

PRELIMINARY OBSERVATIONS OF THE 1991-1992 EL NIÑO IN THE CALIFORNIA CURRENT

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ABSTRACT

The successful prediction that an ENSO (El Niño Southern Oscillation) event would occur in the equatorial Pacific during 1991, and the timely and widespread distribution of coastal temperature and sea-level data have increased public interest in understanding how El Niño affects the California Current. The effects of El Niño were apparent in the California Current during late 1991 and early 1992. Sea-surface temperatures (SST) and sea level were elevated, and there was a strong poleward counter-current along the coast. Maximum sea-level anomalies at La Jolla were similar to values observed during the 1982-83 El Niño. Chlorophyll and primary production were low during the period of elevated sea level. The 1991-92 event was relatively short, with elevated sea level lasting about 8 months, and it appeared to end abruptly. There was a rapid change in structure in April-May 1992. Sea level (at least at La Jolla) rapidly decreased; the strong southward flow of the California Current returned; and chlorophyll and primary production increased. This appeared to mark the decline of El Niño. However, SST remained anomalously high over much of the California Current throughout 1992. Observation of the change in structure associated with El Niño may yield insights into the physical processes that enrich this system and the ways in which the system may respond to global change. (A note added in proof indicates that El Niño conditions were again present in the California Current in late 1992 and early 1993, and that it was premature to describe the change in structure which took place in April-May 1992 as the decline of El Niño.)

RESUMEN

El interés público por entender como los eventos tipo "El Niño" afectan a la corriente de California aumentó debido al éxito de la predicción que un evento "El Niño-La Oscilación del Sur" ocurriría en el Pacífico ecuatorial en 1991, y a la ocurrencia oportuna y amplia distribución geográfica de la

temperatura y nivel del mar. Los efectos de El Niño se notaron a finales de 1991 y principios de 1992. Los valores de temperatura superficial y nivel del mar fueron elevados, y hubo una fuerte corriente paralela a la costa hacia el polo. Las máximas anomalías del nivel del mar en La Jolla tuvieron valores similares a las de El Niño 1982-83. Los valores de clorofila y producción primaria fueron bajos durante el período de nivel del mar alto. El evento de 1991-92, con nivel del mar alto durante 8 meses, fué relativamente corto y al parecer finalizó abruptamente. Hubo un cambio rápido de la estructura en Abril-Mayo de 1992. El nivel del mar bajó rápidamente (por lo menos en La Jolla); de nuevo, hubo un flujo intenso de la corriente de California hacia el norte, y además, hubo un incremento de clorofila y producción primaria. Esto parecía haber marcado el final de El Niño. Sin embargo, en una gran porción de la corriente de California, las anomalías de temperatura superficial permanecieron altas durante 1992. Observaciones sobre el cambio de estructura asociado con El Niño podrían ayudar a vislumbrar los procesos físicos que enriquecen el sistema y la manera en que éste pudiera responder al cambio global. (Una nota añadida en capilla indica que las condiciones El Niño se habían presentado de nuevo a finales de 1992 y principios de 1993, y que fué prematuro haber descrito el cambio de estructura que ocurrió en Abril-Mayo 1993 como el fin de El Niño.)

INTRODUCTION

There is considerable public interest in understanding the effects of El Niño in the California Current because of recent successful predictions of the 1991-92 equatorial ENSO event (e.g., on computer bulletin boards); widespread distribution of coastal temperature and sea-level data (e.g., the CoastWatch Program); and hopes that the onset of El Niño would signal the end of drought in California. El Niño events can represent large perturbations in the environmental structure of the California Current (Chelton et al. 1982; Simpson 1983; McGowan 1984).

Although individual events differ, several structural aspects appear characteristic of El Niño in the California Current. Sea-surface temperature (SST) is typically elevated over a broad area (Simpson 1983, 1992). However, not all "warm events" in the California Current are associated with ENSO events (e.g., Fiedler et al. 1986). SST anomalies are associated with a deepening of the mixed layer and thermocline. Sea level, as measured from coastal tide gages (Lyles et al. 1988; Roemmich 1992), rises during El Niño; this elevation is associated, in turn, with a strong poleward countercurrent in the coastal zone (Lynn 1983; Huyer and Smith 1985). Range extensions of, especially, southern warm-water species are observed (Brinton and Reid 1986; Pearcy and Schoener 1987), presumably due to a combination of advection and a changed habitat structure. The deeper thermocline is also reflected in a deeper nutricline (McGowan 1984), apparently reducing the nutrient supply to the euphotic zone. Lower primary production and lower phytoplankton and macrozooplankton biomass values are observed (Chelton et al. 1982; Fiedler 1984; McGowan 1984). The biomass and production of the upper trophic levels may also be affected, and abundance both declines and increases (Stewart et al. 1984; Fiedler et al. 1986).

This report presents preliminary observations of the effects of the 1991-92 El Niño in the California Current and compares these effects to patterns observed during prior events.

METHODS

Time series of data collected at the Scripps Institution of Oceanography (SIO) pier, and plots of property distributions from eight CalCOFI survey cruises conducted during 1991 and 1992 are presented. The sampling plan, analytical methods, and raw data are listed in the data reports of individual cruises (Scripps Institution of Oceanography 1991, 1992a, 1992b). Primary production data are presented in units of $\text{mg C m}^{-2} \text{ half-day}^{-1}$ to allow comparison with data collected by similar methods in the central North Pacific. Cruise mean values of vertically integrated chlorophyll, vertically integrated primary production, and macrozooplankton biomass were calculated as the average of all measurements made on a cruise. There were typically about 75 stations per cruise for chlorophyll and macrozooplankton, and about 12 stations for primary production. Pattern in the seasonally corrected anomalies from long-term mean distributions (e.g., 1916-91 for SIO pier temperature or 1950-92 for

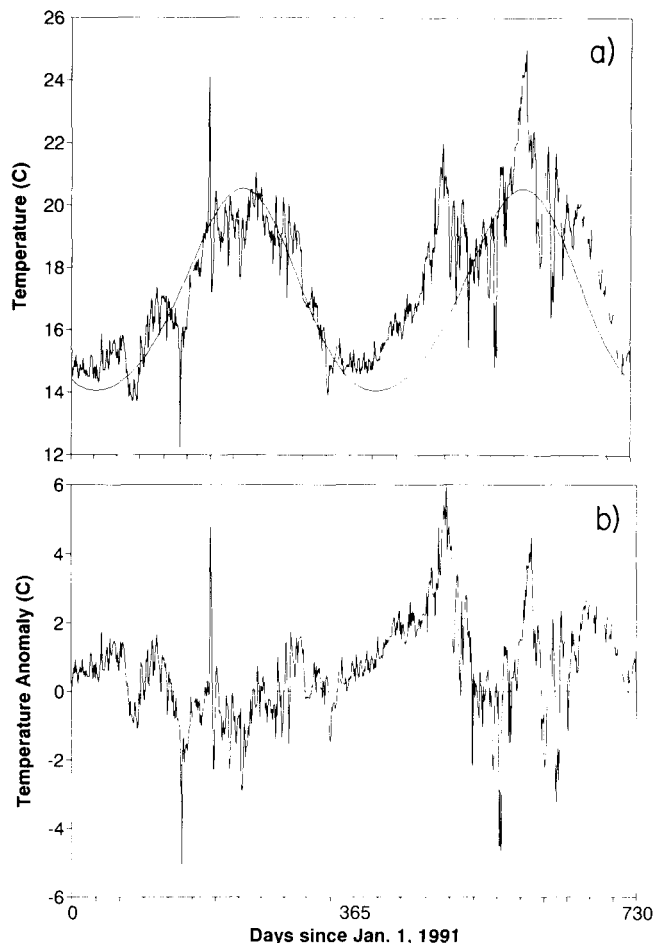


Figure 1. Sea-surface temperature and long-term (1916-91) harmonic mean temperature (a), and temperature anomalies (b) at the SIO pier for 1991 and 1992.

CalCOFI hydrographic data) are shown for several properties.

RESULTS

Extensive regions of positive SST anomalies are commonly considered to be indicators of El Niño. SST at the SIO pier was near the long-term mean throughout 1991 (figure 1). Temperature anomalies at the SIO pier began to increase steadily in January 1992, and they reached a maximum of over 4°C in April. The SST anomalies decreased rapidly in early May; June and July had nearly normal temperatures. Anomalously high temperatures were again measured at the SIO pier in the fall and winter of 1992. Large-scale SST maps, distributed by the Coast-Watch Program, showed anomalously high SST values throughout the California Current for most of 1992 (figure 2). These large-scale warm anomalies persisted until the end of 1992.

Sea-level (tide-gage) data are collected at several stations along the California coast. There has been a

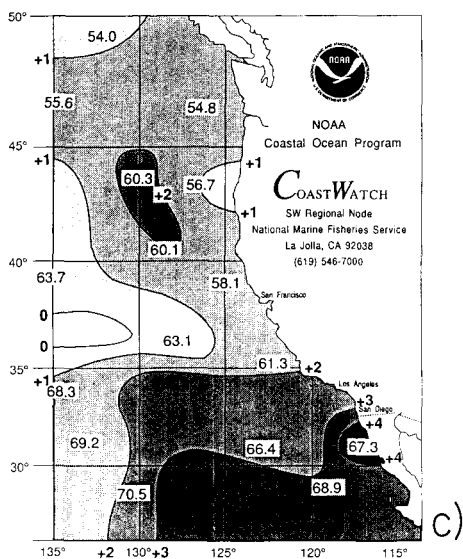
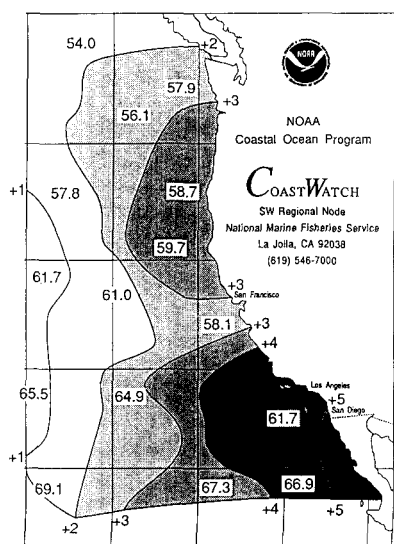
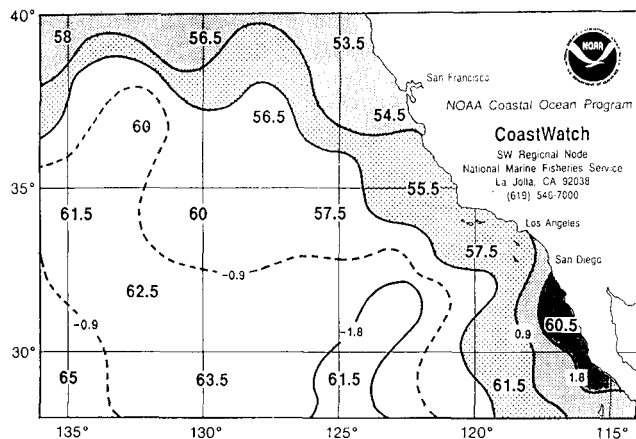


Figure 2. SST (°F) and anomaly field for the California Current during (a) January, (b) June, and (c) November 1992 (distributed by the CoastWatch Program). Note that the contour intervals differ between panels.

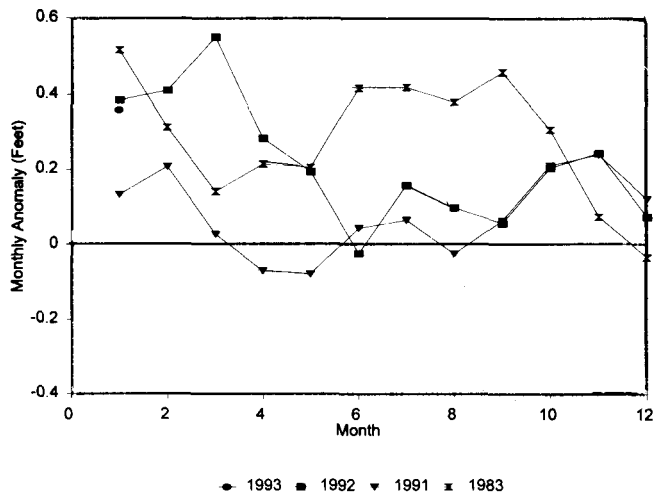


Figure 3. Monthly sea-level anomalies for La Jolla for 1983, 1991, 1992, and January 1993. The anomalies have been corrected for the secular rise in sea level.

secular increase in sea level at La Jolla of about 2.5 mm per year over the last 65 years (Roemmich 1992), and calculations of monthly anomalies from the long-term mean have been corrected for this. Corrected sea level at La Jolla (SIO pier) began to show positive anomalies starting in September 1991 (figure 3). High values persisted until March 1992, when sea level began to decline rapidly. Sea level was near normal from June through September, but anomalously high again in October, November, and December 1992. The maximum sea-level anomalies during 1992 were similar in magnitude to those observed during the 1982-83 El Niño (about 12-18 cm). However, the 1991-92 El Niño event, at least as defined in terms of sea-level anomalies, was much shorter than the 1982-83 event (8 months versus 14 months).

Data from CalCOFI cruises are used to examine pattern in circulation, vertical distributions, and biological structure. The change in structure associated with the onset of El Niño is not well resolved because no CalCOFI cruises were scheduled between March and August 1991, the period immediately preceding the rise in sea level. There was a strong poleward countercurrent in the coastal region and equatorward flow offshore during CalCOFI cruises 9108, 9110, and 9202 (figures 4 and 5). Comparison of the 9202 dynamic height map with the long-term mean dynamic height field (figure 5) shows that the anomalies are greatest in the coastal region and that the change in pattern from the long-term mean represents an increase in the strength and spatial extent of the coastal countercurrent. Poleward flow in the coastal region of northern California was also observed during March 1992 on the

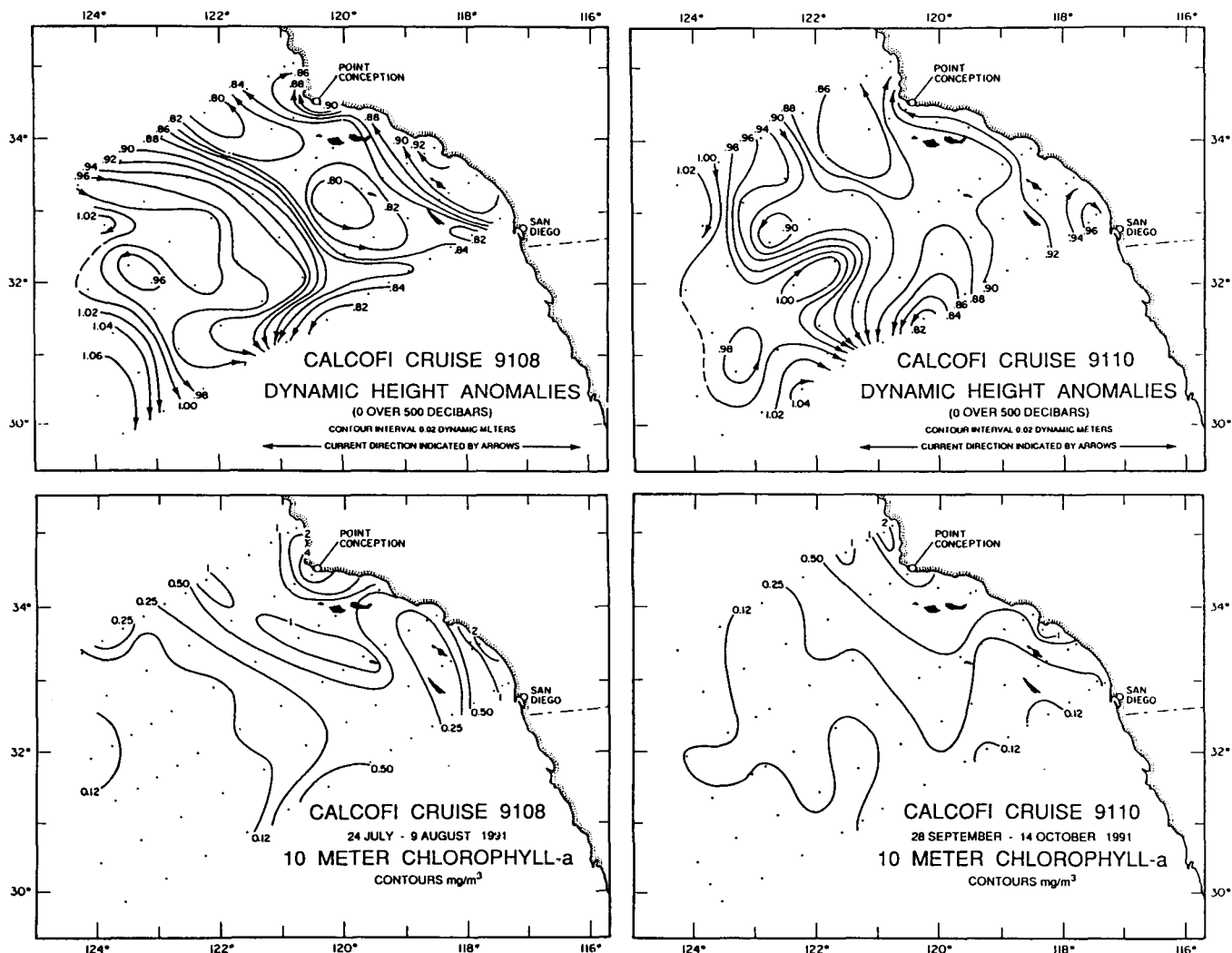


Figure 4. Spatial maps of dynamic height anomaly (0 over 500 db) and surface chlorophyll for CalCOFI cruises 9108 and 9110. The dynamic height anomaly indicates the total geostrophic flow in the upper 500 m, not the seasonally corrected anomaly from the long-term mean. (Figures from Scripps Institution of Oceanography, 1992a.)

PreFORAGE cruise (9203, unpublished observations). This coastal countercurrent is characteristic of El Niño (Lynn 1983; Huyer and Smith 1985). Cruise 9108 took place while sea level was beginning to rise at La Jolla, and 9110 and 9202 while sea level was high. Data from the 9204 CalCOFI cruise, which coincided with the drop in sea level, showed that the system had also returned to a more typical circulation pattern, with strong equatorward flow of low-salinity water in the coastal region. This circulation pattern was also evident on cruises 9207 and 9210.

Sections made along line 90 from CalCOFI cruises 9202 and 9204 show the change in vertical structure associated with El Niño and its decline in the southern California region. Cruise 9202 took place while SST and sea level were high, and there

was anomalous poleward flow. There was only slight shoaling of the pycnocline and nutricline in the coastal region on this cruise, and chlorophyll was relatively low (figures 6 and 7). On cruise 9204 the pycnocline sloped more strongly, and the nutricline was about 25 m shallower in the coastal region. Shoaling of the pycnocline and nutricline was associated with the return of southerly flow, and coincided with much higher chlorophyll values ($>4 \mu\text{g chl l}^{-1}$) in the coastal region. Temperature anomaly sections from both cruises showed that the maximum anomalies occurred at depths that would normally correspond to the upper thermocline, as was the case during the 1982-83 El Niño (Simpson 1983, 1992). However, in contrast to the 1982-83 event, the salinity sections did not show large anomalies in the coastal region (data not shown).

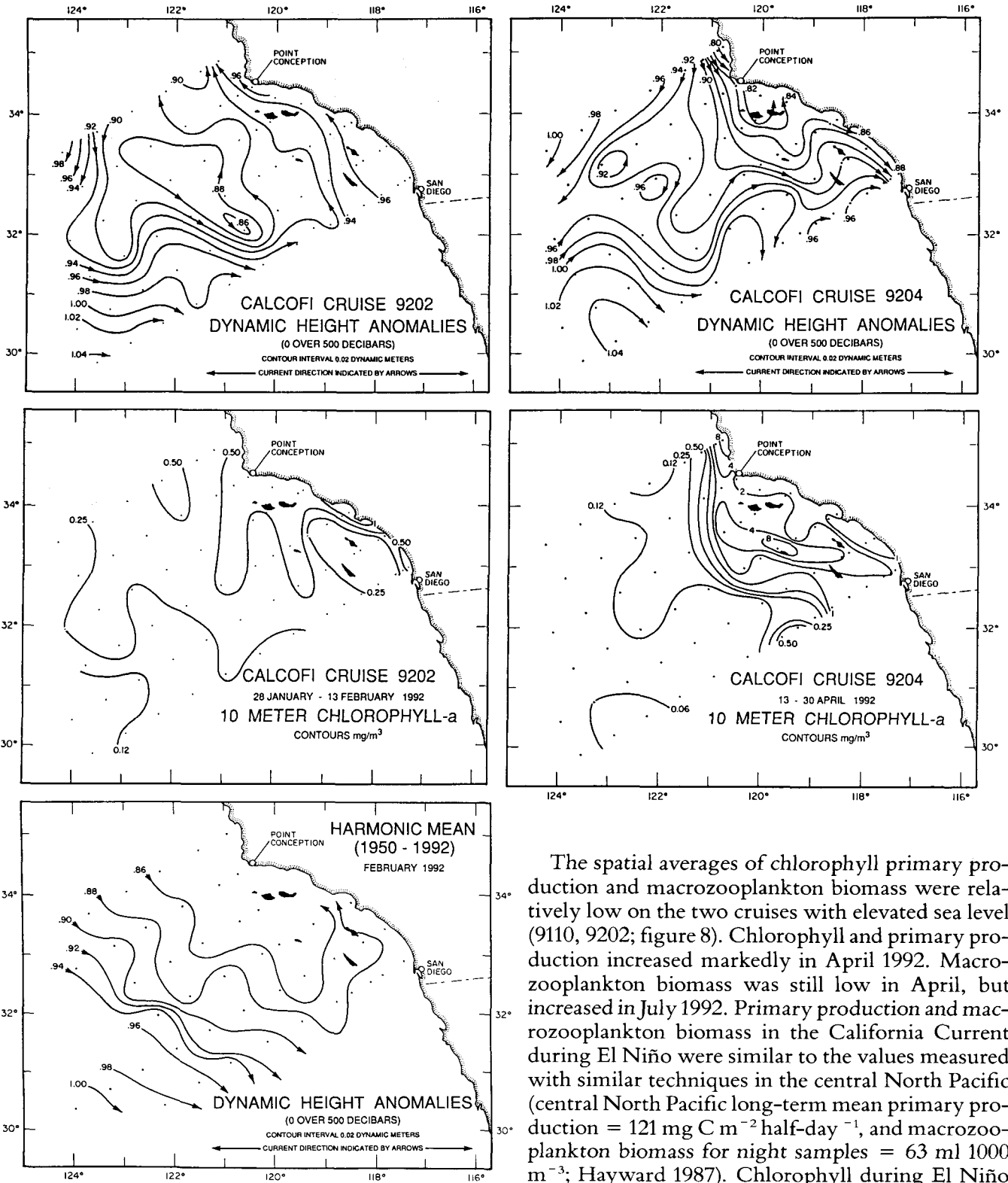


Figure 5. Spatial maps of dynamic height anomaly (0 over 500 db) and surface chlorophyll for CalCOFI cruises 9202 and 9204, and long-term harmonic mean dynamic height anomaly for cruise 9202. The dynamic height anomaly indicates the total geostrophic flow in the upper 500 m, not the seasonally corrected anomaly from the long-term mean. (Figures from Scripps Institution of Oceanography 1992b.)

The spatial averages of chlorophyll primary production and macrozooplankton biomass were relatively low on the two cruises with elevated sea level (9110, 9202; figure 8). Chlorophyll and primary production increased markedly in April 1992. Macrozooplankton biomass was still low in April, but increased in July 1992. Primary production and macrozooplankton biomass in the California Current during El Niño were similar to the values measured with similar techniques in the central North Pacific (central North Pacific long-term mean primary production = $121 \text{ mg C m}^{-2} \text{ half-day}^{-1}$, and macrozooplankton biomass for night samples = $63 \text{ ml } 1000 \text{ m}^{-3}$; Hayward 1987). Chlorophyll during El Niño was only slightly greater than in the oligotrophic central North Pacific ($22 \text{ mg chl-a m}^{-2}$; Venrick et al. 1987).

The wind field implied by the spatial pattern in sea-level atmospheric pressure also changed abruptly in

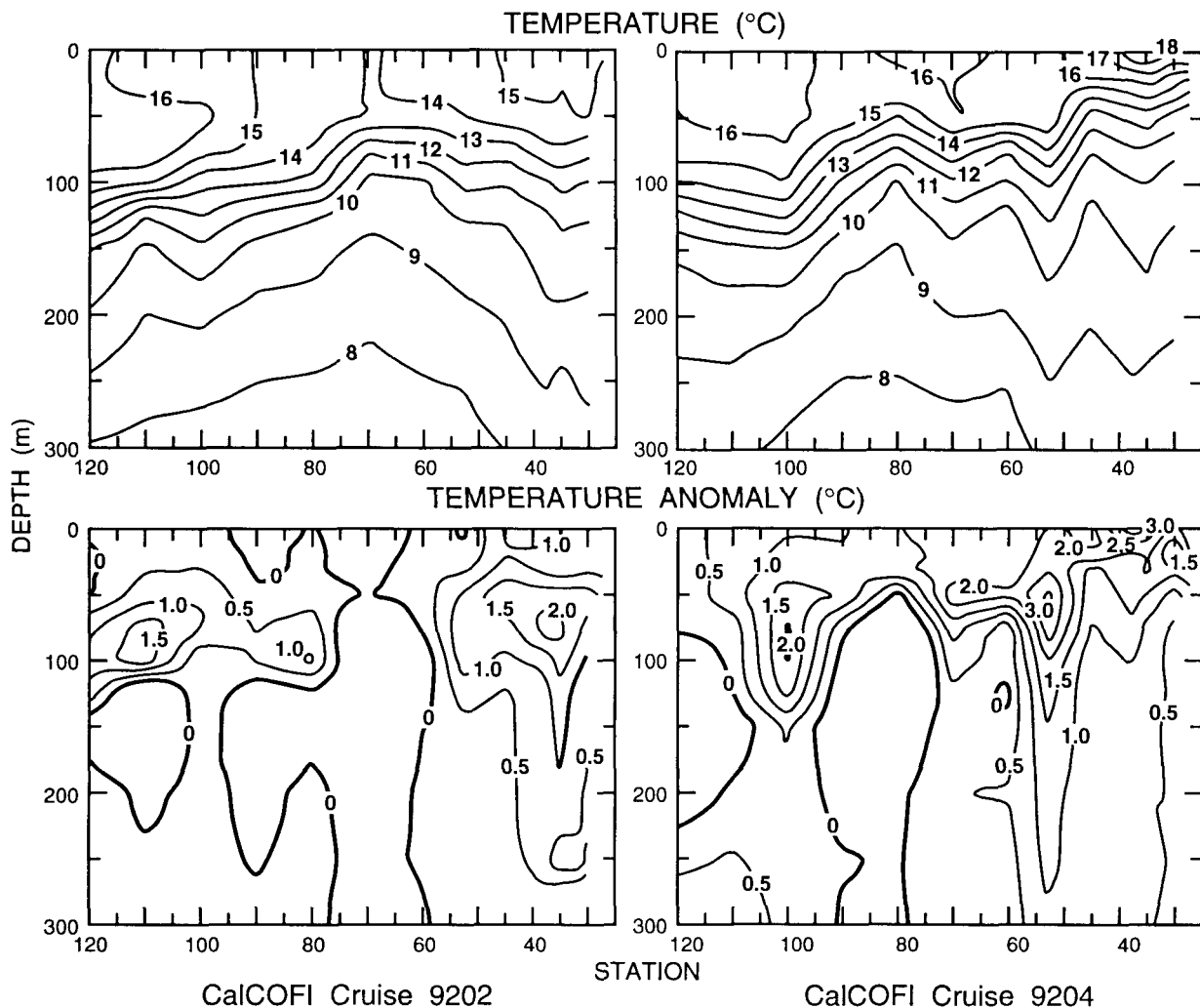


Figure 6. Vertical sections of temperature and temperature anomalies along line 90 for CalCOFI cruises 9202 and 9204.

May 1992. The pattern in sea-level-pressure anomalies changed from one of anomalously weak northerly winds (winds from the north) during April and the several preceding months, to a pattern with anomalously strong northerly winds in May and for the several following months (figure 9). This pattern was superimposed upon the normal annual cycle of the spring transition (Strub et al. 1987), during which the wind field changes from one of episodic winter storms to spring conditions of more regular, northerly, upwelling-favorable winds. The change in the sea-level-pressure anomaly field in April is consistent with intensification of coastal upwelling and increased southerly transport of the California Current.

DISCUSSION

The data presented here are sufficient for a preliminary description of the 1991-92 El Niño event in

the California Current. This description may require revision as more information becomes available. The changes in structure in the California Current during the 1991-92 El Niño event (SST, sea level, poleward flow, reduced plankton populations, and reduced primary production) were qualitatively similar to patterns observed during prior events. The 1991-92 event was relatively short, and it appeared to end abruptly. The anomalies in sea level and SST during the short period of maximum anomalies (3 months) were comparable to those reported during the strong 1982-83 El Niño event in the California Current. The rise and decline in sea-level anomalies preceded the rise and decline in SST anomalies (figures 1 and 3). Sea-level anomalies thus seemed to be a more reliable indicator of other aspects of El Niño (circulation pattern and primary production) than were SST anomalies during this event. Chelton (1981) also observed that low-fre-

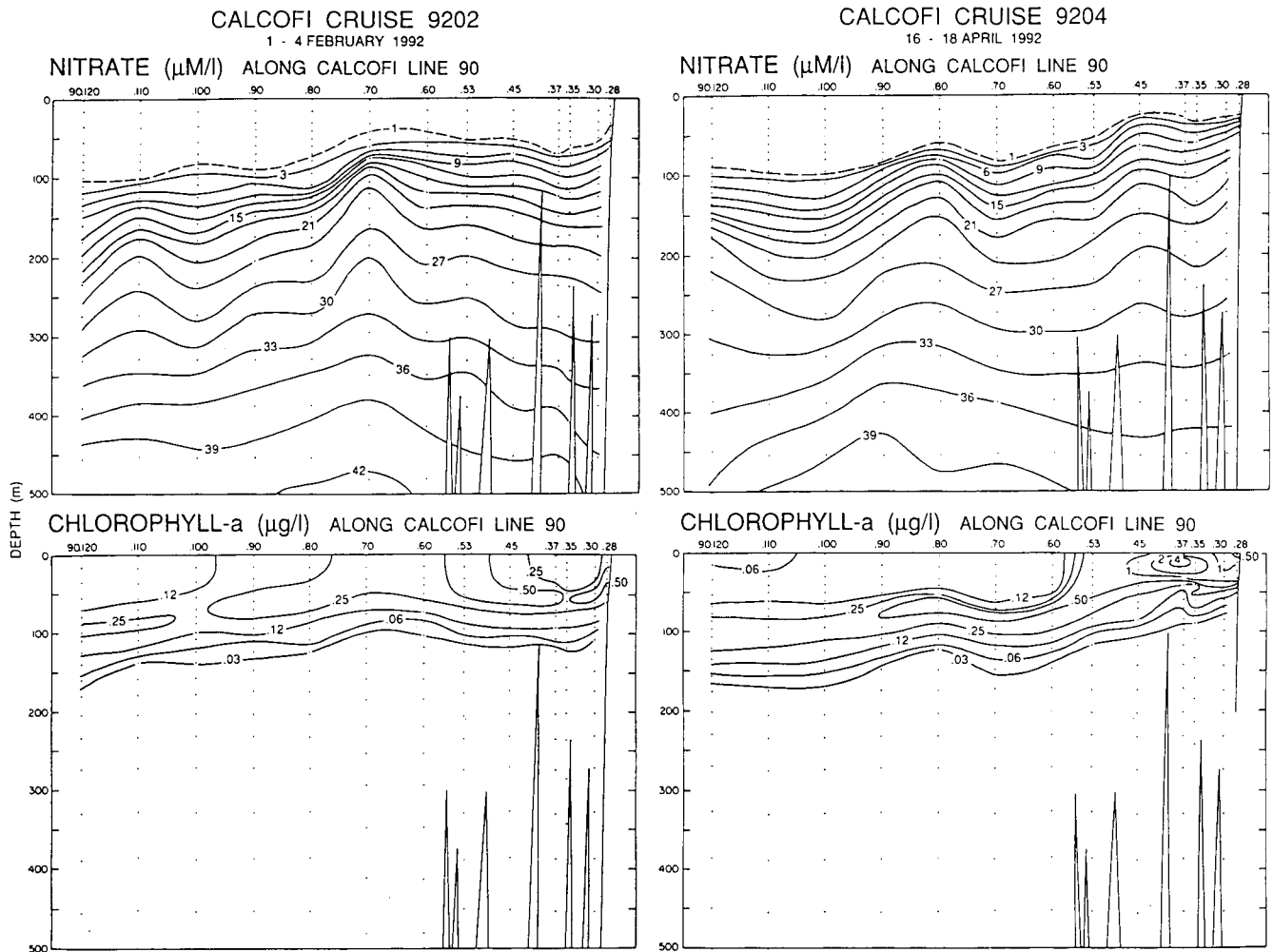


Figure 7. Vertical sections of NO_3 and chlorophyll along line 90 for CalCOFI cruises 9202 and 9204.

quency variability in zooplankton biomass in the California Current is more closely related to sea-level anomalies than to SST anomalies.

Observation of events such as El Niño may foster understanding of the mechanisms linking environmental structure with population dynamics of the upper trophic levels. This, in turn, is an important aspect of understanding and predicting the consequences of global change. Global change will first be detected in those properties for which long time series exist (e.g., SST or sea level; Roemmich 1992). But the ecological consequences of change in properties such as SST are difficult to predict because the direct effects upon organisms are generally small, and because it is uncertain how the distribution of properties (e.g., nutrients) that more directly influence ecosystem structure will be affected. Correlations between low-frequency changes in temperature and sea level and the population dynamics

of pelagic systems have been documented in some cases, and mechanisms linking these correlations have been proposed (Chelton et al. 1982; Smith and Eppley 1982; Mysak 1986). The effects of global increase in temperature upon the upper trophic levels of eastern boundary currents have also been predicted in the context of a mechanism linking circulation and production (Bakun 1990). Understanding the observed correlations and testing such predictions will require additional observations of events such as El Niño where large changes take place, and a better understanding of the mechanisms linking physical and biological structure.

The change in the pattern of circulation, sea level, and primary production in April-May 1992 is interesting because it was both abrupt and strong. It may be easier to relate cause and effect under such circumstances. Although this change in structure may have marked the regional decline of El Niño, it

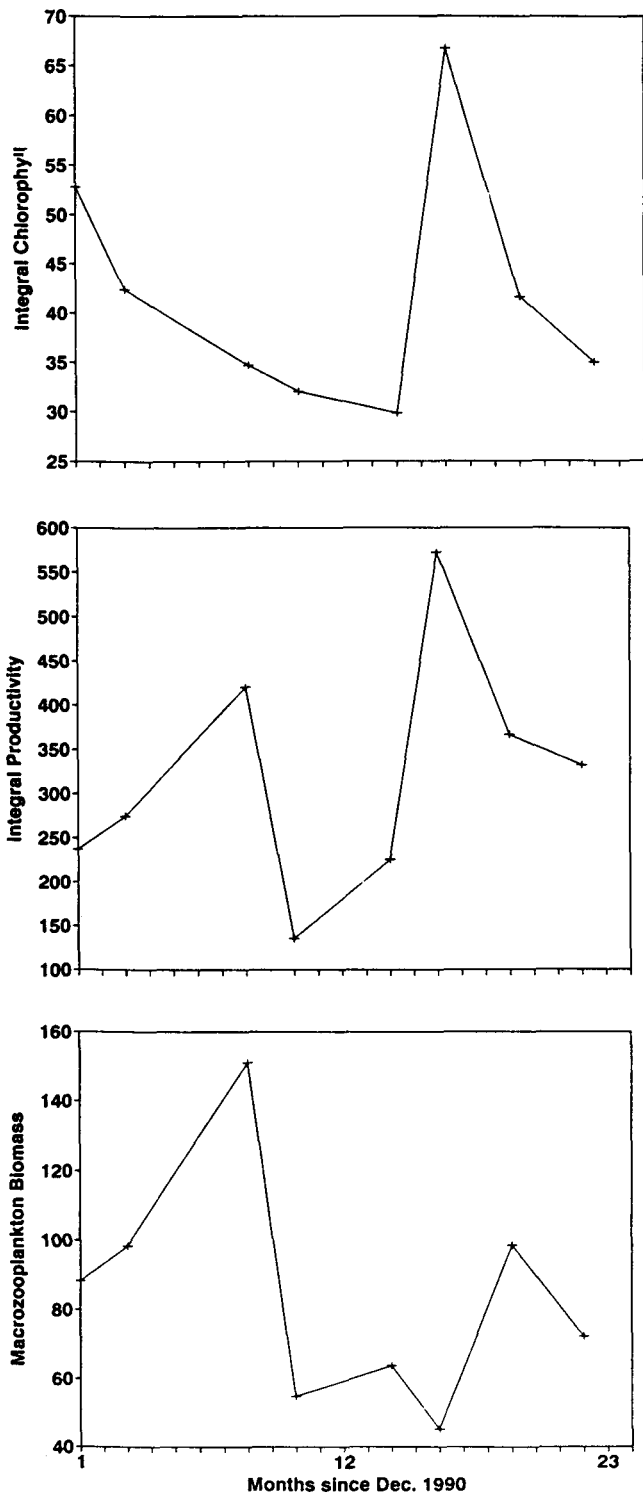


Figure 8. CalCOFI cruise mean values of vertically integrated chlorophyll (mg chl-a m^{-2}), vertically integrated primary production ($\text{mg C m}^{-2} \text{ half-day}^{-1}$), and macrozooplankton biomass ($\text{ml } 1000 \text{ m}^{-3}$) for 1991 and 1992.

seems likely that some component can also be attributed to the annual cycle which is observed in, at least, the wind field (Strub et al. 1987) and macrozooplankton biomass (Chelton et al. 1982). Further

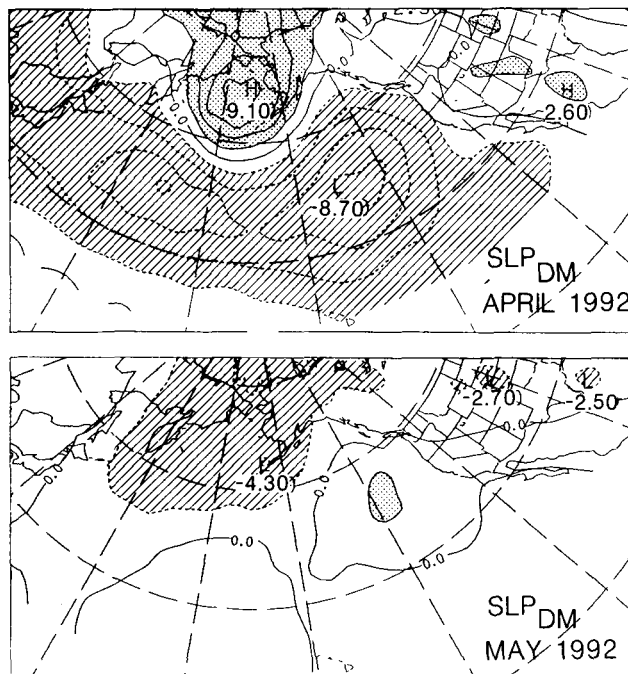


Figure 9. Monthly sea-level atmospheric-pressure anomaly field (mb) for April and May 1992.

study is needed to separate the effects of processes on these two time scales. The mechanism linking increased primary production and plankton biomass with the rise in sea level and the return of southerly flow was probably an increase in the nutrient supply to the euphotic zone due to shoaling of the nutricline. The nutrient input due to coastal upwelling and related processes should be greater when the nutricline is shallower.

Note Added in Proof

This manuscript derives from a talk presented on November 4, 1992, at the CalCOFI conference, and it is based upon the data that were processed and available at that time. Additional data collected in late 1992 and early 1993 suggest that some aspects of this early interpretation were incorrect. In spite of this, I did not substantially change the text of the manuscript that went out for review, because the structure of the California Current continues to evolve rapidly and in unexpected ways, and a synthesis is premature. I have, however, modified figures 1, 2, and 3 to include the latest information available. Large positive SST anomalies were again present at the SIO pier in late 1992 (figure 1), and sea level at La Jolla also began to rise in the fall of 1992 (figure 3). The pattern in sea level in late 1992 and January 1993 was remarkably similar to that seen during the winter of 1991-92. Thus it now appears to have been premature to attribute the change in

structure in the spring of 1992 to the decline of the 1991–92 El Niño.

ACKNOWLEDGMENTS

The data shown here were collected and processed by CalCOFI technical staff, and I thank them for timely data processing and rapid preparation of preliminary data reports and anomaly fields. I also thank Arnold Mantyla and Ken Plummer for help with processing and interpreting the data, Ron Lynn for the long-term harmonic means for CalCOFI hydrographic data, Dan Cayan for the sea-level-pressure anomaly fields, and Pat Walker for the SIO pier data. Helpful comments from two reviewers improved the manuscript. The data analysis was supported by the Marine Life Research Group of SIO, and the Office of Naval Research.

LITERATURE CITED

- Bakun, A. 1990. Global climate change and intensification of coastal ocean upwelling. *Science* 247:198–201.
- Brinton, E., and J. L. Reid. 1986. On the effects of interannual variations in circulation and temperature upon euphausiids of the California Current. In *Pelagic biogeography*, A. C. Pierrot-Bults, S. van der Spoel, B. J. Zahuranec, and R. K. Johnson, eds. UNESCO Tech. Pap. Mar. Sci. 49:25–34.
- Chelton, D. B. 1981. Interannual variability of the California Current—physical factors. *Calif. Coop. Oceanic Fish. Invest. Rep.* 22:34–48.
- Chelton, D. B., P. A. Bernal, and J. A. McGowan. 1982. Large-scale interannual physical and biological interaction in the California Current. *J. Mar. Res.* 40:1095–1125.
- Fiedler, P. C. 1984. Satellite observations of the 1982–1983 El Niño along the U.S. Pacific coast. *Science* 224:1251–1254.
- Fiedler, P. C., R. D. Methot, and R. P. Hewitt. 1986. Effects of California El Niño 1982–1984 on the northern anchovy. *J. Mar. Res.* 44:317–338.
- Hayward, T. L. 1987. The nutrient distribution and primary production in the central North Pacific. *Deep-Sea Res.* 34:1593–1627.
- Huyer, A., and R. L. Smith. 1985. The signature of El Niño off Oregon. *J. Geophys. Res.* 90:7133–7142.
- Lyles, S. D., L. E. Hickman, and H. A. Debaugh. 1988. Sea level variations for the United States, 1855–1986. United States Department of Commerce NOAA technical report.
- Lynn, R. 1983. The 1982–83 warm episode in the California Current. *Geophys. Res. Lett.* 10:1093–1095.
- McGowan, J. A. 1984. The California El Niño. *Oceanus* 27:48–51.
- Mysak, L. A. 1986. El Niño, interannual variability and fisheries in the northeast Pacific Ocean. *Can. J. Fish. Aquat. Sci.* 43:464–497.
- Pearcy, W. J., and A. Schoener. 1987. Changes in the marine biota coincident with the 1982–1983 El Niño in the northeastern subarctic Pacific Ocean. *J. Geophys. Res.* 92:14,417–14,428.
- Roemmich, D. 1992. Ocean warming and sea level rise along the southwest United States coast. *Science* 257:373–375.
- Scripps Institution of Oceanography. 1991. Physical, chemical and biological data, CalCOFI cruises 9101 and 9103. SIO Ref. 91-22.
- . 1992a. Physical, chemical and biological data, CalCOFI cruises 9108 and 9110. SIO Ref. 92-16.
- . 1992b. Physical, chemical and biological data, CalCOFI cruises 9202 and 9204. SIO Ref. 92-20.
- Simpson, J. J. 1983. Large-scale thermal anomalies in the California Current during the 1982–1983 El Niño. *Geophys. Res. Lett.* 10:937–940.
- . 1992. Response of the Southern California current system to the mid-latitude North Pacific coastal warming events of 1982–1983 and 1940–1941. *Fisheries Oceanogr.* 1:57–79.
- Smith, P. E., and R. W. Eppley. 1982. Primary production and the anchovy population in the Southern California Bight: comparison of time series. *Limnol. Oceanogr.* 27:1–17.
- Stewart, B. S., P. K. Yochem, and R. W. Schreiber. 1984. Pelagic red crabs as food for gulls: a possible benefit of El Niño. *Condor* 86:341–342.
- Strub, P. T., J. S. Allen, A. Huyer, and R. L. Smith. 1987. Large-scale structure of the spring transition off western North America. *J. Geophys. Res.* 92:1527–1544.
- Venrick, E. L., J. A. McGowan, D. R. Cayan, and T. L. Hayward. 1987. Climate and chlorophyll-a: long-term trends in the central North Pacific Ocean. *Science* 238:70–72.