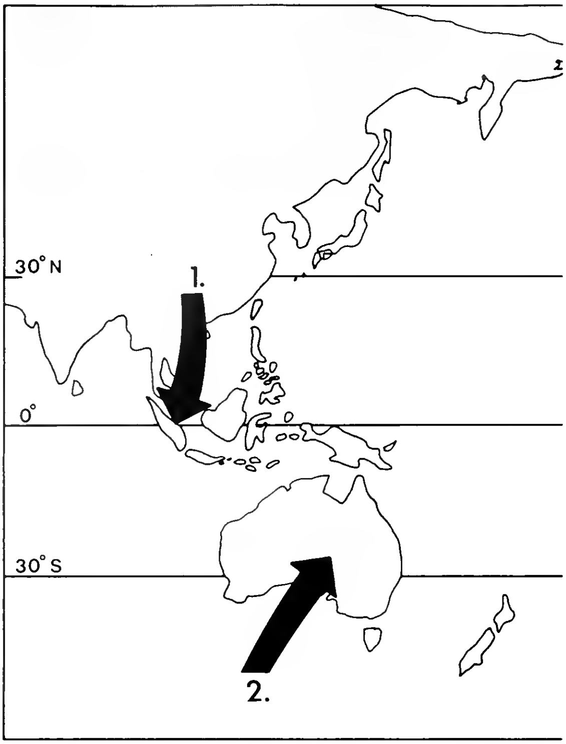
Another major El Niño took place during 1972–73. This time, the world's press and politicians took notice for several reasons. First, it was accompanied by widespread droughts in West Africa, East Africa, Ethiopia, the Soviet Union, Australia, and Central America. There also was severe flooding in the Philippines, parts of Australia, and Kenya.

The 1972–73 drought in the Soviet Union led to a sharp decline in cereal production that prompted the Soviets to buy U.S. grains (corn and wheat) in large quantities. This generated a shortage in U.S. grains available for export to other nations plagued by drought-related shortages. In 1972, per-capita global food production declined for the first time since the late 1940s. Worldwide fish catches, to the surprise of most observers, also declined for the first time since the end of World War II, suggesting that living marine resources were being exploited at levels near their upper limits.

More than simply coinciding with the El Niño of 1972–73, many of these anomalies and their societal impacts were blamed on it. Many observers believed that El Niño stimulated, or at least abetted, a global food shortage of great magnitude.

Moreover, by the late 1960s Peru had become the leading fishing nation in the world (by volume, not value, of catch). The El Niño of 1972–73 combined with high levels of overfishing to bring about the near collapse of the Peruvian anchoveta fishery, dealing a major blow to the local economy by idling fleets and fishmeal-processing factories for the following decade. In 1973, using the El Niño-related reduction of biological productivity in its coastal waters as rationale, the socialist government of Peru nationalized its fishing industry. In 1976, when fishing prospects had not improved, the government denationalized the fleet. Today it is in the midst of the politically difficult process of denationalizing other parts of the industry.

Another major reason that the attention of those interested in global food problems later focused on the El Niño of 1972–73 was that when fishmeal was unavailable or too expensive by reason of reduced availability, farmers bought soymeal as a feed supplement. As the demand and price for soymeal increased farmers appropriated corn and wheat fields to grow soybeans. This transfer, in turn, exacerbated the global food shortages of the mid-1970s.

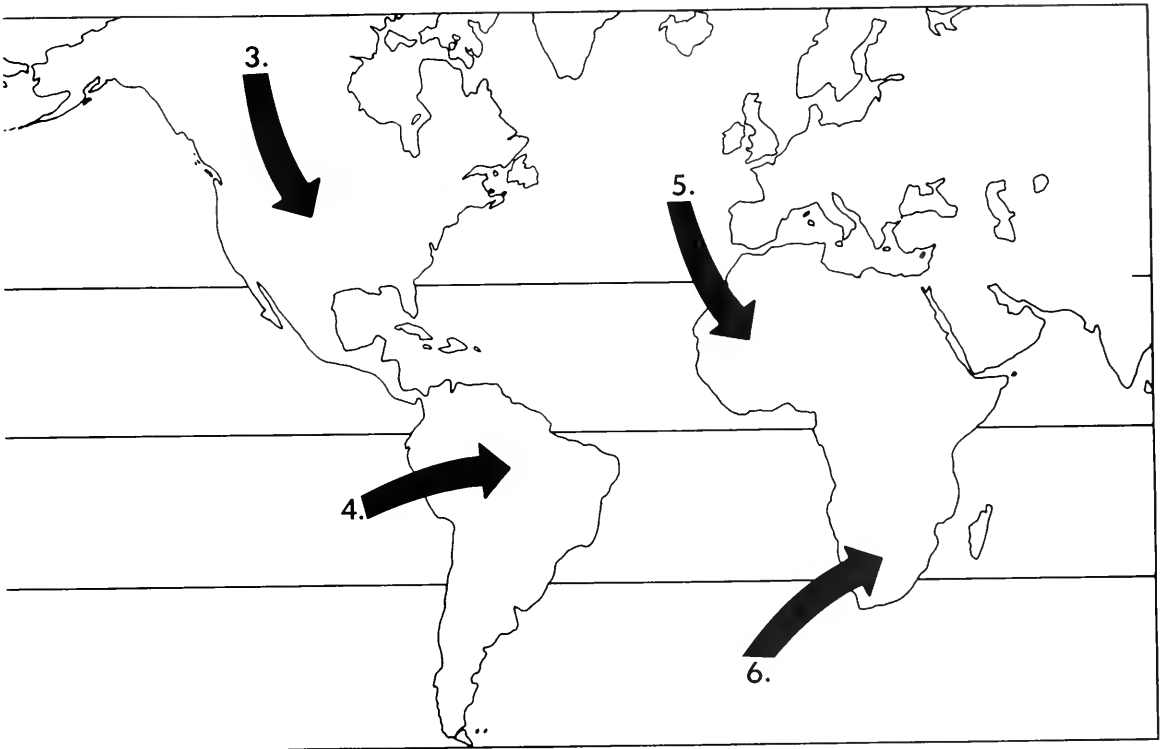


Arrow 1. Indonesia was plagued with severe drought, resulting in reduced agricultural output, especially rice, and in famine, malnutrition, disease, and hundreds of deaths. This drought came at a bad time, as this country had made great strides toward self-sufficiency in food production. In the few years immediately preceding the 1982–83 El Niño, it was emerging as a rice exporter. This drought, however, coupled with worldwide recession, huge foreign debts, and declining oil revenues, has set back Indonesia's economic development goals for the near term.
Arrow 2. Australia had its worst drought this century. Agricultural and livestock losses, along with widespread brushfires mainly in the southeastern part of the country, resulted in billions of dollars in lost revenues. An Australian journalist wrote that "the drought is not just a rural catastrophe, it is a national disaster." The drought has been linked to El Niño.
Arrow 3. The eastern part of the United States was favorably affected by its warmest winter in 25 years. According to an

International interest in the scientific and societal aspects of El Niño was heightened by the adverse effects of the El Niño of 1972–73 on the Peruvian economy and on international food supply. Scientists reasoned that if El Niño events could be understood and predicted, and if its connections with other climate anomalies could be established, it might be possible to forecast the societal impacts of the associated climate anomalies.

1982–83

The El Niño of 1982–83 is rated as one of the most extreme on record, in part because of the unusually high sea-surface temperatures in the eastern



estimate by the National Oceanic and Atmospheric Administration, energy savings were on the order of $500 million. (The opposite was the case, however, during the cold winter that accompanied the 1976–77 El Niño.) The United States once again was adversely affected by devastating coastal storms and mudslides along the California coast, flooding in the southern states, and drought in the north central states, reducing corn and soybean production. Salmon harvest along the Pacific northwest coast were sharply reduced.

Arrow 4. In addition to the highly publicized damage to infrastructure and agriculture in Peru and Ecuador as a result of heavy flooding during this El Niño, there were severe droughts in southern Peru and Bolivia. A major drought continued in northeast Brazil, adversely affecting food production, human health, and the environment, and prompted migration out of the region into already crowded cities along the coast and to the south. There also were destructive floods in southern Brazil, northern Argentina, and Paraguay.

Arrow 5. Large expanses in Africa have been affected by drought. For example, the West African Sahel, once again, has been plagued by a major drought. While the human and livestock deaths resulting from this drought appear to be fewer than those in 1972–73, the food production situation is considered poor. The view that the Sahel has been in the midst of a long-term trend of below-average rainfall since 1968 is gaining credibility.

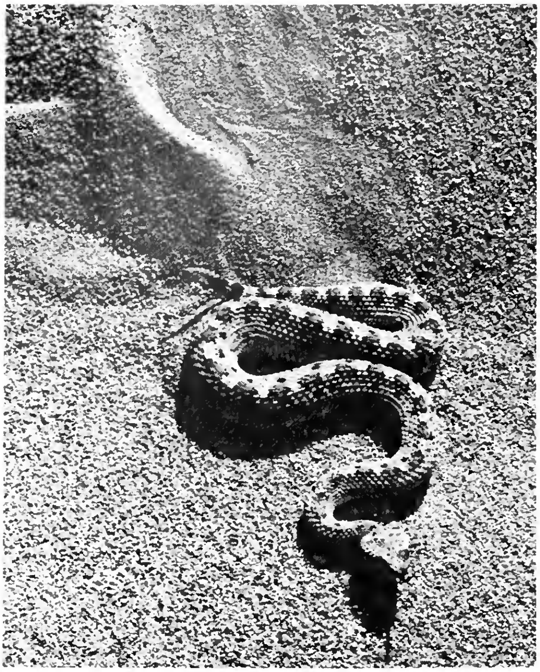
Arrow 6. Southern Africa has witnessed some of its worst droughts this century. This was not the case during the 1972–73 event. In 1983, for example, the Republic of South Africa, a major grain producer in the region, was forced to import from the United States about 1.5 million tons of corn to replace what was lost in their drought. Zimbabwe, a regional supplier of food, also was devastated by drought and was forced to appeal for food assistance from the international community. Likewise, Botswana, Mozambique, Angola, Lesotho, and Zambia, and the so-called Black National Homelands in the Republic of South Africa had their economies devastated by the drought of 1982–83.

equatorial Pacific, and in part because of the unusual worldwide climate anomalies that occurred simultaneously. Again, world leaders and the media paid close attention to this phenomenon. Unlike the 1972–73 episode, however, they took notice of the importance of this El Niño while it was still in progress.

In the months preceding the onset of this El Niño, researchers believed that they had described the "typical" El Niño. But the El Niño of 1982–83 did not develop according to the typical pattern of earlier events. In fact, most scientists investigating El Niño failed to recognize its development until months after onset. Scientists later postulated that the El Niño formed in a sequence different from previous ones; anomalously warm sea-surface temperatures were first observed in the central and western Pacific instead of the coastal regions of Peru. The El Niño of 1982–83 dramatized how much is yet unknown.

Most, if not all, weather anomalies around the world during these two years were linked by one observer or another to the El Niño of 1982–83. Several maps and charts appeared in the popular press suggesting worldwide, continental, and national impacts of this El Niño. Selected examples of suggested societal impacts are shown on the above map.

In addition to the impacts illustrated on the map, the El Niño of 1982–83 was blamed for droughts in Sri Lanka, the Philippines, southern India, Mexico, and even Hawaii; floods in Peru,



An increase in rattlesnake bites. (Photo by Tom Mc Hugh)

Ecuador, Bolivia, southern Brazil; severe, unseasonal hurricanes in French Polynesia and Hawaii, and suppressed hurricane activity in the Atlantic. Many of these events were record-setting extremes: the worst hurricane, the most intense rainfall, the warmest winter, the longest drought, and so forth.

El Niño also has been associated with secondary societal and environmental effects; this was true of dust storms in Australia and brush fires in the Ivory Coast, Ghana, and Australia. As for the United States, the recent El Niño has been blamed for such secondary effects as encephalitis outbreaks in the East (the result of a warm, wet spring providing the proper environment for mosquitoes), an increase in rattlesnake bites in Montana (hot, dry conditions at higher elevations caused mice to search for food and water at more densely populated lower elevations; the rattlesnakes followed), a record increase in the number of bubonic plague cases in New Mexico (as a result of a cool, wet spring that created favorable conditions for flea-bearing rodents), an increase in shark attacks off the coast of Oregon (because of the unseasonally warm sea temperatures), and an increase in the incidence of spinal injuries along California's coast (as a result of swimmers and surfers being unaware of the weather-altered coastal sea floor).

Winners and Losers

El Niño means different things to different people. To a Peruvian fisherman it can be a two-edged sword: a sharp increase in fish catches may be realized for a short period of time. As the anchoveta congregate in pockets of upwelled water along the coast, they are more accessible to the fleet. After a few months, however, the fish population can be sharply reduced.

To the Peruvian government, El Niño is a harbinger of bad news. It brings a sharp decline in productivity in the fishing sector. This means that exports and, therefore, foreign currency earnings will drop sharply, causing the government to curtail development programs. This, in turn, may lead to high unemployment in the fishing sector and to labor unrest. In addition, El Niño probably would be accompanied by very heavy rains that could destroy costly infrastructure, such as roads, rail lines, bridges, and buildings.

To a Chilean fisherman, El Niño can be good news, as changes in ocean temperatures may cause pelagic fish populations to migrate south from the usually rich Peruvian waters into Chilean coastal waters. This was clearly the case during the recent El Niño episode, making Chile—at least for now—one of the major fishing nations in the world.

El Niño can cause a sharp increase in the demand for soymeal as a supplement for reduced supplies of fishmeal. This demand would probably be accompanied by an increase in the price that American and Brazilian producers receive for soymeal.

As for scientists interested in El Niño, nature is essentially performing an experiment that might provide them with the missing scientific information they need in order to unlock some of the mysteries of the causes and impacts of air/sea interactions on regional as well as global scales.

During this last major El Niño, there also were climatic anomalies with favorable economic impacts. Often, the favorable anomalies occur along with unfavorable ones in the same country. For example, while severe droughts in northeastern China and flooding in localized southern regions adversely affected agricultural production in those areas, higher temperatures in northern China and good rains in southern China led to favorable crop production. India's grain production was much less severely affected by drought than had been expected. And there were fewer hurricanes along the eastern seaboard of the United States.

The commodities market, where traders are buying and selling soybean and other grains for future delivery, seems to have benefited from the most recent El Niño. One business analyst even asked, "Did El Niño trigger a record season?"

Warm water advanced from off the coast of the border between Southern California and Mexico as far north as the coasts of Washington and Oregon. This shifted to the north the traditional paths taken by, for example, Fraser River salmon stocks. Canadian fishermen were able to capitalize on this shift in the migratory route of the salmon into their waters: instead of the usual 50-50 split of salmon catches between Canada and the United States, during 1983 it was a 90-10 split. While Alaskan salmon fisheries continued to fare well, American fishermen along the Pacific Northwest coast were falling deeper into debt as a result of El Niño and the poor state of the fishing economy that already existed.

As with other adverse climatic impacts on

How the Term 'El Niño' Evolved

We think of El Niño today as a spectacular oceanographic/meteorological phenomenon that develops in the Pacific, most often off Peru, and is accompanied by devastating rains, winds, drought, and other events that wreak economic disasters.

In 1892, a scientist named Camilo Carillo reported that Peruvian fishermen of the port of Paita had coined the term "Corriente del Niño" or "Current of the (Christ)Child" in reference to an invasion of warm waters off the coast that occurred around Christmas and caused diminished returns from fishing efforts.

Over the years, many other authors have used the term with the word "current" eventually being dropped in favor of "phenomenon" because the event involves a transitory irregularity in the ocean/atmosphere system. In 1958, Warren Wooster of the University of Washington at Seattle, who would later play a major role in the International Decade of Ocean Exploration, proposed a definition for El Niño that generalized its characteristics to encompass oceanographic/meteorological processes that occur off the coasts of California, Southwest Africa, Western Australia, and Vietnam.

The first documents referring to an El Niño-like condition go back to ship captains' logs in the years 1795 (Colnet), 1822–23 (Lartigue), and Carranza (1891). The most notable occurrences of El Niño, which appears at irregular intervals in time with variable intensity and peculiarities, were in 1891, 1925, 1934–41, 1965, 1972–73, and 1982–83.

human activities in general, there are winners and losers during an El Niño event. If, for example, the Florida citrus crop is reduced by an untimely freeze, that would clearly have an adverse impact on the regional as well as the state's economy. Yet citrus growers in Texas and California might well benefit from the price increase that accompanies a reduction in the overall availability of citrus fruit. A freeze in Florida might have minimal impacts on revenues that accrue to the Federal Treasury from the citrus industry, as tax losses in Florida could be balanced out by tax gains elsewhere. This strongly suggests that groups attempting to compile economic costs associated with the impact of climate anomalies must provide a complete picture of both costs and benefits. Otherwise, the public is left with a distorted view.

That no two El Niño events are exactly alike, and that their worldwide ecological and economic implications will also be dissimilar, makes it difficult to identify winners and losers in advance of any El Niño event.

Note of Caution

It is important to bear in mind that there are climatic anomalies affecting food production every year. When such anomalies occur at the same time as a major El Niño, it does not necessarily mean that they were caused by El Niño. History shows that during the El Niño of 1976–77 drought plagued the western part of the United States, whereas during the 1982–83 event California was battered by severe coastal storms, and the Colorado River experienced its greatest spring runoff on record.

Some of the hypothetical teleconnections might be relatively easy to ascribe to El Niño, but others will be more difficult. While these teleconnections need considerably more scientific scrutiny, those linkages that do withstand such examination may provide policymakers with a long-range forecast months in advance of climatic anomalies that may affect their countries. These will have to be used with extreme caution, however. Forecasts based on erroneous teleconnections may prove to be worse than no forecast at all.

As scientists gain more knowledge, if not consensus, about this phenomenon, researchers should be able to determine with more confidence which "teleconnected" impacts may be blamed on, or linked to, El Niño. They then will be able to use knowledge about the phenomenon for the purposes of developing a reliable long-range climate-related forecast. Only then can teleconnections be used to identify potential winners and losers and reduce the number of losers.

Michael H. Glantz is head of the Environmental and Societal Impacts Group at the National Center for Atmospheric Research, Boulder, Colorado. NCAR is sponsored by the National Science Foundation.

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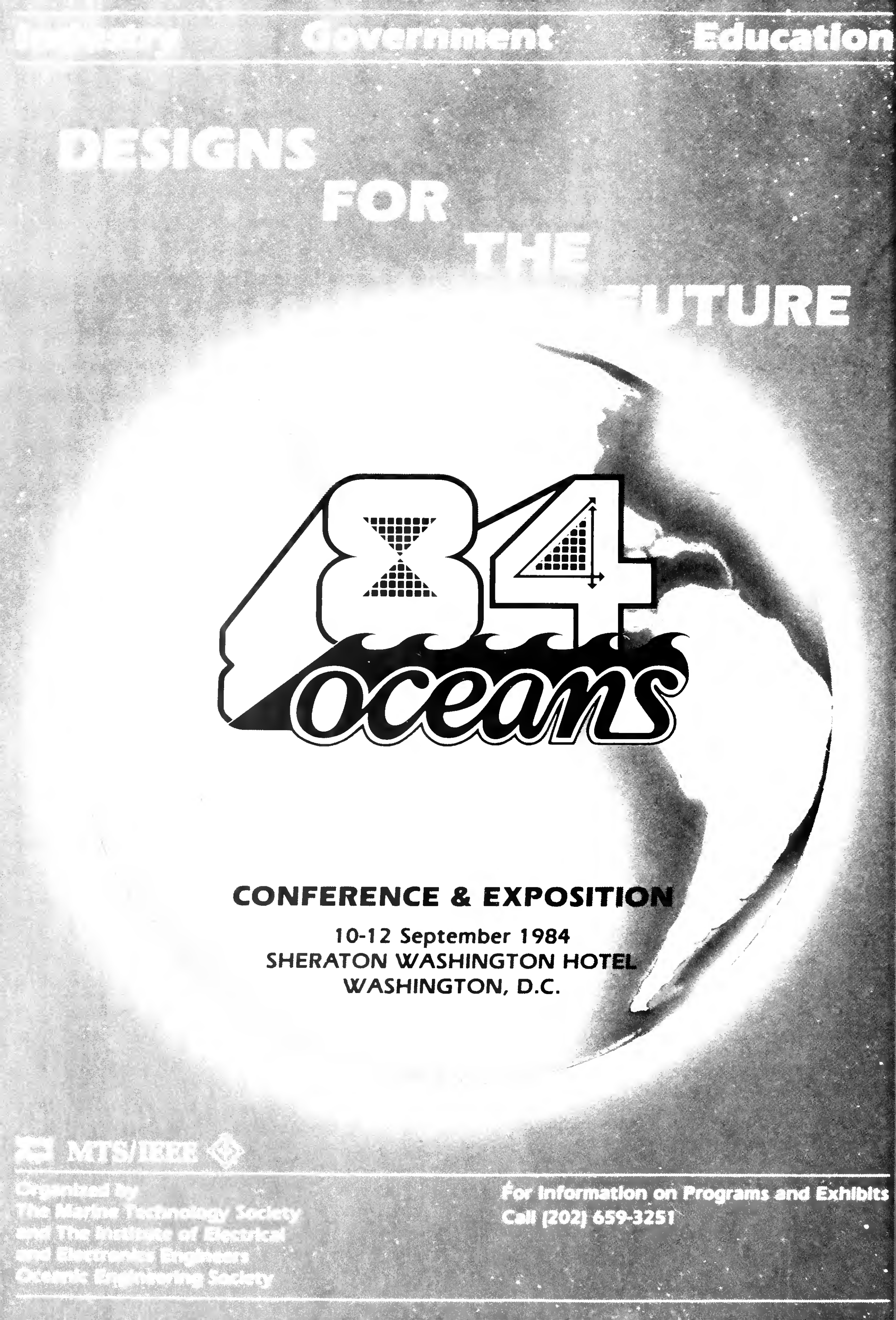
84
oceans

Changes in the Pacific During the 1982–83 Event

by D. E. Harrison and M. A. Cane

The warm event in the Pacific in 1982–83 was unusual in many respects. Rather than exhibiting surface warming first along the northeastern coast of South America in the spring, sea-surface temperature (SST) first significantly exceeded climatological values along the equator in the eastern central Pacific during late summer. Not for several months after the equatorial surface warming began did temperatures along the west coast of South America meet the international definition of an El Niño. The maximum SST anomalies, more than 6 degrees Celsius, according to the National Oceanic and Atmospheric Administration's (NOAA) Climate Analysis Center, were larger than is usual, even for an El Niño; SST was greater than 29 degrees Celsius all along the equator at the time of maximum anomaly. Thus this event offers an excellent opportunity to test existing ideas about the genesis and evolution of El Niño events in the ocean.

Fortunately, the effects of the 1982–83 event were better observed on and below the sea surface than those of any previous event, thanks in large measure to support from the National Science Foundation (NSF) and NOAA, especially the Equatorial Pacific Ocean Climate Study (EPOCS) and the Pacific Equatorial Ocean Dynamics (PEQUOD) experiments. Although some very interesting observations have appeared in *Science* magazine, the *Tropical Ocean-Atmosphere Newsletter*, and the Climate Analysis Center's (CAC) *Special Diagnostic Bulletins* and *Quick Look Atlas*, data analysis is still under way. Of interest here are the changes in the ocean and atmosphere within 5 degrees latitude of the equator, and within a few degrees of the American coasts. These narrow strips are peculiar because they are waveguides for a special class of ocean variability. Within them, the ocean can respond very quickly to changes in forcing, and the response can quickly propagate away from the region of unusual forcing.

As sea-surface-temperature changes are a major part of the El Niño/Southern Oscillation phenomenon, it is instructive to examine the 1982–83 event by comparing the long-period changes in SST with those of the other events. Three-month averages of anomalous SST, according to the Climate Analysis Center 1982–83 report and to Rasmusson and Carpenter (1982) for the post-1950 composite* El Niño, are shown in Figure 1. The very different timing and pattern of warming are evident from comparison of similar periods in the two instances. From Figures 1a and 1b, it is clear that there was no large-scale warming in the March-to-May period of 1982. At this time of year the composite El Niño has its peak phase, with significant warming along the west coast of South America and weak warming along the equator out to 120 degrees West. In the next period, June through August of 1982, significant warming occurred and was narrowly trapped to the equator and the coast of South America (Figure 1c); monthly-mean maps show that the equatorial warming preceded the coastal warming.

The August-to-October period for the composite is its transition phase, with well-developed warming on a large scale (Figure 1d), comparable to September through November, 1982 (Figure 1e); the zonal extent of warming is very similar, but the fields suggest that warming was more strongly trapped near the equator in 1982. Both show warming along the coast comparable to warming around 150 degrees West. The mature phase for the composite, the December-to-February period following the onset of warming, shows the maximum areal extent of warming (Figure 1f) and can be contrasted with December, 1982, through February, 1983 (Fig. 1g). Again the patterns are similar, with the maximum warming near 135 degrees West on the equator. But, there is a narrow region of quite warm water along the coast shown in Figure 1g that has no counterpart in the composite. The final SST comparison, May through July for the composite (Figure 1h) versus June through August of 1983 (Fig. 1i), reveals very different patterns. The 1983 warming pattern is reminiscent of the composite warming of March to May of the El Niño year (Figure 1a), while the composite field shows anomalously cool water over the same region. Although not shown here, SST returned to roughly normal in October of 1983.

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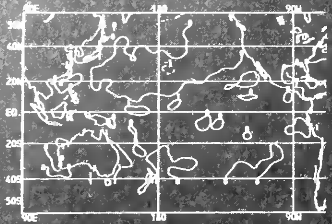
* The composite is defined as the average (over the different El Niño events) anomalous behavior. Because each El Niño is different in intensity and timing, the composite El Niño anomalies are generally smaller than those of a particular event.

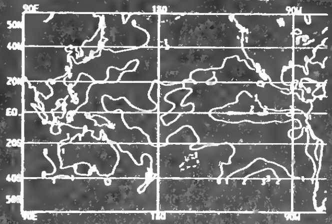
SEA-SURFACE TEMPERATURE ANOMALIES

1982–83 EL NINO:

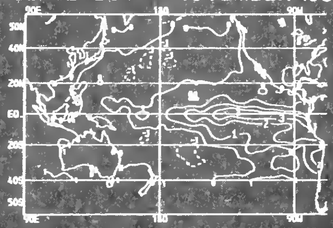
a) MARCH — MAY 1982:



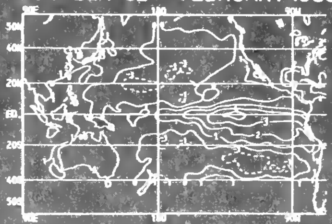
c) JUNE — AUGUST 1982:



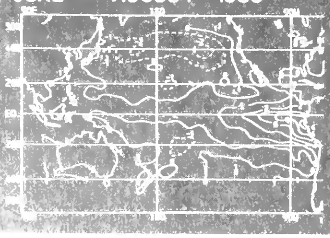
e) SEPTEMBER — NOVEMBER 1982:



f) DECEMBER 82 — FEBRUARY 1983:

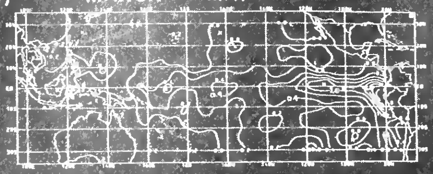


i) JUNE — AUGUST 1983

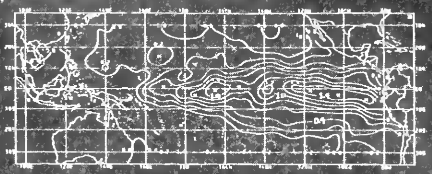


COMPOSITE EL NINO:

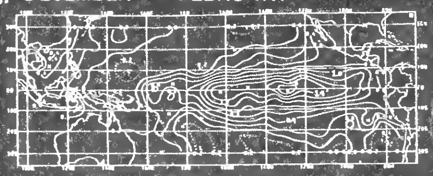
b) MARCH — MAY:



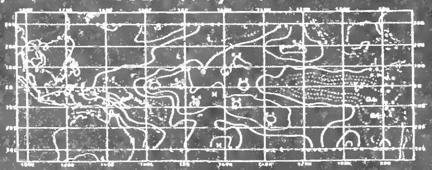
d) AUGUST — OCTOBER:



g) DECEMBER — FEBRUARY:



h) MAY — JULY (+1 year)



Surface-Wind Behavior

Variations in zonal wind stress can force large changes in the ocean within a few degrees of the equator, so it is useful to consider how the surface wind behaved over the tropical Pacific during the 1982–83 event.* Changes during the main phase of the 1982–83 event were quite large, so analysis relies on winds from weather-center fields; unless otherwise noted, only the monthly-mean or lower frequency zonal winds on and near the equator are considered.

The zonal winds along the equator appear to have been within 2 meters per second of normal until June 1982. Figure 2 shows heavily averaged wind anomalies at 850 millibar height (well above the surface) from the Climate Analysis Center results. It is assumed that variations in winds at this height are roughly similar to those at the surface; this assumption is under investigation. Around June, 1982, the normally weak easterly winds between 150 and 180 degrees East weakened and became westerly; they continued to be westerly for months thereafter. The region of anomalous westerly winds moved eastward with time until spring, 1983. Although the details of the anomalous wind fields vary considerably with analysis procedure, this figure suggests that, along the equator, strongly anomalous conditions were ultimately experienced as far to the east as 100 degrees West and actual westerlies were observed at least as far east as 150 degrees West.

The rather abrupt onset of the strongly anomalous winds west of the dateline has not been satisfactorily explained. Ship data and numerical-model fields suggest that they arose immediately subsequent to a period of several weeks of anomalously southerly winds east of Australia, which ultimately extended across the equator between 150 and 160 degrees East. Figure 3 shows monthly-mean winds from U.S. Navy weather-center fields at 19.5 meters height that illustrate the evolution. The large-scale surface-pressure fields over the western Pacific, as measured by the Southern Oscillation Index (SOI), were anomalous for several months prior to June of 1982, but not strongly so. Whatever the mechanisms responsible for the unusual zonal winds along the equator, these winds forced strong changes in the ocean all along the equator and the West Coast of the Americas.

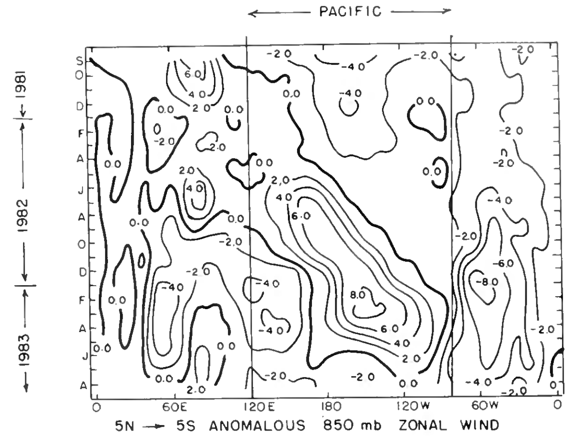


Figure 2. Anomalous zonal wind at 850 millibar height averaged over the band 5 degrees North to 5 degrees South between September, 1981, and August, 1983 (NOAA, Climate Analysis Center, 1983). The Pacific basin longitudes are indicated. Note the appearance of westerly anomalies west of the dateline in June, 1982, and the subsequent strengthening and eastward movement of the area of westerly anomalies. The data have been substantially smoothed, to show the large-scale structure of the wind changes.

Changes in Sea Level

Another important change variable in the ocean is sea level. Sea-level data are available from several islands near the equator and from coastal stations along the South American coast. Figure 4 shows daily-averaged sea-level records at four equatorial stations. Nauru Island is in the area where the significant westerly winds began in mid-year; spikes in sea level from strong short-term episodes of westerly wind near and to the west of it are seen, and sea level was higher than climatology for the period late June through early September of 1982. Christmas and Fanning islands are east of the region where the sustained westerlies began, and show a significant rise of sea level in early July followed by a continuing rise into September. Santa Cruz Island in the Galapágos, almost on the South American coast, shows a modest abrupt rise in early August and a larger abrupt rise in late September.

Sea-level data from another Galápagos Island (North Isabela) and at three Southern Hemisphere

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* Unfortunately surface wind was not well observed over most of the area of interest; ship reports and island observations at best yield a fragmentary reconstruction of the wind field. The movement of cloud patterns above the atmospheric boundary layer gives important information when the relationship between motions at cloud level and motions at the surface are known. The most convenient way to examine the wind field is to use the analysis/forecast fields produced by the national meterological centers, since they give gridded data for the whole area. Unfortunately it is not yet clear how well such fields reproduce the real variations of the tropical atmosphere; the surface divergence patterns, in particular, often appear quite different from those obtained from ship or cloud-motion vectors. Further, preliminary studies suggest that the monthly-mean fields produced from different data and techniques generally differ by about 2 meters per second RMS (root mean square). This is a significant fraction of the annual cycle of the wind over much of the tropics and of the changes observed during El Niño events. Still, very large wind changes are often found to be generally consistent from analysis to analysis.

Figure 1. (Facing page) Anomalous (actual minus climatology) sea-surface-temperature fields for the El Niño of 1982–83 (NOAA, Climate Analysis Center, 1983) and for the composite (average) post-1950 El Niño event (from Rasmusson and Carpenter, 1982). Note the very different timing and spatial patterns for the two events. The 1982 event did not show significant warming until late boreal summer 1982, and it first showed up along the equator in the central Pacific, instead of along the South American coast.

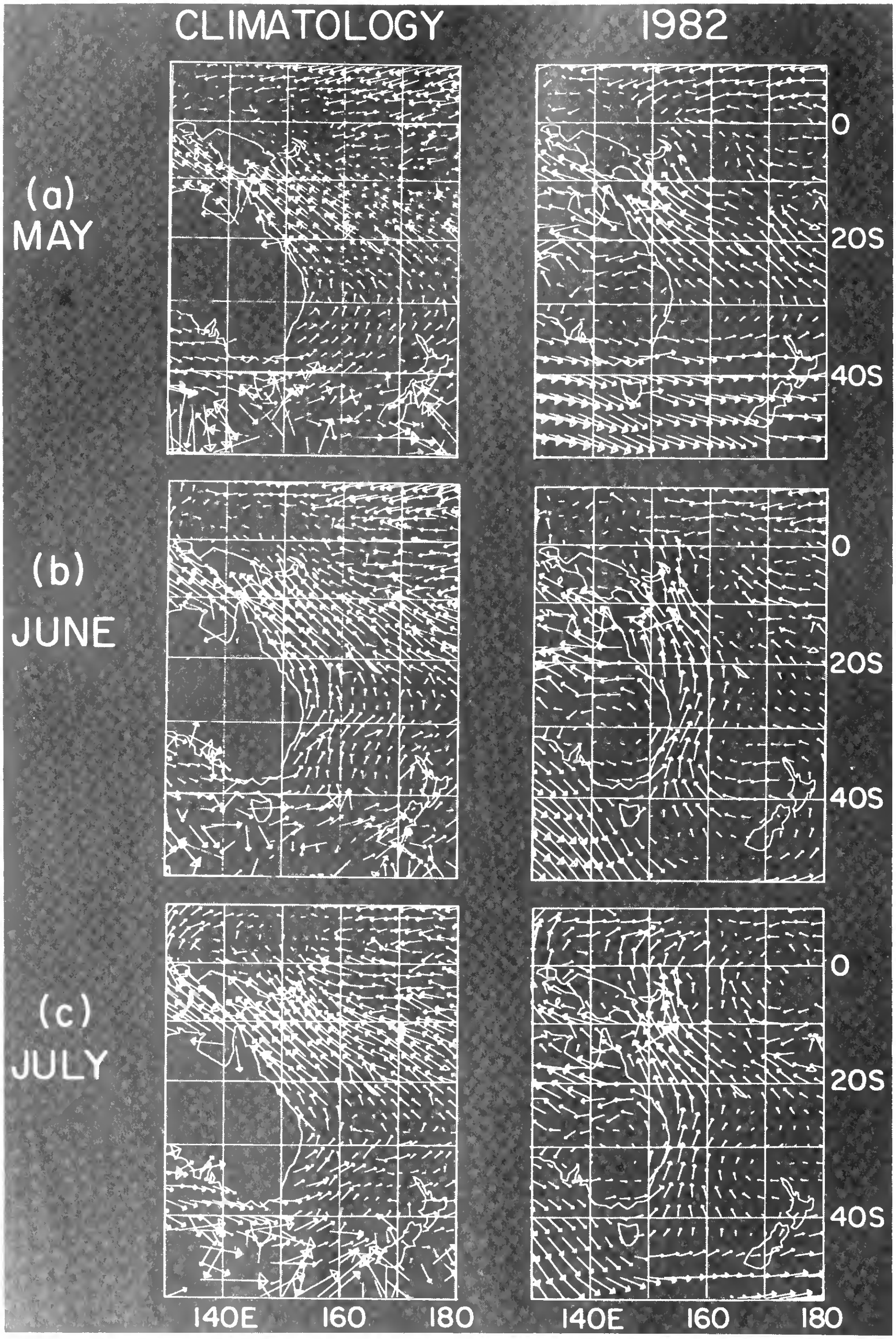

Figure 3. The origin of the westerly anomalies in June, 1982, based on monthly mean 19.5-meter winds from the U.S. Navy weather center fields. For comparison with the 1982 wind fields, the climatological monthly-mean surface wind from ship reports is shown for corresponding months. Note the anomalous behavior east of Australia, from 40 degrees South to north of the Equator in both June and July of 1982. (From Harrison, 1984)

coastal stations are also available (Figure 5). At North Isabela a steady increase in late July through early August continued at least into October. The coastal stations show considerable high-frequency variability superimposed on a slower time-scale increase of sea level beginning in September, 1982. These records are generally consistent with the notion that the wind changes in the western Pacific beginning in late June of 1982 forced a special kind of equatorial motion, a low vertical mode Kelvin wave front, that subsequently propagated across the Pacific in July and August of 1982.* After the initial period, sea-level data suggest that there was a period of larger-scale response to the larger-scale wind changes.

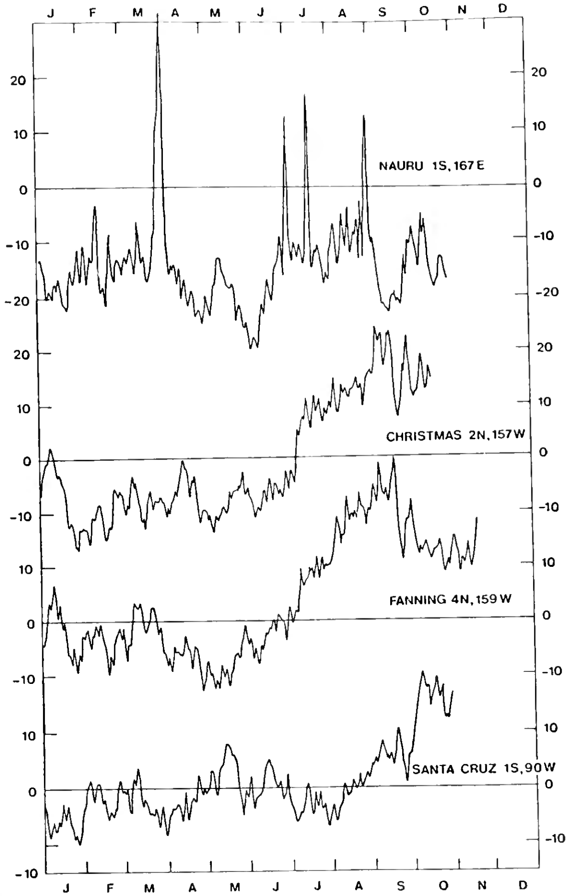

Figure 4. Equatorial daily-mean sea-level records (tides removed) from Pacific islands during 1982. Note the tendency for sea level to increase with time at the three islands east of the dateline between July and September of 1982. The sea-level rise begins first in the west and spreads eastward. No large, low frequency changes are observed at 167 degrees East. (From Wyrtki, 1983)

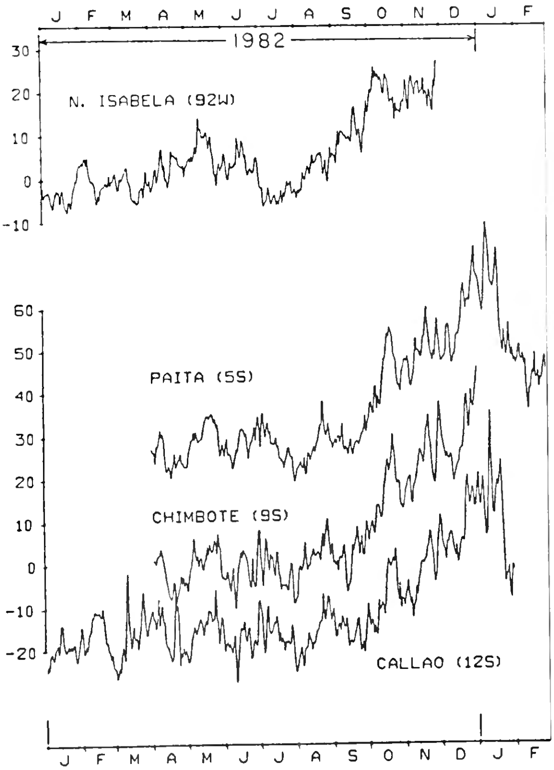

Figure 5. Sea-level (tidal and diurnal signal removed) records from the Galápagos island of North Isabella and along the South American coast. Again, note the period of generally rising sea level at each station beginning in mid- to late-boreal summer 1982. The rise begins first at the equator in late July/early August and later along the coast. (From Enfield, Hayes, and Smith, 1983)

Current, Subsurface Data

Of course, sea-surface changes do not tell the whole story. Consider some current and subsurface-temperature data. Filtered time series of temperature and zonal current between the surface and 500 meters on the equator at 159 degrees West are shown in Figure 6. Figure 6a shows that the 28 degree Celsius isotherm descended about 50 meters, beginning in July, 1982, and remained much deeper than normal at least through November, 1982. The whole thermocline was more intense than normal between August and December of 1982. The zonal currents (Figure 6b) underwent a major disruption between July, 1982, and January, 1983. The equatorial undercurrent (the band of eastward flow in the thermocline) weakened tremendously in August, 1982; there was flow to the west between 100 and 150 meters from mid-August through mid-October; and, the normally westward near-surface current was eastward during most of the period July, 1982, through December, 1982.

Roughly 5,000 kilometers east of 159 degrees West, at 110 degrees West along the equator, 30-day running averages of subsurface conditions are available. Figure 7a shows temperatures for 1981 and 1982; at 100 meters depth the temperatures

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* Within the equatorial waveguide, and for the frequencies and wavelengths forced by the 1982 winds, there are two oceanic modes of response to an abrupt change in zonal wind stress: Kelvin and Rossby waves. Kelvin response can be thought of as a special kind of sloshing of water eastward from the forced region. The changes in sea level associated with the lowest mode Kelvin front propagate very quickly, crossing the Pacific in a month or so.

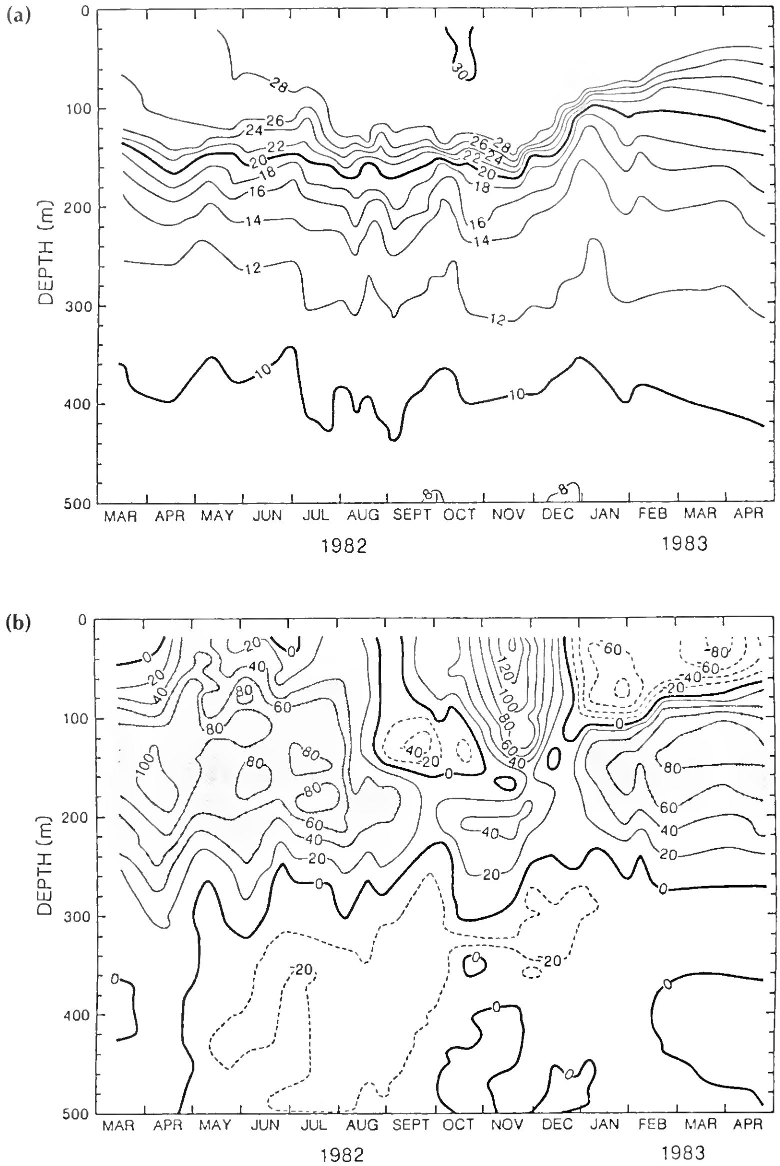

Figure 6. Time series of (a) temperature versus depth and (b) zonal current versus depth on the equator at 159 degrees West, from March, 1982, through April, 1983. Note the increasing temperature of near-surface water beginning in June and July of 1982, the reversal of zonal current (from eastward to westward) in the main thermocline (120 to 160 meters depth) between August and October of 1982, and the acceleration of a strong eastward near-surface current from September through November of 1982. (From Firing and Lucas, 1983)

were within 2 degrees Celsius of each other at corresponding times (until August, 1982) after a period of rapid warming had been under way for more than a month. At 15 meters depth, the 1981 and 1982 data differ by more than 2 degrees Celsius between mid-February and mid-March, and from late July onward; 1982 is again warmer than 1981. The zonal currents are shown for 1980, 1981, and 1982 in Figure 7b and indicate considerable year-to-year variation. Note that the August '82 warming corresponds to a period of stronger than normal eastward flow at both depths and that the 15-meter current remains anomalously eastward through September, 1982.

Two meridional sections of subsurface temperature at 85 degrees West (Figure 8) illustrate other large differences brought about by the 1982 ENSO event. South of the equator, the 1982 temperatures above the thermocline are well above those of 1981; the thermocline is much deeper than in 1981, and the sharp near-surface front that exists in 1981 is not present. On and north of the equator, the thermocline is unusually deep and diffuse, and the temperatures above 150 meters are warmer in 1982. The differences are strong on the equator.

Not a great deal of data has been reported near the coasts, but temperature and current data are available at 100 meters depth near 12 degrees

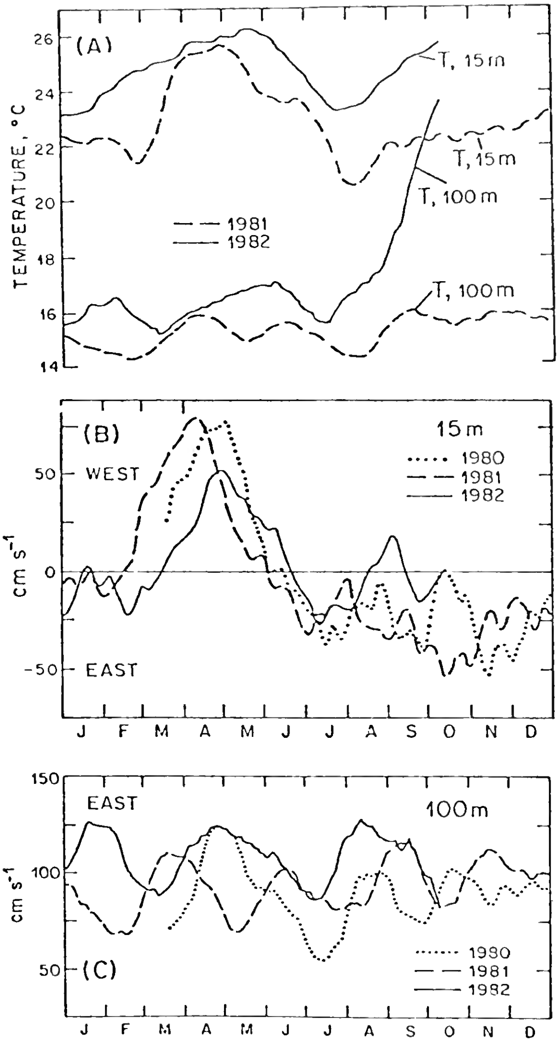

Figure 7. Thirty-day running averages of equatorial temperatures and zonal currents at 110 degrees West at 15 and 100 meters depth. Data from 1980, 1981, and 1982 are shown. Note the strong subsurface warming that began in August/September, 1982, and the interannual variations of current. (From Halpern and others, 1983)

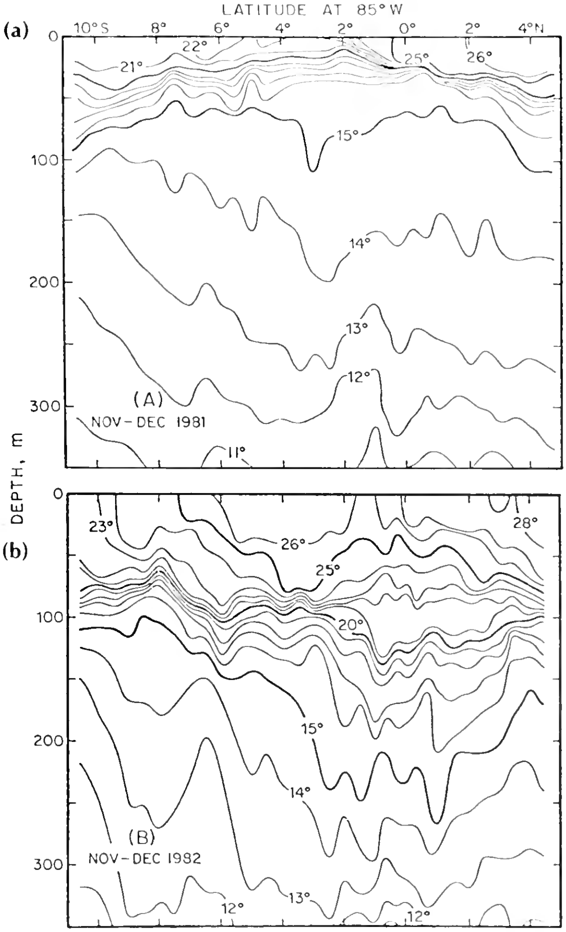

Figure 8. Two meridional sections of temperatures at 85 degrees West. a) November and December of 1981, (not El Niño) and b) November and December of 1982 (El Niño). Note the very large temperature changes within 5 degrees latitude of the equator. (From Halpern and others, 1983)

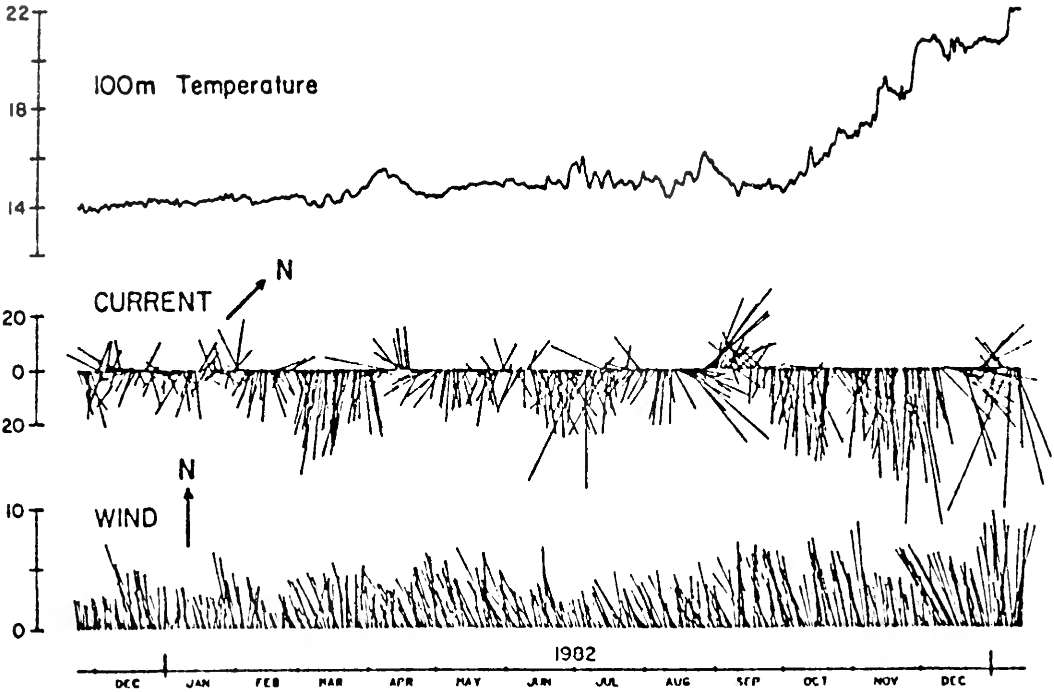

Figure 9. Temperatures and alongshore currents at 100 meters depth on the South American shelf near 10 degrees South and nearby surface winds during 1982. Note that temperature began to rise substantially in September and October of 1982, as the poleward alongshore current also began to increase. (From Smith, 1983)

South (Figure 9). Temperature begins to rise in late September, 1982, and continues through the end of the record (December, 1982). Although there is substantial along-shelf current variability evident in the current time series, middle to late September marks the beginning of a period of increased along-shelf current away from the equator. The current and temperature evolution are consistent with the idea that the warming began as the result of anomalous advection of warmer water from the north. The northward wind also tended to be stronger after September—an upwelling, favorable increase—so that changes in local upwelling were not the dominant temperature-change mechanism.

A Suggested Connection

It is clear that the warm event of 1982–83 involved important changes in winds, near-surface temperatures and currents, depth of the ocean mixed layer and thermocline, and upper-ocean thermal structure across the Pacific Basin and along the North and South American coasts. Many aspects of the oceanic changes are different from those observed in previous events and much work is needed to form an understanding of the dominant physical processes at work during the various phases of the event. The strongest physical connection suggested by the data presented here is that during the early months of the event (July through October of 1982), the wind changes that began in the Western Pacific during June and July of 1982 forced equatorial disturbances to propagate eastward along the equatorial waveguide across the Pacific, and then poleward along the American coasts. These disturbances brought unusual warm water currents in their wake. But, much remains unclear even in this scenario. The next few years should bring exciting results concerning many aspects of the behavior of the ocean and atmosphere during the 1982–83 event.

D. E. Harrison is a visiting Associate Professor at the Center for Meterology and Physical Oceanography, Massachusetts Institute of Technology (MIT). M. A. Cane, formerly an Associate Professor at MIT, is now at the Lamont-Doherty Geological Observatory, Columbia University.

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Sea-Surface Temperature in the Equatorial Pacific

by John M. Toole

The dramatic increase in sea-surface temperature (SST) in the eastern equatorial Pacific is one of the more familiar signatures of El Niño. So clear has been this signal in the past that the international oceanographic community has adopted a definition of El Niño based on the extremity of SST anomalies along the South American coast. Warm surface waters are much more than an indicator of El Niño, however. The coupling of the ocean and atmosphere, a key aspect of the El Niño/Southern Oscillation (ENSO)phenomenon, is dependent on the temperature of the air/sea interface. Ocean evaporation rates, among the primary connections between ocean and atmosphere, are enhanced at higher ocean temperatures. In turn, the subsequent condensation of water vapor in the atmosphere drives global-scale climate changes. Thus, sea-surface temperature is an important factor in the evolution of Southern Oscillation events. Since many processes can affect sea-surface temperature in the lower latitudes, and the existing database is sparse, the study of SST changes is both difficult and interesting.

Typical Conditions

The mean sea-surface-temperature field at low latitudes in the Pacific is characterized by relatively cold water in the east, relative to water temperatures in the west (Figure 1). Low-temperature water is found along the South American coast and in a cold tongue extending west along the equator. This zonal SST gradient is also reflected in the vertical structure of the temperature field (Figure 2). The thermocline, a transition layer between the warm surface waters and the colder abyss, is very near the surface in the eastern Pacific. In contrast, this boundary is deeper than 100 meters in the far western Pacific. The slope of the thermocline is believed to be caused by the trade winds, which blow from east to west near the equator. Viewed in terms of the surface layer's thickness, this thermocline structure allows for a thick surface layer in the west while limiting the eastern layer to a thin shell. Sensitivity to heating and cooling is correspondingly greater in the east because the heat capacity of the western layer is so much larger.

Despite being warm, the upper waters of the low-latitude oceans, on average, gain heat via air/sea

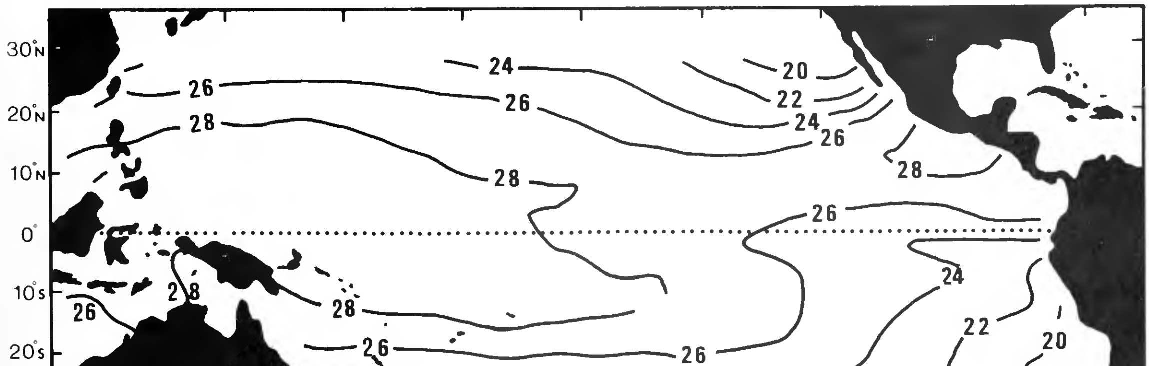

Figure 1. Mean sea-surface temperature of the tropical Pacific Ocean given in degrees Celsius (after Niiler and Stevenson, 1982). Note that temperatures in the East are some 4 degrees cooler than those in the West.

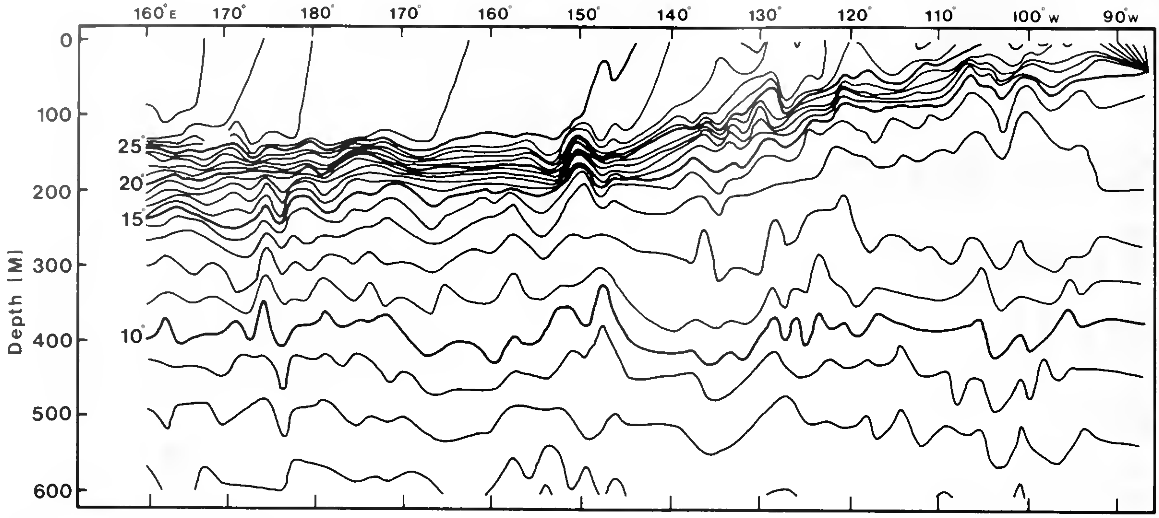

Figure 2. Section of temperature along the equator in degrees Celsius (after Colin and others, 1971). The thermocline is the depth interval of tightly packed isotherms centered around 200 meters in the West, rising to 50 meters in the East.

exchange. The net heat flux into the equatorial Pacific has been estimated to be around 50 watts per square meter, with upwards of 100 watts per square meter gained by the relatively cool eastern waters (Figure 3). How, then, does the eastern Pacific SST remain cool? This area also exhibits the largest temperature anomalies during El Niño periods. Are the same mechanisms that establish the average SST involved with the interannual variations?

Mechanisms Affecting SST

The vertical structure of the ocean near its upper boundary is generally characterized by a homogeneous layer lying above a stratified interior. This layer is believed to be maintained by turbulent mixing driven by wind and waves. SST reflects not only the interface conditions but the temperature of this surface-mixed layer.

The problem of understanding SST can be cast as an examination of surface-mixed-layer dynamics. By focusing on a small volume of the mixed layer in the eastern Pacific one can examine the processes that cause the temperature to change in that three-dimensional area (Figure 4).

Air/Sea Exchanges

The flux of heat across the upper surface of the test volume can occur in four different ways. (Refer to

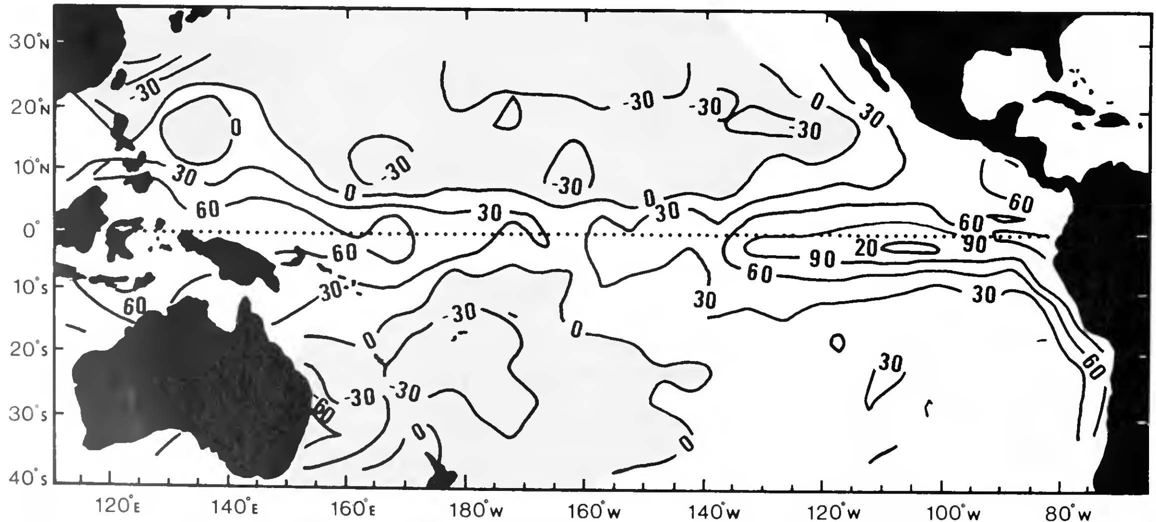

Figure 3. Long-term average exchange of heat between the atmosphere and the tropical Pacific Ocean in watts per square meter (From Weare and others, 1981). Positive values denote heat gain by the ocean; within 10 degrees of the equator (latitude), the ocean gains heat at rates upwards of 100 watts per square meter.

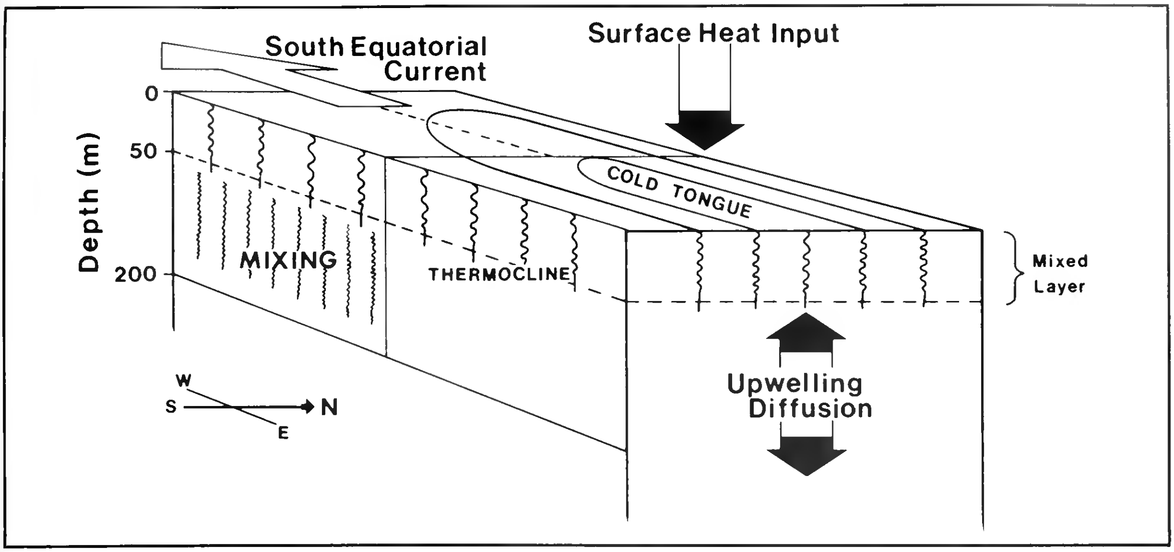

Figure 4. The surface-mixed layer in the eastern equatorial Pacific.

Figure 4 throughout discussion.) Direct solar radiation, or insolation, tends to warm the layer. The rate of heating is a function of the angle of the sun from vertical and the amount of energy absorbed and reflected by the atmosphere and the amount reflected at the ocean's surface. A typical value for the average solar radiation absorbed by the eastern Pacific is 200 watts per square meter. If left unbalanced, this flux would produce a 1 degree Celsius warming in a 25-meter thick mixed layer in less than a week.

All objects at temperatures above absolute zero radiate heat. The rate at which heat is given up is a function of temperature; the warmer the body, the greater the flux. The ocean, being warm, radiates energy away at its free surface. The atmosphere also radiates energy, some of which is absorbed by the ocean. The combined result is an exchange of heat between the ocean and atmosphere by long-wave radiation (so called, because the characteristic wavelength of the emitted radiation is long in comparison to that typical of solar radiation). In general, heat is transferred from the warmer partner to the cooler, though clouds and other parameters can influence the rate. The average temperatures of the tropical ocean and atmosphere are nearly the same, so the net exchange of long-wave energy is small; typically, 30 watts per square meter is transferred out of the ocean.

Heat also is exchanged between the ocean and atmosphere by turbulent processes. The diffusion of heat across the air/sea interface, termed the sensible flux, depends on the temperature difference between ocean and atmosphere and the intensity of the turbulent mixing (usually estimated in terms of the wind speed). An analogue of the sensible-heat exchange is the wind-chill factor, used to equate discomfort levels due to low temperatures and wind. As the air/sea temperature differences are minor at low latitudes, the sensible-heat flux is usually small, averaging less than 10 watts per square meter.

The fourth way in which heat is lost by the mixed layer is evaporation. Air parcels in direct contact with the sea surface equilibrate by becoming saturated with water vapor. The overlying air is typically not saturated, so turbulent mixing in the atmosphere boundary layer effects a moisture flux away from the interface. This, in turn, is balanced by more evaporation, thereby cooling the ocean. The rate of cooling by evaporation—the latent-heat flux—is thus a function of both the turbulence intensity (related to wind speed) and the amount of moisture in the atmosphere, comparable to cooling by evaporation after a swim.

At warm ocean temperatures, the air in contact with the sea surface can hold large amounts of water vapor, much more than is typically present in the overlying atmosphere. Here, latent-heat flux is usually significant, reaching values on the order of 100 watts per square meter out of the ocean in the eastern Pacific.

The net exchange of heat across the air/sea interface is the sum of solar, long-wave, sensible-heat, and latent-heat fluxes. A typical value for the region shown in Figure 4 is 100 watts per square meter, which will warm a 25-meter thick layer by 1 degree Celsius in less than two weeks. Clearly, processes in the ocean to remove this heat are at work, since stable estimates of mean sea-surface temperature can be constructed.

Mixed-Layer Base Exchange

The eastern equatorial Pacific is unique for having a very shallow thermocline. As a consequence, relatively cool water is found close to the base of the mixed layer, which proximity makes possible the cooling of the ocean-mixed layer via vertical upwelling or turbulent mixing of the cool waters.

Blowing equatorward along the South American coast and generally westward about the equator farther west, the southeast trade winds drive a divergent circulation in the ocean's mixed layer. This gives rise to upward flow in the water below. This upwelling produces a thinning of the mixed layer as the thermocline is displaced closer to the surface. The upward displacement also brings the thermocline into contact with strong turbulence generated at the air/sea interface. This turbulence, in turn, entrains the colder water into the mixed layer, thickening it and effecting a decrease in temperature. Direct estimates of the vertical heat flux produced by these processes are few but suggest the flux is significant.

Horizontal Exchanges

Ocean currents can transport heat horizontally into the area depicted in Figure 4. Relatively warm water is found west of the site, cooler water to the east. The advection of surface water to the east, for example, would produce an apparent warming at the test site. On average, the near-equatorial surface flow is to the west (the South Equatorial Current); hence, there exists a tendency for cooling by ocean currents at the site.

The mean state is brought about through a balance among the heat fluxes. Air/sea exchange acts to warm the ocean; vertical advection and mixing and horizontal advection act to cool it. Recently, Klaus Wyrtki of the University of Hawaii developed a box model for the sea-surface temperature cold tongue to estimate mean circulation rates. This study indicated that vertical upwelling and mixing were the largest cooling terms in the heat budget of the surface layer. Lateral advection was weaker, but not negligible.

Interannual SST Variability

Observations of sea-surface temperature and upper-ocean stratification during El Niño events reveal dramatic warming of the near-surface waters in the eastern Pacific. Which of the mechanisms outlined previously are responsible? Before reviewing the likely causes it is necessary to examine the rate of warming typical of an El Niño/Southern Oscillation event.

Figure 5a presents a composite time series of El Niño sea-surface-temperature anomalies for the eastern Pacific. Onset is quite sudden, with sea-surface temperature rising 1 degree Celsius above normal in two months, exceeding 2 degrees Celsius after four months. (Averaging done in constructing this composite tends to elongate the event in time. Warming rates of individual events are often twice these values.) A net heat flux on the order of 20 watts per square meter into a mixed layer of 25-meter thickness is required to produce this temperature increase during onset. The actual changes in surface-mixed layer heat content are generally greater than this because the layer thickens during onset due to convergent horizontal flow.

This onset phase is often represented as the passage of an equatorially trapped Kelvin wave* generated by usually strong winds in the far western Pacific (see Harrison and Cane, p. 21). For the purposes of this article it is only necessary to understand that this wave disturbance depresses the thermocline in the eastern ocean (yielding a thicker surface layer) and produces anomalous eastward flow near the equator.

Figure 5b gives a representative plot of the heat-content change of the surface layer based on the temperature data given in Figure 5a and a layer thickness that increases from 25 to 50 meters during the first three months of the event and decays to 25 meters during the final three months. The diagram indicates that a net flux into the ocean on the order of 50 watts per square meter is characteristic of onset.

Exchanges During El Niño

One way in which the surfce-mixed layer could warm is an increase in the heat flux from the atmosphere to the ocean. Recall that four mechanisms are involved in this exchange and that insolation and latent-heat flux are the largest terms in the mean budget. Solar radiation could cause the ocean's temperature to rise if the amount of cloud cover decreased. A decrease in the evaporation rate produced by a decrease in wind speed, for example, also could produce warming.

Several studies have carefully monitored the net air/sea heat exchanges during recent El Niño/Southern Oscillation events. Comparison among the resulting estimates is difficult because different analysis techniques were used in each case. A. K. Reed and others report near-zero heat flux into the ocean during onset. Others, including A. Leetmaa, found enhanced flux into the ocean during periods of SST warming. The importance of heat exchange between the atmosphere and ocean in producing warm sea-surface temperature is not clear. On average, the ocean is gaining some 100 watts per square meter from the atmosphere; should this flux be unbalanced for a time, significant warming would result.

Upwelling and vertical mixing were found to be important cooling mechanisms for the surface-mixed layer. Upwelling is the result of the divergent wind-driven circulation of the low-latitude surface waters. When the winds abate, upwelling, and the associated cooling, is suppressed. Yet during onset, the winds in the eastern Pacific are near-normal, so upwelling continues.

The properties of the water that upwells, however, appear to change during the event. Onset of El Niño in the eastern Pacific is associated with a depression of the thermocline (and an associated thickening of the surface layer). This downward displacement effectively insulates surface waters from the relatively cold thermocline layers that are normally entrained into the mixed layer. Although upwelling continues, it is relatively warm water that is introduced into the surface layer. This removal of

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* Thermodynamic unit of measurement.

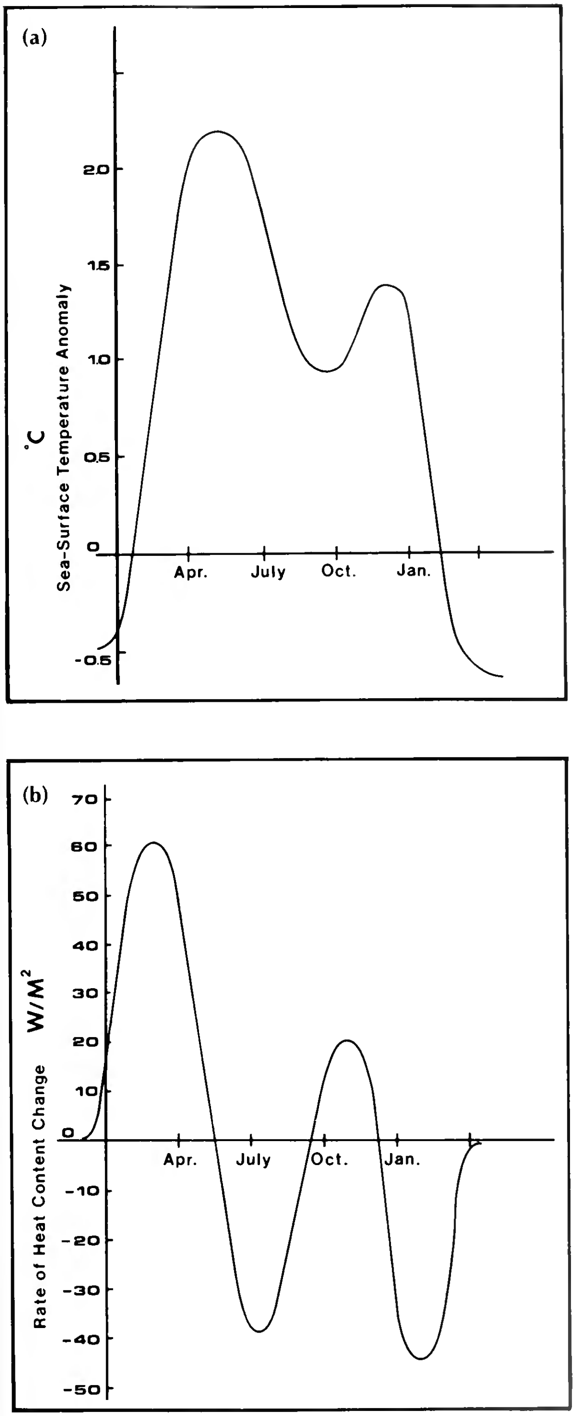

Figure 5a. Time series of sea-surface-temperature anomaly during El Niño (after Rasmusson and Carpenter, 1982). In any month, the anomaly is the difference between the temperature of the ocean during an El Niño and the long-term average temperature for the month. 5b. The rate of change of surface-mixed layer heat content during El Niño based on the curve in Figure 5a, and an initial mixed-layer thickness of 25 meters that increases to 50 meters during the event.

the cooling tendency of the vertical-exchange mechanisms, coupled with the near-normal heat exchange from atmosphere to ocean, can lead to a sea-surface-temperature increase.

The maintenance of the mean sea-surface-temperature field also involves westward advection of cold water. Warming could result from a current reversal whereby warm water from the west is transported into the eastern Pacific. The magnitude of the advective effect is a function of both the strength of the flow and the temperature gradient in the direction of the current.

Onset of El Niño appears to be associated with anomalous eastward flow, which is related to Kelvin waves. Yet the direct SST change produced by this advection is small in the typical event (one that begins early in the calendar year). The weak effect derives from the small temperature gradient along the equator during this season. (The mean state in Figure 1 is made up of one season of near-zero gradient and one season with twice that shown in the diagram.) Thus, the horizontal advection of *warmer* surface water from the west is of secondary importance in producing the anomalies in the east. Nevertheless, advection is intimately involved with warming, since the eastward transport of surface water is associated with the depression of the thermocline.

Advection is not always of secondary import. Consider the 1982-83 event.

Unlike the typical Southern Oscillation, the El Niño of 1982–83 began during the season of strong zonal sea-surface-temperature gradient. The eastward flow not only yielded thickened surface layers, but actually transported much warmer water into the eastern ocean. The positive sea-surface-temperatures that resulted were some of the largest on record. It is obvious that many processes are involved with SST anomalies and different mechanisms may be dominant in each event.

Still harder to identify are the mechanisms responsible for the return of sea-surface temperatures to normal values at the end of El Niño. Warm ocean temperatures coupled with high cloudiness can produce ocean-heat loss via air/sea exchange. The observed restoration of the thermocline to its near-surface location (via unconfirmed mechanisms) reintroduces cold water into the upwelling/mixing zone. The return of the South Equatorial Current, and the associated advection of cool waters to the west, usually accompanies the thermocline restoration. It is still not clear which, if any, of these processes is dominant.

Tropic Heat Program

Sea-surface temperature in the equatorial Pacific is a complicated variable, dependent on many oceanic and atmospheric processes and, in turn, significantly influencing the coupling between the two. To date, our understanding of the relative importance of the various mechanisms affecting sea-surface temperature is conjectural, drawn from a thin database. Since sampling during any one El Niño/Southern Oscillation episode has been limited, compositing techniques have been applied to construct typical fields. Yet each event may be unique, with different dominant processes affecting sea-surface temperature: A composite may bear little resemblance to any individual event.

Continuous sampling on fine-space scales during an actual event would provide much valuable information. Such an effort would require use of self-contained oceanographic sensors and satellite remote-sensing techniques as opposed to ship-borne instrumentation.

Development of quantitative scenarios of sea-surface-temperature evolution also is hindered by uncertainties in all of the heat-flux terms. Bulk formulas for air/sea exchanges may be in error by a margin of 10 percent or more; long-term direct estimates of the oceanic vertical-heat flux do not exist. A major field program called Tropic Heat, in which refined estimates of the various fluxes are being sought, is under way. The ultimate goal of this program is to develop an accurate heat budget for the surface waters of the equatorial Pacific.

John M. Toole is an Assistant Scientist in the Physical Oceanography department at the Woods Hole Oceanographic Institution.

Acknowledgments

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El Niño and Peru: Positive Aspects

by Wolf E. Arntz

EDITOR'S NOTE: The strong El Niño of 1982–1983, like former events, proved to be an ecological catastrophe for the Peruvian upwelling system; yet, it showed some positive characteristics, too.

When biologists or journalists mention El Niño, they usually refer to it as a catastrophe. The damage caused by the warming of otherwise cool ocean waters and the cessation of upwelling to the marine fauna and flora and to the fisheries industry is obvious, as are the disastrous effects of heavy rainfall in normally arid areas and the lack of rain in the humid parts of Peru.

The particularly strong event of 1982–83 was no exception.[1] During the summer and fall of 1983, northern Peru and Ecuador were virtually drowned with precipitation, reaching values 1,000 percent greater than the 15-year monthly average. Large cultivated areas were flooded; towns and fishing terminals destroyed; there were innumerable avalanches in the inter-Andean region; the Panamerican Highway was interrupted; hundreds of people died and thousands of fishermen became unemployed.[2] The sand beaches were scattered with

Fishermen at Samanco, Peru, with usual abundance of shrimp in August, 1983. (Photo by author).

dead cormorants, boobies, sea lions, bivalves, crustaceans, and sea urchins. And the rocks—normally inhabited by a rich invertebrate fauna that provides a livelihood for many small-scale fishermen—were bare.

Local fishermen set their nets in vain search of their traditional prey; pejerrey, *Odontesthes regia*, lenguado, *Paralichthys* species, cojinoba, *Seriolella violacea*, and many other fishes disappeared from shallow waters and headed south, or toward the ridge of the Continental Shelf to find cooler temperatures. Instead, enormous quantities of swimming crabs, *Euphylax robustus* and other species, and large rays invaded the area, destroying the nets or filling them with a catch that could not be sold.

The situation of the industrial fishery was even worse. Anchovy, *Engraulis ringens*, the main prey item of the purse seiner fleet (not yet recovered from its breakdown after the El Niño of 1972–73[3]) migrated southward and withdrew to deeper waters where they stayed beyond the reach of the nets. During the summer of 1983, only minute concentrations in extremely bad physical condition were left in some remaining upwelling areas south of Pisco.

Something similar happened to the sardine, *Sardinops sagax* (which has replaced the anchovy to some extent in past years as a product for the fishmeal industry), although there are indications that this species survived the abnormal situation better. However, since the sardine also stayed in deeper waters, they could not be taken by the purse seiners either, leading to a breakdown of the national enterprise Pesca Perú, which was also hurt when 11,000 tons of guano were washed by the rain from the northern islands.[4]

Carpets of Flowers

Despite these disasters, which caused the Peruvian government to declare a State of Emergency in the fishery, El Niño had a couple of positive effects. In the face of the general catastrophe, however, these are likely to be overlooked.

In many parts of the coastal desert, rains and unusually strong fogs lead to a hitherto unknown outburst of vegetation that covered wide areas with carpets of flowers for several months, enabling the local settlers to raise cattle, sheep, and goats. A similar phenomenon is known to happen every spring in very restricted parts of Peru, such as the hills of Lachay (north of Lima), but nothing equal to last year's outburst has been observed during other recent El Niño events, although one may have accompanied the strong event of 1925–1926. Apparently, the seeds and bulbs of many plants survive in the desert for many decades until a strong El Niño creates appropriate conditions for the type of explosion observed this year.

Something similar occurred on the rocks of the intertidal zone. Because of an absence of grazing (the phytophagous animal species either were killed by the high temperatures or migrated to deeper waters), large beards of green algae started growing on the rocks between March and July, 1983. This phenomenon was observed to be stronger in the northern and central zones of the coast, where El Niño caused more damage because of higher temperatures, than in the south.

Evidence of 1983 scallop boom around Pisco, Peru. (Photo by author).

Only with the appearance of large numbers of juveniles of the rock fauna did the green algae gradually vanish, but its place was taken by mats of red and brown algae. It seems that the brown algae could develop only when temperatures returned to a certain normality; during the peak of the event, large "forests" of *Macrocystis* (kelp) were killed, even in deeper water, and washed ashore.

El Nino's effect at the seafloor was characterized by a decisive increase in dissolved oxygen. Under normal conditions, oxygen values just above the seafloor are extremely low (less than 1 milliliter, in many cases less than 0.5 milliliter) off central and southern Peru below 20 to 30 meters depth, and the sea bottom is covered with mats of filamentous bacteria.[5] During the El Niño of 1982–83, oxygen values rose to more than 1.5 milliliter, and to more than 2.5 milliliter off Huarmey, Callao, and Pisco (10 to 14 degrees South). By August, 1983, oxygen values were found to be somewhat lower although still far above normal values.

As a consequence of improved oxygen conditions, some macrobenthic groups, mainly polychaetes (numerous types of worms) and nemerteans (ribbon worms) developed high densities and a high biomass during the initial phase of the event, improving the food conditions for bottom-dwelling fish, which also were favored directly by the greater availability of oxygen.

During the summer of 1983, hake, *Merluccius gayi peruanus*, and many other bottom-dwelling fish extended their area to the south and into deeper waters; the immediate effect of this shift in distribution on the trawl fishery was negative, but there may well be a positive effect on recruitment and on the fishery after El Niño. Despite continuing high oxygen values, the macrobenthos off the central coast was reduced again by May and August of 1983, possibly because of increased predation by fish, shrimps, and swimming crabs. The filamentous bacteria were apparently favored by the increase of oxygen up to a certain limit, but declined under high oxygen conditions where macrobenthic species were more competitive.

Dorado Plentiful

The local fishermen suffered great losses in general, but some positive effects of El Niño were obvious. At the peak of the phenomenon, several tropical and subtropical fish species abounded off Peru; especially dorado, *Coryphaena hippurus*, skipjack, *Katsuwonus pelamis*, Spanish mackerel, *Scomberomorus maculatus sierra*, and even yellowfin tuna, *Thunnus albacares*. Bonito, *Sarda chiliensis chiliensis*, which had become scarce after the decline of the anchovy, was once again common, and the same was true for dogfish, *Mustelus whitneyi*. Although it took the Peruvian customer some time to appreciate the new species, the dorado, in particular, reached a high market price and thus compensated the fishermen for some of the species that had disappeared.

A similar situation occurred in the shellfish fishery during the later phase of El Niño. The scallop, *Argopecten purpuratus*, not only survived under the higher temperatures but had a virtual population explosion off the central coast. In the Pisco area, monthy landings reached 600 metric tons in August, 1983. Catches per unit of effort increased by a factor of more than 20, and growth was strongly enhanced. Scallops became a popular food in Lima, at prices per "manojo" (96 scallops) between $0.30 and $2.50, according to size.

During the El Niño of 1982-83, eagle ray (shown) and other rays, sharks, and octopi were unusually abundant. (Photo by author).

Octopi greatly increased their population and were landed in large numbers; according to the fishermen they fed "exclusively on scallops." The snail, *Thais chocolata*, a scavenger, also seems to have increased its population. Another great boom was observed in the shrimp (mainly *Xiphopenaeus riveti*) fishery. Under normal conditions, this species is caught only off northern Peru and Ecuador; however, this year it extended its range down to 14 degrees South. It is now being landed all along the central coast of Peru, even with beach seines, and supplies the local and export (U.S.) market, as does the scallop. Thus, it made up to some extent for the decline in catches of the giant shrimp, *Penaeus vannamei*, off northern Peru, where an enormous invasion of swimming crabs nearly caused a breakdown of the fishery.

Snakes, Blood, Sharks: The Early Observations

Gerhard Schott's groundbreaking 1931 description of the Peru Current and the tropical northern regions to the north in normal years—years not marked by an El Niño episode—was made possible, in part, by accounts given by the American biologists Robert Cushman Murphy and William Beebe. Aboard *Arcturus* in 1925, the pair recorded conditions between Panama and the Galápagos Islands.

Murphy considered the El Niño of 1925 the most powerful since 1891 and understood it as a "warm countercurrent." Noting abrupt rises in sea-surface temperatures, he attempted to narrate the devastation created by the migrating conditions. Presumably, though, he was unable to top the wild biological observations made in 1891: "the appearance of yellow-bellied water snakes . . . cast up on the beach, dead or dying. . . . phosphorescent lightenings all over the beach" which, during the day, "was covered with blood-like patches many acres in extent caused by minute microorganisms, whether animal or vegetable, I cannot say." Finally, in addition to a proliferation of "man-eating sharks" and snakes following the observers' boat, "one afternoon, riding along the beach, I flushed a fair-sized alligator which hoisted its tail and dashed into the sea. I am of the opinion that he drifted down from Guayaquil."

Concluding that "the demonstrations of El Niño are seasonal and rhythmic, and that the causes behind them are meteorological in the broadest sense" Murphy cites a curious historical footnote. "The march which Pizarro made through Piura, while on his triumphal journey toward Cuzco (1533) was made possible only because he chanced to land upon the desert shores during one of the rare years of abundant water and vegetation."

Beebe added to this, commenting on the remarkable frontal zone, "a wall of water against which all the floating jetsam for miles and miles was drifted and held" denoting the convergence of a northeast/southwest line of "two warm, westwardly flowing streams of water." This "current rip" between Panama and the Galápagos was characterized by "throw and shift of the currents so strong hereabouts that the nets and lines were often swept beneath the keel," a foam line, and an accumulation of pelagic animals that fed on the organisms concentrated on the line, south of which "showed dark and rough (water), while to the north it was lighter and smoother."

Preserved in the invaluable *Oceanography of the Past*, edited by Mary Sears and Daniel Merriman (Springer-Verlag, 1980), these accounts aptly convey the mystery that shrouds El Niño. Decades later, the veil is largely intact.

There are few positive words that can be said about the other main components of the upwelling system. In general, there was a temporary enrichment of species (tropicalization), but this had no measurable effect on national economics with the exception of the shrimp and the few fish species mentioned. Horse mackerel, *Trachurus symmetricus murphyi*, and mackerel, *Scomber japonicus peruanus*, may have increased[6]; however, this will have little effect on Peruvian fisheries because there is no midwater trawling. Some seabirds, especially pelicans, *Pelecanus thagus*, and Inca tern, *Larosterna inca*, survived the El Niño much better than others by sticking close to fishery terminals and markets, but, as guano producers, the pelicans will not make up for the millions of cormorants and boobies that died during the event.

Innately resilient, the Peruvian upwelling system will recover quite soon. The Humboldt Current will transport larvae of the traditional species from southern Peru and Chile and, once normal temperatures are re-established, most of the species will find appropriate conditions for survival. Even an exceptionally strong El Niño like the 1982–83 event will not basically change the system, although there is a good deal of concern over some heavily exploited species; anchovy are the prime example. However, the priority that has been given in the past to the pelagic fish species has led to the point of view that El Niño is the incarnation of a general ecological catastrophe. It was the purpose of this article to demonstrate that "The Child" also had—admittedly restricted—positive properties.

Wolf E. Arntz is a biologist with the Institute of Marine Research in Bremerhaven, West Germany. He participated in a cooperative fisheries research program between Peru and West Germany from 1979 to 1983, and worked in Peru during the recent El Niño episode.

References and Notes

[1] A more complete presentation of the impact of the El Niño of 1982–1983 will be given in the Proceedings of the El Niño Symposium, IX Latin American Congress of Zoology, Arequipa, Peru, 10–11 October 1983, which will be published in 1984 in Boletin IMARPE, Instituto del Mar, Lima-Perú. If not otherwise cited, the results presented in this article refer to this symposium.

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El Niño: Implications for Forecasting

by Jerome Namias and Daniel R. Cayan

At the September, 1982, meeting of an international committee on predicting El Niño (SCOR* Group #55), the first topic of conversation was whether such an event was in the making. Discussion was prompted by the fact that sea-surface temperature (SST) in an area of the eastern tropical Pacific had risen quite sharply (by a few degrees Celsius) during the past couple of months. But, according to the most prominent theory, strong warming along the South American coast was impossible during the ensuing year, judging from precursory signs involving trade winds, height of sea level, and other parameters.

The sole contesting theory stemmed from the rather widespread tropical oceanic warming that had appeared to the west of the coast. As far as we know, at that time no categorical prediction was made about an El Niño emerging—let alone the greatest episode on record. This reveals gaps in our understanding of the El Niño phenomenon and its often humbling aftermath for those who attempt to predict complex long-range phenomena in which multiple causes operate.

As El Niño developed during the late fall of 1982 and most dramatically throughout the winter of 1982–83, information flashed around the world, providing the grist for hundreds of newspaper and magazine articles, as well as radio and television coverage. Scientists eagerly described, and attempted to explain, what was transpiring in the tropical Pacific and even what might ensue. Bold meteorologists and oceanographers projected El Niño into weather scenarios for the United States and other areas of the world; understandably, some of these comments led to media and public misconceptions about the role of El Niño in weather and climate prediction. To the layman, it might appear that success in predicting El Niño would be a panacea for all weather- and climate-forecasting problems.

Over the time spans of short-period climate variability, the atmosphere and ocean are strongly coupled. Other articles in this issue describe the connection between the tropical/subtropical atmosphere and conditions in the equatorial Pacific Ocean, the so-called El Niño/Southern Oscillation (ENSO) phenomenon. During El Niño, the eastern tropical Pacific is in its warm phase, associated with a western shift in atmospheric mass and a dramatic alteration in the Walker and Hadley atmospheric circulations.

During the last five years, countless published articles and scores of conferences, commissions, and study groups have investigated the mysteries of ENSO, and the potential for better understanding and hopefully better *prediction* of regional and remotely related phenomena over the globe. In the words of a recent National Research Council report, ENSO is identified as "the most powerful family of atmospheric and oceanic variations" on time scales of months to several years—time scales with major impacts on human decisions and socioeconomic conditions.

The hope of finding a unified theory to explain a broad spectrum of atmospheric phenomena, ranging from droughts to hurricanes, is most compelling. Many researchers believe ENSO is the key to a unified theory.

A balanced presentation, in which some important predictive aspects associated with El Niño are cited and some myths exposed, is overdue. While such a treatment uncovers some areas of ignorance, it also highlights the need for research that attempts to make of the El Niño phenomena important weather and climate forcasting tools.

What reliable predictions might be achieved or improved with better knowledge of El Niño? What predictions are probably not achievable? Expert opinions on El Niño's predictability range from the extremes of pessimism—considering the large number of factors involved—to optimism about the ability to foresee future events at lead times of several months.

El Niño and the Global Climate System

In low latitudes, the presence and potency of ENSO, without doubt, is spectacular. Testifying to the quality of Sir Gilbert Walker's imaginative work during the early 1900s, many recent studies have related the variations of the tropical Pacific to a

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* Scientific Committee on Oceanic Research of the Intergovernmental Oceanographic Commission (IOC), sponsored by the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

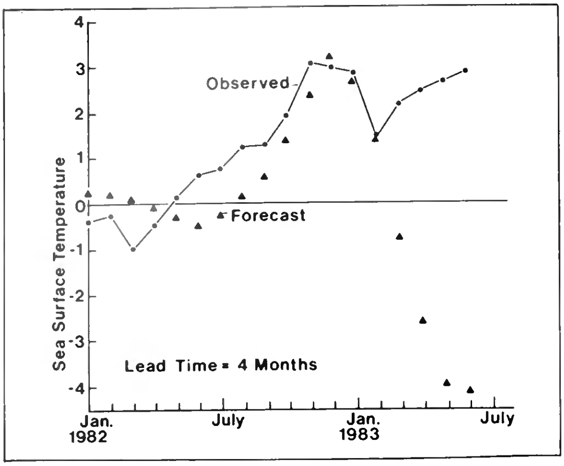


Figure 1. Prediction of the evolution of anomalous sea-surface temperature (SST) off the coast of South America, using observed equatorial Pacific trade winds 4 months in advance of each predicted SST value, along with observed SST anomalies (from a simple linear model developed by T. Barnett, Scripps Institution of Oceanography).

variety of phenomena that literally span the tropics and areas beyond.

For instance, during the El Niño of 1982–83, links were established to heavy tropical rains in Peru and Ecuador, droughts in northeast Brazil, Australia, and Indonesia, failure of the Asiatic monsoon, and even a relatively hurricane-free season in the tropical Atlantic. Through a history of several events, investigators have traced the development of these assorted phenomena to evolutionary stages of El Niño. In addition to understanding physical links in the system, one ultimate goal is prediction: given the orderly behavior of such identifiable ENSO features as tropical Pacific trade winds and sea-surface temperatures, other related phenomena might be predictable.

As with all such interannual variability, none of the relationships previously mentioned are ironclad, but enough empirical evidence has been assembled to tempt atmospheric and oceanic theoreticians. Despite the difficulties imposed by the 1982–83 case, there are positive signs that El Niño itself might be skillfully forecast.

For example, Figure 1 shows the results of a simple statistical model that relies on tropical western and central Pacific trade winds to forecast eastern tropical Pacific sea-surface temperatures at lead times of four months. When applied to the 1982–83 case, we see that the onset and growth of the warm sea-surface temperatures could have been quite convincingly foretold by the trade winds employed in this model, although the "decay phase" of the anomalies would not have been forecast. That this simple scheme could have been used to predict the early development of the El Niño of 1982–83 implies that modeling efforts that include more sophisticated physics might capture more of the event's evolutionary features.

The Nonuniqueness of ENSO

The long-range forecast problem, as one turns to temperate latitudes, is more complicated. Atmospheric scientists have long known that short-period (months to years) mid-latitude variations are more complex than tropical variations: ENSO has to share its role with other competing players. Unique influences are difficult to uncover amid a tangle of interactive and often synergistic forces.

To be sure, ENSO frequently displays some well known "teleconnections" with the mid-latitudinal atmospheric circulation, especially during the cold season. This strong correlation, which is receiving a good deal of attention, was brought to light by Jacob Bjerknes about two decades ago, partly in association with the North Pacific Experiment (NORPAX), a program to study North Pacific air/sea interaction phenomena and their downstream consequences on weather over North America. Figure 2 shows that during the Northern Hemisphere winter, in the El Niño phase of ENSO (warm sea-surface temperatures in the eastern tropical Pacific), there is a tendency for the Aleutian-Gulf of Alaska low-pressure center to be strengthened, higher-than-normal pressure to inhabit western Canada, and anomalously low pressure to be seated in the southeastern United States. When this idealized pattern (now called the Pacific-North American [PNA] pattern) is realized, as it was in the winter of 1958 (Figure 3), the surface temperature in the eastern half of the United States assumes a frigid countenance, while

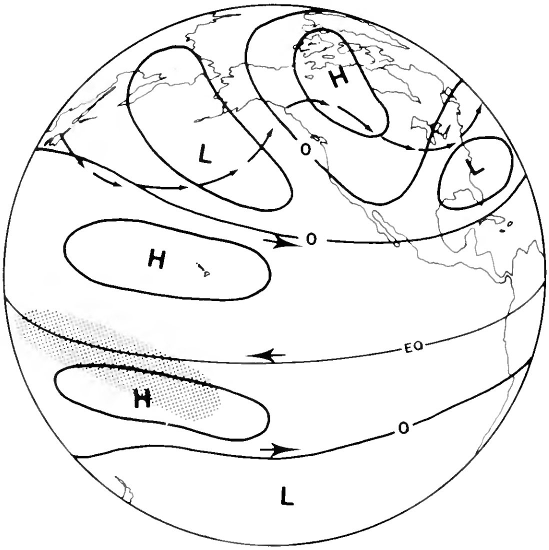


Figure 2. Idealized anomalous-pressure pattern in the upper troposphere during a Northern Hemisphere El Niño episode in winter. Short arrows reflect the strengthening of the subtropical jets in both hemispheres and stronger easterlies near the equator. Long arrows depict an actual streamline as distorted by the anomaly pattern, with pronounced troughing over the central North Pacific and ridging over western Canada. Shading indicates enhanced cloud and rain. (From J. Horel, Scripps Institution of Oceanography, and M. Wallace, University of Washington.)

in the West above-normal temperatures reign. The eastern cold and other features often cause El Niño to be blamed for a host of ills.

A census of U.S. temperature patterns during the nine well-recognized El Niño events since World War II is shown in Figure 3. Although these cases exhibit a disposition toward above-normal temperature in the Northwest (7 out of 9 cases, to some extent) and below-normal temperatures in the Southeast (5 out of 9 cases), it would be risky to use a single El Niño pattern to forecast temperature over the United States. The variability exhibited by the first 8 of these prompted the National Oceanic and Atmospheric Administration's Climate Analysis Center early in the fall of 1982 to caution against doomsday predictions of a cold eastern winter in 1982–83. Indeed, as it turned out, winter temperatures across the continental United States were exceedingly mild.

Turning our attention to precipitation (Figure 4), we discover an even stronger pattern of nonuniqueness; the variety of patterns in the same nine post-World War II El Niño episodes yields little consensus for a broad-based prediction of United States precipitation, although there is a tendency toward heavy precipitation in parts of the Southeast. Clearly, each El Niño has different characteristics, which implies that other mechanisms are at work. Subtle shifts in the position of tropical Pacific oceanic heating may greatly affect any mid-latitude atmospheric response.

What value, then, is ENSO in predicting seasonal climate variability across the United States? It should be emphasized that in *most* long-range forecast schemes, no predictor is employed singly, but rather each is considered in collaboration with others. Thus, if consensus can be achieved from ENSO indications along with others, a more intelligent forecast can be made.

Some evidence exists that the extreme winter of 1976–77, which displayed persistent warmth and extensive drought in the West and severe cold in the East, was a season whose weather resulted from multiple causes. These probably included a conspiracy of anomalous mid-latitudinal Pacific sea-surface temperatures, North American snow cover laid down early in the fall of 1976, forcing by the Rocky Mountains on the winds, as well as El Niño—all of which amplified the seasonal changes in atmospheric circulation that mark the transition from fall to winter. Indeed, in late fall, 1976, a number of seasonal forecasts,

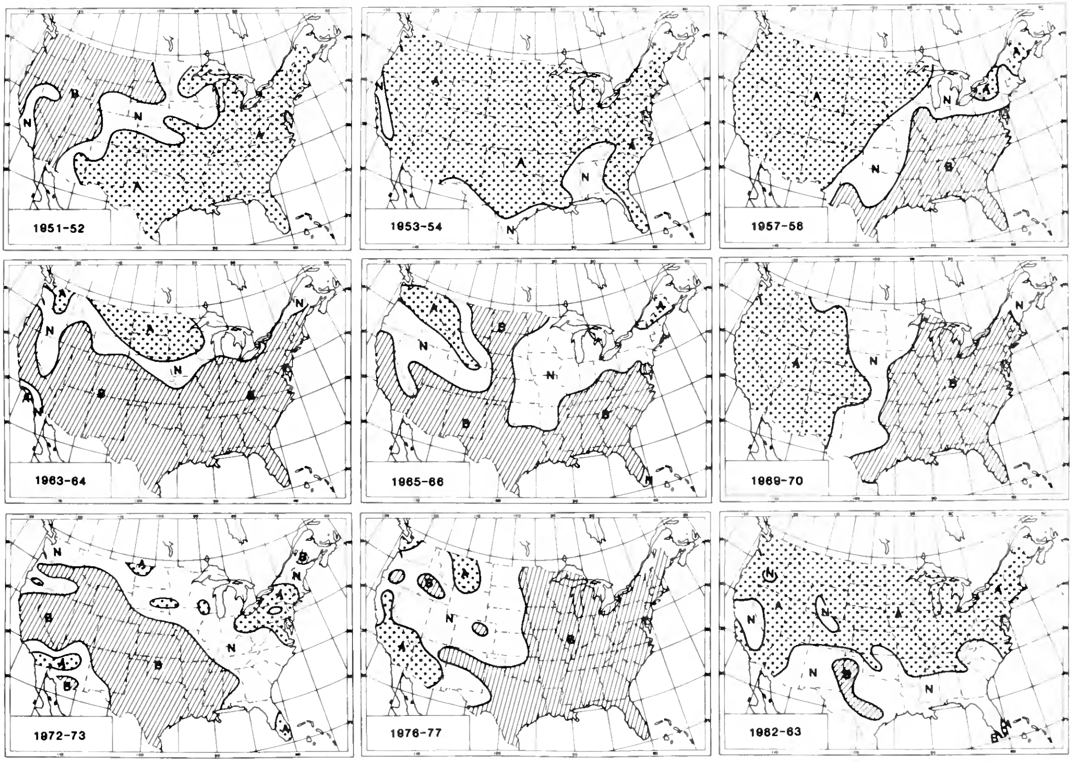


Figure 3. Observed winter average-temperature anomalies for the contiguous United States during nine El Niño episodes since World War II. This figure (excepting winter, 1982–83) was originally shown in fall, 1982, by J. Winston of the NOAA/Climate Analysis Center. Temperature anomalies portrayed in three climatologically equally occurring classes: A (Above Normal), N (Normal), B (Below Normal).

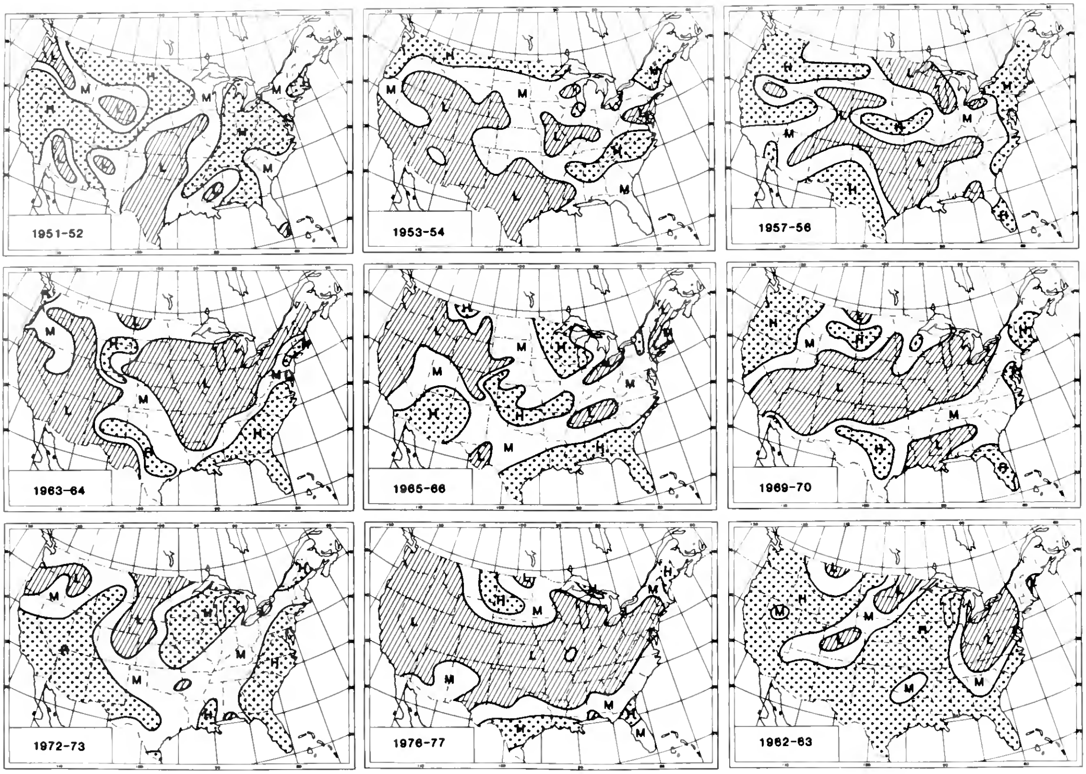


Figure 4. Observed winter-accumulated-precipitation anomalies for the contiguous United States during nine Niño episodes since World War II. Precipitation anomalies shown in three climatologically equally occurring classes: L (Light), M (Moderate), H (Heavy).

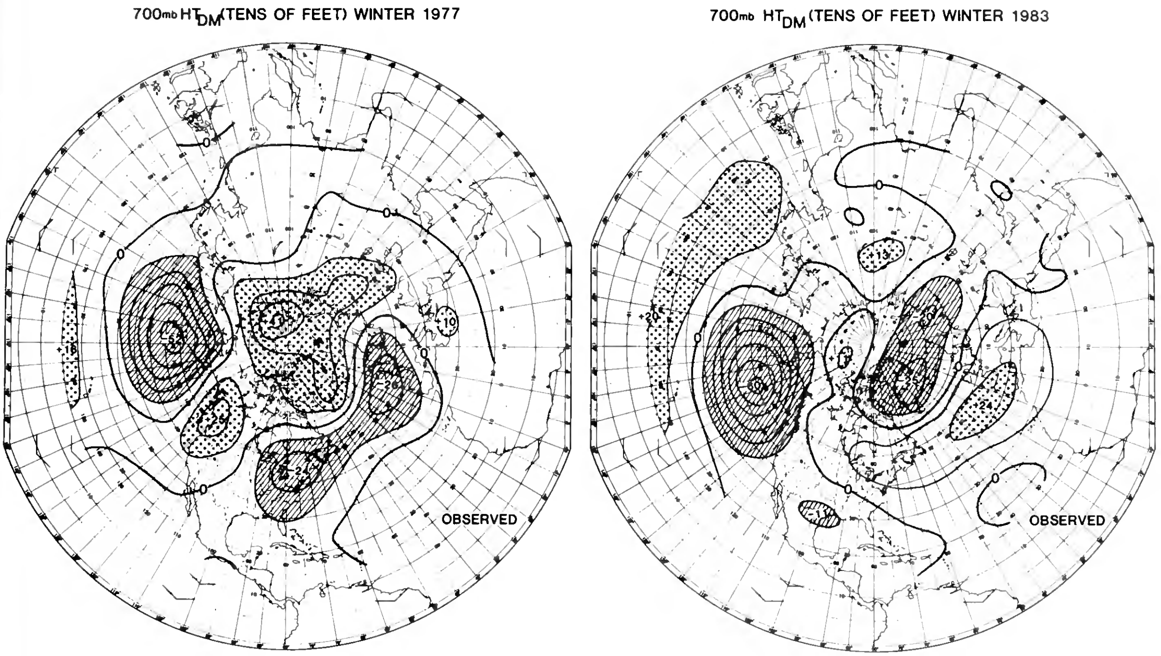
none of which relied on El Niño alone, captured the essence of the impending winter-temperature pattern for the United States.

To reinforce the problem of nonuniqueness of El Niño winters in the United States: winter, 1976–77, with its large-amplitude wavelike structure in the atmospheric flow, was in many ways unlike the most recent case, the winter of 1982–83 (Figure 5). Variations in positioning of the long waves as well as their amplitudes depend in part on the area in which tropical oceanic warming takes place but probably rely as much on the longitudinal contrasts of sea-surface temperatures and overlying air masses in temperate latitudes. During the winter of 1977, the latter factors were especially important, whereas the winter of 1982–83 saw the north/south contrasts eclipse the longitudinal contrasts between the tropics and mid-latitudes.

The 1982–83 Case

As highlighted in numerous reports in the popular and scientific press, as well as in other articles of this issue, the El Niño of 1982–83 rivals any in recorded history. In these years, the North Pacific seasonal-mean pressure and wind patterns for winter and spring were more intense than any on record since 1947. The winter 1982–83 Gulf of Alaska Low was about four standard deviations below normal, while the subtropical pressure near Hawaii was about five standard deviations above normal (regional extremes that are unlikely to recur for several decades). This anomalous pattern led to very strong westerly winds, approaching twice their normal speed across subtropical latitudes of the North Pacific during January and February (Figure 6).

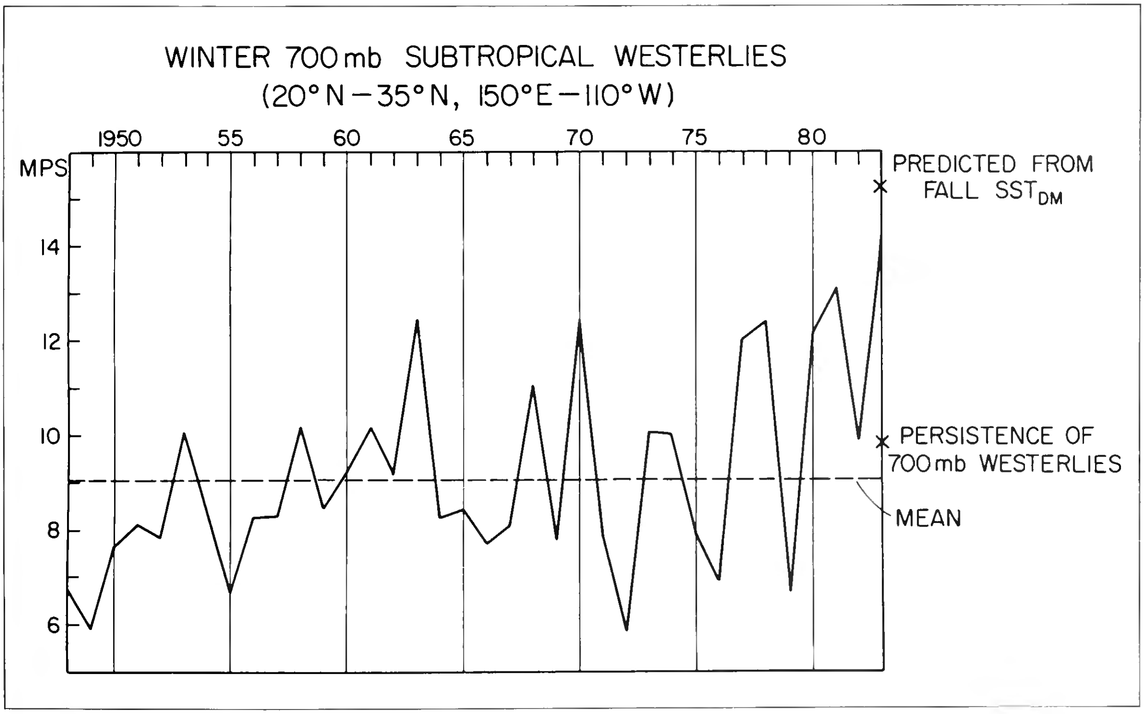
As shown in Figure 6, these high subtropical westerlies essentially were predicted using November, 1982, sea-surface-temperature values in the North Pacific exclusive of the tropics, so that the El Niño effect may have been written into the mid-latitude ocean/atmosphere system as of late fall. Unlike the 1976–77 case, the strong zonal westerlies and associated storms were sustained throughout the continental United States, releasing copious precipitation from Pacific and Gulf of Mexico moisture sources during winter and spring of 1983. In addition, the southward penetration of higher latitude northerly winds was inhibited, so that temperatures across the northern two-thirds of the United States were unusually mild. As a result, the national (48 states) average winter temperature was 35.8 degrees Fahrenheit, the warmest winter



700mb HT_{DM} (TENS OF FEET) WINTER 1977

700mb HT_{DM} (TENS OF FEET) WINTER 1983

Figure 5. Anomalous pattern of height of the 700 millibar surface (about 10,000 feet aloft) during two recent El Niño winters, 1976–77 and 1982–83, over the Northern Hemisphere. Units are given in tens of feet. Strong difference over North America indicates large contrast in circulation between the two winters. Figures 3 and 4 show accompanying temperature and precipitation.



WINTER 700 mb SUBTROPICAL WESTERLIES
(20° N – 35° N, 150° E – 110° W)

Figure 6. Observed winter subtropical westerly winds (solid lines) over the North Pacific from 1948 to 1983, as calculated from the height of the 700 millibar surface. Note that prediction of winter, 1983, value from fall, 1982, mid-latitude North Pacific sea-surface-temperature anomalies (upper cross) was fairly accurate, while its prediction from persistence of 700 millibar height anomalies from fall, 1982 (lower cross), was far too low.

Chinese Scientists See Possible El Niño Link

Two Chinese meteorologists recently described a possible teleconnection mechanism between the sea-surface temperatures in the eastern equatorial Pacific and surface-air temperatures over northeastern China.

Ming-Lie Zhang and Zhau-Mei Zeng of the Institute of Atmospheric Physics, Academia Sinica, Beijing, China, reported in the January, 1984, issue of the Tropical Ocean-Atmosphere Newsletter, *published by the University of Washington's Joint Institute for the Study of the Atmosphere and the Ocean, that it was unusually cold in the summer of 1982–83 in most cities of northeastern China. In June and July of 1983, for example, the temperature averaged 2 to 4 degrees Celsius lower than usual, with surface-air temperature in Mudangjiang (44 degrees, 34 minutes North, 129 degrees, 36 minutes East) reaching its lowest value since 1881.*

The scientists reported that during the last two decades cold summers have occurred every three or four years in northeastern China with disasterous effects for the agricultural industry—a 15-percent reduction in grain production, for example.

The report added that surface-air temperatures and sea-surface temperatures were out of phase: a cold summer in northeastern China being coincident with the appearance of El Niño along the Peru and Ecuador coasts. "During the last 30 years, very cold summers have occurred in northeastern China in 1957, 1964, 1965, 1969, 1972, and 1976; in 1969 there was a minor El Niño event. On only one occasion (1964) were the eastern equatorial Pacific sea-surface temperatures and the northeastern China surface-air temperatures both cold. The appearance of cold summers in northeastern China may be due to the warm sea-surface fluctuations in the eastern equatorial Pacific, because the low surface-air temperatures occurred when the sea-surface-temperature anomaly changed from positive to negative."

of the last 30 years; average precipitation was 7.97 inches, compared with the long-term normal value of 6.35 inches. Consideration of the predicted zonal winds previously cited contributed to rather successful precipitation forecasts for the winter of 1982–83 and the subsequent spring (Figure 7). However, less success was achieved with temperature forecasting for these two seasons, particularly the winter.

Prospects

El Niños and other ENSO phenomena, like all atmospheric and oceanic behavior, come in all shapes, sizes, and intensities, and they compete with other climatic influences. This is especially true of those El Niños in extratropical latitudes. However, observations and theoretical attempts arising from ENSO investigations are bound to

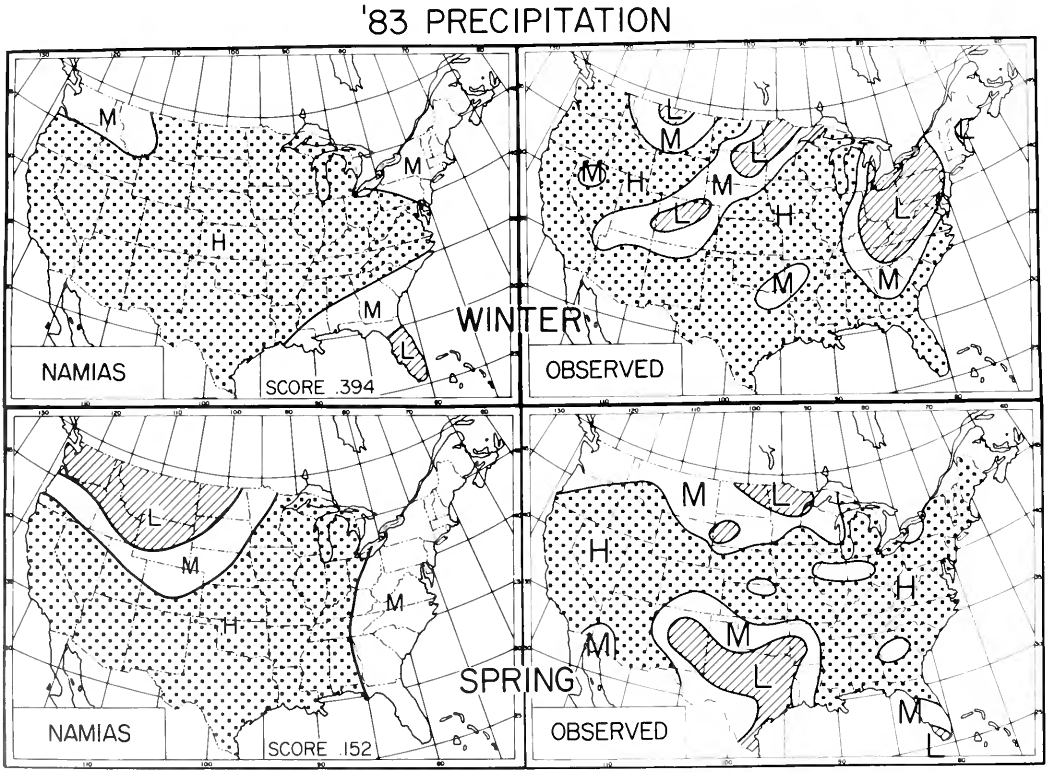


Figure 7. Forecast of anomalous precipitation over contiguous United States for winter, 1982–83, made in late November, 1982, along with observed (top), and forecast anomalous precipitation for spring, 1983, made in late February, 1983, along with observed (bottom). Precipitation portrayed in three climatologically equally occurring classes: L (Light), M (Moderate), H (Heavy).

contribute to the overall knowledge of possibilities and limitations for atmospheric long-range predictions—a field that generally is approached with empirical-statistical methods. Although many aspects of the 1982–83 case proved to be quite perplexing from a forecaster's point of view, it served as a powerful catalyst for a host of numerical-dynamical studies. One potential offspring of these studies is a physically-based numerical model that incorporates atmosphere/ocean interaction to help produce monthly and seasonal forecasts.

Future ENSO studies hopefully will resolve the differences between one El Niño and the next, identifying a host of associated patterns not only in the tropics but in extratropical latitudes, as well. Indeed, it is now realized that the Pacific-North American pattern widely acknowledged to result from ENSO is *not* unique to ENSO, but may be one preferred and important mode of a system that can be instigated by a variety of sources.

It does appear that there are areas especially sensitive to El Niño. Aside from strong weather connections within the tropics, regional associations in mid-latitudes have been documented. For example, the tendency for heavy precipitation in the southeastern United States during cold seasons, and warmth in the northwest quadrant of the United States and adjacent Canadian provinces, provides useful application to seasonal forecast schemes, especially when coupled with other predictors. Other sensitive areas will emerge from ongoing research.

If nothing else, the recent studies, along with the remarkable 1982-83 case, emphasize the fact that short-term climate variability and its prediction demand an accounting of nearly global-scale influences and thus global monitoring of both the atmosphere and the ocean and such factors as solar radiation, cloud, snow cover, and soil moisture. To supplement the increasing variety of international scientific programs to study the tropical aspects of ENSO, other investigations must focus on the interactions of ENSO and extratropical latitudes where they occur. It is hoped that funding support will be forthcoming in the near future for these important endeavors.

Jerome Namias is a Research Meteorologist with the Climate Research Group at Scripps Institution of Oceanography, University of California, San Diego. Dr. Namias has predicted much of the unusual winter weather experienced in the United States in recent years. His forecasts are experimental and are part of a continuing research program on both regional and global climate sponsored by the National Oceanic and Atmospheric Administration and the National Science Foundation. Daniel R. Cayan is a Research Associate with the Climate Research Group.

The California El Niño, 1983

by John A. McGowan

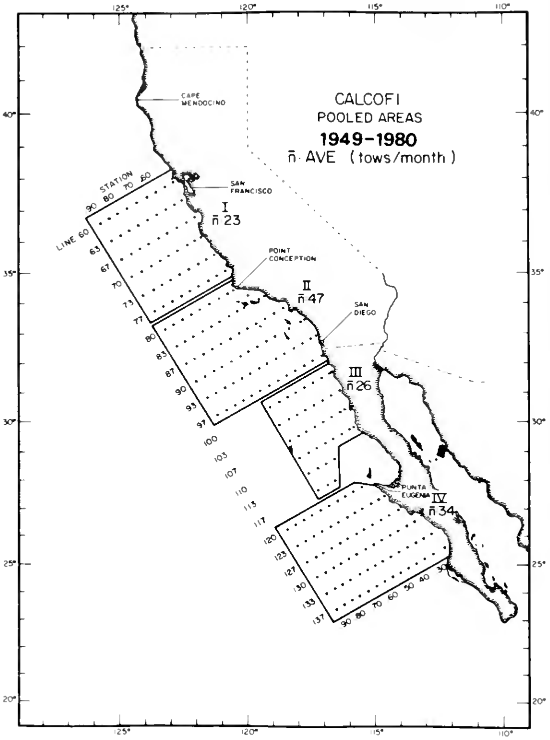


Figure 1. The pattern of stations most frequently occupied by the California Cooperative Fisheries Investigations for the years 1949 through 1980. Both physical and biological measurements were made at each locale ("n" = mean number of stations per month).

Climate, oceans, and biotic communities are highly variable in time and space but are presumed to be interrelated. At least in the case of the ocean and its populations this variability is seen across a broad spectrum of time and space scales. However, there are so few time series of measurements for anywhere in the world's oceans that it is very difficult to study either the physics or biology of this variability—especially that of low-frequency, interannual events such as El Niño. This is because it is essential that the long-term means of the variables be available in order to gauge the magnitude of the departures (anomalies) from normal (that is, the mean). Without such background information we have no real idea if observed changes are large or small, significant or trivial; without this knowledge, we can hardly hope to achieve any understanding of the climate-ocean-biology linkage.

Analysis and Results

One program of measurement, for physical and biological properties both, does exist. Since 1949, the California Cooperative Fisheries Investigations (CalCOFI) has monitored temperature, salinity, oxygen, and zooplankton abundance on a regular schedule in the California Current (Figure 1). This program has produced the only data set anywhere in which both ocean physics and biology have been measured simultaneously over time and space scales that allow for the study of interannual variability of entire pelagic populations.

Analyses of this time series have revealed some remarkable facts about the close relationship between ocean physics and biology, as well as strong inferences about the role of climate in affecting both. In a series of papers based chiefly on their doctoral theses, P. A. Bernal and D. B. Chelton have shown that there are large-amplitude, low-frequency anomalies compared to the long-term (30-year) mean in temperature, salinity, transport of water from the north, and zooplankton abundance. Moreover, these anomalies were coherent over very large spatial dimensions; that is, almost the entire California Current.

Even more remarkable is the high correlation between these four properties (Figure 2). It is evident that the periods of strong transport from the north led to low temperatures, low salinity, and high zooplankton, while lessened southward transport led to high temperatures, high salinity, and low zooplankton. One of the low-transport warm-water episodes that stands out very clearly in these data is that of 1957–59. This is the largest signal in the entire 30-year series and it occurred almost synchronously with a major equatorial El Niño. Other, smaller amplitude anomalies also seemed to coincide with equatorial events.

A Major Anomaly

In October of 1982, it was becoming evident to us that another, perhaps major, anomaly was developing in the California Current. The sea level, as measured at the end of Scripps Institution of Oceanography's pier in La Jolla, was anomalously high (Figure 3), as it was during the period 1957–59. The sea-surface temperatures (SST) off Southern California showed a pattern of large, coalescing blobs of water 2 to 4 degrees Fahrenheit warmer than normal, and finally, shoals of red crabs (also known as tuna crabs or squat lobster) began washing in on the beaches of Alta, California. These surface-living pelagic crabs, *Pleuroncodes planipes*, are normally found in near-shore waters off the southern tip of the Baja California peninsula. During the warm years 1957–59, great numbers of them were washed up on the beaches as far north as Monterey, some 1,800 kilometers north of their normal range. These incidents, plus the reports of the spectacular equatorial SST warm anomalies, were compelling evidence that something unusual was happening in the California Current, something with all the earmarks of a second, major, California El Niño.

Organizing a Study

There was no doubt that the developing phenomenon should be studied. It presented a remarkable opportunity to investigate the relations between climatic forcing, the response of the ocean to the forcing, and the response of the biology to the changing ocean. It was especially crucial in our case because of our extensive databank and 30-year accumulation of knowledge. But CalCOFI was not scheduled to repeat its measurements until January, 1984. Research ships and technician teams are complicated, expensive, and somewhat touchy. They generally are scheduled at least a year in advance via a large, unwieldy committee and several layers of helpful administrators. But, despite this bureaucracy (or perhaps because of it), a few Marine Life Research (MLR, a part of CalCOFI) oceanographers managed to get the ship time and technical help to study the developing California El Niño.

The plan was to take the traditional set of measurements along a line of stations (line 90, Figure 1) that satisfied two criteria: 1) the locales were representative of conditions in a much larger area, and 2) they were a set of locales where, during the last 20 years, the frequency of measurement had been high.

In addition to the traditional measurements (this included Nansen bottles and reversing thermometers), a new set of properties to be measured was added. Chlorophyll, pheophytin, nitrate, nitrite, phosphate, and silicate had but a 14-cruise history of previous measurement versus the 173-cruise history of temperature, salinity, oxygen, and zooplankton measurements; hence, the former are still considered rather new, and perhaps a bit suspect, by the conservative old salts of the MLR.

These properties were measured monthly, beginning in March, 1983. Of course, we would have liked to study more properties over a larger area more frequently, but like NASA and the Pentagon we, too, have budgetary restrictions.

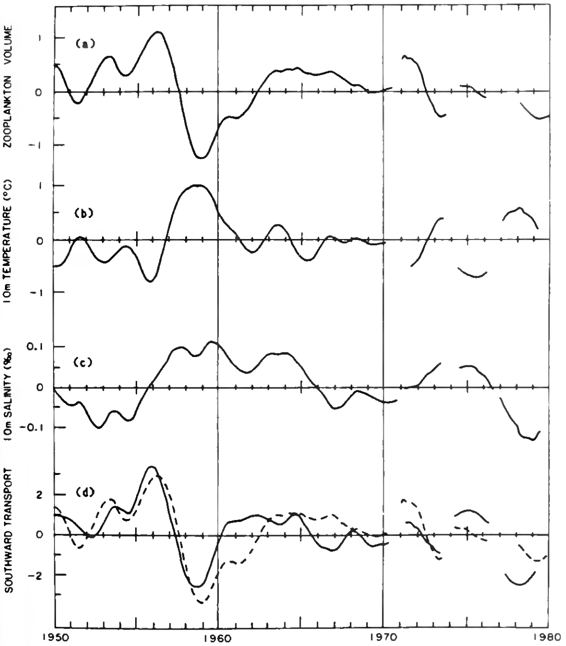


Figure 2. The low-frequency (low-pass-filtered) anomalies from the long-term mean for the years 1950 through 1980. The dashed line in the lower panel is the same zooplankton time series shown in the upper panel (a).

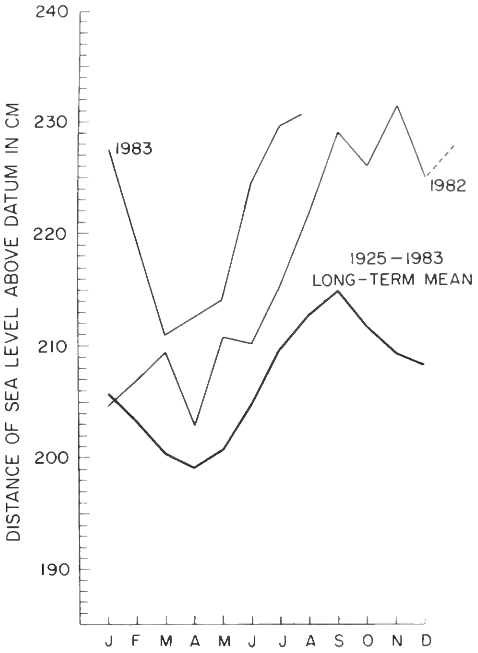


Figure 3. Mean monthly sea level at Scripps Pier (La Jolla, California) for the years 1925 through 1983 and the monthly means for 1982 and 1983.

Results

Our first complete 1983 section (April) showed that there were large anomalies in subsurface waters as well as SST. While the near-shore (less than 100 kilometers) thermocline* had deepened considerably, the most dramatic change had occurred offshore (between 100 and 250 kilometers). Low salinity, a doming upwards of the isopycnals,** high concentrations of the plant nutrients nitrate and phosphate, and a peak in plankton abundance characterize this area throughout most of the year. These familiar features were totally absent in 1983. Instead, we found a very deep thermocline with cool waters (normally at the surface) at depths of 60 to 70 meters (Figure 4a). Instead of typical low-salinity, high-nutrient water of subArctic origin, there were no measurable nutrients in the lighted zone and the water was relatively salty (Figure 4b). In near-shore areas, the plant and animal plankton distributions were not particularly abnormal; offshore things were quite different. A very deep chlorophyll maximum layer appeared, coinciding nicely with the top of the thermocline (Figure 4c). Curiously, the nutricline*** here was at least 30 meters deeper than either the chlorophyll maximum or thermocline, while all three tended to coincide quite well in near-shore regions. This difference was the first evidence that the near-shore and offshore signatures of El Niño are not the same.

These spatial patterns persisted until June. Then, the offshore thermocline, nutricline, and chlorophyll maximum all shoaled off by about 40 meters. Bad weather (and a small ship) limited our July research, but by August it was evident that another major change had occurred: shoaling had reversed and there was a very deep thermocline everywhere, with a chlorophyll maximum riding on top of it. Again, nutrients behaved somewhat differently, in that the nutricline was not tracking the top of the thermocline but tended to be somewhat deeper, especially near shore (Figures 5a, b, and c). There was little zooplankton anywhere. In what is normally an offshore peak area, zooplankton was about 20 times less common than the 1949–69 median (Figure 6).

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* A layer in the water in which temperature changes rapidly with depth.

** Lines representing regions of constant density.

*** A layer of water in which the concentration of nutrients changes rapidly with depth.

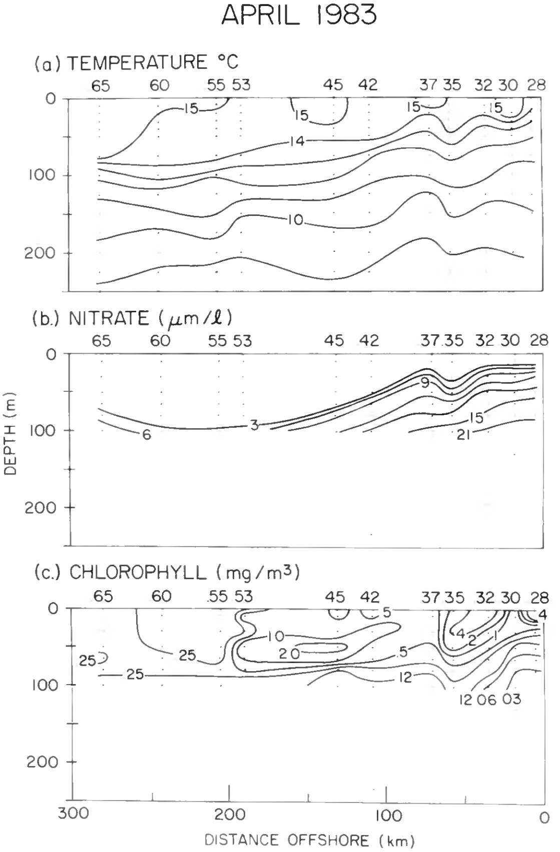

Figure 4a. Temperature (degrees Celsius) along CalCOFI line 90 in April, 1983. The 28-year mean temperature at 50 meters at station .32 is 12.79, at station .45 is 12.49, and at station .60 is 13.31. 4b. The concentration of Nitrate (micromoles per liter) in April, 1983. 4c. The concentration of chlorophyll in April, 1983.

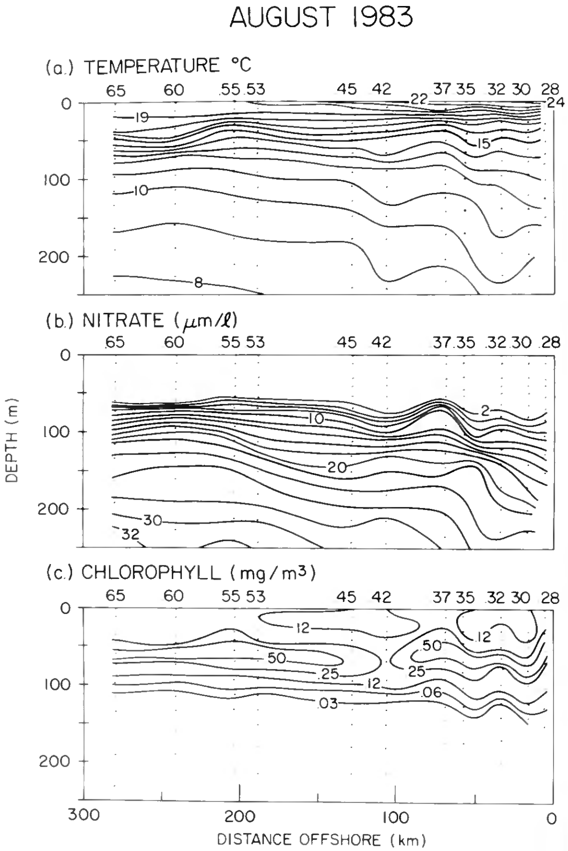

Figure 5a. Temperature (degrees Celsius) along CalCOFI line 90 in August, 1983. The summer 28-year mean at 50 meters at station .32 is 11.07, at station .45 is 11.31, and at station .60 is 13.10. 5b. The concentration of Nitrate (micromoles per liter) in August, 1983. 5c. The concentration of chlorophyll in August, 1983.

This August pattern persisted through the fall and winter of 1983. By January of 1984 monthly two-ship, large-spatial-pattern CalCOFI cruises began. These cruises collect very large amounts of data with consequent increases in processing and analysis time. Although our most recent (January–March, 1984) cruise data are available, they have not been completely digested. Preliminary impressions are that the physical and biological anomalies are still present, though possibly weakening.

What Have We Learned?

What can be said about this Californian El Niño? Not as much as we can say about it when it is finally over. At present it seems that it might persist for a while, just as the 1957–59 episode did. Ongoing documentation of this relaxation phase (if estimations are correct) with two large ships, spatial coverage and lots of help should reveal more.

We do have some preliminary ideas about what happened within the California Current. In many ways, the near-shore picture resembles a greatly intensified but familiar seasonal cycle. Normally, a relatively warm, saline, oligotrophic, northward flowing, near-shore counter-current develops south of Point Conception in April or May. This persists, and may intensify, through the summer and early fall. By October or November there is a relaxation. The behavior of the near-shore waters from spring through fall of 1983 seemed to be a greatly exaggerated version of this normal pattern. No doubt the unusual occurrence of red crabs, albacore and yellow-fin tuna, marlin, dorado, and other tropical organisms in near-shore areas off Southern California is attributable to this aspect of our El Niño. But offshore, the normal pattern seemed greatly altered. The isopycnal and nutrient dome completely disappeared and plankton were rare. The normal offshore low-salinity core of the California Current was greatly diminished in size and pushed shoreward, so that there was actually a negative salinity anomaly in the counter-current. Further, the zone where this low-salinity water is normally found, and just seaward of that zone, showed a strong positive salinity gradient to the west. Despite these obvious changes, we have not as yet observed unusual occurrences of tropical species in this offshore zone. The behaviors of the water and biota offshore show a different pattern than those near shore, complicating what already is a complex phenomenon.

The major reduction in nutrients, production, and zooplankton should lead to a reduction in the amount of food for our dominant pelagic fish—anchovy, mackerel, and hake—but it is not yet clear that their population sizes have been so affected. It is clear that 1983 was a very bad year for chinook salmon (commercial catches decreased by 86 percent), market squid (down 74 percent), crab (down 70 percent), shrimp (down 74 percent), and many other species. Winter is the normal spawning period for our important pelagic fish and CalCOFI is completing winter surveys of their eggs and larvae. The spawning fish should have suffered greatly from lack of food during the past year, which should have greatly affected their fecundity. We shall see.

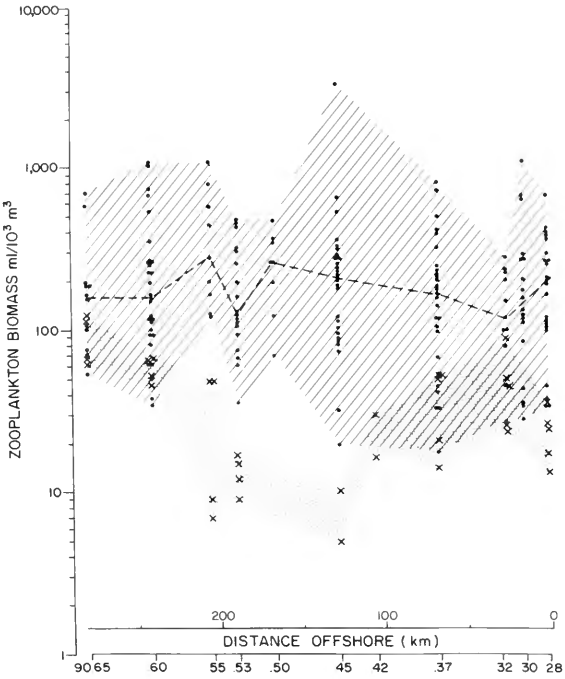

Figure 6. Zooplankton abundance along line 90. The dots are values for cruises made in July, August, and September of the years 1949 to 1969; the El Niño years of 1958–1959 are not included. The cross hatching covers the range of all values. The dashed line connects the median values. "X" = values for the same months of 1983, and stipples cover the range of those data. Please note log scale on the vertical axis.

John A. McGowan is a Professor at the Scripps Institution of Oceanography, La Jolla, California, a part of the University of California at San Diego.

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El Niño and the Earth's Rotation

by David A. Salstein and Richard D. Rosen

It has been known for some time that the speed of Earth's rotation is not exactly a constant. Our planet's spin is variable, so the length of one day differs slightly from that of another. The first observations of a nonconstant length of day (lod) were made in the 1930s. At that time, fluctuations of lod on a decadal time scale were detected astronomically from star-position data. In addition, variations from summer to winter were measured using a pendulum clock, and lod was actually determined to be as much as 1 to 2 milliseconds longer in January than in July. In more recent years, variations in Earth's rotation during periods of less than a year have been discovered using atomic clocks and a number of sophisticated new measuring techniques.

Among these techniques, which supplement the classical method of star observation, is that of very-long-baseline interferometry (VLBI), in which different antennas receive radio emissions from the same source outside the galaxy. Also important is the method of laser ranging, which uses accurate measurements of the round-trip time it takes laser

Figure 1. The Laser Geodynamic Satellite (LAGEOS) was fitted with special surfaces to reflect laser light beams from sources on the earth. Measurement of the laser transit time yields accurate information about the earth's rotation. This is one of several techniques presently used to measure length of day (lod). (Photo courtesy of NASA)

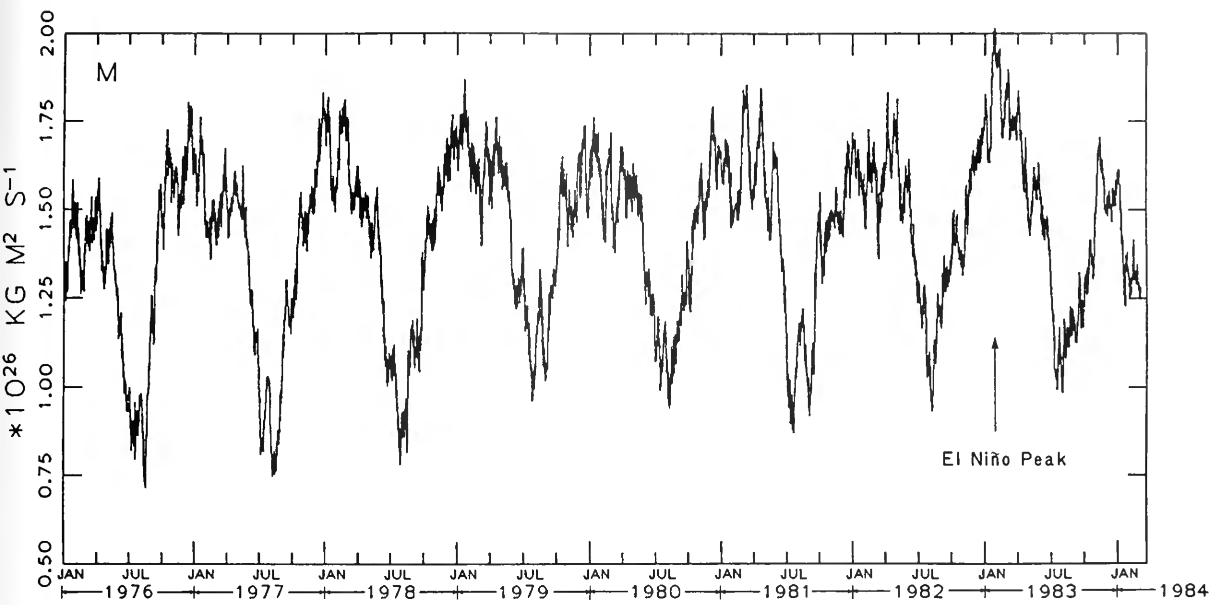


Figure 2. Angular momentum of the atmosphere relative to Earth's rotation. Values were taken twice daily from 1 January 1976 to 29 February 1984 and are computed from all but the upper 10 percent, by mass, of the atmosphere.

light pulses to travel between Earth and a remote reflector. Reflectors for this purpose were placed on the moon by the astronauts and also were fitted on LAGEOS, the laser geodynamic satellite (Figure 1). Information acquired with this combination of techniques has provided for unprecedented accuracy in Earth-rotation estimates.

Small variations in Earth-rotation rate and changes in the actual position of the Earth's pole, which also are well documented, are not mere curiosities; astronomical observation and navigation require very accurate knowledge of how Earth rotates. Careful measurement of Earth's rotation has revealed such fundamental facts about Earth's interior as information on the elasticity and the exact shape of Earth. Therefore, it was natural for scientists to study the nature, and seek the origin, of Earth-rotation variations. For part of the explanation, they turned to a medium that is highly variable and in direct contact with Earth—namely, the atmosphere.

The distribution of atmospheric winds over the globe also has been determined with increasing accuracy in recent years. New types of atmospheric observations via satellite now supplement those made by the conventional rawinsonde (radio/wind/sounding device) station network. From this wind distribution, it is now possible to calculate reasonably accurate values for the relative angular momentum of the atmosphere about Earth's axis; in effect, the "rotation" of the atmosphere. Such calculations demonstrate that the entire atmosphere's angular momentum varies considerably with time.

The principles of dynamics dictate that changes in Earth rotation (that is, the angular momentum of the Earth) must result from interaction with an agent outside itself, and the same applies to changes in the atmosphere. Thus, it was natural to think of the entire planet as a closed dynamical system and hypothesize an interchange of angular momentum between the atmosphere and the solid planet. In such a system, any acceleration of the atmosphere would occur simultaneously with a deceleration of Earth, and a change in lod would be proportional to changes in the atmosphere's angular momentum. (Obviously, because of the huge mass difference between Earth and the atmosphere, Earth's response would be relatively slight.)

In fact, the hypothesis of atmosphere/Earth interaction has been confirmed on annual and shorter time scales. (The core of the Earth is thought to be involved in the longer, decadal variations.) Although this correlation suggests that the direct role of the oceans in exchanging momentum with Earth is less important, the effect of the oceans cannot be discounted entirely. Any phenomenon with sufficient influence on the strength of the winds to cause a significant change in atmospheric angular momentum will influence the rotation rate of the solid planet. The El Niño oceanic-warming episode that peaked in early 1983, with its strong associated wind anomalies, was apparently just such an event.

Global Atmospheric Angular Momentum

At the world's large weather centers, wind observations from a variety of sources are combined by modern computer-analysis techniques and the results are placed onto three-dimensional global grids. From these wind fields the (relative) angular momentum of the atmosphere, M, can be computed: M is equal to the sum, over all parcels in the atmosphere, of the triple product of their mass, westerly (eastward) wind strength, and their distance to Earth's rotation axis.

One record of M, based on the U.S. National Meteorological Center's twice-daily analysis, goes back to January, 1976. In Figure 2 it is shown through February, 1984. Similar calculations, based on the British Meteorological Office analyses, were performed by R. Hide and others in 1980. This British group is continuing its computations with the wind archives of the European Centre for Medium-Range Weather Forecasts.

In the dominant pattern for each year represented in Figure 2, peak values of M in January/February are about twice as large as those in July/August. This very sizable intra-annual variation reflects an imbalance between the two hemispheres: whereas the Northern Hemisphere winter westerlies are a great deal stronger than those of summer, the Southern winds are generally steady throughout the year. This annual cycle was identified prior to the availability of the global grids, and it explains the annual variation in length of day mentioned earlier.

Some January/February peaks are higher than others, but it is clear that the strongest recorded angular momentum of the atmosphere occurred late in January, 1983, some 8 percent higher than any previous value. As expected, this maximum was mirrored in record high values of lod. Remarkably, the day was observed to be about 0.2 milliseconds longer than was previously recorded after accounting for decadal variations. Earth's rotation was the slowest on record attributable to the atmosphere.

This extraordinary event is a prominent feature in both curves of Figure 3. The dotted line represents two years of measured changes in length of day (as determined by T. M. Eubanks of the Jet Propulsion Laboratory in California). Changes in lod that would be expected if the atmosphere was the sole influence on earth rotation (derived from our M values) are presented in the solid line, which is generally parallel to the other line. High correlation between these two types of series is observable in similar plots back to 1976, made by R. Langley and colleagues.

The El Niño Connection

Although the extreme in atmospheric angular momentum occurred on 25 January 1983, the whole first quarter of that year was characterized by M values substantially higher than those of other years. Not coincidentally, this was the peak period of the El Niño/Southern Oscillation event of 1982-83.

Associated with El Niño sea-surface-warming events are strong jet-stream winds over the North

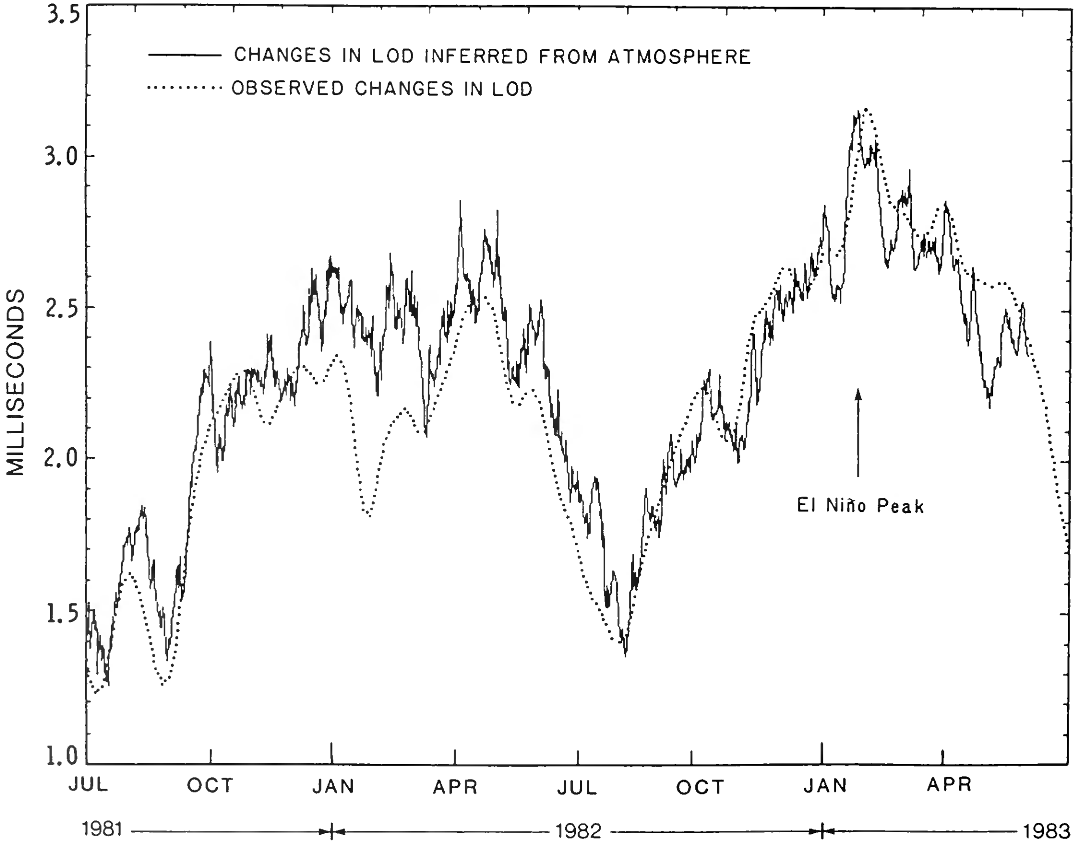
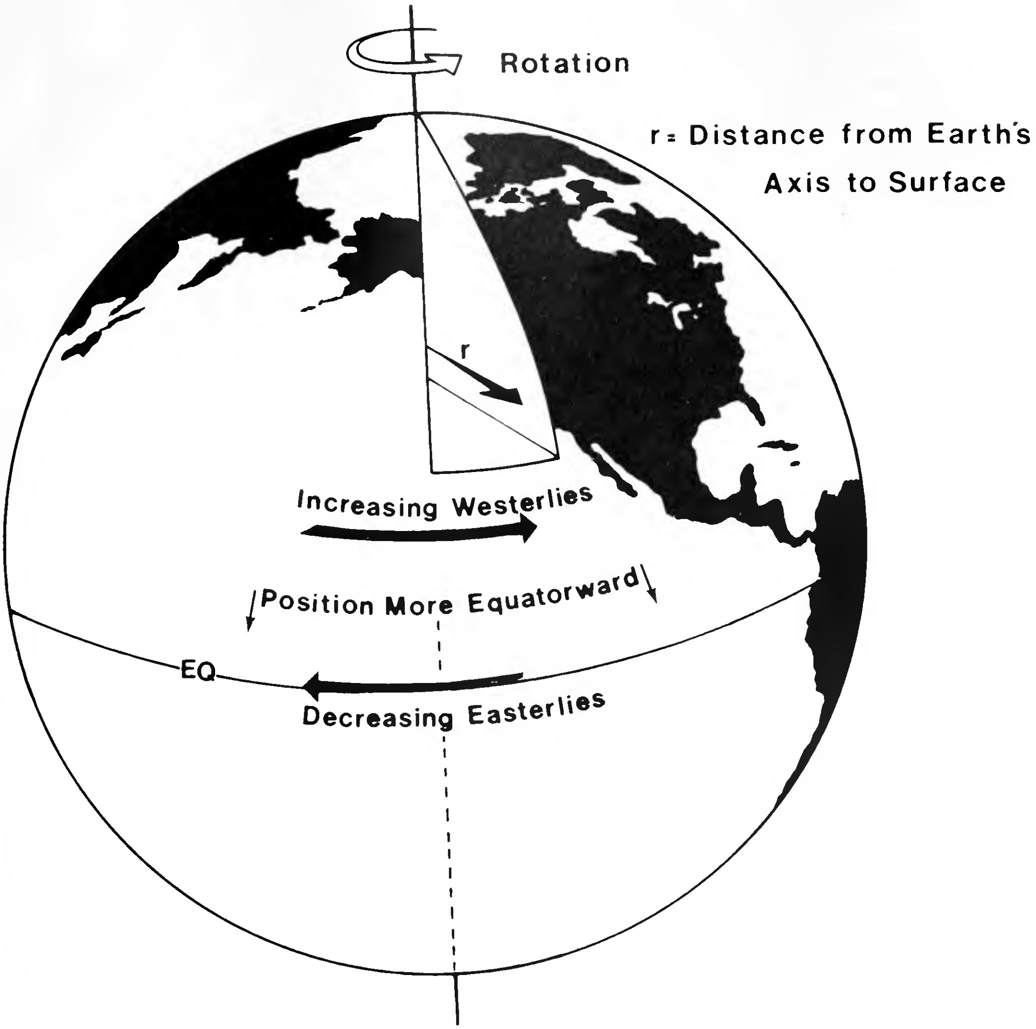


Figure 3. Changes in the length of day (lod) as inferred from the angular momentum of the atmosphere (solid line) and observed changes in lod (dotted line). (Tides have been removed from the lod changes; from Rosen and others, 1984.)



$$M = \underbrace{\Sigma}_{\text{sum over entire atmosphere}} (\underbrace{m}_{\text{mass}} \times \underbrace{u}_{\text{westerly wind}} \times \underbrace{r}_{\text{distance to earth's axis}})$$

Figure 4. Wind changes during the El Niño of 1982–83, and their relation to Earth rotation.

Pacific, and during the 1982–83 event they were particularly excessive. These and other strong westerlies over the Gulf of Mexico, the Atlantic, and elsewhere (see Rasmusson p. 5), contributed to the anomalously high values of M. Also contributing to an increase in net (westerly) angular momentum was a weakening of the easterly trade winds near the equator. Furthermore, throughout much of the Northern Hemisphere, shifts in the jet stream to a more southward (equatorward) position had the effect of increasing the total angular momentum since the contribution of the wind to the total angular momentum is proportional to the distance between its location and Earth's axis. A schematic of wind modifications during the El Niño period is given in Figure 4.

Plots of angular momentum in equal-area latitude belts which gird the planet illustrate how contributions to angular momentum are distributed globally (Figure 5). The sum of the values in all 22 belts composes M for each day. These time-latitude diagrams represent a) the 1982–83 winter and b) an "average" winter of four earlier years. Although averaging over all longitudes, as was done here, obscures behavior at specific locations, these diagrams conveniently show the general progression of angular momentum throughout the winter.

Easterly winds (shaded areas) narrowed in latitude considerably near the end of January, 1983 (Figure 5a). This weakening of the easterlies occurred at about the same time as the peak in M and lod. The most notable feature, though, appears in the

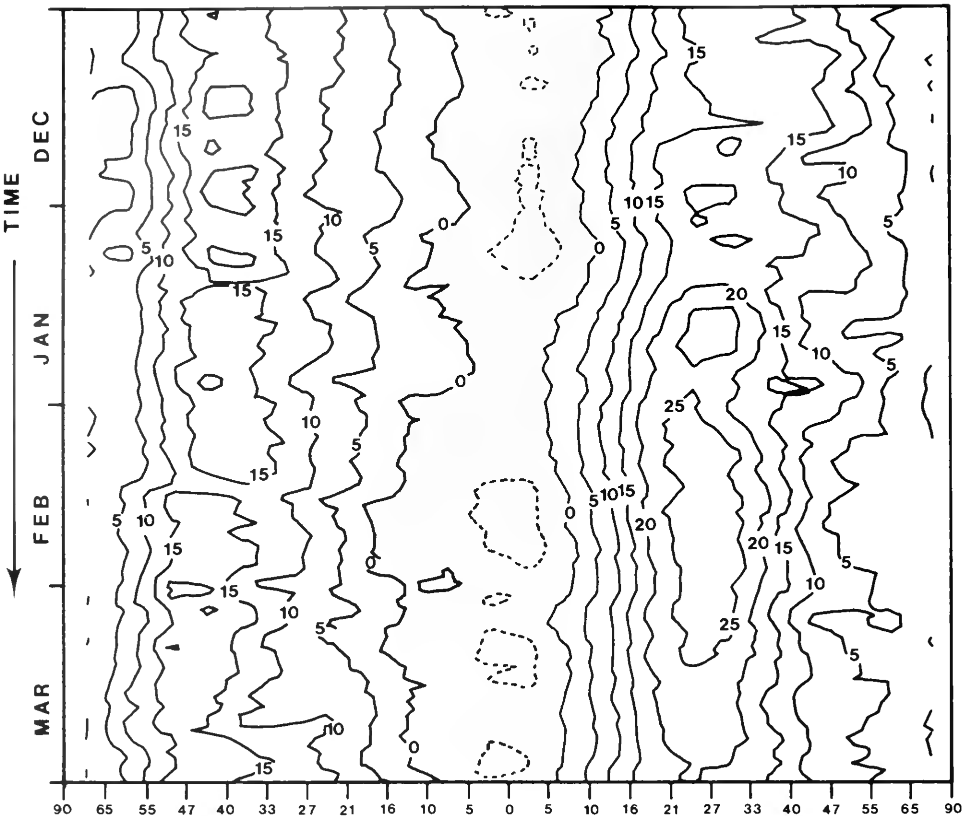


Figure 5a. The angular momentum in each of 22 equal-area belts over the globe on a daily basis for the winter of 1982–83 (values × 10^{24} KG M^2 S^{-1}). Negative values (corresponding to easterly momentum) are shaded. (From Rosen and others, 1984)

Northern Hemisphere subtropics (20 to 30 degrees North latitude), where stronger-than-average westerly winds persisted from late December through March (note the 25 contour in Figure 5a, which is absent in Figure 5b.) These diagrams confirm the importance of wind variations over the tropics and much of the subtropics during the El Niño period.

The Dynamic Link

While it is true that the observed strengthening of the winds during this El Niño winter was associated with a slowdown of Earth's rotation, a yet unanswered question is: By what means was westerly momentum transferred from Earth to atmosphere? The answer to this question must involve one of the two mechanisms that dynamically link the atmosphere and the solid Earth—"friction" and "mountain" torques.

Friction torque, which involves the transfer of momentum by means of wind drag on Earth's surface, is thought to be relatively constant in magnitude. On the other hand, the much more variable mountain torque involves the dynamic interaction between atmospheric pressure gradients and mountainous topography. When a region of high atmospheric pressure lies to the east (or a low to the west) of mountains and is not compensated for on the other side, a mountain torque results. Such a torque can be viewed as the rigid Earth pushing on, and imparting momentum to, the atmosphere. Of course, the opposite pattern would transfer momentum back to Earth.

The El Niño oceanic warming is part and parcel of one phase of the so-called Southern Oscillation, a shifting of atmospheric mass across the breadth of the Pacific Ocean. This oscillation is described by anomalously high pressures over the West Pacific-Australian-Indonesian region and low pressures farther to the east, over the central Pacific. In fact, the historic Southern Oscillation Index, which computes the difference in normalized pressures between a representative station in the east central Pacific (Tahiti) and one in the west Pacific (Darwin, Australia) was at an all time low in January, 1983, as noted by Quiroz.

This large-scale prevailing pattern suggests that the mountain torque was indeed the dominant Earth/atmosphere transfer mechanism during the period under study. During the El Niño/Southern Oscillation event, the high-pressure area situated in the west Pacific falls to the east of the high mountains of Asia, and the net effect is a deceleration of the Earth and acceleration of the atmosphere. The low eastern Pacific pressures to the west of the American mountains have a similar

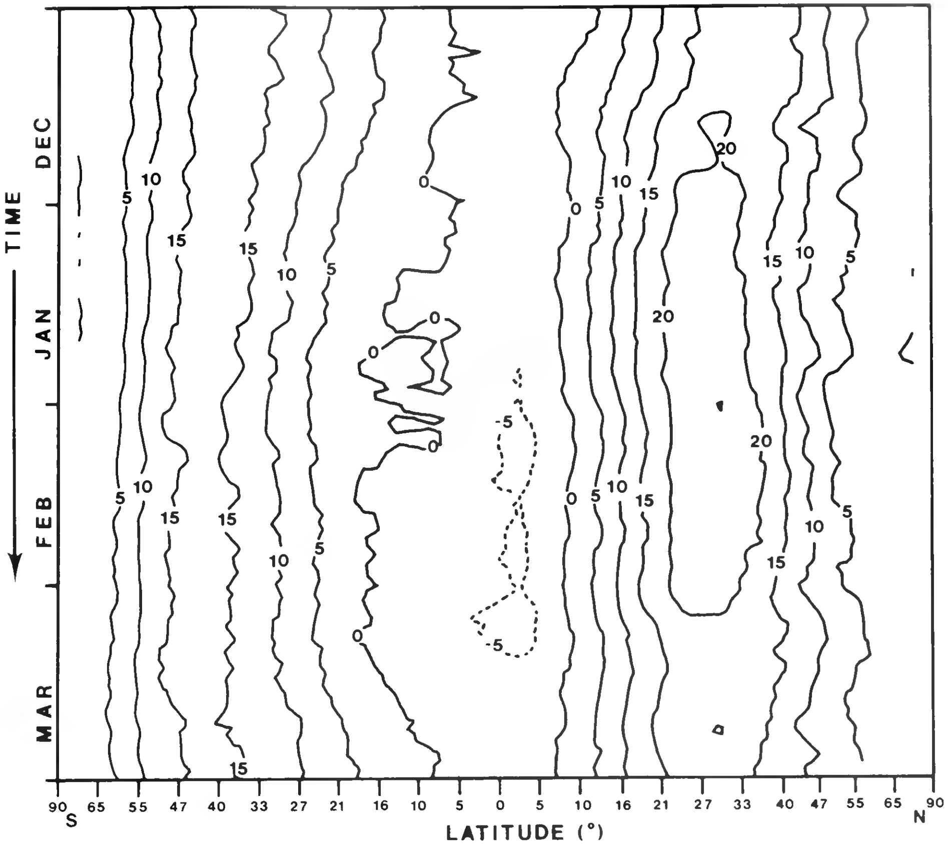


Figure 5b. Same as in (a) but for the mean of four earlier winters (beginning in December, 1976).

effect. Although this scenario explains qualitatively the transfer of angular momentum from Earth to atmosphere, exact measurements of this effect await calculation.

The Puzzle of Variations

The remarkable atmospheric response to the El Niño of 1982-83 warming event had an interesting consequence: the winds generated were sufficiently strong that Earth slowed down. While the additional increase in the length of day (about ⅕ of a millisecond) is obviously too minute for a person to make any use of, it was undeniably recorded by sophisticated scientific instruments. Such changes, though small, are in themselves significant to earth scientists and astronomers.

It is interesting that the oceans did play a role, albeit indirect, in their interaction with Earth, using the atmosphere as an intermediary. The influence of the oceans and atmosphere on the global momentum budget is ongoing. The decay of the El Niño of 1983 and the subsequent increase in the easterlies over the Pacific by January/February of 1984 dramatically turned the picture around and produced low values of atmospheric angular momentum. (See the 1984 values of M in Figure 2, which are well below average for this time of year.)

Geodesists have long been trying to solve the puzzle of variations in Earth rotation and polar motion. It is apparent that the atmosphere does play a central role in this problem. Understanding how certain atmospheric events can interact with Earth will help in the task considerably.

David A. Salstein and Richard D. Rosen are scientists employed by Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts.

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Lake Eildon, Victoria, Australia, during 1983 drought. (Photo by Bill Bachman/PR)

Studying El Niño on a Global Scale

by Ferris Webster

New discoveries and understanding of the El Niño/Southern Oscillation (ENSO) phenomenon are prompting the development of an international research program to understand year-to-year climate variability on a global scale. This program, "Interannual Variability of the Tropical Ocean and the Global Atmosphere," is known by its acronym, TOGA. "Interannual variability" denotes year-to-year climate variations, of which an El Niño is the strongest: this variation in climate has had worldwide economic consequences.

Though El Niño and the related atmospheric event, the Southern Oscillation, are centered in the Pacific, TOGA is seen as a global-scale program that will involve both oceanography and meteorology. As a consequence, atmospheric and oceanic researchers in many countries are now working through international organizations to design and carry out the research program.

Implementing an international oceanic and atmospheric research program presents a number of challenges. Who will define the program? How will the various nations decide to participate? Can oceanographers be organized to work with meteorologists? While oceanographers are reputed for their independence, meteorologists have a tradition (from the Global Atmospheric Research Program, for example) of working on global-scale programs.

The organization of TOGA is being carried out under the auspices of a number of international agencies. Arrangements are complicated. With two scientific research communities (oceanographers and meteorologists) and two international operational agencies to be represented, the organization of this research program is a magnificent example of international bureaucratic architecture. A brief outline of this organizational structure illustrates the point.

For research planning, oceanographers have the Committee on Climatic Changes and the Ocean (CCCO). Meteorologists have the Joint Scientific Committee (JSC) of the World Climate Research Program (WCRP). Jointly, CCCO and JSC sponsor the scientific steering group for TOGA. The TOGA steering group meets every few months, to formulate priorities and to provide guidance on the implementation of the TOGA program.

Objectives

The official objectives of the TOGA program, hammered out in international committee meetings, are threefold:

> 1. to understand the variations of the tropical ocean and global atmosphere on time scales of months to years (to what extent are these variations predictable?);
>
> 2. to model the ocean-atmosphere system for the purpose of predicting the variations in the tropical ocean and global atmosphere; and,
>
> 3. to provide a scientific basis for designing a practical system for prediction (if models show that prediction seems feasible).

The scope of TOGA is greater than simply studying the ENSO phenomenon. Changes in atmospheric circulation correlate with anomalies in temperature and motion at the surface in all the tropical oceans (not just the Pacific). The tropics are important because near the equator the ocean responds to changes in the atmosphere more rapidly than it does at higher latitudes. That is, on the time scales that seem important to this problem, the response of the nontropical ocean seems to be so slow that it is not a factor in modifying atmospheric circulation. The rapid response at the equator means that there, changes at the surface of the ocean, particularly in its sea-surface temperature, can have a major influence on the atmosphere, extending to latitudes far from the tropics.

Thus, the oceanographic part of TOGA will focus on the upper ocean in the tropics. If the dynamic factors that control ocean-surface temperature and the coupling between the ocean and the atmosphere can be understood for the tropics, it is argued, the evolution of the global response in the atmosphere can be modeled to provide a predictive capability.

An important component of TOGA in South America is the regional program known as ERFEN (from Estudio Regional del Fenómeno El Niño). ERFEN participants are looking at the physical oceanography of the El Niño event of 1982–83 off the coast of South America, and are studying the coastal biological and fisheries impacts of the recent El Niño.

The TOGA program is to begin on 1 January 1985 and run for 10 years, a period long enough that one, and possibly two, full cycles of the El Niño phenomenon can be observed. About 1990, with luck, satellite sensors will be sent into orbit; that will change the character of the observational program during the second five years of TOGA. Intensive field observations are planned for the first five years.

Because our knowledge of the ocean basins of the world varies considerably, research for the TOGA program will not start on equal footing around the world. For instance, we already have a substantial body of information on the Pacific El Niño and Southern Oscillation that can be used to define TOGA research there. In the tropical Atlantic, there are experiments now underway, particularly U.S./French cooperative research, the results of which can be used as a basis for planning TOGA in that ocean. In the Indian Ocean, though, first there must be considerable exploratory oceanography in order to develop our knowledge of that region so that we may confidently design TOGA research for that ocean.

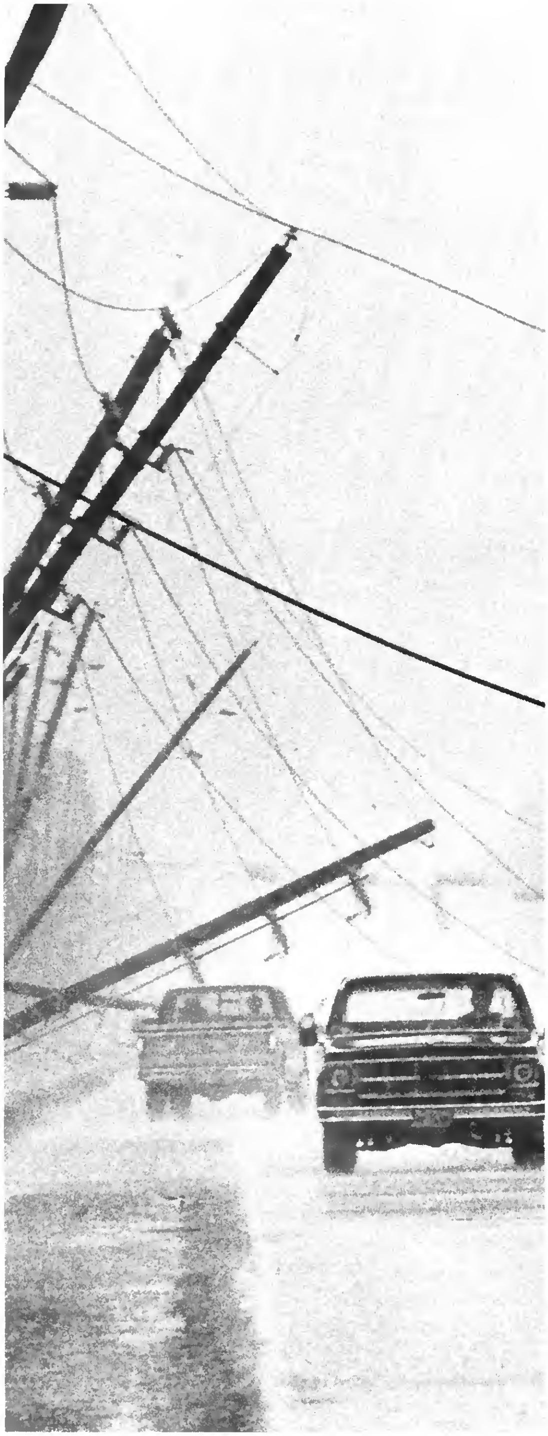
Program Components

TOGA planning is in a relatively early stage. A number of program components have been proposed. As planning intensifies and evolves in the next year or so, the plans for these components are likely to change; I outline here the major elements of the program as now envisioned.

An ocean observational component of TOGA is being designed to describe the temperature, circulation, and pressure fields in the upper layer of the tropical oceans (the band of latitudes about 20 degrees on either side of the equator). Measurements of the physical state of the ocean in this region, taken on a monthly basis, will be used first to describe physical processes and then to carry out forecasting experiments.

There also will be an atmospheric observational component. Observations made for this component of TOGA will supplement the existing World Weather Watch, in order to provide a more comprehensive description of global

Previously submerged trees appear in Lake Eildon, Victoria, Australia, during 1983 drought. (Photo by Bill Bachman/PR) atmospheric circulation. For TOGA, special emphasis will be put on monsoon circulation and on filling in gaps that exist in the coverage of atmospheric circulation in the Southern Hemisphere.



Hurricane on coast of Gulf of Mexico, 1983. (Photo by Sam Pierson/PR)

To carry out a surface-flux component, scientists will examine variations in the transfer of momentum, heat, and moisture across the air/sea interface. A knowledge of these fluxes is critical for developing and validating models of the atmosphere/ocean system. TOGA planners envision a decade-long experiment collecting such measurements each month.

A modeling component is planned, to try to create models that realistically couple the ocean and the atmosphere. At first, ocean models and atmosphere models will be separate. Ocean models may be limited to the tropics. Atmosphere models will begin by testing the reaction of the atmosphere to forcing over a range of time scales. Ultimately, the challenge will be to merge ocean and atmosphere models into a coupled system.

Scientific Problem

Before attempting to understand the interannual variability of the coupled atmosphere/ocean climate system, an understanding of the climatological mean annual cycle is needed. What is the average annual cycle? If we can determine this, we can more confidently describe the year-to-year variations from the mean. In the tropical and subtropical atmosphere, the annual cycle is dominated by monsoon circulations. These circulations are found world-wide, but are strongest in Asia, where the air/sea contrasts are great and the land mass is asymmetrically distributed on either side of the equator.

As described by Rasmusson (p. 5 in this issue), our awareness of interannual variability dates back to the studies of the Indian monsoon, carried out by Sir Gilbert Walker in the early part of this century. Walker did the original work that led to our understanding of the atmospheric phenomenon known as the Southern Oscillation. We know now that the Southern Oscillation is sensitive to tropical sea-surface temperature; however, our understanding is not a sufficient basis for long-range climate forecasting. We do not yet know if the system is predictable, and if so, to what degree. There are considerable differences among Southern Oscillation events. How much could be accounted for by an understanding of the dynamics of the process? If we can gain such an understanding, the chances are better that we will be able to develop predictive ability.

The atmosphere influences the ocean through a number of processes. The strongest is the stress of the wind on the surface of the sea, inducing ocean currents. For TOGA, atmospheric general-circulation models will have to be developed that do a better job than do existing models at specifying the surface wind stress.

On the other hand, the influence of the ocean on the atmosphere comes about through the distribution of oceanic sea-surface temperatures. To develop ocean general circulation models that do a realistic job of specifying the sea-surface temperature, we need answers to questions such as: How does this distribution vary in space and time? and, What processes are important in controlling the distribution?

As with the atmosphere, the first oceanic priority for TOGA is research to gain a solid description of the mean annual cycle. Then it will be possible to pinpoint when and where the sea-surface-temperature field is anomalous. The strongest and most persistent of these fields is found in the eastern tropical Pacific, associated with El Niño, though year-to-year tropical sea-surface-temperature variations are observed in all oceans.

The Southern Oscillation continues to dominate the study of interannual climate variability. However, atmospheric climate variability, not necessarily correlated with the Southern Oscillation, occurs over the Atlantic and Indian oceans. TOGA program participants will embark on studies of interannual atmospheric variability over all sectors of the tropical ocean.

Our knowledge of interannual climate variability has greatly expanded during the last decade. However, the duration of the observational record is short relative to the time scale of climate phenomena. We cannot yet say with assurance that sea-surface-temperature anomalies over the tropical oceans induce global climate variations. Some correlations have been found; in addition to this statistical evidence we will have to use general-circulation models that couple the atmosphere and the ocean, simulating the climate system, in order to demonstrate that the tropical oceans influence climate variability.

Observation System

In order to carry out the TOGA program, an observational system covering the global atmosphere and the tropical ocean will have to be established. This will be done by augmenting the existing network of atmospheric observing stations. In addition, satellites, ships, shore stations, and drifting buoys will be used for collecting data from around the world, with particular emphasis on collecting data at the air/sea boundary.

The kinds of things that need to be measured include sea-surface temperature, wind stress on the sea surface, heat fluxes across the air/sea interface, precipitation, sea level, and ocean currents. The data will be used to develop, test, and verify research models, and ultimately should be used as input to forecasting models.

Even before any analysis or interpretation of the data can be done, a system is needed for collecting, transmitting, processing, and distributing the global data sets for TOGA. As TOGA evolves to the stage where satellites provide a significant amount of the data, it will be a major challenge to the meteorologists and especially for the oceanographers just to keep up with the flow.

Part of the data-handling problem may be traced to the differing customs of the two scientific communities involved in TOGA. Meteorologists have the habit of dealing with global data sets, and, particularly during the Global Atmospheric Research Program, such sets were routinely managed and distributed. Oceanographers, on the other hand, do not have such a tradition. Even the largest-scale oceanographic experiments have had regional limits. However, if TOGA plans come to fruition, there will soon be earth-orbiting satellites collecting oceanic data at a rate that exceeds by many times the capacity of the existing oceanographic-data-handling system. Furthermore, oceanographers are used to collecting their own data, and working on them alone for a year or two before sharing them. Meteorologists expect worldwide data to be collected and made available promptly, often in a few hours. Somehow, practitioners of these two styles of research-data management must accommodate each other if they are to co-exist and TOGA is to be successful.

Modeling

Models provide a means to identify and understand processes at work in climatic phenomena. Oceanic

Mill Valley, California, 1982. (Photo by Steve Skloot/PR) and atmospheric modeling likely will continue for a while as separate activities, but as TOGA evolves, the two must converge. One aim might be to understand the linkages between the ocean and the atmosphere that account for the intermittent occurrence of El Niño events. Such a model need not be completely realistic in order to represent satisfactorily the processes that are critical.

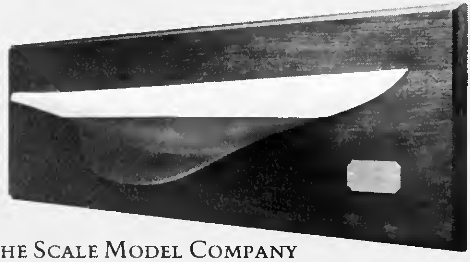
An ocean modeling aim might be to predict the distribution of sea-surface temperature over the tropical ocean. A model to do this might take the observed initial state of the ocean and predict for periods of months to years. To be successful, it probably would have to be coupled to an atmospheric general-circulation model that realistically portrays the atmospheric forcing at the sea surface. Such an atmospheric model might be based on those used for atmospheric climate simulation and long-range weather prediction. Again, the atmosphere models must be designed to respond to forcing by sea-surface-temperature distribution, which would be provided by ocean models.

The Future

To communicate with governments and scientists worldwide, a TOGA conference will be held at UNESCO headquarters in Paris in the autumn of 1984. Representatives from each country that is a member of the World Meteorological Organization or the Intergovernmental Oceanographic Commission have been invited. TOGA is scheduled to begin officially a few months later. The conference, it is hoped, will serve to inform national representatives and scientists of the program and to stimulate participation.

The prospect of being able to predict year-to-year (or interannual) climate variations a season in advance has excited many oceanographers and meteorologists. If the TOGA program achieves its objectives, we may well develop the capability to predict the onset of future El Niños far enough in advance to take steps to mitigate their effects.

Ferris Webster is a Professor in the College of Marine Studies at the University of Delaware in Lewes.



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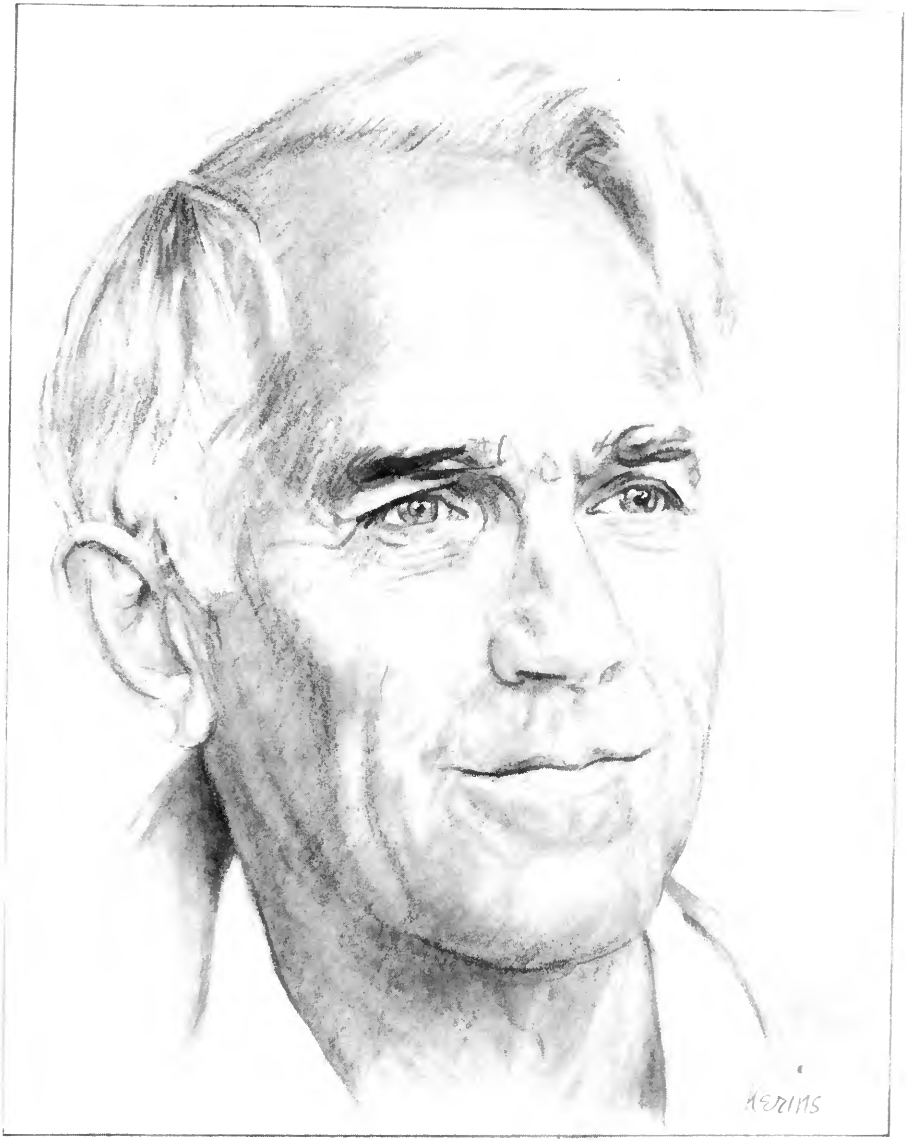

Portrait by Charles Kerins

Explorer

by Michael B. Downing

Late in September of last year Willard Bascom addressed a letter to the editor of this magazine. Opening with a commendation of the *Oceanus* profiles published to date, it went on:

> *If you are going to continue the series and are looking for other subjects, you might consider me, mainly because I have been involved in many unusual projects.*

Indeed. Born in 1916 and raised by his mother in New York City—"I want you to know I hated the place"—he made good on his early resolve to clear out, but only after several stints as a driller in the subway tunnels of New York. Under the legal age, he was several times fired at his mother's behest; she believed that the 12-hour suspension of his capacity for hearing after each shift in the tunnels would be detrimental in the long run. Persistent, he would return to the well-paid work ($10 a day during Depression years), to make an appropriate start on a life spent exploring the deep.

Four years at the Colorado School of Mines followed, and one might expect a pattern had begun to develop. But in 1942 he left the school without a degree after a good many disagreements with members of the faculty. Post-war America was inclined to downplay the importance of certification. Many lives had been interrupted. Bascom worked metal mines from Arizona to Idaho during the war years.

Visiting San Francisco in 1945, he agreed to meet a friend's "funny brother who works at Berkeley." John D. Isaacs was the brother, and after uncovering musical and literary affinities, Isaacs watched Bascom catch a wine glass knocked from a waiter's tray by an errant child. "How would you like to work for the University of California?" Seems that the engineer for Isaacs' upcoming cruise had just quit and he was in need of an immediate replacement.

Without ocean-going experience, without a degree, Bascom dismissed questions about his qualification for the research engineer position he took up at the Berkeley campus of the University of California, where he stayed until 1950, long after Isaacs had moved on to the Scripps Institution of Oceanography. "You see, I never really considered doing oceanography in the way it was being done at that time, calculating dynamic heights using salinity and temperature. I began with the Isaacs survey of beaches and managed to find my way into the projects that overlapped with my interests."

In 1950, he joined Isaacs at Scripps and became a regular commuter between La Jolla and Los Alamos. He was becoming "something of an expert" in marine defense matters, among other things. "In 1945, Isaacs and I both set out, rather unconsciously, to become generalists. We decided that being satisfied by our subjects should be a priority. There really is no limit to what your brain can absorb, so we thought we should give everything a try. In the long run, I think Isaacs was the more successful. He was smarter. I am more energetic."

"We sped into a fantastic level of fallout."

Energetic and a determined optimist, even in retrospect. He remembers the 1952–53 Scripps *Capricorn* expedition as "a tremendous opportunity" despite unexpected consequences. Following hard on the heels of the first thermonuclear explosion in the Pacific, Bascom was leading a project to record blast-pressure and long-period waves. At the time of the explosion "I was standing on a raft beside a small skiff carrying John Isaacs and a Navy commander, securing a 137,000-volt connection." They watched the colorful mushroom rise over the horizon. Bascom wanted to stay put and watch the instruments run, check measurements as they were recorded. But a command from a Navy admiral was radioed to all task ships in the area: proceed to the east at high speed, to avoid danger.

The winds in the area were generally from the east and it was predicted that the nuclear material would travel west. The command was based on a miscalculation. "We sped into a fantastic level of fallout. Everyone was unaware that a shot of this size would puncture the troposphere. All the material fell from very high altitudes to the east. An Army major aboard to monitor radiation who considered bureau standard levels of 10 milliroentgens per hour a big dose was getting readings of 100 to 200 per hour." Even with a jury-rig washdown system much "hot" deck equipment was thrown overboard. The aftermath provided him with no particular worry. "I was in the anomalous position of having cancer before I went on the cruise. I had been receiving radiation treatments for some time." Having outlived all the doctors who initially treated his cancer, and having spent some time studying radiation effects, Bascom tends to believe that "radiation is highly overrated as a problem."

His ocean-going career at full tilt, he accepted a post with the National Academy of Science (NAS) in Washington, D.C. "for one year, like everyone else, and ended up spending a number of years trying to get away." After working with the NAS committee on civil defense, he joined the Nobska Project at Woods Hole in 1956. With more than 65 other scientists and technicians he expanded the U.S. submarine fleet's role beyond torpedo launching.

Bascom began the work convinced that submarines were better attack vehicles than the Navy had previously believed, especially in the northern seas bordering Russia. He cites among his contributions the introduction of the polar projection map for planning, at that time used only by the Air Force. "The world looked very different to the Navy from that perspective. Moscow and Leningrad were much closer" and appeared more vulnerable to properly designed submarines.

There were impasses to innovation. Bascom recalls the "awful idea" of stationing ships to fire Jupiter missiles at Russia from the Arabian Sea over India and Iran, which was being considered by the Navy. The Nobska Project proposed an answer, "largely due to my shoving: Standardize the size of the missile-firing tubes. Before long you will have adequate rockets with sufficient throw."

Association with the increasingly influential

"We were all temporary heroes."

Rockefeller brothers and Henry Kissinger during this time did not convince Bascom that he had finally found a niche. In fact, as the Rockefellers prepared a report on the strategic future of the nation for the Eisenhower Administration in 1956, Bascom "quit everything, sold everything," and moved with his wife, Rhoda, to Tahiti; "the first and only year of my life when I had ample time to read and write."

Perhaps better than most, Willard Bascom understands that all good things must end. But it is his uncanny ability to uncover and exploit new possibilities that characterizes him best. "Down to about our last franc in Bora Bora, I got a cable from NAS: 'All is forgiven, great job for you.'" He returned to become the first—and the only—science advisor to the Columbia Broadcasting System's *Conquest* series. This was 1958 and the idea of drilling to Earth's mantle was beginning to surface. "No one was thinking specifically about deep drilling in ocean basins. No one knew how."

Bascom cites his article for *Scientific American* as the source of the project name: Mohole. A $15,000 grant from the National Science Foundation (NSF) for a feasibility study; an address to disbelieving scientists at the United Nations; and, a great deal of attention were spent on the proposal to drill through the Earth's crust to the Mohorovičić discontinuity. "I gave hundreds of lectures about our plans, and always included the phrase 'we hope to explore the oceans by drilling, culminating someday with a hole to the mantle'; nobody heard the first part."

The many geological, biological, and physical questions that might be answered by such a program were secondary for Bascom. "The real guts of the problem was, Could it be done?" NAS took over the ad hoc American Miscellaneous Society (AMSOC) and Bascom became project director. Choosing the *CUSS* from among five or six available ocean drilling ships, he identified the central problem. "In four or five kilometers of water, if you anchor a ship, even with four anchors, it will move about so much that the bending stress in the drill pipe would break it." His solution made it possible to maneuver a ship within a circle of taut-moored buoys;"everyone else likes to think they invented it."

The technique is known as dynamic positioning and it involved hanging outboard motors at the ship's corners and centrally controlling their movement with "a joystick." Pipe bending is reduced sufficiently to allow for deep-sea drilling. A test drill off La Jolla, however, uncovered minor structural defects in the ship and Bascom and Walter Munk of AMSOC had to convince the others to go ahead with the drilling of five holes at 12,000-foot depths. "The tests were a roaring success. And we were all temporary heroes."

Historical controversy owns the rest of the story of Mohole. Documenting his opposition to the foolish plan to drill a single large hole through to the crust in NAS reports, Bascom resigned from the ill-fated project, which eventually turned into an embarrassment for the Johnson Administration and the scientists who Bascom feels "understood exactly what they wanted when they got there, but had no sense of the problem of how to get there."

Nearly three decades of wide-ranging oceanographic work behind him, it was time again to change spheres. With four colleagues from NAS he crossed over into the private sector, founding Ocean Science and Engineering, Incorporated.

From 1962 to 1972, the firm located mineable undersea diamonds off Namibia and tin off Thailand, designed and built the first mining ship, *Rockeater*, the first deepwater search and recovery ship, *Alcoa Seaprobe*, and the *Gulfrex*, the first all-system geophysical ship.

He sold the company in 1972, "tired of being in business and managing what were essentially six companies." It is a typically bald explanation. The more compelling, perhaps underlying, motivation for this and likely for many of the other changes of personal direction are explicated in his classic account of *Waves and Beaches*, published in 1964, revised in 1980, and endlessly informative and provocative. In his epilogue, he recounts his time

> *watching waves and examining beaches, trying to understand them . . . It has covered thousands of miles of shoreline in twenty countries without producing any hope of complete understanding. The subject is too complex. But somehow there is satisfaction in being aware enough of the ways of waves and beaches to detect the special softness of a new layer of sand underfoot means the berm is building or to observe a slight change in the appearance of breakers and think,* "There must be a new storm in the Gulf of Alaska."

It is some atypical melding of wonder and absolute impatience with programs and theories that do not take full account of the fundamental character of a given issue that defines him. He has "little respect for oceanographers who have not kept up their at-sea experience and understanding of the practical problems of getting precise measurements from something as seemingly simple as placing and maintaining a buoy."

"The secondary problem of interpretation should not hold up the satellite program."

It is a constant battle, though, his desire to bring technological and scientific considerations into complimentary focus. Certainly this struggle is at the heart of his championing the importance of satellites in the future of oceanography. As chairman of the NAS Ocean Science Board investigating the potential of oceanography from space, he discovered that most "physical oceanographers were interested in altimetry and nothing more." Despite others' qualms about stockpiled data, he still believes *Seasat B* should have been launched directly after *Seasat A* failed: "It would have been dirt cheap, we had only to launch it. I don't honestly know what we would have done with all the data, but we would have had it. Look at the images we got from the SAR. Take the five best images, throw out the rest, and even with just those five you have more than paid for the entire effort. The secondary problems of interpretation should not hold up this program."

As the proponent of wind-driven oceanographic vessels for the 1980s, Bascom knows that many of his ideas will not have easy births. Often, he seems to be at cross purposes with the times. Variously credited with, and accused of, being a jack-of-all-trades, he will "study any problem like crazy until I am sure I know enough to satisfy me. The day I tire of it, I stop." Here, the influence of John Isaacs is indelibly imprinted on him. "Isaacs read extensively, and he remembered what he read. He had a fundamental understanding of the world—geologically, biologically astronomically, physically—unlike anyone else I have ever met. He would have called himself a mathematician. The fact is, John just understood how the world works."

In 1972, while Bascom was writing about his work in underwater archaeology for *Deep Water, Ancient Ships,* Isaacs approached him about the directorship of the Southern California Coastal Water Research Project. Uncredentialed in environmental sciences, Bascom was presented with "very talented people and funding" and a management problem. Besides, observed Isaacs, "you don't seem to be doing very much these days."

Surprised by his tenure in the job, which extends to this writing, Bascom feels it is his initial, unaccomplished goal that keeps him going now. "I want to inject some common sense into the study of environmental problems. A true environmentalist, it seems to me, would look at all the options for disposal and make a decision based on the smallest degree of damage to land, sea, or air. Present laws prevent anything as simple as that."

Railing against the variety of "so-called" measurement and monitoring programs under way, he believes that the hit-and-miss character of environmental programs often precludes the possibility of uncovering solutions. Unsupported allegations and inconclusive findings produce "fancied threats." Reluctantly, he admits that most environmental lobbies seem more interested in protecting their fundraising stature than sensibly evaluating pollution and disposal problems. He was distressed at the resistance that a study of oil platforms off Georges Bank produced among the powerful anti-oil groups. "They refused to acknowledge the data that showed that drilling platforms just are not harmful. Sooner or later I hope we can integrate working scientists into the legislative and regulatory processes, make them more effective in getting across the facts. We need honest assessments. Slowly, I believe we'll get there. It is just taking a heck of a lot longer than I first thought it would."

He seems to make time. His is an uncontestable record of exploration that continues to defy expectations. In 1979, the Colorado School of Mines awarded Bascom its Distinguished Achievement medal. But it was the decision of the Explorers Club to award Bascom its gold medal in 1980—the first time an oceanographer has been so honored—that finally provided an appropriate credential to "this boy dreamer from New York City." Hardly unaware of his laurels, the possibility of resting on them does not occur to him: "The world is such a marvelously complicated place that I just don't see any end to exploration at all."

Typifying his style, his suggestive letter of September concluded:

> *Have written five books, about a hundred papers, and made three prize-winning films [and is working on another]. This somewhat brazen suggestion came to me at a moment when I had so much damn work to do I couldn't decide which thing to start on and picked up an old* Oceanus. *Now I can go back to work. Kindest thoughts.*

Always the explorer.

Radwaste Disposal Risks Assessed at LDC Meeting

The continuing international debate over ocean disposal of radioactive wastes involves a complex mix of scientific, legal, economic, and social policy variables. It mirrors domestic radwaste-disposal-assessment controversies that are in progress in such nations as Britain and Switzerland, which have dumped low-level wastes (LLW) in recent years, and in Japan, the United States, and other Nuclear Energy Agency Seabed Working Group countries that are considering LLW or high-level wastes (HLW) disposal in the future. It involves the Nordic and South Pacific countries, and Spain—nations with no plans for such disposal which question whether disposal by others is an acceptable risk to the health of the oceans.

During 1983, for the first time since the 1940s, no radioactive wastes were dumped at sea. The halt in radwaste disposal was directly related to decisions made in 1983 by governmental parties to the London Dumping Convention (LDC), the global treaty that regulates such activities. At the recent February, 1984, LDC meeting, LLW and HLW issues again dominated the deliberations. As a result of decisions made at that meeting, those issues will continue to be at the forefront of LDC activities during 1984–85.

In February, 1983, three decisions made by the LDC parties set the stage for the continuing international focus on radwastes: an LLW moratorium resolution was adopted (19–6, with 5 abstentions); a two-year scientific review of the risks associated with such disposal was initiated; and a mechanism was established to address the question of the legality of seabed disposal of HLW (see, *Oceanus*, Vol. 26, No. 1, Spring 1983, *Ocean Dumping Nations Vote Radwaste Suspension*, pp. 76–78). Prior to 1983, four Western European nations—Great Britain, Switzerland, Belgium and the Netherlands—had been dumping LLW regularly at a Northeast Atlantic site (see Figure 1). Despite protestations from representatives of those nations at the 1983 LDC meeting that the moratorium resolution was not legally binding, and that they intended to carry out dumping operations during 1983, a *de facto* moratorium exists. In the spring of 1983, the Netherlands government revised its position, announcing that it would honor the moratorium. In Great Britain, a groundswell of opposition to dumping during the moratorium arose within the transport trade unions in the spring and summer of 1983. Union boycott resolutions were adopted that black-listed the handling of any LLW slated for sea disposal. Similar transport-union boycotts were adopted in Switzerland and Belgium, and all three of those nations cancelled their proposed dumping operations.

During 1983, the LDC's international scientific review of LLW risks began to unfold. The International Atomic Energy Agency (IAEA) and the LDC secretariat (the International Maritime Organization [IMO])—gathered pertinent studies and reports from governmental parties and others. This information was presented to the parties at the February, 1984 meeting. On the question of the legality of HLW disposal under the LDC, an Ad Hoc Group of Legal Experts was convened in London in December, 1983. The findings and recommendations of that group were forwarded to the recent meeting, serving as a prelude to the divided views on the HLW issue. In the context of these and other developments, the LDC parties, as well as observers from other nations, international agencies, and nongovernmental trade associations and environmental groups, met at the London headquarters of the IMO this past February.

Scientific Risk Review

In order to complete the international scientific review of risks associated with LLW dumping initiated in 1983, delegations attending the February, 1984, meeting recognized that certain terms of reference needed to be clarified. There were two principal areas of concern: the structure of the review, and the substantive questions that should be addressed.

Delegation views on the structure of the review centered on how experts would be selected, the level of involvement of LDC parties, and the length of time needed to complete the intersessional review. As for the experts, some governments (led by Britain) proposed that IAEA and the International Council of Scientific Unions (ICSU) each select experts to review the evidence and make recommendations for consideration by the LDC parties at their 1985 meeting. Other governments (led by Canada and Nauru) felt that the experts should be chosen by the governmental parties, with the panel reflecting different interests and regions. As a compromise, a two-staged review accommodating all

	Dumping site				Quantities dumped											
					By the UK				By other countries (d)				By all countries			
					Weight gross Te	Activity		Tritium (a) Ci	Weight gross Te	Activity		Tritium (a) Ci	Weight gross Te	Activity		Tritium (a) Ci
	Latitude N °	′	Longitude W °	′		α Ci	β & γ Ci			α Ci	β & γ Ci			α Ci	β & γ Ci	
1949	48	30	13	00	9		1		NIL				AS UK			
50	49	50	02	18	350	2	20		"				"			
51	49	50	02	18	319	1	18		"				"			
51	55	20	11	20	33	1	5		"				"			
52	49	50	02	18	534	2	29		"				"			
53	55	08	12	10	57	2	2		"				"			
53	49	50	02	18	758	10	39		"				"			
54	49	50	02	18	1145	23	55		"				"			
55	49	50	02	18	1164	35	44		"				"			
55	32	37	14	05	1453	12	33		"				"			
56	49	50	02	18	1038	44	33		"				"			
57	49	50	02	18	1537	109	161		"				"			
57	32	42	19	30	4404	955	808		"				"			
58	32	42	19	30	2694	695	1085		"				"			
58	49	50	02	18	1011	58	57		"				"			
59	49	50	02	18	1198	4	74		"				"			
60(h)	49	50	02	18	2551	74	218		"				"			
61	49	50	02	18	1967	20	308		"				"			
61	32	38	20	05	4360	563	1630		"				"			
62	46	27	06	10	253	17	163		"				"			
62(c)	49	50	02	18	1444	5	76		"				"			
63	49	50	02	18	1543	3	44		"				"			
63	45	27	06	16	5809	368	7071		"				"			
64	45	27	06	36	4392	444	15090		"				"			
65	48	15	13	15	1759	114	13754		"				"			
66	48	15	13	15	1044	78	2742		"				"			
67	42	50	14	30	722	91	1682		10178	159	5918		10900	250	7600	
68	48	20	13	16	3164	731	74837		NIL				AS UK			
69	49	05	17	05	1878	390	17590		7302	110	4410		9180	500	22000	
70	48	19	13	15	1674	233	20224		NIL				AS UK			
71	46	15	17	25	1434	323	8615		2536	307	2585		3970	630	11200	
72	46	15	17	25	1885	674	19049		2245	6	2551		4130	680	21600	
73	46	15	17	25	1453	739	11641		2897	1	1019		4350	740	12660	
74	46	15	17	25	1256	399	94126		1009	17	6230		2265	416	100356	
75	46	15	17	25	1350	704	52481	25840	3110	76	8019	4160	4460	780	60500	30000
76	46	15	17	25	2269	789	49777	18730	4501	91	3723	2270	6770	880	53500	21000
77	46	00	16	45	2140	930	74830	31328	3465	28	1621	558	5605	958	76451	31886
78	46	00	16	45	2080	814	69307	32700	5966	287	10321	3913	8046	1101	78629	35614
79	46	00	16	45	2014	1381	81080	40991	3402	33	2286	1449	5416	1414	83366	42440
80	46	00	16	45	2693	1791	106079	40169	5698	61	59818	57966	8391	1852	165897	98135
81	46	00	16	45	2517	2032	104709	38243	6918	85	48858	36129	9435	2117	153567	74372

Notes

(a) Specific data available for tritium only since 1975, prior to that year tritium was included in β and γ For consistency with earlier years tritium is also included in β and γ for 1975-81 in the above Table

(b) Includes 289 Te from Belgian sources

(c) Includes 438 Te from Belgian sources

(d) Estimates for 'other countries' in 1967, 1969 and 1971-81 were deduced by subtracting the UK contribution (exact figures) from the NEA totals (rounded values)

Source Nuclear Energy Agency, Organization for Economic Co-Operation and Development, January, 1983

Figure 1. Quantities of radioactive waste dumped at sea 1949–81.

parties' concerns was endorsed.

As for timing, some governments wanted the review to be completed within one year so that the next LDC meeting would be in February, 1985, as previously scheduled. Others felt that the next meeting date should be set to allow for a thorough and adequate review, and that 12 months was too short a period of time. As described in the annotated timetable (Figure 2) a nineteen-month review period was set, with the next formal LDC meeting scheduled for September, 1985. In relation to the extended review, parties affirmed by consensus a statement by Spain's chief delegate that the original two-year moratorium should be similarly extended.

With respect to the substantive terms of reference (that is, jury instructions) four of the parties (the United States, Denmark, Nauru, and Spain) and Greenpeace International submitted lists of questions they believed should be addressed. The written questions focused on the safety of past and projected LLW disposal at sea (quantities involved in such dumping, an inventory of all forms of radwastes entering the marine environment from human

Figure 2. Low-level waste scientific review schedule.

4/13/84	IAEA and ICSU each select 5-10 experts in pertinent disciplines. Prof. Engstrom (Sweden), the chairperson of the LDC from 1979-1983, agreed to serve as the LDC liason to ensure that experts reflect regional balance
10/31/84	Meeting and preparation of draft report by expert panel
11/30/84	Circulation of draft report to LDC parties and observers for comments
3/29/85	Submission of comments to IMO Secretariat
4/30/85	Expanded meeting, which would include experts from first meeting and experts from LDC parties and observers. Final report will be prepared at that meeting by all the participants
6/28/85	Circulation of final report to LDC parties and observers
9/23-27/85	Next formal meeting of LDC parties and observers

sources, adequacy of modeling and monitoring to predict impacts, and the adequacy of containment measures and assessments of land-based alternatives, among other concerns) and overall conclusions (including restatements of several of the above concerns and variations on the burden of proof question—who needs to prove what level of safety or harm). A working group was established during the meeting to consolidate the written questions, but that effort failed. Instead, the parties agreed that the reviewing experts must respond to all the questions presented in those five written submissions, as well as any other questions the experts believe to be appropriate.

With the intersessional review in hand, the parties attending the September, 1985 LDC meeting will revisit the question that was before them in 1983 when the moratorium and review were put into effect: Should the LDC be amended to prohibit ocean dumping of any radioactive wastes? If at least two-thirds of those present agree that the answer to that question is yes, they would have to decide whether a global ban should take effect immediately, or be phased-in over several years. Attention would also be directed toward an improved definition of *de minimus* quantities of radwastes that fall outside such a ban. If more than one-third of those in attendance vote no an amendment could not be adopted. If that were to happen, it is likely that such issues as tighter definitions of HLW and LLW (including *de minimus* quantities) and regulatory oversight (including the adequacy of monitoring requirements, dump-site locations, and land-based alternative assessments) would be further refined.

Year	*USA*	*Non-USA*	*Total*
1974	*1.50*		
1975	*.26*		
1976	*1.15*		
1977	*1.30*	*.25*	*1.55*
1978	*3.70*	*.40*	*4.10*
1979	*3.70*	*2.10*	*5.80*
1980	*6.80*	*4.60*	*11.40*
1981	*6.90*	*7.02*	*13.92*
1982	*4.90*	*7.62*	*12.52*
1983	*5.70*	*11.00*	*16.70*
*1984**	*9.60*	*11.00*	*20.60*
1985	*10.60*	*12.10*	*22.70*
1986	*11.90*	*13.45*	*25.35*
1987	*12.60*	*13.70*	*26.30*
1988	*12.35*	*15.15*	*27.50*

Figure 3. Subseabed disposal: international funding (millions of dollars).

** Note: 1984 to 1988 projections are based on the Seabed Working Group 5-year plan.*

Legality

While considerable time was devoted to the LLW risk review at the February, 1984, meeting, the major debate centered on the legality of HLW disposal into the seabed. Since the mid-1970s several industrialized nations have been assessing the feasibility of burying HLW in deep-ocean sediments (Figures 3 and 4). The LDC, as written, prohibits "disposal at sea" of HLW. Does disposal at sea refer to the final resting place of the wastes, or does it refer to the place where the disposal activities occur? The LDC does not address this point specifically, and HLW seabed disposal was not under consideration as a potential disposal option when the LDC was finalized in 1972.

Considerable time was devoted to achieving consensus on this issue. In the end, that effort failed; however, two basic points were agreed upon:

> *"1. The Consultative Meeting of the Contracting Parties to the [LDC] is the*

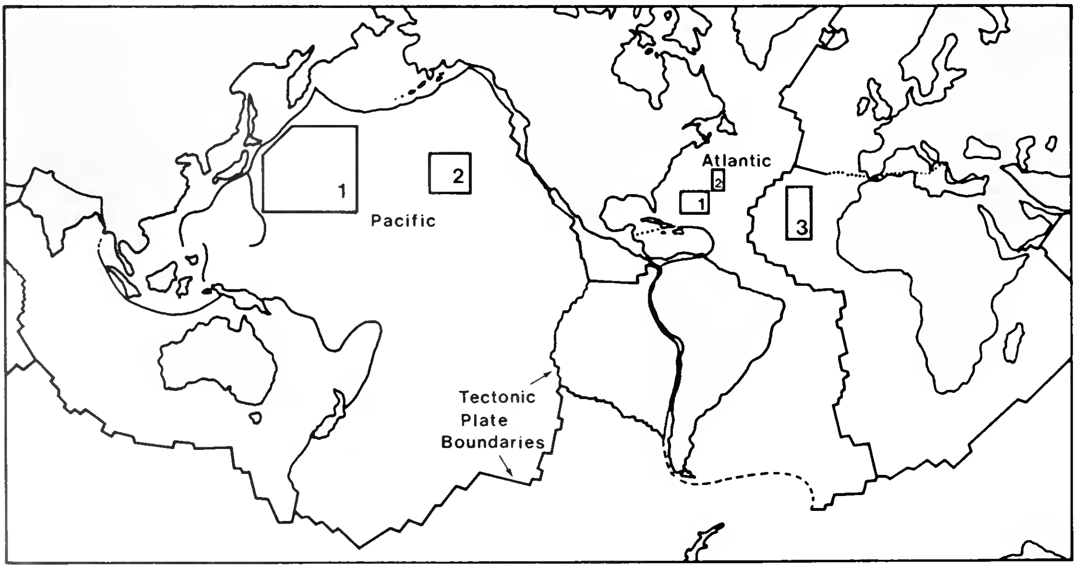

Figure 4. Locations of five study regions in the North Atlantic and Pacific basins.

> *appropriate international forum to address the question of the disposal of high-level radioactive waste and radioactive matter into the seabed, including the question of the compatibility of this type of disposal with the provisions of the LDC; [and]*
>
> *2. No such disposal should take place unless and until it is proved to be technically feasible and environmentally acceptable, including a determination that such waste can be effectively isolated from the marine environment, and a regulatory mechanism is elaborated in accordance with the provisions of the [LDC] to govern the disposal into the seabed of such radioactive wastes."*

Beyond that basic agreement, two principal blocs expressed notably different views on the legality issue. The dominant coalition of nations—a large majority of those who stated a position—argued that HLW disposal is covered by the LDC and, therefore, is prohibited; these nations were referred to as sponsors of the Nordic resolution.* While the express language of the LDC may be unclear, those nations agreed that protection of the marine environment under the LDC requires an interpretation that views seabed disposal as "disposal at sea." In addition to their basic position that such disposal is covered and prohibited, they agreed that their interpretation applied to experimental as well as operational activities. Some of those nations discouraged further study of that disposal option, while others felt it should continue.

A minority bloc took the position that HLW seabed disposal is not covered by the LDC as now written and, therefore, is not prohibited. The United States, Britain, and France each offered a preliminary resolution advocating a variation on this position, but by the end of the week they coalesced around a U.S. resolution.** That resolution focused only on future regulation of operational activities, left unclear how such disposal might be permitted and regulated under the LDC, and encouraged further study.

A number of delegations at the meeting were concerned about forcing the HLW legality issue to a formal vote at the meeting. Others felt that if consensus was not possible it would be better to wait until the next meeting. The suggestion that a formal vote would be too divisive, especially given the high tensions that were experienced at the 1983 meeting in relation to the adoption of the LLW moratorium resolution, was dismissed by some supporters of the Nordic resolution, who felt that the LDC was an effective treaty that could easily survive a vote. In the end, they deferred to those who preferred to focus efforts on strengthening support for that resolution and allowing for the possibility of consensus. A formal vote was not taken, but it was agreed that the Nordic and U. S. resolutions would be attached to the final report of the meeting. Moreover, the text of the final report contains statements by the various parties and observers, expressing their respective views.

Conclusion

Evidence to date suggests that past LLW disposal at sea has not caused serious degradation of the marine environment, especially when contrasted with land-based discharges of radioactive and other toxic wastes. Moreover, studies and assessments of future HLW seabed disposal are still at an early, indeterminate stage of technical and environmental feasibility. Nonetheless, radwaste disposal crystallized attention within the world community, raising concern about the incremental and cumulative impacts of marine pollution, the adequacy of consideration given to land-based alternatives, and the broader rights and responsibilities of nations in relation to the use of the common resources of our oceans. The issues are complex. The current review of radwaste policies, within the global framework of the LDC, presents a challenging opportunity for a diverse group of nations to forge policies and solutions that safeguard our marine resources.

Clifton E. Curtis,
Executive Vice President,
The Oceanic Society

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* The Nordic resolution supporters include Argentina, Brazil, Canada, Chile, Cuba, Denmark, Dominican Republic, Finland, West Germany, Iceland, Ireland, Mexico, Nauru, Norway, Panama, Spain, and Sweden.

** The supporters of the U.S. resolution include France, Japan, the Netherlands, Switzerland, Britain, and the United States.

Letters

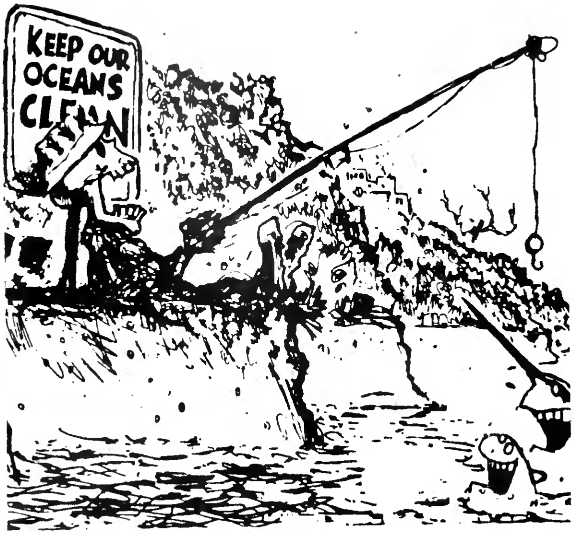
To the Editor:

Sorry that my first act as a subscriber is to complain mildly about the article on "Ocean Dumping" (*Oceanus*, Vol. 25, No. 4, pp. 39–50, Winter 1982/1983). While I admire the writers (John Farrington, Judith Capuzzo, Thomas Leschine, and Michael Champ) individually, an article on a controversial subject by four authors has to satisfy the lowest common denominator. "Buck" (Ketchum) would have been more incisive.

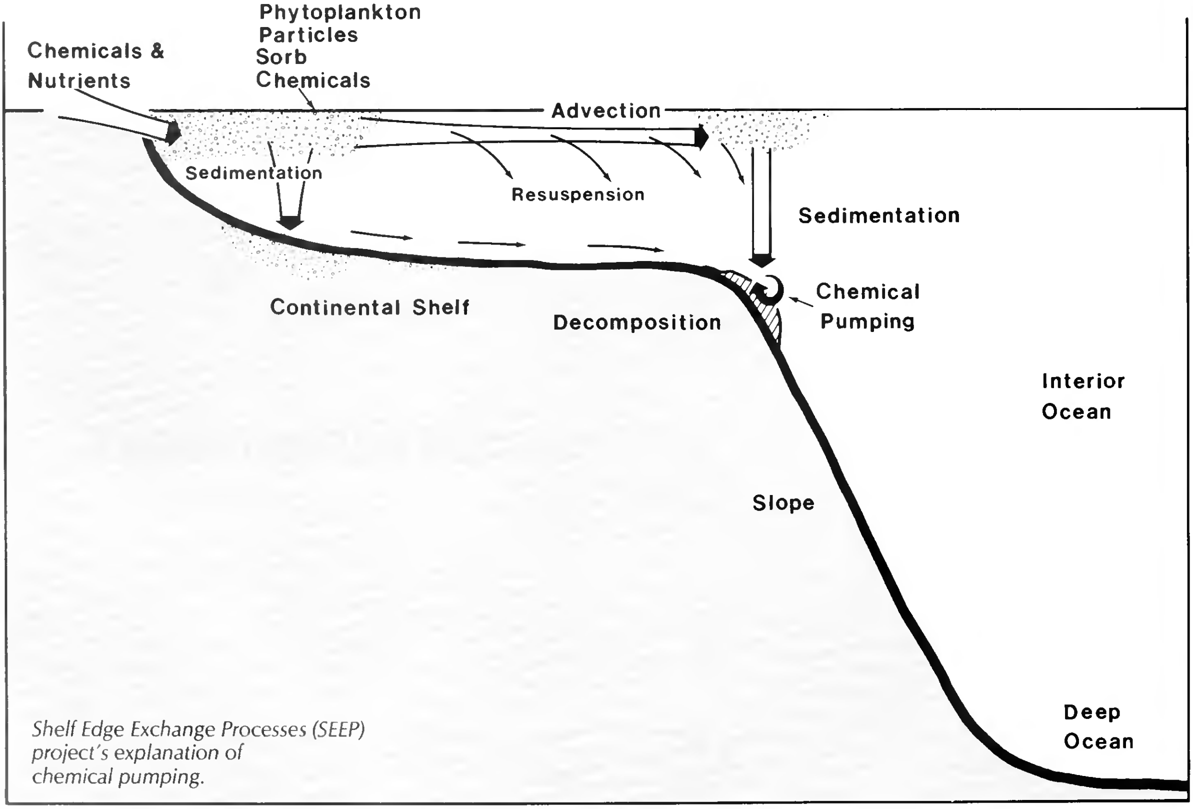
Perhaps the lead-in by Henry Brooks Adams that *Simplicity is the most deceitful mistress that ever betrayed man* is an argument to avoid the basics. I prefer Edward Morrow's *The obscure we see eventually, the completely apparent takes a bit longer.*

Although it took a while, it is now apparent to me that the land is better designed than the sea to provide food. Plants, animals, nutrients, and sunlight are together at the surface, harvesting is relatively easy, and food chains are short and efficient. In the ocean, productivity is low as sunlight is at the surface and nutrients are mostly in the deep darkness, harvesting is difficult because of the third dimension (edible biomass is only one part per million, according to your own [Bill] von Arx), and food chains are long and inefficient. Thus, the land provides 99 percent of our food (Roels, 1982), 97 percent of our protein (Holt, 1969), all of our drinking water, and most of our fibers, building materials, and radioactivity.

On the other hand, the ocean is better designed for waste disposal. Cleansing processes carry pollutants into the depths on particles, often to be safely locked in the sediments, and long food chains reduce the flow of pollutants to man (Bowen and others, 1971). On land, pollutants tend to leak into our drinking water—not so in the ocean. Since 4 billion people depend on freshwater, which makes up less than 1 percent of the planet's water supply, it must be protected, which means protecting the land.



As for the need for retrievability, we certainly don't apply that standard to what we burn, or even the pollutants that leak into the groundwater. As ["Ed"] Goldberg says, it's easier to stop eating fish from a certain part of the sea than it is to quit relying on water from a contaminated aquifer.



Shelf Edge Exchange Processes (SEEP) project's explanation of chemical pumping.

For a second-generation article (after your good special issue on The Ocean as Waste Space in 1981), this one was pablum, coming down on all sides of all issues. It took the usual obligatory swipe against radionuclides in the ocean, neither knowing nor caring that man's contribution of radioactivity is about one one-thousandth of that of nature and is massively diluted by stable elements in seawater, and discriminated against by the long food chains, making its contribution to dose in man infinitely small compared with that from land.

I'm sending a cartoonist's answer to the sludge sea monster and a figure similar to the one used in the article, only mine emphasizes the cleansing processes, including the "chemical pump" of the Woods Hole Oceanographic Institution's (Derek) Spencer and (Michael) Bacon. The figure is a part of the Shelf Edge Exchange Processes (SEEP) project that Spencer and Bacon participate in with Department of Energy funding.

Charles Osterberg,
Damascus, Md.

Response by Farrington:

We sincerely wish that Buck Ketchum had lived much longer and further shared his wisdom with the readers of Oceanus. No doubt Buck would have written a better article.

Contrary to the suggestion of Osterberg, we did not avoid the basics of modern, up-to-date ocean sciences. We also did not advocate a particular option for waste disposal; land, sea, air, or recycling. Rather, we attempted to present several of the pros and cons which were, and still are, being debated in the scientific and political arenas. We had understood that this was the type of article Buck was writing. If a balanced presentation is "pablum" to Osterberg, we hope it was informative to some others who have not had the benefit of his many years of research management in ocean sciences. Despite the fact that more food by far is produced on land (a fact we agree with and is beside many of the main points of the waste disposal issues), there are segments of U.S. society and elsewhere in the world that depend on seafood catch for their livelihood and a significant portion of their diet.

We are surprised at Osterberg's contention that we took an "obligatory swipe against radionuclides in the ocean, neither knowing or (sic) caring that man's contribution of radioactivity is about one-thousandth of that of Nature..." We specifically stated in the insert on p. 48 that there were different types of radioactive substances; we referred the reader to other articles for further information; we do "know" the difference despite Osterberg's insinuation that we do not. We know that plutonium is long lived and man made and was not present in the world prior to man's entry into the nuclear age.

As with Osterberg's figure, our's shows burial of some chemicals. Osterberg refers to the Department of Energy SEEP program with which he is closely associated as a DOE official. This is one of several ongoing research programs focused on understanding how chemicals move through marine ecosystems to provide knowledge in support of policy and management practices. Yet, if the issues were as clear cut and "incisive" as Osterberg seems to contend, there would be little need for the SEEP program.

John W. Farrington,
Senior Scientist,
Chemistry Department,
Woods Hole Oceanographic Institution

To the Editor:

I would like to comment on the article in the Spring 1984 issue by Michael Stewart Connor on At-Sea Incineration.

As far as it goes, this article is an excellent synthesis of the situation and some of its problems. Mr. Connor fails to perceive some of the problems which he touches upon, however. Page 70, Column 1: "... with high-temperature incinerators capable of maintaining temperatures at the incinerator wall of at least 1,100 degrees Celsius during the burns." Ah, but the incinerator on both *Vulcanus I* and *II* is asymmetrical and the cross-sectional temperature thus is not uniform. Column 3, "... in waters about 1,400 meters deep." While this might contribute to the vertical column capable of mixing with the surface, it doesn't. Most biological life is in the uppermost portion of the water column where light reaches photosynthetic plankton; these are the most impacted by the acid and other toxins, thereby allowing any PCBs or other decomposition products (some of which are likely toxic and not detected by tests for PCBs) to be accumulated in the food chain, until that area becomes sterile, or at least hazardous for man's food.

The Federal Maritime Administration is now pressing for a permit for *Vulcanus II*, a vessel with outmoded incinerator technology; in fact, it was built from scratch to match the retrofitted older design of *Vulcanus I*. State of the art is not of concern to the Feds, it would seem.

Research studies have been uniformly unsatisfactory. Suitable controls have not been used. Page 71, Column 1: "Changes in the adenylate-energy-charge ratio were ascribed to stress during shipboard handling." Fooey. If proper controls had been available the data would have been clear cut one way or the other. We cannot afford guesses! "Sufficiency of research program"—that is another point, no research protocol was available; those studies that were done were not repeated because of incinerator problems; many that were done were done incorrectly, also. Particulates shown so well in the photograph were not analyzed; 100 percent deposition in the Gulf is expected, but again, the studies are poor.

Page 72, Column 1: "To anyone who has spent any time at sea, it is obvious that ship incinerators can not operate as efficiently as their land counterparts." Now that is interesting. Why to "anyone who has spent any time at sea"? What has this to do with efficiency? I was told that incineration was the same, only at sea there were no scrubbers? Who is correct? It is worth noting that a Federal joint committee on ocean incineration is already considering the presence of several incinerator vessels in the Gulf site at the same time and is therefore looking at scrubbing as a necessary addition. But where would the scrubbing sea water then go, in the Gulf? Why into the water of course!

Next sentence, "But their emissions may present minimal risks to public health since ocean-based incineration is conducted more than 200 kilometers from the nearest population centers." This statement reflects several misconceptions, or lack of sensitivity. What is minimal risk? Do I, a Galveston resident, need to assume this risk? (No way.) What about offshore recreational boats whose passengers are exposed? What about the fishing industry? What about the fish that I eat that have accumulated part of that 0.01 or 0.001 percent of the waste which was never incinerated?

Page 73, Column 4: "While the agency monitor can likely prevent unauthorized disposal, he would be hard put to verify location, watch for much more than 24 hours at a time, and perhaps even verify incinerator conditions if the instruments break down as often as they have in the past." Hot hydrochloric acid is not kind to instrument sensors.

Page 74, last column: "The ocean-incineration industry has too much momentum for the EPA not to issue permits in the coming year"—Wow, perhaps it *is* true that industry always gets it permits? Perhaps EPA refers to it being an agency that does, or sanctions, pollution?

There are many, many problems also with land-based incineration. When man is considering marine food as an imperative because of inadequate land production and greater urbanization, we cannot afford to damage our oceans. Or will we need a supermaxi-fund in 10 years to clean that up, and where do we put the waste then?

The article is good as far as it goes, it just doesn't go far enough and is not strong enough. For example, at the edge of the continental shelf just north of the designated site in the Gulf of Mexico are located the Flower Garden Banks, the northernmost coral reef in the Gulf—what will the effect of the waste burning, or spilling, be on this?

I am glad you have published Mr. Connor's article. It's a start. What does the ocean have to say about being used as a dump? Those of us who have probed in depth into the EPA permitting process for this incineration proposal are aghast.

F. Hermann Rudenberg,
Coastal Affairs Chairman,
Lone Star Chapter, Sierra Club,
Galveston, Texas

Response by Connor:

The Sierra Club letter very nicely illustrates the vehemence of the opposition expressed by local residents to ocean-based incineration. The specific points raised by Dr. Rudenberg represent some of the areas of scientific uncertainty surrounding the proposed permits. Proponents of ocean-based incineration would counter his arguments by claiming that:

- *Regardless of the shape and temperature profile of the incinerator, observation and monitoring show that it achieves the required destruction efficiencies.*
- *Since PCBs are quite lipophilic, they will sorb to particles and very quickly be sedimented to the bottom far from the surface waters about which Dr. Rudenberg is concerned.*
- *Research into biological effects has been hampered by many of the same problems which make it so difficult to find pollution effects in offshore waters where rapid dilution erases any chemical trace of the incinerator plume once it grounds.*
- *The major purpose of scrubbers is to remove hydrochloric acid which would have an insignificant effect on the pH (acidity) of a large expanse of well-buffered ocean water.*
- *Monitoring of burns has been possible in other instances.*
- *The risks associated with incineration at sea are several orders of magnitude less than the daily risks of transporting the millions of tons of other industrial chemicals.*

All hazardous-waste disposal options have these sorts of uncertainty surrounding them. But underlying this dispute over facts are even greater differences in values. At issue are several important questions of policy. Is it sufficient to simply find that a project is safe because the risk is predicted to be below some probability level (and who should determine that level and that probability)? Must the preferred alternative be safer than all other "also safe" alternatives? How important should considerations of cost be? It is inevitable that different alternatives will present risks to different portions of the population. How can we preserve the rights of citizens neighboring a disposal area? Can mitigation and compensation procedures be provided to calm their fears, or will this be perceived as selling out health concerns?

These wastes probably represent greater risks to the population while they sit in storage awaiting a decision than they would under any of the disposal options. The challenge to environmental organizations is to offer politically acceptable and economically feasible alternatives for the disposal of these liquid wastes. Historically, at-sea incineration has developed as an alternative to the ocean dumping of the same wastes. For that reason, the National Wildlife Federation has been an active participant in the development of acceptable ocean-based incineration practices and regulations. I am heartened by how far we have progressed with our waste-disposal practices. Increased awareness and discussion of these issues can further increase that progress.

Michael Stewart Connor,
Research Fellow,
Interdisciplinary Programs
in Health,
Harvard School of Public Health

book reviews

Commercial Diving Manual by Richard Larn and Rex Whistler. 1984. David & Charles, Devon, England and North Pomfret, Vt. 484 pp., $32.00

Commercial Diving Reference and Operations Handbook by Mark Freitag and Anthony Woods. 1983. John Wiley & Sons, Chichester, England. 414 pp., $41.95.

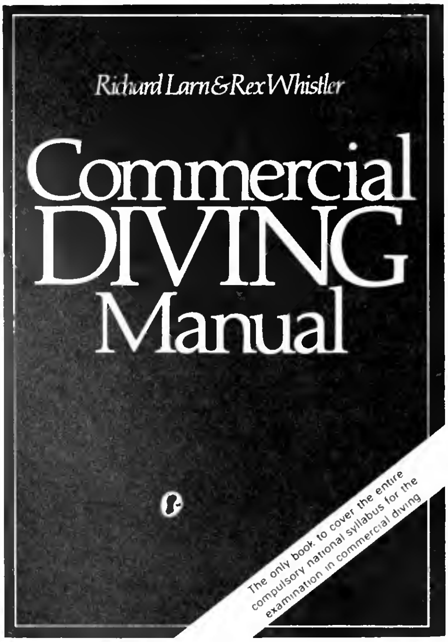
Commercial divers are required to be skilled and knowledgeable in many fields. Not only must they be trained thoroughly in the disciplines necessary to penetrate the alien (to terrestrial creatures like us) aquatic environment, they must be able to perform tasks safely and effectively. Diving is, after all, simply a conveyance to a job site. Jobs, however, are usually more difficult to perform underwater, and commercial divers cannot always choose the conditions under which they must work. Turbid, cold water, with currents, foul weather, long hours, and complex missions are standard for commercial work.

Therefore, any book intended as a manual or reference work for the commercial diver must contain a substantial body of information. Two new publications from England meet this requirement—albeit from different points of view.

The *Commercial Diving Manual* is intended to be a primary text for trainees enrolled in a commercial diving course. Although there are already numerous professional diving texts, the authors contend that these manuals "all have a high degree of specialization . . . Other publications are oriented toward the offshore diving industry, or sport diving, for example, and whilst excellent and very necessary in their particular field, again they do not meet the needs of a trainee diver entering the commercial diving world."

This book adequately covers the scope of commercial diving subjects required by the British Health and Safety Regulations. It is oriented toward general commercial diving, rather than specializing in North Sea oil-field operations. Mixed-gas and saturation diving are not considered. Its goals are covered in two parts: Basic Diving Practice, and Surface and Underwater Skills. The former section provides the trainee with a good technical overview of the standard subjects—diving physics, medicine, decompression, and equipment—comparable with the well-known British Sub-Aqua Club manual. Additionally, commercial subjects such as surface-supplied equipment and procedures, diving emergencies, recompression chambers, and treatment tables are well covered. Diving history is the only chapter this reviewer feels is treated in a cursory manner.

The latter section introduces many of the skills commercial divers must master. These include search, rigging, basic power and hand tools, underwater cutting and welding, concrete work, explosions, photography, nondestructive testing, and, of course, the inevitable report writing. Salvage laws, conversion factors, and British diving regulations are also covered.



With one notable exception, all units of measurement are given in the International Metric System of Units (SI). This is of special interest for American divers, most of whom still use the archaic English system. Although the U.S. metrification program is currently stalled, it is inevitable that this country will follow the rest of the world in adopting the metric standard. The exception in this manual is that it presents the U.S. Navy (U.S.N.) decompression tables exclusively, and the U.S.N. treatment tables along with the Royal Navy therapeutic tables. I thought it a curious anomaly that the U.S.N. tables were, for the most part, not converted to metric here, since Britain adopted the SI system years ago.

Other interesting points for American readers pertain to differences in British terminology and procedure. Buoyancy compensators, for example, are called ABLJs (Adjustable Buoyancy Life Jackets). Scuba cylinder valves are known as "pillar valves" in Britain. Line-pull signals are quite different from those used in the U.S. Navy.

Overall, the *Commercial Diving Manual* is a worthwhile text for commercial diving training, and also would make a creditable acquisition for the general diving library. My major criticism is of its hard-cover format. The diving industry has recently undergone a dynamic phase of growth in technology. Because of this, much of the material covered in diving texts is outdated even as it is published. It is expensive to update hard-cover books as rapidly as the changing needs of industry demand. The loose-leaf binder format is much more inexpensively and easily revised by the simple addition or deletion of pages. The U.S. Navy Diving Manual has used this format successfully for several years.

Further, it is impossible to cover the wide range of topics necessary for commercial operations in just one volume. Cofferdams and patching, for example, are significantly absent from the book. The publishing of several volumes would allow for more in-depth treatment of many of these subjects, and further increase the value of the text as a reference to the diver after graduation.

The *Commercial Diving Reference and Operations Handbook* is also a valuable work for the commercial diver, but it has a format radically different than the CDM. Standard subjects are not covered. There are no descriptions of the different hats, no physics lectures, and very few illustrations. This book is not intended to be a primary text, but is instead a planning and decision-making tool for operations managers, diving system engineers, and experienced dive teams.

This handbook is organized in a logical, easy-to-access way, with graphs, tables, checklists, flow charts, sample reporting forms, as well as descriptive text. The reasons governing procedures are clearly and concisely given. Of special interest are the trouble-shooting outlines describing system failures, and emergency and medical procedures. The scope of this book includes mixed-gas and saturation diving. Personnel qualification, responsibilities, and organization also are covered in this reference.

Although much of the information is applicable to offshore oil-field operations, there is much for the inshore contractor as well. The authors have compiled such a wealth of advance operations material that interested nondiving parties, including governmental agencies, can easily grasp the nature of commercial diving procedures.

Terrence Rioux,
Diving Supervisor,
Woods Hole
Oceanographic Institution

***America Looks to the Sea: Ocean Use and the National Interest* by Douglas L. Brooks. 1984. Jones and Bartlett Publishers, Boston, Mass. 226 pp, $16.25.**

This book considers national ocean-policy issues at a time when "a momentous change in the way mankind uses the sea is under way." The concept of "freedom of the seas is ending. The new age of the 'managed ocean' is about to begin."

The author, who has had "a ringside seat" for 20 years in the national ocean-policy arena, including seven years as head of staff for the National Advisory Committee on Oceans and Atmosphere (NACOA), sees as the most critical issues in the years to come "nuclear weapons control, coping with a new Law of the Sea treaty to which we are not party, preserving fishery habitats, and integrating offshore oil and gas exploration, waste disposal, and international shipping and port operations into the larger fabric of multiple use of offshore and coastal areas."

This book will be useful to ocean policymakers, government officials, businessmen, scientists, and others with interest in ocean affairs. It is divided into 11 chapters: Sea Change for Mankind; Oceanus: The Water Planet; Politics at Sea; Fencing in the Range; "Down to the Sea in Ships"; Troubled Waters; "Out of Sight . . ."; The Crowded Margin; Games Planners Play; The Global Commons; and, The Managed Ocean. In addition, there are eight important appendices; among them one on Strategic Nuclear Forces as of 30 June 1982, and Ocean Legislation of the late 1960s and 1970s.

Brooks states in his preface that "this book is written with both sea and land people in mind. I hope it will reinforce the sense of community among the users of the sea by linking their involvement as individuals to the broader horizons of mutually compatible ocean use, constructive conflict resolution, and the national interest. I hope it will provide members of the nonocean community with some insight into the special conditions sea-going people encounter as they go about their lives and work and as a result with reasons for respecting and preserving at least some of the special points of view deriving from these conditions."

This writer urges readers to run out and buy this book for Chapter 9 alone, if for no other reason. "Games Planners Play," subtitled "The Sea and Defense: Getting Out of the Nuclear Weapons Trap," is a subject that has not been addressed by many marine policymakers but is one that bears close scrutiny and open debate. In the author's words: "By far the most portentous, controversial, and misunderstood use of the sea for military purposes is in connection with the mission of nuclear war deterrence." Brooks' thesis is that "the seaborne component of strategic nuclear weapons is emerging as of almost transcendent importance in efforts to avoid that ultimate catastrophe, all-out nuclear war, that our generation is the first to face—and one way or another may be the last." The chapter outlines how the sea is used for defense, the "science of war," how we as a nation fell into the nuclear trap, and takes a look at the possible ways out.

In the words of the author, "the genie is out of the bottle." He argues, quoting Jonathan Schell (author of *The Fate of the Earth*), that "deterrence theory, however flawed, does offer the hope of certain benefits, the main one being a degree of 'stability.'" Brooks also sites M. S. Blackett, British Nobel laureate in physics: "I think we should act as if atomic and hydrogen bombs have abolished total war and redirect our efforts on working out how few atomic bombs and their carriers are required to keep it abolished. In the next few years I see the problem not as how many atomic bombs we can afford but as how few we need."

"This number will shrink," Brooks concludes, "just to the extent military planners on both sides focus on systems whose survivability depends on their freedom from preemption rather than on their numbers. In this context, land-based systems are for all intents obsolete. The best advice for those engaged in deciding where and how to deploy the residual weapons for attaining a stable stand off is just what it has been for twenty years and more: look to the sea!" This is a thought-provoking book, and I highly recommend it.

Paul R. Ryan

***Folklore and the Sea* By Horace Beck. 1983. Stephen Greene Press, Brattleboro, Vermont. 463 pp. +xvii. $11.95.**

Although this is certainly a scholarly work, readers needn't be scholars of folklore to enjoy it. Because of the nature of the subject matter, a thorough discussion draws together the history and sociology of sea-going peoples, as well as the practical science involved in traveling across the oceans. The author's straightforward prose and thoughtful treatment of his subject leads one through the book (which is rather thick) with ease.

Folklore encompasses the traditional beliefs, practices, legends, and tales of the common people, transmitted orally. According to Beck, folklore survives because in some way it is functional. This book is a collection, description, and analysis of the traditions and legends of people who live by the sea, chiefly in the British Isles and North America; in it Beck makes the functions of many items of folk knowledge quite logical and clear.

The sequence of chapters follows a design beginning with the lore and traditions concerning items of obvious practical significance and proceeding through to subjects whose nature is increasingly derived from, or embellished by, imagination and creativity. Shipbuilding first, for without ships there would be no sea-farer, only a shore dweller. Also discussed are language, weather lore, and navigation. Mid-point in the book are chapters on art and songs. Songs of the sea, now sung primarily for pleasure, once served as aids to work (chanteys) or for entertainment during idle times at sea (fo'c'sle songs). Beck includes the tunes and words of several little-known songs, and explains their significance. The final chapters delve into what many will immediately recognize as the realm of folklore: mermaids, superstition, legends, spectre ships, and more. Many tales are related verbatim as told to Beck by his sources, and others are paraphrased for adaptation to the printed page.

For the veteran and continuing afficionado of sea-faring literature, this book clarifies many misconceptions about terminology and practices at sea. The chapter on language is particularly helpful in this respect—my foggy mental visions of what was being described in *Two Years Before the Mast* could have been much clearer if only I'd read this book first. Otherwise, it's an interesting and readable compilation of folk knowledge, a part of our heritage that will intrigue anyone drawn by the continuing mystery and romance of the sea.

Elizabeth Miller

COMMUNITY INPUT SOUGHT

The Board on Ocean Science and Policy of the National Academy of Sciences/National Research Council is seeking community input for a report **on future trends and new opportunities in Ocean Science and Policy to the year 2000.**

Information concerning the needs and opportunities in the field as broadly defined, ranging from augmentation of existing activities to new facilities to new ideas just on the horizon, is sought. In its first stage, the study will consist of a series of reports focused on the following areas to be put together by the person or persons indicated:

Dr. John H. Steele, co-chairman, Oceans 2000
Woods Hole Oceanographic Institution
Woods Hole, MA. 02543 617/548-1959

Dr. Brian J. Rothschild, co-chairman, Oceans 2000:
Chairman, Fisheries
Center for Environment and Estuarine Studies
University of Maryland
Box 38
Solomons, MD. 20688 301/326-4281

Dr. D. James Baker, Jr
Co-chairman, Physics
President
Joint Oceanographic Institution, Inc.
2100 Pennsylvania Avenue, NW
Washington, D.C. 20037 202/331-9438

Dr. Charles L. Drake
Co-chairman, Geology and Geophysics
Department of Earth Sciences
Fairchild Building
Dartmouth College
Hanover, NH. 03755 603/646-3338

Dr. Edward D. Goldberg
Co-chairman, Waste Disposal
Geological Research Division, A-020
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA. 92093 619/452-2407

Dr. G. Ross Heath
Chairman Minerals
Dean, School of Oceanography
Oregon State University
Corvallis, OR. 97331 503/754-4763

Dr. Judith T. Kildow
Chairman Policy Science and Law
Assoc. Professor
Dept. of Ocean Engineering
MIT
Cambridge, MA. 02139 617/253-5310

Dr. James J. McCarthy
Chairman, Biology
Director, Museum of Comparative Zoology
Agassiz Museum
Harvard University
Cambridge, MA. 02138 617/495-2330

Dr. Roger Revelle
Chairman, Weather/Climate
Prof. of Science and Public Policy
Humanities Library Building, B-007
University of California, San Diego
La Jolla, CA. 92093 619/452-4849

Dr. Robert M. Solow
Chairman, Economics and Business
Institute Professor of Economics
E-52-383b
MIT
Cambridge, MA. 02139 617/227-4436

Dr. Karl K. Turekian
Chairman, Chemistry
Dept. of Geology/Geophysics
Yale University
New Haven, CT. 06520 203/436-0377

The persons listed above are now gathering information from a wide variety of sources. Individual reports will be discussed at a meeting of the Board in August and therefore we would appreciate receiving relevant information as soon as possible. After the first stage, the study will focus on themes that link the somewhat arbitrarily defined disciplinary areas. Ideas and suggestions about linking themes also are welcome.

Please send your ideas and comments to the appropriate person listed above or to Dr. Nancy Maynard, Executive Secretary, Board on Ocean Science and Policy, 2101 Constitution Avenue, Washington, D.C. 20410 202/334-2714.

Dr. James Baker,
Acting Chairman,
Board on Ocean Science and Policy

Books Received

Aquaculture

***Fish Farming Research* by E. W. Shell. 1983. Alabama Agricultural Experiment Station, Auburn University, Ala. 108 pp. + ix. $4.00.**

Aquaculture production is increasing rapidly, and experimentation is needed to gain new information for fish farming. This book is a compilation of information on the application of the scientific method to fish-farming research, with emphasis on the conduct of research on the production of fish in earthen ponds and identifying and solving farmers' problems. The chapters include administration of research, planning effective research, problems in fish-production experiments, and evaluating experiments.

Biology

***Animals as Navigators* by E. W. Anderson. 1983. Van Nostrand Reinhold, New York, N.Y. 207 pp. $19.50.**

In the animal world, navigation is used to search for food and mates. Animals use sensory navigational instruments to formulate courses based on the sun's movement, Earth's lines of magnetism, sonar echos, and other natural phenomena. The author of this book, an expert on human navigation, surveys our knowledge of animal navigation: animals' senses and the methods they employ to home in on quarry or travel across the globe. The discussions are drawn from the results of zoological research and comparisons to human marine and aerial navigation.

***The Return of the Sea Eagle* by John A. Love. 1983. Cambridge University Press, New York, N.Y. 227 pp. + xiii. $29.95.**

The white-tailed sea eagle (*Haliaeetus albicilla*) is a bird of prey once not uncommon on the British Isles. In this century, however, trapping, poisoning, shooting, and egg-collecting have taken their toll, and the sea eagle all but disappeared. Conservationists are trying to reintroduce the sea eagle to Britain's shores, and the purpose of this book is to provide background information on the species for wildlife biologists and other interested parties. The author describes the distribution, breeding, and food habits of the bird, traces its demise in Britain, and considers conservation measures undertaken in Europe. The final chapters are devoted to the reintroduction scheme on the Isle of Rum in the Inner Hebrides. The biology and survival of this bird and its relatives, such as the American bald eagle, are considered on a world scale.

***Studies in the History of Biology, Volume 7,* William Coleman and Camille Limoges, eds. 1984. The Johns Hopkins University Press, Baltimore, Md. 145 pp. $20.00**

There are three papers in this volume, the last of the series. In "Buffon, Organic Alterations, and Man," J. H. Eddy, Jr., writes about Georges-Louis Leclerc, comte de Buffon (1707–1788). He discusses Buffon's explanation of human racial diversity within the context of the theoretical structure Buffon created to explain living nature. The second paper, by L. S. Jacyna, is "Principles of General Physiology: The Comparative Dimension of British neuroscience in the 1830s and 1840s." The author wishes to portray a neglected source of change in concepts of the neurosystem during the period and to show how adherence to the biological approach to neurology was implicated in many theoretical commitments and practical concerns. The third paper in this volume, "Preparing for Darwin: Conchology and Natural Theology in Anglo-American Natural History," by Neal C. Gillespie, is about the development in one branch of natural history of a group of ideas that prepared working naturalists for a naturalistic explanation of new species—evolution.

***A Comparative Atlas of Zooplankton: Biological Patterns in the Oceans* by S. Van Der Spoel and R. P. Heyman. 1983. Springer-Verlag, New York, N.Y. 186 pp. $49.50.**

The topic of this book is large-scale biogeographic trends in marine biota. For fundamental comparisons between zoogeographic problems and ecological, oceanographic, and taxonomic ones, the major types of distributions are examined in order to elucidate forces affecting marine biogeography. There are chapters on the taxon and its range, types of distribution, verticle distribution, general trends (historical, for instance), the dualistic nature of plankton, with regional and alphabetical indices to the distribution maps. There are 143 maps and 50 figures.

***Marine Ecology: A Comprehensive, Integrated Treatise on Life in Oceans and Coastal Waters. Volume V, Part 2: Ocean Management, Ecosystems and Organic Resources.* Otto Kinne, ed. 1983. John Wiley & Sons, New York, N.Y. 447 pp. + xv. $84.95.**

Part 2 of *Marine Ecology* concentrates on interacting and interdependent biotic and abiotic components of ecosystems. After reviewing the ecosystems of open-sea areas, coasts, and estuaries, Part 2 considers the significance of these areas' resources for supporting human life.

***Vibrios in the Environment*, Rita R. Colwell, ed. 1984. John Wiley & Sons, New York, N.Y. 634 pp. + ix. $45.00.**

During the last 10 years, research on the Vibrionaceae has greatly added to information available on the ecology and distribution of vibrios. This book contains a series of papers, on epidemiology and serology; pathogenics; molecular genetic aspects of vibrios; methods for isolation, characterization, and identification; ecology; and implications for the seafood industry. Pathogenic and nonpathogenic vibrios are shown to have widespread distribution in the aquatic environment.

***Marine Biodeterioration: An Interdisciplinary Study*, J. D. Costlow and R. C. Tipper, eds. 1984. Naval Institute Press, Annapolis, Md. 384 pp. + xxi. $29.95.**

This volume comes from a symposium on marine biodeterioration, held in April, 1981, and sponsored by the Office of Naval Research. It covers basic and applied research in six major topic areas. Each topic is given a comprehensive overview, followed by current technical papers. The major topics are: marine wood-boring organisms; microfouling; fouling larvae and settlement; macrofouling; coatings and technology; and fouling-control technology. An appendix supplies information on the performance of selected U.S. Navy antifouling coatings.

Environment

***Coastal Design: A Guide for Builders, Planners, and Home Owners* by Orrin H. Pilkey, Sr., Walter D. Pilkey, Orrin K. Pilkey, Jr., and William J. Neal. 1983. Van Nostrand Reinhold, New York, N.Y. 226 pp. $25.50.**

Because of the historically negative effects of coastal development, beaches are getting narrower and narrower and many are already destroyed. In this book, a team of geologists and civil engineers suggests ways in which we can build and live in harmony with our coasts, so that we do not destroy them and storms do not destroy us. It is a practical book with information about such issues as siting and constructing beach houses, assessing older coastal buildings, planning a safe beachfront high-rise building, as well as what to expect from, and how to prepare for, storms.

***Effluent Transport and Diffusion Models for the Coastal Zone*; part of the series, Lecture Notes on Coastal and Estuarine Studies; by D. C. L. Lam, C. R. Murthy, and R. B. Simpson. 1984. Springer-Verlag, New York, N.Y. 168 pp. $17.00.**

This monograph summarizes modeling capability of simulating the transport and dispersion of effluents in the coastal zones of lakes and oceans. Coastal zones are complex, subject to coastal-boundary layer effects, turbulent eddies, and circulatory patterns unique to local bathymetry and shoreline configuration. This book uses theoretical analyses and numerical examples as background for investigating water-quality problems and other practical, multidisciplinary coastal zone concerns. After the introduction, there are six chapters on topics including parameterization of advection and diffusion processes and marching-technique solutions for straight-plume equations.

***Sandy Beaches as Ecosystems*, part of the Series, Developments in Hydrobiology, Anton McLachlan and Theuns Erasmus, eds. 1983. Dr. W. Junk BV Publishers, The Hague, the Netherlands. 757 pp. $120.00 (U.S.); Dutch guilders 300,00.**

This book is based on the proceedings of a symposium of five sessions covering physical and chemical aspects, ecology, ecophysiology and management topics relating to sandy beaches. Each section of the book covers a session of the symposium, and includes a review paper, several plenary papers, and a report on a workshop/discussion. The symposium, held in Port Elizabeth, South Africa, 17 to 21 January 1983, was meant to bring together all scientists studying sandy beaches, to encourage a holistic systems approach and interdisciplinary interaction, and to review the state of knowledge of sandy beaches and develop guidelines for research.

Field Guides

***The Audubon Society Field Guide to North American Fishes, Whales and Dolphins* by Herbert T. Boschung, Jr., James D. Williams, Daniel W. Gotshall, David K. Caldwell, and Melba C. Caldwell. Visual key by Carol Nehring and Jordan Verner. 1983. Alfred A. Knopf, New York, N.Y. 850 pp. $12.50.**

This book contains 585 identification photographs of North America's most common fresh- and salt-water fishes; it also has 30 photographs and 45 paintings of whales and dolphins known to occur in North American waters north of Mexico. The introduction briefly defines fish and describes the parts of a fish; it includes line diagrams helpful for identifying and measuring fish and cetaceans and contains other information pertinent to the organization of the book. A short list of examples explains "how to use this guide." The color plates follow.

Finally, the keys to families of fishes and the appendices make up the bulk of the text.

***Life in the Chesapeake Bay* by Alice Jane Lippson and Robert L. Lippson; illustrations by Alice Jane Lippson. 1984. Johns Hopkins University Press, Baltimore, Md. 230 pp. $12.95.**

Written for curious beachcombers and serious students of estuarine ecology, this book covers primarily the marine animal life of the Chesapeake, with mention of some commonly encountered seaweeds and plants. This includes discussion and illustration of 35 species of plants and more than 20 invertebrate and 100 fish species. For usefulness in the field, it is organized by habitat: sand beaches; intertidal flats; piers, rocks, and jetties; shallow waters; seagrass meadows and weed beds; marshes; oyster bars; and deeper, open waters. Finally, the authors include a glossary, species and distribution lists, and references.

***Red Sea Reef Fishes* by John E. Randall. 1983. IMMEL Publishing, London, England. 192 pp. £19–50; and, *The Diver's Guide to Red Sea Reef Fishes* by John E. Randall. 1982. IMMEL Publishing, London, England. 96 pp. £11–50.**

Two books on the coral reef fishes of the Red Rea—the first, a large volume for at-home study; the second, a waterproof edition meant to be brought along on underwater excursions. *Red Sea Reef Fishes* includes four pages on the morphology of fishes and the basic habitats found in the Red Sea. Species accounts make up the bulk of the book. Arranged by family, each account gives general family characteristics and includes separate information on commonly encountered species. Altogether, 57 families including 325 species are discussed. The species descriptions contain major morphological features, important behavioral or ecological notes, maximum length and other statistics, geographical region of occurrence, and information on poisonous or dangerous aspects of the animal. Each species is illustrated with a color photograph of a side view of the animal, while each family is illustrated with an underwater, *in situ* photograph showing a member of the family. *The Diver's Guide* includes the same "posed" photographs as the larger volume, for the best possible identification underwater. It has a brief introduction outlining how to use the book, and an index.

***Under Alaskan Seas: The Shallow Water Marine Invertebrates* by Lou and Nancy Barr; Photographs by Lou Barr. 1983. Alaska Northwest Publishing Company, Anchorage, Alas. 208 pp. + xiv. $14.95.**

Presenting a sample of Alaska's shallow-water marine invertebrates, illustrated in their natural habitats and describing their appearances and ecology. The invertebrates are grouped according to their scientific classification. The book begins with a 64-page section of color photos, each labeled with the organism's genus and species, information on where the picture was taken, and a large numeral indicating where to find the discussion of that species in the text.

***Seashells of the Arabian Gulf* by Kathleen R. Smythe. 1982. George Allen & Unwin, Boston, Mass. 123 pp. $25.00.**

Part of the Natural History of the Arabian Gulf series, this book was created to help collectors identify their specimens from the Arabian Gulf. In the varied habitats of the Gulf (extending northwest from the Strait of Hormuz to Kuwait and Iraq) are found many species of molluscs. Along the coastline are long stretches of sandy beach, home for bivalves and burrowing gastropods; rocky areas and cliffs inhabited by murexes, thaids and limpets; sheltered bays and creeks; offshore deep lagoons; and flat patches of limestone and shell conglomerate, each occupied by specialized fauna. Smythe introduces readers to the history of shell collecting and classification in the Arabian Gulf region and discusses nomenclature, collecting techniques and care of specimens, and identification. The major portion of the book is devoted to species descriptions, with color and black-and-white photographic plates. Also included are a glossary of terms, a bibliography, and an index to scientific names.

Marine Policy

***Frozen Stakes: The Future of Antarctic Minerals* by Barbara Mitchell. 1983. International Institute for Environment and Development, Washington, D.C. 135 pp. + iii. $3.80.**

Based on a report by the author for the U.S. National Oceanic and Atmospheric Administration and the EPA, this book evaluates possible arrangements for the management of Antarctic minerals that would be acceptable to the parties involved and at the same time ensure sound management of Antarctica. After the introduction, the chapters examine the Antarctic resource base and the problems with extracting resources from Antarctica; review environmental implications; assess the political background of the current efforts to negotiate an Antarctic minerals regime; detail the requirements of an acceptable regime; and summarize the findings of this study.

***Waste Disposal in the Oceans: Minimizing Impact, Maximizing Benefits,* Dorothy F. Soule and Don Walsh, eds. 1983. Westview Press, Boulder, Col. 296 pp. + xv. $25.00.**

This book is a result of a 1982 symposium, "Ocean Disposal in the

1980s," sponsored by the Southern California Academy of Sciences and organized to re-evaluate ocean disposal as an alternative for waste management. It suggests the examination of situations on a case-by-case or regional basis rather than a national one. Participants were all scientists, from public agencies, academe, and research institutions. The sixteen papers in the volume examine some of the major uses and effects of ocean disposal, methods for evaluating effects, and efforts at developing management strategies for ocean waste disposal.

Physical Sciences

***Physical Oceanography of Coastal Waters* by K. F. Bowden. 1983. Halsted Press, John Wiley & Sons, New York, N.Y. 302 pp. $69.95.**

Based on lectures given by the author, this book uses an approach combining theoretical and observational techniques; it is meant for undergraduate and graduate students of oceanography and ocean engineering. Coastal waters are defined by the author as the waters on the continental shelf and in adjacent semi-enclosed seas (but not estuaries). Their distinctive features, physical characteristics, and practical significance are outlined by the author; the chapters are on tides and current, surface waves, wind-driven currents, coastal upwelling, density currents and salinity distribution, temperature and thermocline, mixing, and interaction between coastal and oceanic circulation.

***Introductory Dynamical Oceanography*, 2nd Edition, by Stephen Pond and George L. Pickard. 1983. Pergamon Press, New York, N.Y. 329 pp. + xx. $12.50.**

Meant for seniors in college and beginning graduate students, this textbook introduces the basic objectives and procedures, as well as some of the limitations, of dynamical oceanography, and relates the field to observational (descriptive) oceanography. The dynamical approach uses physical laws to try to find mathematical relationships between the forces acting on ocean waters and their consequent motions. Therefore, mathematics must be used; a course in calculus is assumed.

General

***The Underwater Photographer's Handbook* by Peter Rowlands. 1983. Van Nostrand Reinhold, New York, N.Y. 240 pp. $20.50.**

Today's array of underwater camera equipment has made underwater photography a reasonable possibility for everyone, from the beginning snorkler to experienced Scuba divers. Photography beneath the sea requires a certain amount of knowledge; this book, illustrated with plenty of color photographs for inspiration and drawings for instruction, covers the physics of light underwater, equipment selection, photography using available and artificial light, underwater subjects, dive sites, and maintenance of equipment. A glossary of technical terms and a list of useful addresses are included.

***Women in Science: Portraits from a World in Transition* by Vivian Gornick. 1983. Simon and Schuster, New York, N.Y. 172 pp. $15.95.**

To try to determine what it is like to be a woman in science in America today, the author interviewed more than 100 women scientists. Approaching them with the question, "What has it been like for you?" Gornick found her expectations about these women—that they would be few, in subordinate positions, with subdued personalities and conservative philosophies—were not to be met. In fact, women scientists are resourceful and varied, impelled by inner determination to contribute to scientific experience. Their identities and those of their employers are disguised in the text.

***Stove by a Whale: Owen Chase and the Essex* by Thomas Farel Heffernan. 1981. Wesleyan University Press, Middletown, Conn. 274 pp. + xiii. $25.00.**

In November, 1820, the whaleship *Essex* was rammed and sunk by a whale. The survivors of this amazing episode—the first recorded sinking of a ship by a whale—subsequently lived through 3 months at sea in an open whaleboat, eating crusts of bread saved from their ship and the bodies of their dead companions. After their rescue, first mate Owen Chase wrote down the story. Twenty years later the tale was read by another young seaman named Herman Melville. In this book, Heffernan analyzes the history of the *Essex* and its crew, and its role in the creation of *Moby Dick*.

***Rivers of the World* by Eberhard Czaya. 1984. Van Nostrand Reinhold, New York, N.Y. 246 pp. $15.50.**

From tiny brooks to thundering waterways, rivers are essential to life on the continents. Shaping the landscapes they cross, and at the same time reflecting the climate and geology of a region, rivers are critical components of Earth's hydrological cycle, the drainage channels for water on the planet's surface. This book examines rivers of all kinds, taking examples from the world over. The author looks at how rivers fit into the hydrological cycle and their major characteristics; how rivers shape valleys; cataclysmic events in river history; waterfalls and rapids; fluvial lakes; inland drainage; lowland rivers and mouths; and human interactions with rivers, especially efforts to irrigate or effect flood control in a region.

***The Severn Bore* by Fred Rowbotham. Third Edition, 1983. David & Charles, North Pomfret, Vt. 104 pp. $12.95.**

The former district engineer of the Severn River Board (Gloucestershire, England) explains the origin, traces the course, and details when and where to view the Severn River bore, and how to ride it. Black-and-white photographs are provided to illustrate the tidal wave as it pushes upstream. The author describes his experiences with the bore, and includes lore of the river and a summary of facts and figures concerning the bore.

***A Guide to the Queen Charlotte Islands* by Neil G. Carey. 1983. Alaska Northwest Publishing Company, Anchorage, Alas. 82 pp. $3.95 (U.S.); $4.95 (Canada).**

Approximately 60 miles across the Hecate Strait from the coast of British Columbia, the Queen Charlotte Islands lie on the edge of the continental shelf. Tourists can visit by airplane or take a 34-hour ferry trip through part of the Inside Passage to Alaska. This guide has travel information for anyone wishing to visit the Charlottes, with their tree-covered coastal mountains and deep, protected bays. It provides practical knowledge on such topics as weather and what to wear, a large map of the islands with a key to abandoned Indian settlements, and a recreational directory to transportation, places to stay, sports, shops and other useful travel information sources.

***The Sociology of Production in Rural Malay Society* by Connor Bailey. 1983. Oxford University Press, Kuala Lumpur and New York, N.Y. 225 pp. + xv. $32.50.**

The author examines three types of Malay society—a rice-farming community, a rubber-tapping settlement, and a fishing village—in addressing the question, How is society affected by its predominant modes of production? This study is based on five years of living and working in rural Malay villages. By using a comparative approach, the author was able to identify social and cultural differences among these Malay societies; the conclusions drawn here may interest not only students of sociology, but planners and administrators of rural-development and social-welfare projects in the field.

***The Mediterranean was a Desert: A Voyage of the Glomar Challenger* by Kenneth J. Hsu. 1983. Princeton University Press, Princeton, N.J. 197 pp. + xv. $17.95.**

A firsthand account of the 1970 voyage of the *Glomar Challenger*, Leg 13, the results of which led to the hypothesis that about five and a half million years ago the Mediterranean Sea was a desert. The author was co-chief scientist for the eight-week cruise. He wrote the first draft of this book in the driller's shack of the vessel, recording the joys, frustrations, and other emotions of the scientists on the mission.

***Principles of Aquatic Chemistry* by Francois M. M. Morel. 1983. John Wiley & Sons, New York, N.Y. 446 pp. + ix. $49.95.**

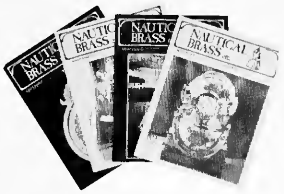
Aquatic chemistry links the cycles of elements at Earth's surface with the workings of biological systems. This is a text for beginning graduate and advanced undergraduate students, requiring background knowledge only of general college chemistry. First, there are three introductory chapters, dealing with conservation of mass, thermodynamics and kinetics, and chemical-equilibrium equations. Following are five chapters that develop the subject of aquatic chemistry in particular: alkalinity and pH; solid dissolution and precipitation; complexation; oxidation-reduction; and reactions on solid surfaces. Each chapter ends with a short treatment of more advanced topics.

***The Legal Regime of Fisheries in the Caribbean Region* by W. R. Edeson and J. F. Pulvenis. 1983. Part of the series, Lecture Notes on Coastal and Estuarine Studies. Springer-Verlag, New York, N.Y. 204 pp. + x. $16.50.**

Focusing on the legislative, treaty, and administrative regimes of fisheries management and conservation in the Western Central Atlantic (Caribbean) region, this book began in a seminar organized by the Food and Agriculture Organization of the U.N. It has five parts following the introduction: international law background, national legislation relating to fisheries, bilateral and joint venture agreements, fisheries administration, and conclusions. The authors visited 27 countries in the region to gather information, and used public sources to obtain information from those countries not visited. In their concluding remarks, the authors propose areas for consideration when countries review their legislation on fisheries and the Law of the Sea.

Geology

***Physical Geology: Principles and Perspectives,* Second Edition, by Edward A. Hay and A. Lee McAlester. 1984. Prentice-Hall, Englewood Cliffs, N.J. 463 pp. + xii. $25.95.**

Written for introductory physical geology students, to be used in conjunction with lectures and problem-solving activities, this book presents material on minerals, rocks, geologic time, earth structure, plate

tectonics, and land sculpture. Following a discussion of geology in relation to other sciences and other disciplines is a model for modern geology based on plate tectonics. Then, a chapter on "building blocks"—minerals and matter—and two chapters on geological processes; one explaining the geologic time scale and its elucidation; and six chapters on various geologic processes, such as weathering, glaciers, and seismology. Penultimately, the authors discuss geology in relation to human concerns, such as water and mineral resources and engineering; finally, there is a chapter on extraterrestrial rocks. A glossary defines words important to the text.

***The History of the Earth's Crust* by Don L. Eicher, A. Lee McAlester and Marcia L. Rottman. Prentice-Hall, Englewood Cliffs, N.J. 198 pp. $18.95.**

A chronological account of the changing geography and environments of Earth's outermost layer of rock, the crust, from our planet's beginning at the birth of the solar system almost 5 billion years ago to the rise of modern humanity during the last few hundred-thousand years. Eicher explains how geologists study Earth's crust, especially the sedimentary rocks, to gain insight into Earth's history and work out sequences of events; he explains radiometric dating and its contribution to the study of Earth's history. A chapter is devoted to the origin of the solar system, this planet, the oceans, and the atmosphere, the beginnings of life, and the moon. The final three chapters cover segments of geologic history: Precambrian Earth; Paleozoic Earth; Mesozoic Earth; and Cenozoic Earth.

***Volcanoes in the Sea: The Geology of Hawaii,* Second Edition, by Gordon A. MacDonald, Agatin T. Abbott, and Frank L. Peterson. 1983. University of Hawaii Press, Honolulu, Hawaii. 517 pp. + x. $29.95.**

Intended for those with little or no experience in geology, this book tries to answer (with the best available knowledge) the questions: How were the great Hawaiian Mountains formed? and, What processes shape the ridges and valleys of today? Anyone who has visited these islands will be curious about how they could have formed—and the color pictures in the center of this book will help those who have not been there to visualize the drama and beauty. Covered in the book are volcanic activity; historic eruptions; the work of wind, water, and ice; plate tectonics; and more, including chapters on the regional geology of each of the major Hawaiian islands. There are many black-and-white photos and explanatory diagrams, and references to suggested readings for those wishing to delve further into the subject.

***The Making of a Continent* by Ron Redfern; photographs by Ron Redfern; illustrations by Gary Hincks. 1983. Times Books, New York, N.Y. 242 pp. + ix. $27.95.**

The science of plate tectonics reveals Earth as a dynamic planet, with constant transformations of the crust. These changes subsequently influence Earth's natural and human history. In this book, Redfern concentrates on the North American plate and its evolution. Using a special scheme of illustration, he emphasizes the interrelationships of the North American plate and the Eurasian and African plates, with the Mid-Atlantic Ridge separating them. There are numerous color photographs and illustrations of the geology of this continent: building and destruction of mountains; rising and falling seas; earthquakes, volcanics, and drastic erosions; evolution of landscapes with concurrent adaptation or extinction of life forms; and the adaptation of human life to the North American plate.

***Developments and Interactions of the Precambrian Atmosphere, Lithosphere and Biosphere,* B. Nagy, R. Weber, J. C. Guerrero, and M. Schidlowski, eds. 1983. Part 7 of the Series, Developments in Precambrian Geology. Elsevier Science Publishing, New York, N.Y. 475 pp. + xii. $89.25 (U.S. and Canada); Dfl. 210.00 (Rest of World).**

Articles from a joint meeting of International Geological Correlation Program Projects 157 and 160, held in January 1982 in Mexico City. The central point of the discussions was the problem of oxygen partial pressures, especially in the early history of Earth. About 40 specialists in astrophysics, microbiology, oceanography, and geology, from eleven countries, contributed the 22 papers, on such topics as primitive Earth environments, the emergence of Metazoa, and "stratiform copper deposits and interactions with coexisting atmospheres, hydrospheres, biospheres and lithospheres." No general consensus was reached by the assembly, as the workshop was structured to encourage creative conflict and to allow the presentation of unconventional ideas.

***Glacial-Marine Sedimentation,* Bruce F. Molnia, ed. 1983. Plenum Press, New York, N.Y. 844 pp. + ix. $65.00.**

A volume of 18 papers describing the glacial-marine sedimentary environment in a variety of temporal and spacial settings, this book is meant to show the differences among glacial-marine environments in various settings and their resulting glacial-marine deposits and facies. Three papers describing ancient glacial-marine environments are included. The contents are divided into three sections: glacial-marine sediment in space and time; quaternary glacial-marine sedimentation (with 14 papers, on Alaska, Antarctica, Arctic Ocean, Kane Basin, Baffin Island, Puget Lowlands, and North Atlantic Ocean); and older glacial-marine sedimentation (neogene, paleozoic, and precambrian). The book is indexed by author, subject, and geographical area.

***The Coast of Puget Sound: Its Processes and Development* by John Downing. 1983. Puget Sound Books, Washington Sea Grant, Seattle, Wash. 126 pp. + xiii. $8.95.**

Including information for owners of shore property on Puget Sound, data for engineers unfamiliar with the problems of shoreline development there, information for planners wishing to review coastal processes, and an introduction to the coastal zone for students in earth sciences, this book is directed toward a wide readership. It has chapters on coastal-zone origins, river deltas, waves and currents, sediment transport and beaches, wave climate, coastal hazards, and progress and problems in coastal development. The examples are exclusively from the shores of Puget Sound, and as such the book provides a very detailed study of the region. A glossary and bibliography are provided to help with terminology and further research.

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- **General Issue**, Vol. 21:3, Summer 1978—The lead article here looks at the future of deep-ocean drilling. Another piece, heavily illustrated with sharply focused micrographs, describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.

- **Marine Mammals**, Vol. 21:2, Spring 1978—Attitudes toward marine mammals are changing worldwide.

- **The Deep Sea**, Vol. 21:1, Winter 1978—Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss.

- **General Issue**, Vol. 20:3, Summer 1977—The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.

- **Sound in the Sea**, Vol. 20:2, Spring 1977—The use of acoustics in navigation and oceanography.

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Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International; 300 North Zeeb Road; Ann Arbor, MI 48106.

- **Industry and the Oceans**, Vol. 27:1, Spring, 1984—Positive uses of the oceans, including genetic engineering, salmon ranching and striped bass raised in the effluent of a power plant, and products from kelp, horseshoe crab blood, and fisheries waste. Also included, a new article on marine science in China, and a history of the Naples Zoological Station.
- **Oceanography in China**, Vol. 26:4, Winter 1983/84—Comprehensive overview of the history of marine studies in China, including present U.S.-China collaboration, tectonic evolution, aquaculture, pollution studies, seaweed-distribution analysis, the changing role of the Yangtze River, and the administrative structure of oceanographic programs.
- **Offshore Oil & Gas**, Vol. 26:3, Fall 1983—Historical accounts of exploration methods and techniques, highlighting development of seismic theory, deep-sea capability, estimation models, as well as environmental concerns, domestic energy alternatives, and natural petroleum seeps.
- **General Issue**, Vol. 26:2, Summer 1983—Articles cover the effects of carbon dioxide buildup on the oceans, the use of mussels in assessments of chemical pollution, a study of warm-core rings, neurobiological research that relies on marine models, the marginal ice zone experiment, and career opportunities in oceanography. A number of "concerns" pieces on the U.S. Exclusive Economic Zone round out the issue.
- **Seabirds and Shorebirds**, Vol. 26:1, Spring 1983—This issue contains articles on the feeding methods, breeding habits, migration, and conservation of marine birds.
- **Marine Policy for the 1980s and Beyond**, Vol. 25:4, Winter 1982/83—The articles focus on the problems of managing fisheries, the controversy over dumping wastes in the oceans, the lack of coordination in United States Arctic research and development, military-sponsored oceanographic research, the Law of the Sea, and the potential for more international cooperation in oceanographic research. Each author makes recommendations for the future.
- **Deep Ocean Mining**, Vol. 25:3, Fall 1982—Eight articles discuss the science and politics involved in plans to mine the deep ocean floor.
- **General Issue**, Vol. 25:2, Summer 1982—Contains articles on how Reagan Administration policies will affect coastal resource management, a promising new acoustic technique for measuring ocean processes, ocean hot springs research, planning aquaculture projects in the Third World, public response to a plan to bury high-level radioactive waste in the seabed, and a toxic marine organism that could prove useful in medical research.
- **General Issue**, Vol. 24:2, Summer 1981—A wide variety of subjects is presented here, including the U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.
- **Senses of the Sea**, Vol. 23:3, Fall 1980—A look at the complex sensory systems of marine animals.
- **A Decade of Big Ocean Science**, Vol. 23:1, Spring 1980—As it has in other major branches of research, the team approach has become a powerful force in oceanography.
- **Ocean Energy**, Vol. 22:4, Winter 1979/80—How much new energy can the oceans supply as conventional resources diminish?
- **Ocean/Continent Boundaries**, Vol. 22:3, Fall 1979—Continental margins are being studied for oil and gas prospects as well as for plate tectonics data.
- **General Issue**, Vol. 21:3, Summer 1978—The lead article here looks at the future of deep-ocean drilling. Another piece, heavily illustrated with sharply focused micrographs, describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.
- **Marine Mammals**, Vol. 21:2, Spring 1978—Attitudes toward marine mammals are changing worldwide.
- **The Deep Sea**, Vol. 21:1, Winter 1978—Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss.
- **General Issue**, Vol. 20:3, Summer 1977—The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.
- **Sound in the Sea**, Vol. 20:2, Spring 1977—The use of acoustics in navigation and oceanography.