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Effects of El Niños on the West Coast Wave Climate

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THE CORRELATION BETWEEN EL NIÑOS and the severity of West Coast wave events was first established by Seymour et al. (1984). This work was motivated by the many severe storms that occurred during the strong El Niño event of 1982-83, which included the largest waves measured up to that time along the West Coast of the United States. These storms were also unique for the very long period swells they produced, as great as 25 seconds. One such storm is described in detail by Earle et al. (1984). Seymour et al. (1984) established a record of storms in Southern California during the period 1900-93 that produced deep water significant wave heights (H_S) greater than 3 m. It was shown that all storms with H_S> 6 m and having peak periods greater than 19 sec occurred during El Niño years, based largely on a history of El Niño events established by Quinn et al. (1978). This series was updated about a decade later to include storms through the Spring of 1995, and the threshold was raised from 3 m to 4 m (Seymour, 1995). That paper further showed the El Niño effect of producing large wave events and expanded the scope to indicate the effects to the north on the coasts of Oregon and Washington. The northern wave climate response to El Niños was found to be significantly different from that in California, indicating a change in the storm paths between different El Niño events. Further, Seymour (1995) showed that winters experiencing severe wave events could be predicted with good skill from a simple parameter based on anomalies in tropical sea surface temperatures.

The decade from 1988 to the present has been marked by an unusual density of El Niño events, including, by some measures, the strongest El Niño on record during the 1997-98 season. Prior to the 1980s there were no deepwater wave measurements and correlations with El Niños depended on hindcasts of storm waves. The further back in time these hindcasts reached, the poorer the atmospheric data became, with a corresponding loss of accuracy in the wave predictions. Therefore, the current decade provides, with comprehensive wave measurements and an abundance of El Niños, an opportunity to look closely at the cross-connections and how they vary along the approximately 2400 km of coastline on the Western continental boundary of the United States.

DATA SOURCES

The data used in this study were obtained through the Coastal Data Information Program (CDIP), supported by the US Army Engineers and the California Department of Boating and Waterways, and operated by the Scripps Institution of Oceanography (Seymour et al., 1993). Harvest Platform, operated by Chevron and located in 225 m of water depth offshore of Point Conception in South-Central California, has hosted instruments for measuring deep water wave data since 1988. Prior to that time, representative deep water data were obtained from 1982 to 1987 through a Waverider buoy operated by the US Navy offshore of Begg Rock, west of the Channel Islands in Southern California. This location has been shown to yield slightly lower wave heights than the Harvest Platform, but to vary with time in a similar manner.

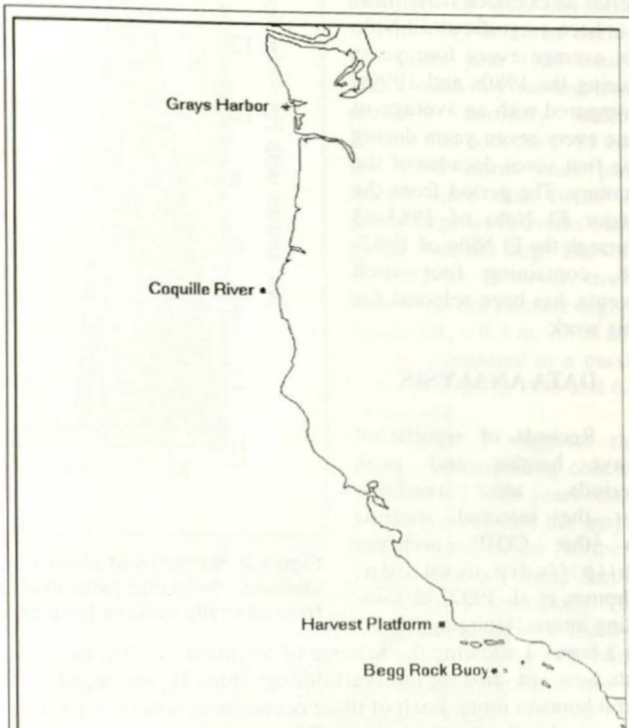

Figure 1 Locations of the measurement stations used in this study.

In the North, two Waverider buoys were used to characterize the deep water wave climate. One was off the mouth of the Coquille River in Oregon and the other off Grays Harbor on the Washington Coast. The Coquille River buoy operated from 1981 to 1996, with four years during which it was inoperative for periods long enough to invalidate its use for climate characterization. Fortunately, the Grays Harbor buoy, operational from 1985 to the present, overlapped all but one of the missing years. The locations of all of these stations are shown in Figure 1.

EL NIÑO SERIES

In the previous work, the definition of when an El Niño occurred was taken for the most part from the series established by Quinn et al. (1978). In Seymour (1996) an index based on the average over a storm year (July to June) of the tropical sea surface temperature anomalies (Areas N3 and N4) was shown to be correlated with the number of storms exceeding threshold during that year. Anomalously high sea surface temperatures in the Equatorial Pacific have long been accepted as one of the principal El Niño indicators. The latter series has been extended here to include the 97-98 El Niño.

Based on the Quinn et al. series as extended here, there has been a significant El Niño on average every four years during the 1980s and 1990s, compared with an average of one every seven years during the first seven decades of the century. The period from the major El Niño of 1983-83 through the El Niño of 1997-98, containing four such events, has been selected for this work.

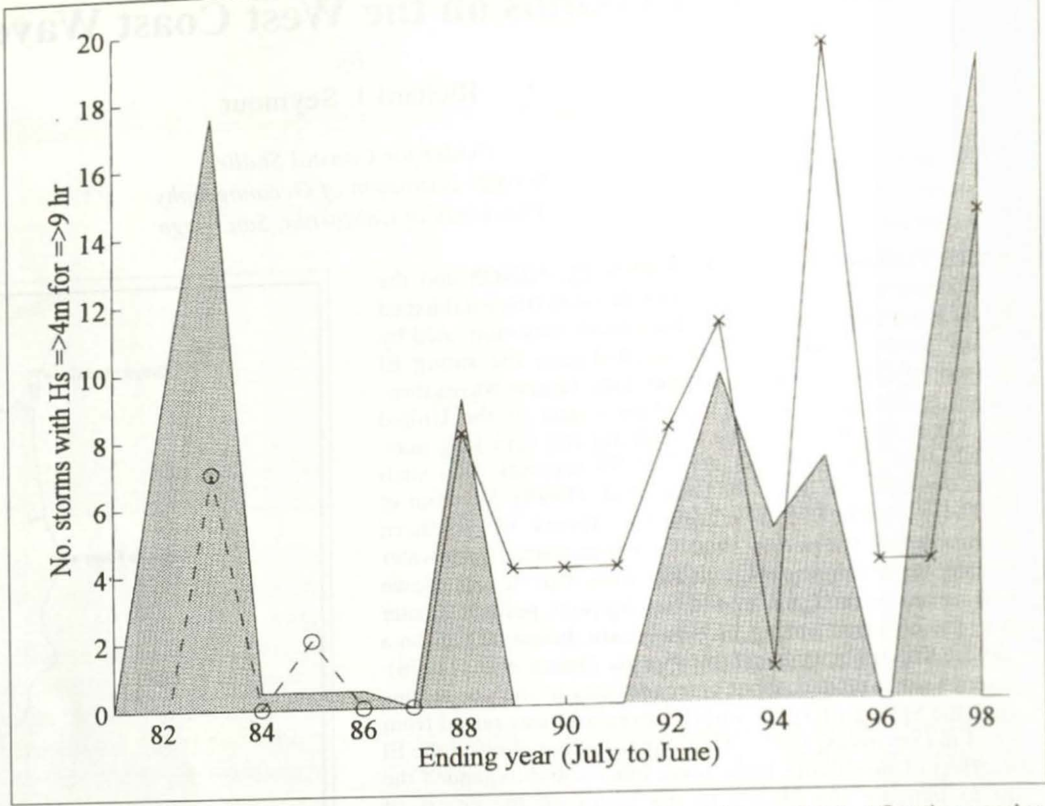

Figure 2 Numbers of storms exceeding threshold (Hs => 4 m, duration => 9 hr) at Southern region stations. Solid line (with x) is Harvest Platform, dashed line (with o) is Begg Rock. Relative El Niño intensity indices (tropical sea surface temperature anomalies) are shown in shaded areas.

DATA ANALYSIS

Records of significant wave heights and peak periods are available for the selected stations in the CDIP archives (http://cdip.ucsd.edu, Thomas et al. 1997) at sampling intervals ranging from 1 to 3 hours. Following the scheme of Seymour (1996), the data sets were searched for intervals during which H_S exceeded 4 m for 9 hours or more. Each of these occurrences was then recorded as a significant storm event. The absolute number of these events in a given storm year (arbitrarily defined as July through the following June) yields a rough estimate of the severity of the year. The convention here is to refer to the storm year by its last calendar year – that is, July '95 through June '96 will be designated as '96. The storm years investigated were '82 through '98. As noted previously, four El Niños occurred during this period.

The number of storms in each storm year for the two Southwest Coast stations is shown in Figure 2. The relative El Niño indices are shown in the shaded areas (not to a specific scale). Figure 3 shows a similar display for the two Northwest Coast stations.

Because many of the storms in this record greatly exceeded the minimum values of 4 m and 9 hr, a more representative means of evaluation was sought. The total energy per unit crest length delivered by each of these storms can be approximated by multiplying the power per unit crest length by the duration of the storm. The power density in deep water is approximately proportional to the height squared multiplied by the peak period

$$P \sim H_s^2 T_p \tag{1}$$

where P is proportional to the power per unit crest length, H_s is the significant height and T_p is the period of peak energy. Therefore, a measure of the energy per unit crest length delivered during the storm is given approximately by

$$E = Pt \tag{2}$$

where t = the storm duration.

A relative incident energy index was formed from Eqs.1 and 2 by expressing the height in meters, the period in seconds, the duration in hours and dividing the result by 1000 to suppress large values.

$$E_r = \frac{E}{1000} \tag{3}$$

The value of E_r indicates the relative energy impinging on the shoreline during a storm exceeding the defined threshold values, and summing this energy over a storm year provides an indication of the total impact of potentially damaging storms. The summed values of E_r for the Southern region of the West Coast are shown in Figure 4, and for the Northern Region in Figure 5.

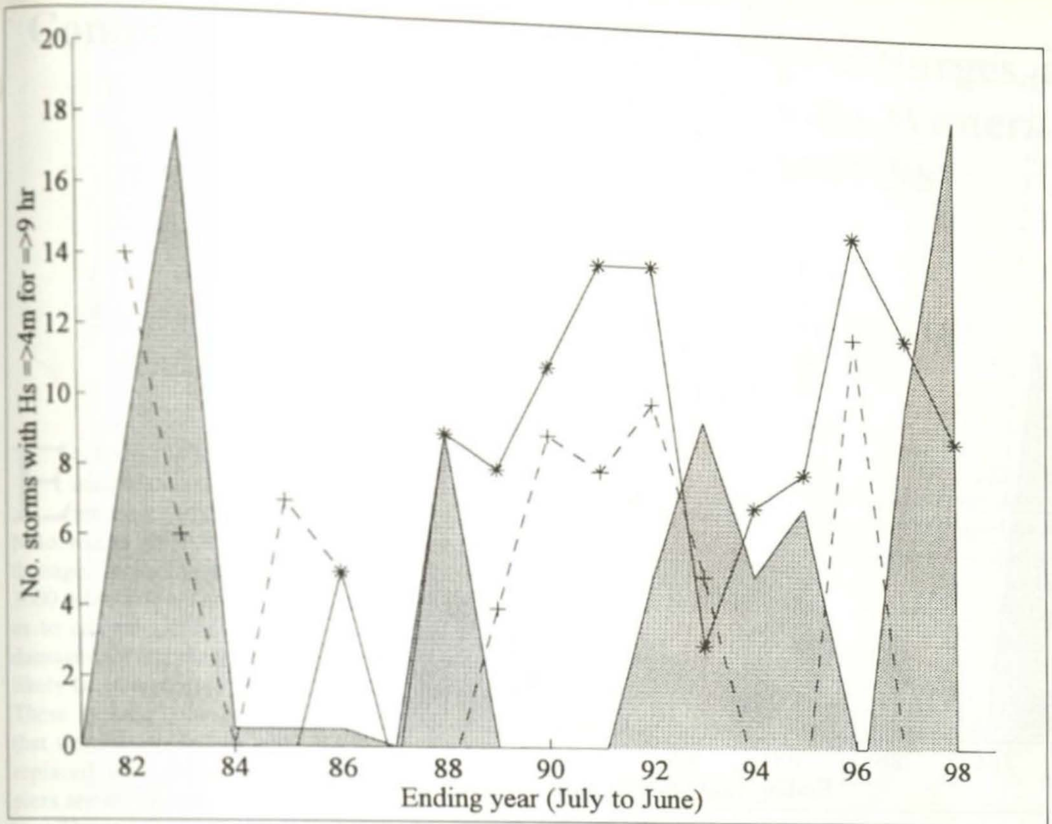

Figure 3 Numbers of storm wave events exceeding threshold at Northern region stations. Solid line (with *) is Grays Harbor, dashed line (with +) is Coquille River. El Niño indices are the same as in Figure 2.

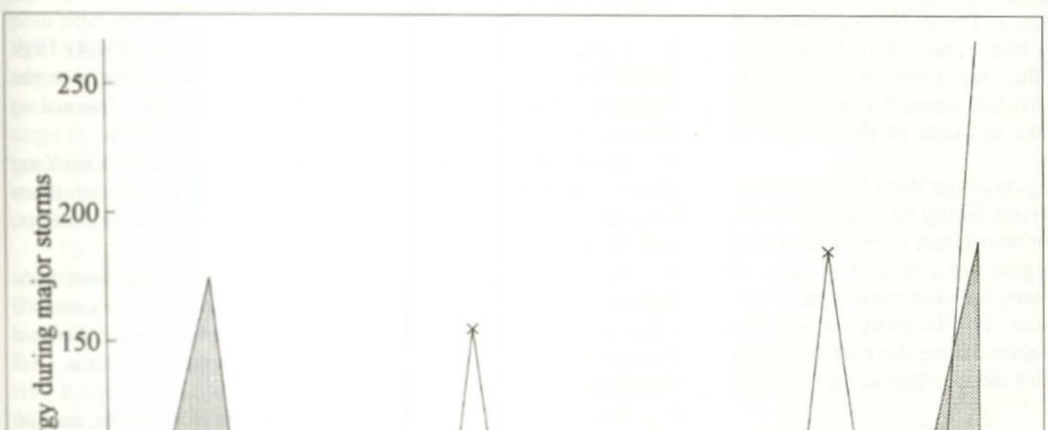

Figure 4 Relative amounts of energy from storms above threshold impacting the nearshore in the Southern Region. Solid line is Harvest Platform, dashed line is Begg Rock. El Niño indices as before.

DISCUSSION OF RESULTS

Figure 2 shows that the Southern region responds to the El Niño signal strongly, producing many more large wave events during these seasons, although the largest numbers of over-threshold storms (18) occurred during the storm year 1995 which had a relatively modest temperature anomaly index. Notice that both the 1995 and the 1998 storm years produced more than twice as many large wave events compared with the large El Niño of 1982-83. However, storm year 1983 did produce higher waves (H_S = 8.2 m, 7.3 m and 7.0 m) compared to a maximum of 6.2m in 1995 and 6.6 m in 1998.

Figure 3 suggests the somewhat surprising conclusion that El Niño years result in only about half the major wave events in the Northern region than are found during the intervening periods. The simplest explanation for this is that the large El Niño atmospheric pressure low in the mid-Pacific, which generates the waves that strike the Southern Region, blocks the Aleutian storm track that otherwise delivers large waves to the Northern region.

Figure 4 shows the relative cumulative energy per unit of coastline involved in these over-threshold storms in the Southern Region. There is once again a strong correlation with the El Niño temperature index. Storm year 1998 was marked with storms of exceptionally long duration (five of more than 30 hours, one at 65 hours and another at 70 hours) which greatly increased the cumulative energy. Taking Figures 2 and 4 together, there is a clear trend towards more severe wave storms and more energy incident on the coast in the Southern region of the West Coast since the beginning of the 1980s.

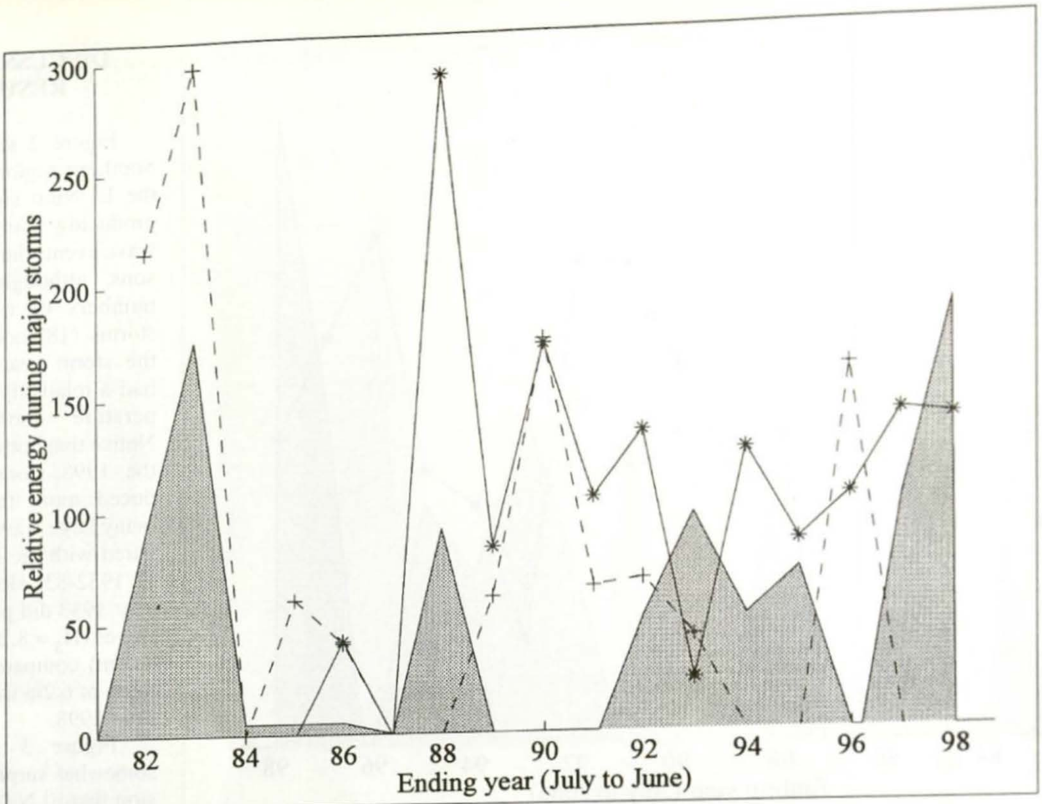

Figure 5 Relative amounts of energy from storms above threshold impacting the nearshore in the Northern Region. Solid line is Grays Harbor, dashed line is the Coquille River. El Niño indices as before.

The relative energy delivered by major storms to the Northern region is shown in Figure 5. The El Niño storm years of 1982 and 1988 produced very high values of incident wave energy, even exceeding the value for 1998 in the South. However, since 1988, the North has had a nearly constant level at about half of the previous peaks and with no discernible El Niño dependence.

In summary, the Southern region of the West Coast experiences greatly increased wave activity during El Niño episodes, both in terms of numbers of major storms and in the cumulative incident energy. The Northern region has a greater number of major storms during non-Niño years, indicating a negative correlation with El Niño occurrences. For incident energy, the result is quite mixed, with high values during the El Niño years 1982 and 1988, and reduced values independent of El Niños in the succeeding years.

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