UC San Diego
Oceanography Program Publications

Title
A Comparison of California Tides, Storm Surges, and Mean Sea Level During the El Niño Winters of 1982-83 and 1997-98

Permalink
https://escholarship.org/uc/item/6w2284ns

Journal
Shore & Beach, 66(3)

Author
Flick, R E

Publication Date
1998-07-01

Peer reviewed

eScholarship.org Powered by the California Digital Library
University of California

Comparison of California Tides, Storm Surges, and Mean Sea Level During the El Niño Winters of 1982-83 and 1997-98

By

Reinhard E. Flick

California Department of Boating and Waterways
Scripps Institution of Oceanography
La Jolla, CA 92093, U.S.A.

EL NIÑO WINTERS IN CALIFORNIA are often associated with storms, extreme waves, high sea levels, and the attendant coastal flooding and beach erosion. The El Niño winter of 1982-83 caused over $100 million in coastal damage, including loss of 33 ocean front homes, damage to 3000 more houses and 900 businesses, and $35 million of losses to coastal public recreational infrastructure. When coastal damages for the recent El Niño of 1997-98 are tallied, they will likely be less costly, owing to a combination of circumstances. These include some winnowing of marginal coastal structures that were destroyed in 1982-83 (or in subsequent winters) and replaced with sturdier construction, or never rebuilt. Coastal piers are an example of this phenomenon.

The key factor limiting damages this recent winter was that wave heights were lower overall than they were in 1982-83 (as documented by the Coastal Data Information Program at Scripps Institution of Oceanography, http://cdip.ucsd.edu). In addition, peak tides were lower and occurred earlier during the winter of 1997-98, compared with the winter of 1982-83. The largest storm surges were higher in the recent winter, but there were fewer, less persistent events in central California than in 1982-83. Storm surge in southern California was comparable in the two winters, but large storm surges (and large wave heights) generally did not occur during times of peak high tides in 1997-98, as they sometimes did in 1982-83, especially during January 1983.

This paper compares and contrasts the tides, storm surges and mean monthly and yearly sea levels in central and southern California during the winters of 1982-83 and 1997-98. Peak high tides, storm surges and El Niño effects all can temporarily raise water levels by several centuries worth of mean sea level rise. It is these factors that pose the greatest potential for flooding and coastal erosion when coupled with high wave events.[2,3,5]

TIDES

Tides are the regular changes of ocean water levels caused by the astronomical forces of the moon and sun. California tides are mixed, with nearly equal semi-daily and daily components, and total open coast elevation changes of up to about 10 ft. Zetler and Flick[10,11] have described a number of interesting characteristics of this regime, which makes California's tides distinctly different from the semi-diurnal conditions that dominate the east coast of the United States. Significant tidal fluctuations on the west coast occur once and twice daily, twice monthly, twice yearly, every 4.4 years, and every 18.6 years.

The two high tides and two low tides that occur each day are, respectively, unequal in amplitude. The lower-low tide of the day generally follows the higher-high after about 7 or 8 hours. The monthly tidal changes are dominated by the spring-neap cycle, with two periods of relatively high tides (springs) around full and new moon, and two periods of lower ranges (neaps) around the times of half-moon. One spring tide range per month is usually higher than the other, a consequence of the moon's distance and declination. The highest monthly tides in the winter and summer are higher than those in the spring and fall as a result of lunar and solar declination effects. Furthermore, the extreme monthly higher-high tides in the winter tend to occur in the morning, sometimes quite early. This is a disadvantage from a coastal flooding perspective, since preparations for storm waves must often be made at night, in anticipation of the high tide the next morning.

Table 1. Los Angeles Winter Predicted Monthly Peak High Tides (Ft)

Month	1982-83	1997-98
Oct	5.9	6.6
Nov	6.7	6.8
Dec	7.1	6.8
Jan	7.1	6.6
Feb	6.7	6.3
Mar	5.9	5.9

Table 1 summarizes the predicted peak high tides at Los Angeles for the months of October through March 1982-83 and 1997-98. The tides at Los Angeles well represent those of southern California, and it is one of the California stations for which tide predictions are routinely published by NOAA's National Ocean Service (NOS). Table 2 shows the same information for San Francisco, another NOS station, and representative of the central California coast.

Table 2. San Francisco Winter Predicted Monthly Peak High Tides (Ft)

Month	1982-83	1997-98
Oct	5.9	6.5
Nov	6.7	6.8
Dec	7.2	6.9
Jan	7.1	6.8
Feb	6.6	6.4
Mar	5.9	6.1

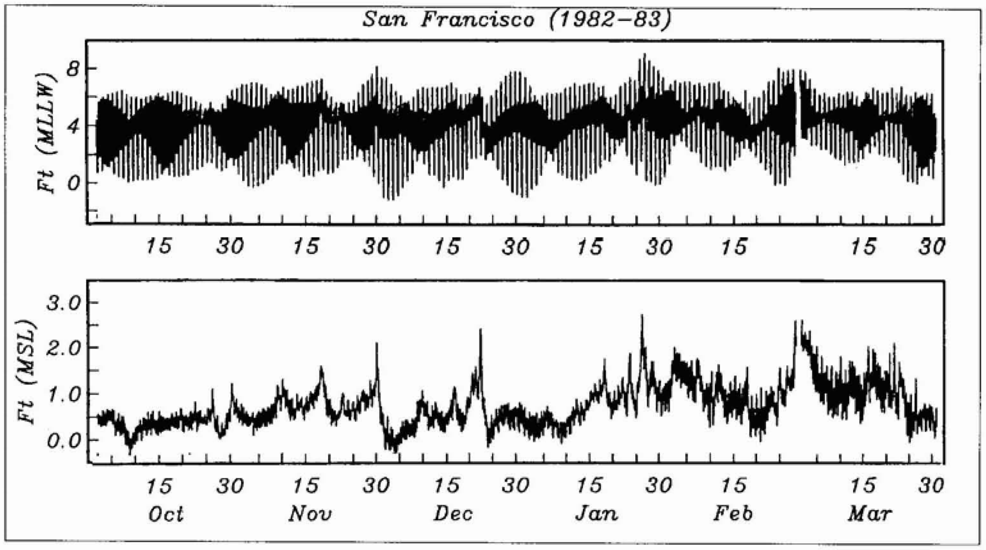

Figure 1. Measured hourly water level (upper) and storm surge (lower) at San Francisco from 1 October 1982 to 31 March 1983.

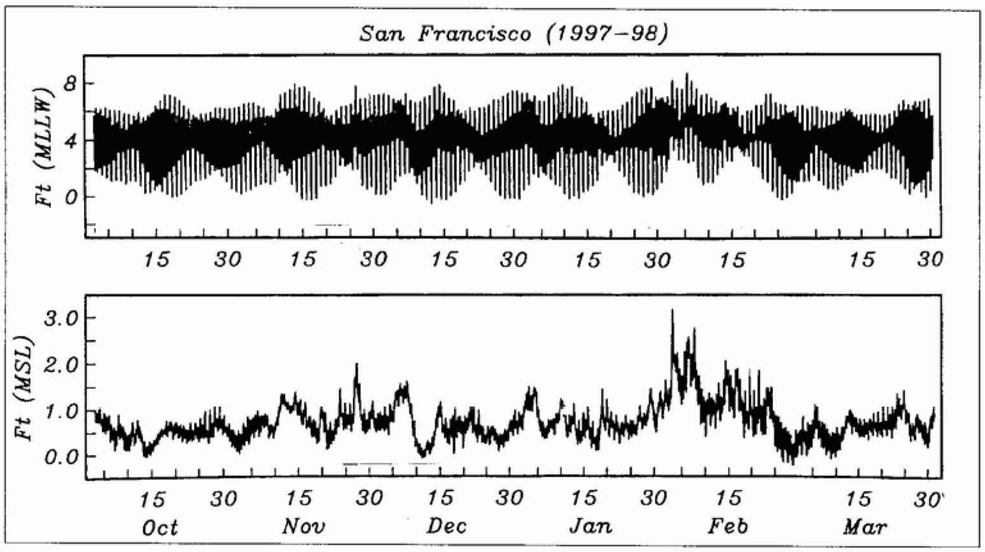

Figure 2. Measured hourly water level (upper) and storm surge (lower) at San Francisco from 1 October 1997 to 31 March 1998.

Inspection of Table 1 reveals that the peak tides at Los Angeles during the recent winter were up to 0.5 ft lower (in January) than they were in 1982-83. Also, the maximum elevations occurred earlier in the winter, with peaks of 6.8 ft in November and December 1997, compared with peaks of 7.1 ft in December 1982 and January 1983. Most importantly, the peak tides had already diminished to only 6.3 ft by February 1998 when the brunt of the storm activity finally impacted the south-central and southern coast of California. In contrast, one of the major sets of storms during the winter of 1982-83 occurred in late January 1983, and coincided with the highest tides of that winter (which were also the highest tides in 4 years). Table 2 shows a similar pattern in San Francisco, although the differences in height and timing of the peak tides between the recent winter and 1982-83 is smaller than in Los Angeles.

The differences in tide height between the two winters is mainly due to the 4.4 yr lunar perigee cycle, with a small contribution from the 18.6 yr lunar node cycle.[10,11] The 4.4 yr cycle enhanced peak tide heights in 1982-83, 1986-87, 1990-91, and 1995-96, and will do so again in 1999-2000. The maximum elevations during years in between are depressed by up to 0.5 ft. The node cycle peaked in 1988, and had a trough in 1997, which depressed peak values by 0.2 ft.

STORM SURGES

Storm surge is that portion of the local, instantaneous sea level elevation that exceeds the predicted tide and which is attributable to the effects of low barometric pressure and high wind associated with storms.[7] Sometimes, the super-elevation of sea level due to waves and wave-induced surges is included in design calculations of storm surge, particularly for structures on beaches. However, as a practical matter, storm surge is usually calculated from tide gauge data, which is gathered in a way that eliminates wave-induced set-up and surges. Storm surge calculated in this way rarely exceeds 1 ft in southern California, and 2 ft in central California.[4] However, wave induced surge on a beach can be of the order of the significant breaker height, which can exceed 10 ft during large wave events.[9]

Figures 1 and 2 respectively present the water level and storm surge time series for the El Niño winters of 1982-83 and 1997-98 at San Francisco. Figures 3 and 4 show the same information for southern California, with data from La Jolla and Los Angeles, respectively. Each figure consists of two graphs covering 1 October to 31 March each winter: The upper graph shows the measured water level, and the lower graph shows the storm surge.

The water level values are hourly data collected and published by NOAA/NOS. They are plotted relative to the respective 1960-78 tidal epoch MLLW datum to facilitate comparison with published tide predictions. The storm surge time series were constructed by subtracting the predicted tide from the hourly data at each location. The tide was calculated from NOAA published constituents, including the respective seasonal components, Sa and Ssa at each location.

In the central part of California, inspection of Figures 1 and 2 reveals similar storm surge patterns in each of the two winters, but with differences in amplitude, number of events, and timing evident. Peak storm surges reached about 3 ft in San Francisco

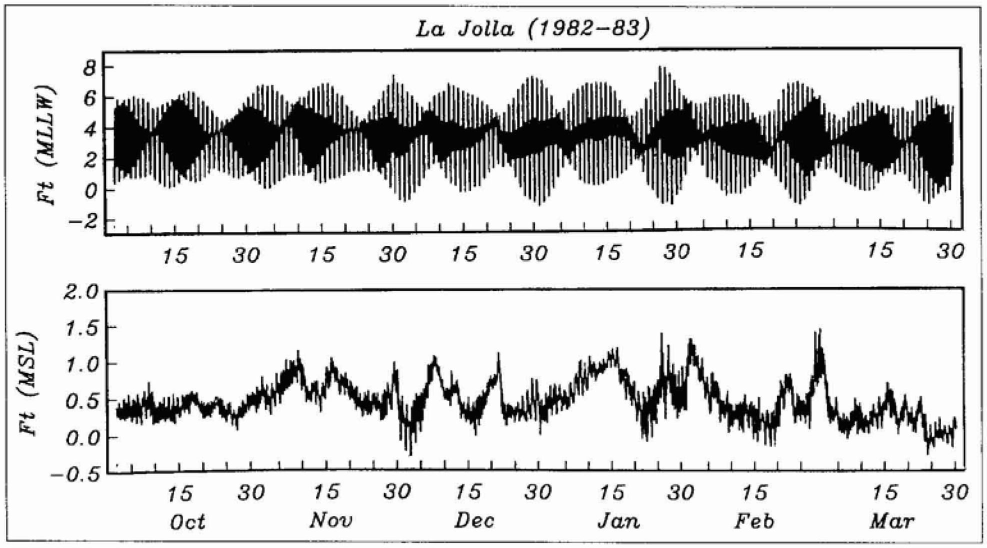

Figure 3. Measured hourly water level (upper) and storm surge (lower) at La Jolla from 1 October 1982 to 31 March 1983.

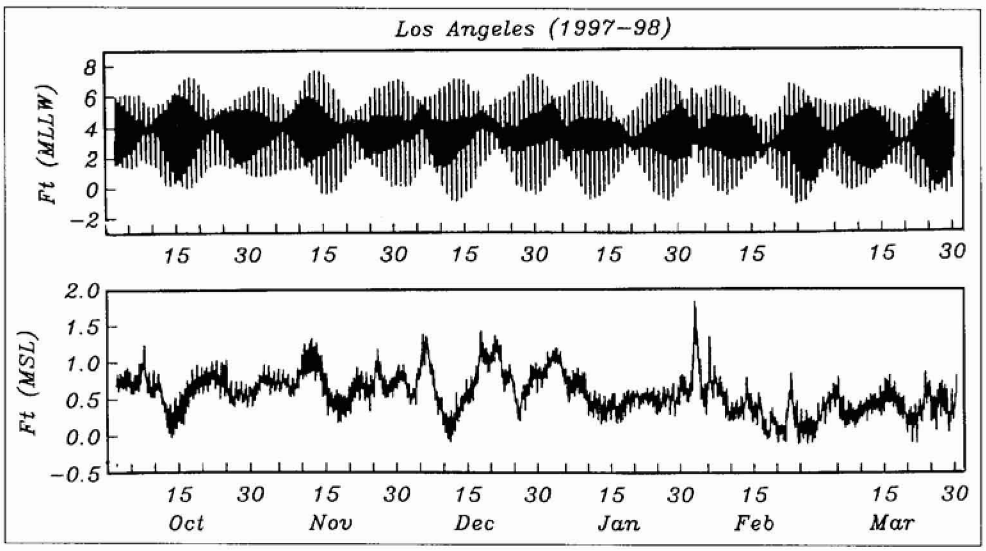

Figure 4. Measured hourly water level (upper) and storm surge (lower) at Los Angeles from 1 October 1997 to 31 March 1998.

during both winters (late January and early March 1983, and early February 1998). There were a few short, intense events in December 1982, and a similar event in late November 1997. The tide gauge at San Francisco failed to record data on 1 March 1983 (data gap in Figure 1), at the climax of an intense storm event that affected all of California. This storm surge event likely exceeded the earlier one of 26 January, which reached 2.7 ft.

In contrast, the storm surge this recent winter reached a new record value of 3.2 ft during the night of 2 February 1998 (Figure 2). Fortunately, this event occurred at a time of diminished high tides, coming at the first neap tide of February. In fact the close coincidence of peak tides and large storm surges is exceedingly rare.[3] The highest observed total water level at San Francisco thus remains the event during the morning of 27 January 1983, which reached 9.0 ft above MLLW Figure 1). The surge at that time reached 2.0 ft. The highest total water level during the recent winter occurred on the morning of 6 February 1998, and reached 8.6 ft above MLLW (Figure 2).

In southern California, inspection of Figures 3 and 4 also shows parallel patterns of similarities and differences in each of the two winters. Data for 1982-83 is from La Jolla, while data for the recent winter is from Los Angeles, because the La Jolla tide gauge seems to have failed in early February 1998. Comparisons between the two stations when they are both operating show that the data are virtually interchangeable, after taking into account the respective tidal datum relationships.

Peak storm surge reached about 1.5 ft on several occasions in January and early March 1983. The maximum storm surge this recent winter occurred on the morning of 3 February 1998, and reached 1.8 ft, which also is likely a record recorded value. This was associated with the same intense storm system that had battered the northern and central parts of California in the previous days. Of course, the storm also coincided with the neap tides in southern California, thereby greatly reducing coastal flooding and damage.

MONTHLY MEAN SEA LEVEL

Monthly mean sea levels describe seasonal patterns of water level. They contain information about the mean water levels that are the background about which the shorter period variations (tides and storm surges) fluctuate. In contrast to the tides, monthly mean sea levels tend to be highest in the fall and lowest in the spring, with differences of about 0.5 ft. This results mainly from the fact that water temperature in the upper layers is a minimum in March and reaches a maximum in about October. Local warming or cooling resulting from offshore shifts in water masses, and changes in wind-driven coastal circulation patterns also seasonally alter the average sea level by several tenths of a foot.[8]

Large scale El Niño warming episodes are also associated with above-average sea levels off California.[1] Anomalous warm-water conditions occurred in mid-1997, and did result in above average mean water levels for the last half of the year, especially in southern California. However, it is not clear whether at least the early stages of this warming were directly related to the El Niño condition, which caused above-average temperatures in the equatorial Pacific Ocean starting about March 1997.

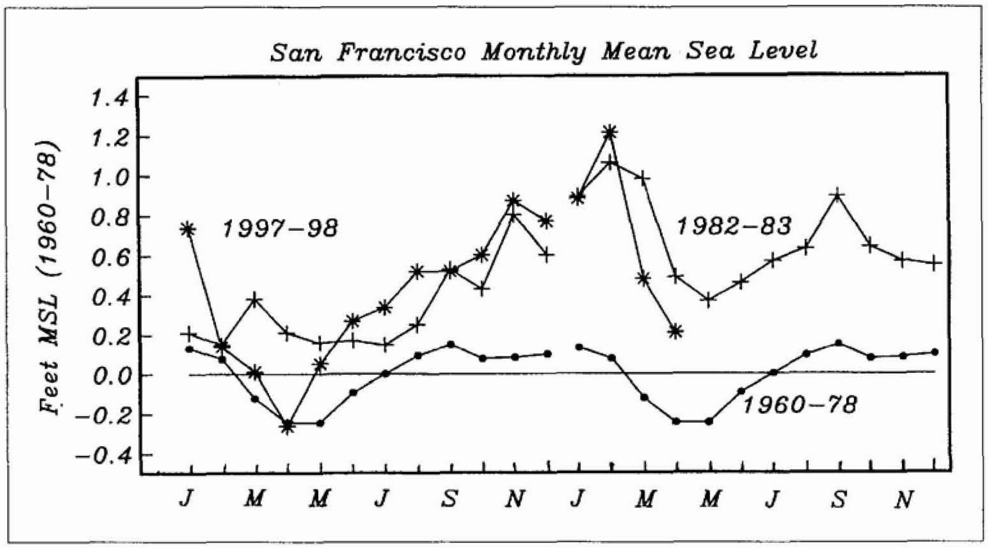

Figure 5. Monthly mean sea levels at San Francisco, winters of 1982-83 and 1997-98 compared with the mean values over the 1960-78 tidal datum epoch.

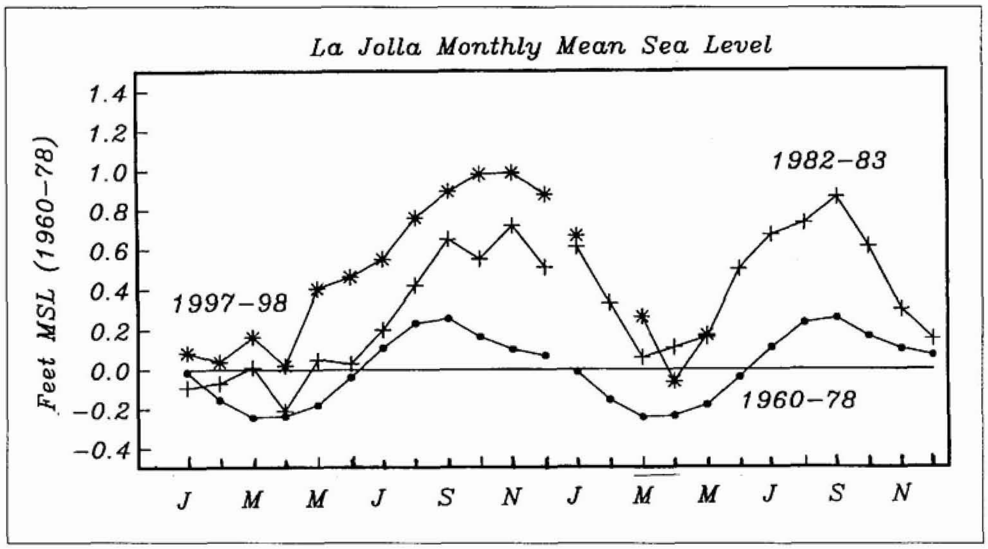

Figure 6. Monthly mean sea levels at La Jolla during winters of 1982-83 and 1997-98 compared with the mean values over the 1960-78 tidal datum epoch.

Figures 5 and 6 show time series of monthly mean sea levels at San Francisco and La Jolla, respectively. These data have been published by NOAA/NOS, except for the La Jolla readings for March, April and May 1998, which were calculated from incomplete published 6-minute NOAA/NOS tide data. These monthly mean values are therefore not official NOAA products, and are subject to revision. However, official NOAA monthly values published for the Santa Monica tide gauge show nearly identical patterns, enhancing confidence in the calculations for La Jolla. Values are plotted relative to the 1960-78 tidal epoch mean sea level (MSL) datum.

Figures 5 and 6 each contain three curves, and cover two successive years of data (24 monthly values). The 1960-78 epoch monthly mean values are shown with dots (·). These 12 monthly values are successively duplicated, and provide a reference. Long-term monthly mean values for all years of record would be an alternative reference. The monthly mean values for 1982-83 are indicated by plus (+) symbols, and those for 1997 through April or May 1998, with stars (*).

All-time monthly mean sea level records were established in 1997-98, both in San Francisco and La Jolla. The highest level in San Francisco was reached in February 1998, with a value of 1.2 ft above MSL, or about 1.1 ft above the normal February value (Figure 5). The highest level in La Jolla occurred in October and November 1997, with nearly identical values of 1.0 ft above MSL (0.9 ft above the normal seasonal value, Figure 6). In San Francisco, mean water levels during the last half of 1997 were comparable to those of 1982. By March 1998, levels had dropped below those of March 1983, but still remained 0.5 ft above normal in April 1998. In La Jolla, mean monthly water levels in 1997 were between 0.2 to 0.4 ft higher than they were during 1982, while the levels of early 1998 were comparable to early 1983, and remained above normal.

YEARLY MEAN SEA LEVEL

Yearly mean sea level data is useful to study trends and inter-annual variations in water levels (for a summary, see National Research Council[6]). Figures 7 and 8 show the annual mean water level data through 1997 from San Francisco and La Jolla, respectively. The San Francisco record begins in 1855, and represents the longest, continuous time series of water level in North America. The La Jolla series begins in 1925. Both time series are plotted relative to their respective 1960-78 tidal epoch MSL datum.

Both San Francisco and La Jolla show an upward trend in mean sea level which varies, depending on the time span examined. The straight lines in Figures 7 and 8 are linear least square fits to the data. From a coastal hazard perspective, the main effect of sea level rise is to continuously worsen the flooding impacts of given high tides, storm surges and wave set-up. Overall, the record at San Francisco shows a rate of rise of about 0.47 ft/century from 1855 to 1997 (Figure 7, long straight line). From 1925 to 1997, the trend is 0.75 ft/century (Figure 7, short straight line), which is nearly identical to the 0.74 ft/century trend at La Jolla over the same period (Figure 8).

Between 1969 (the middle of the 1960-78 tidal epoch) and 1983, mean sea level at San Francisco and La Jolla increased by about 0.1 ft. It increased by about 0.2 ft between 1969 and 1997. This means that about 0.2 ft of the above-normal storm surge and monthly mean water level values this past winter (described

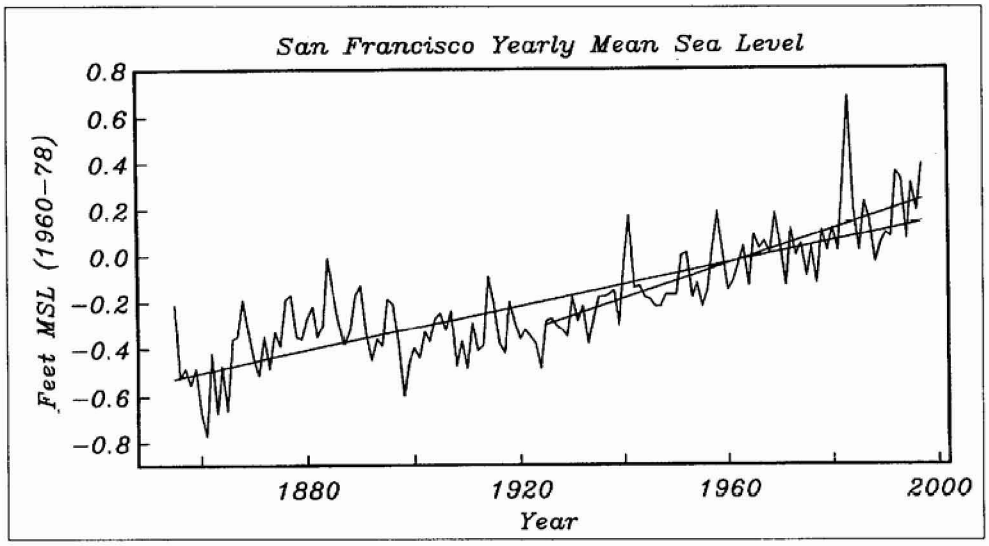

Figure 7. Yearly mean sea levels at San Francisco, 1855 to 1997. Long trend line for series has a slope 0.47 ft/century. Short trend line from 1925-97 has a slope 0.75 ft/century.

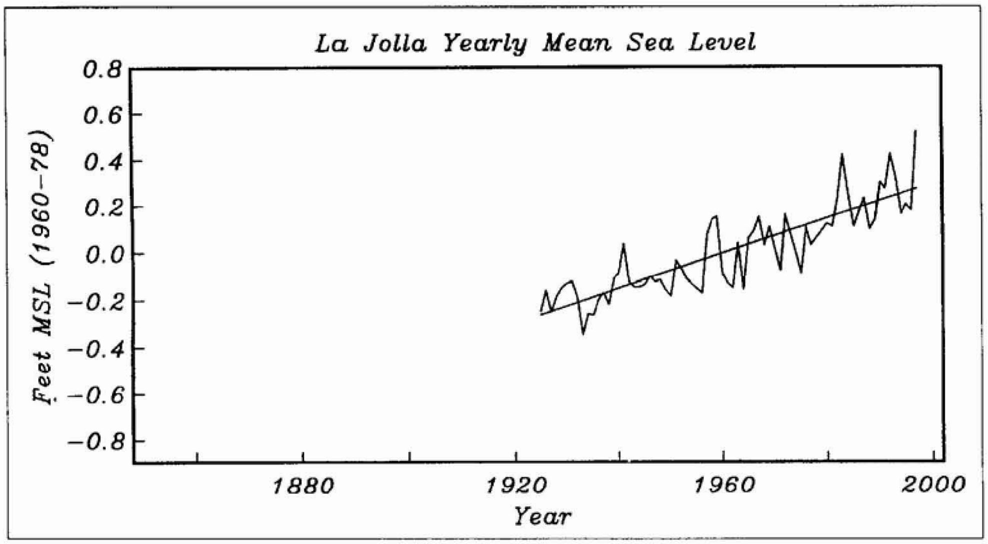

Figure 8. Yearly mean sea levels at La Jolla, 1925 to 1997. Trend line has a slope 0.74 ft/century.

above) can be directly attributed to sea level rise, while the remainder was caused by other factors. Similarly, 0.1 ft of the difference in these factors between 1997-98 and 1982-83 is due to the trend.

The effects of El Niño commonly increase the mean sea level off the west coasts of North and South America, including California.[1] During 1982-83, this effect was relatively greater at San Francisco, where the mean sea level in 1983 was 0.68 ft above datum, while in 1997 the average was only 0.39 ft. The value at La Jolla reached 0.42 ft in 1983, and 0.52 ft in 1997. This difference is attributable to the 0.1 ft trend in sea level over that span, suggesting that the relative effects of the two El Niño events at La Jolla was about the same. To some degree, these similarities and differences may be artifacts of the fact that yearly mean sea levels are calculated on a calendar year basis (see Figures 5 and 6). Nevertheless, the 1982-83 event seemed to raise mean water levels more in the north, while the 1997-98 warming had a relatively larger effect in the south.

CONCLUSIONS

Peak tides were lower and occurred earlier along the California coast during the winter of 1997-98, compared with the winter of 1982-83. The largest storm surges were higher in the recent winter, but there were fewer, less persistent events in central California than in 1982-83. Storm surge in southern California was comparable in the two winters, but large storm surges (and large wave heights) generally did not occur during times of peak high tides during 1997-98, as they occasionally did in 1982-83, especially in January 1983. Mean sea level heights reached new, all-time high values in 1997-98, in both central and southern California. Monthly mean values overall were comparable in central California in the two winters, but were substantially higher in the south during the recent winter. The trend in mean sea level rise contributed an increase of about 0.1 ft in mean water level between 1982-83 and 1997-98.

REFERENCES

1. Chelton, D. and R.E. Davis, 1980. Monthly mean sea-level variability Along the West Coast of North America: *Jour. Geophys. Res.*, vol. 12, p. 757-784.
2. Flick, R.E., 1986. A review of conditions associated with high sea levels in Southern California: *Science of the Total Environment*, vol. 55, p. 251-259.
3. Flick, R.E., 1991. Joint occurrence of high tide and storm surge in California: Proc. *World Marina '91*, Amer. Soc. Civil Eng., p. 52-60.
4. Flick, R.E. and A. Badan-Dangon, 1989. Coastal sea levels during the January 1988 storm off the Californias: *Shore & Beach*, vol. 57, no. 4, p. 28-31.
5. Flick, R.E. and D.C. Cayan, 1984. Extreme sea levels on the coast of California: *Proc., 19th Int. Conf. Coastal Eng.*, Amer. Soc. Civil Eng., p. 886-898.
6. National Research Council, 1990. *Sea-Level Change, Studies in Geophysics*, National Academy Press, 234 pp.
7. Pugh, D. T., 1987. *Tides, Surges and Mean Sea-Level, A Handbook for Engineers and Scientists*, John Wiley and Sons, 472 pp.
8. Reid, J.L. and A.W. Mantyla, 1976. The effect of the geostrophic flow upon coastal sea elevations in the Northern North Pacific Ocean: *Jour. Geophys. Res.*, vol. 81, p. 3100-3110.
9. Seymour, R. J., 1996. Wave climate variability in southern California: *Jour. Waterway, Port, Coastal, and Ocean Eng.*, Amer. Soc. Civil. Eng., vol. 122, no. 4, p. 182-186.
10. Zetler, B.D. and R.E. Flick, 1985a. Predicted extreme high tides for mixed-tide regimes: *Jour. Phys. Oceanog.*, vol. 15, no. 3, p. 357-359.
11. Zetler, B.D. and R.E. Flick, 1985b. Predicted extreme high tides for California, 1983-2000: *Jour. Waterway, Port, Coastal and Ocean Div.*, Amer. Soc. Civil Eng., vol. 4, p. 758-765.