Tsunamis Affecting the West Coast of the United States 1806-1992

NGDC Key to Geophysical Records
Documentation No. 29

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Boulder, Colorado, U.S.A.

Cover: Detail from a wood block print by Hokusai Kasushika (1760–1849) from the series, *Thirty-Six Views of Mt. Fuji.*

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TSUNAMIS AFFECTING THE WEST COAST OF THE UNITED STATES 1806–1992

by

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Acknowledgements

This history of tsunami effects on the United States' west coast is an expansion for this geographic area of work previously done by Lander and Lockridge: *United States Tsunamis (Including United States Possessions) 1690 to 1988* (1989). In compiling that volume, there were many discrepancies and questions which could be answered by further research but our task was already large enough for the time available. Historical tsunami data for the United States west coast seemed both important and in need of substantial improvement.

The 1989 volume acknowledged our debt to earlier compilers including Kumizi Iida, Doak C. Cox and George Pararas-Carayannis, *Preliminary Catalog of Tsunamis Occurring in the Pacific Ocean* (1967); S.L. Soloviev, and Ch.N. Go, *Catalogue of Tsunamis on the Eastern Shore of the Pacific Ocean* (1975) and *Catalogue of Tsunamis on the Western Shore of the Pacific Ocean* (1974); and S.L. Soloviev, Ch.N. Go and Kh.S. Kim, *Catalog of Tsunamis in the Pacific, 1969-1982* (1992 English edition). The importance of their contributions relevant to this area can not be overstated. They provided the basic list of events, information on effects, and reference list. It is only rarely that new and usually minor events are added to the earlier histories. The revisions are more likely to eliminate errors and add details.

In addition to the general catalogs there are regional catalogs which we acknowledge. These include D.S. McCulloch, "Evaluating Tsunami Potential," (1985), Joseph W. Joy, *Tsunamis and their Occurrence along the San Diego County Coast* (1968); E.S. Holden, "A Catalog of Earthquakes on the Pacific Coast 1769 to 1897" (1898); John B. Trask, "Earthquakes in California from 1800 to 1864,"(1864); and C.G. Rockwood, "Notes on Recent Earthquakes" (1872 to 1885).

There are many scientific papers of great value on individual events or topics which are too numerous to mention here but are gratefully acknowledged at the proper places in the text.

We have often called on others for help, and they have responded generously. Stephen Gill, Chief of NOAA's National Ocean Survey's Product and Services Branch, James Hubbard, Chief of the Datums Section, and members of his group, notably Raymond Smith and William Cherry, have provided access to the vast archive of marigrams from 1854 to the present. The writing of this publication involved many visits to their offices to examine and copy original records. Similarly, Dr. Tousson Toppozada, California Division of Mines, gave of his expertise in preparing historical catalogs of California earthquakes and access to his files. There are many more who gave their time and expertise who are acknowledged at appropriate points in the text, and still others too numerous to individually thank. A debt is owed to the libraries in NOAA and to the many state, municipal, and university libraries in Washington, Oregon, and California.

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The principal support was from the National Science Foundation Division of Biological and Critical Systems Hazard Mitigation which provided financial support for a two year effort under project BCS–9208173. This made possible the researching of the original and primary references necessary to clarify the nature of the reported tsunamis and their effects.

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1.0 Introduction

1.1 Purpose

This catalog of tsunamis affecting the west coast of the United States was compiled to provide a more accurate and complete information base on these phenomena for scientific and hazard mitigation purposes. The catalog builds on the section treating the west coast in *United States Tsunamis, 1690 to 1988* (Lander and Lockridge, 1989). In the preparation of the earlier catalog many questions arose regarding tsunami events on the west coast of the United States that could not be answered without further research.

Detailed description information is included to better characterize the tsunami hazard. A simple listing of the occurrence, maximum heights, number of casualties, and dollar losses is not adequate to fully understand the hazard. This understanding is a necessary but not always observed first step toward mitigation.

1.2 Definition of Tsunami

Tsunamis are water waves generated by a sudden vertical displacement of the water surface. These waves travel as gravity waves with velocities dependent on the water depth. The term is a Japanese word pronounced by starting to voice a "t" and switching to "su-na-mi." In English the initial "t" is usually ignored with little effect on the pronunciation. This term is now preferred in the scientific realm, replacing "seismic sea waves"—a cumbersome phrase that has etymological problems. Not all tsunamis are caused by seismic disturbances (earthquakes). Some also feel that this term may be confused with seismic signals transmitted through the ocean water column as "sea quakes," a shaking felt on ships in the epicentral area of submarine earthquakes much as earthquakes are felt on land, or with a T-phase, the seismic energy transmitted great distances in the ocean's low-velocity acoustic channel, SOFAR (the sound fixing and ranging channel).

Tsunamis are most often incorrectly referred to as "tidal waves" by the general public. This term implies a relation with astronomically-generated tides. Tsunamis often do appear as rapidly changing "tides" and their effects are modified by the state of the tides. However, as a phenomena they are not related to tides. The tides are essentially governed by the gravitational attraction of the sun and moon.

Even the Japanese term "tsunami" is not without etymological problems. It literally means "harbor wave" and is used in Japan to include both the impulsively-generated gravitational wave *and* storm surges—waves and elevated sea level associated with hurricanes and typhoons.

Although tsunamis are sometimes confused with storm waves and storm surges, storm surges are the upwelling of the water surfaces under the extreme low pressures in the eye of a hurricane or typhoon which causes flooding when they come ashore. Storm waves are generated by strong winds operating over a long stretch of water (fetch) over time. They are surfacial and depend on the wind for their height and velocity. They may reach shore after the winds have stopped blowing and become confused with true tsunamis but are of much shorter periods. They may excite natural periods of bodies of water such as harbors and coasts with longer periods and be mistaken for tsunamis.

"Tsunami" was used in western literature in the first half of this Century to refer to meteorologically-induced waves *as well as* impulsively-generated gravity waves. The term is *now limited* to describing a single natural phenomena, a traveling gravity wave in water which was impulsively generated. Typically these are generated by sudden uplift or depression of the water surface by: (1) an uplift or drop of a large area of the ocean floor caused by a large earthquake; (2) a land fall into a body of water or movement of material on the bottom by landslides; or, (3) by several volcanic processes such as crater collapse under water, mass flows into the water, explosions, etc. The water, once displaced up or down, will move to regain its equilibrium. Once set in motion it may continue to move perhaps as far as to the opposite side of the ocean.

There is nothing in the definition of a tsunami about size. Large breaking waves popularized by the famous Hokosai picture (Figure 1) are rare and almost unheard of outside of the generating area. Most tsunamis, like most earthquakes, are small and detected only by instruments.

Usually the waves are observed on shore as a relatively rapid rise and fall of the "tide," or as surges with periods from between six to sixty or more minutes. In river channels they appear as bores, a wall of water from several inches to several feet high moving against the current. In harbors and harbor entrances they may appear as swift currents and eddies. The outgoing wave is likely to be stronger than the incoming wave setting up currents which may scour around bridge and pier supports.

The misconception that tsunamis are large, breaking waves leads to a communication problem between scientists, officials, and the public. As recently as April 28, 1992, the *Crescent City Triplicate*, which, because of its history with severe tsunamis would be expected to be more than usually informed, reported that "tides in Crescent City Harbor fluctuated two to four feet—but no tsunami was generated." The same misconception has appeared with every observed tsunami since 1946, even by government sources such as the United States Coast Guard.

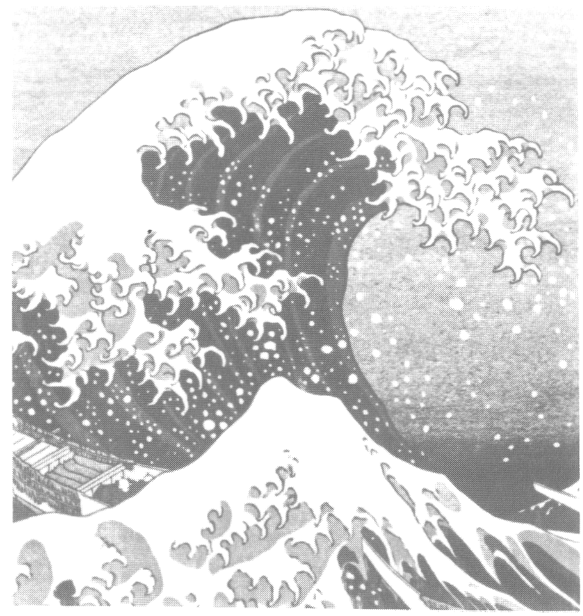


Figure 1. Detail from the wood block print by Hokusai Kasushika (1760–1849).

1.3 Other Definitions

1.3.1 Seiche. Pronounced "say-sh," this phenomenon is closely related to tsunamis but is a standing wave rather than a traveling wave. It is the "sloshing" as with water in a basin; these have periods depending on the length and depth of the water.

In nature, seiches can be generated by wind, water waves, and by seismic waves which impart energy to standing bodies of enclosed or partially enclosed water. If the periods of the forcing source approximate one of the natural periods of the body of water, it will begin to resonate.

The body of water can be a bay or harbor or a basin such as that formed by Channel Islands and the southern coast of California. Seiches are also formed in the shelf water with a node at the break into the continental slope. Tsunamis, as water waves, also generate seiches. Much of what is recorded on the marigram after the initial waves are really seiches.

1.3.2 Tsunami Magnitude. This is an attempt to characterize the strength of the tsunami based on the maximum wave amplitude at the source (Iida, 1963) or an average of amplitudes in the source region (Soloviev and Go, 1974). The tsunami magnitude (m_t) is given by

$$m_t = Log_2 \cdot H$$

where "H" is the maximum height reached in meters (Iida, 1963).

1.3.3 Tsunami Intensity. Since the maximum height is really a measure of intensity, Soloviev and Go's (1974) tsunami intensity for the source area, I_o is similar to the tsunami magnitude and is given by

$$I_o = Log_2 (\sqrt{2} \cdot H)$$

where "H" is the average height in the source area. These systems have several problems. They allow for negative magnitudes, a confusing concept for non-professionals and a minor problem for catalogers. These values are low with respect to the well-known earthquake magnitude scale. A tsunami magnitude of "5" does not convey a sense of great size in the public mind as a magnitude "8" does for earthquakes.

The variability of wave heights along the coast and the directionality of the waves to remote coasts are problems for determining a measure of their total energy implicit in a magnitude. Local tsunamis in semi-enclosed bays may have great heights such as in Lituya Bay (Alaska) in 1958 (1,725 ft. surge) but be confined to a small area.

Table 1. Tsunami Magnitude and Height Relationship

Magnitude (Mt)	Height (H)	
	meters	feet
-2 to -1	<0.30 to 0.75	<1.0 to 2.5
-1 to 0	0.75 to 1.50	2.5 to 4.9
0 to 1	1.50 to 3.00	4.9 to 9.9
1 to 2	3.00 to 6.00	9.9 to 19.7
2 to 3	6.00 to 12.00	19.7 to 34.2
3 to 4	12.00 to 24.00	34.2 to 79.0
4 to 5	24.00 to >32.00	79.0 to >105.0

1.3.4 Teletsunami. This is the preferred term for tsunamis observed at places 1,000 kilometers from their source.

1.3.5 Amplitude. There are several measures of the wave size in use. This volume uses amplitude in the physical sense to be the rise above or drop below the water level. Often it is determined as one-half the total observed rise or fall (wave height). A close reading of reports of directly-observed waves will usually resolve whether they are reporting an amplitude or height. The wave height is the more commonly-reported value in the literature although it is sometimes identified as "amplitude." The wave height relates more directly to the potential for generating currents, and the amplitude more directly to runup and flooding. In this publication the amplitude is given in feet for local observations as this is the most common unit in the original reports and the unit still in predominant use in the region. Meters are used for reports of amplitudes for foreign source regions as it is the internationally used unit. The event summary table (page 119) uses meters.

1.3.6 Runup. This is the measure of the height of the tsunami above a given reference level such as the height of the tide at the time of the tsunami, or mean lower low water (MLLW) or sea level if the tide level at the time of the maximum wave was not observed. It usually is greater than the amplitude since it is the highest combination of the tide and the tsunami.

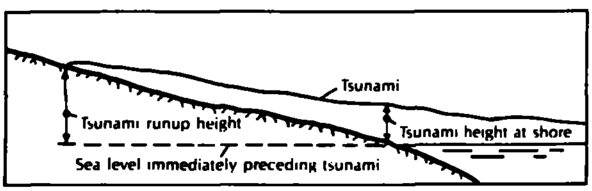


Figure 2. Illustration of runup height (modified from *Earthquakes, Volcanoes, and Tsunamis*, 1982, p. 233).

The MLLW datum is frequently used as it is the reference for coastal maps. Surveys done after the tsunami may report debris or water lines referenced to MLLW. These values represent the maximum runup but not necessarily the maximum wave. Most likely, the maximum runup will be a wave which arrived near high tide.

1.3.7 Period. This is the time between two successive crests or troughs. When available, the period is of the first cycle or largest wave and is given in minutes. The initial period is most representative of the source with longer periods up to sixty or more minutes associated with great tsunamis and short periods with small local tsunamis. The period of the largest wave allows for the calculation of the maximum currents expected. The period is one of the identifying characteristics of tsunamis. A tsunami period is intermediate between the periods of high-frequency storm waves and the twelve-hour tidal period.

1.3.8 Time. Local time units are used except for the initial date and time of teleseismic events. The local time is important as a factor in evaluating effects and responses and is the time reported by local observers. For early reports before the 1884 convention adopting standard zones of about fifteen degrees per hour, the times were given in sun time. Greenwich time can be calculated by dividing the degrees and decimal degree equivalents of the minutes and seconds of the longitude for a location by 15 for the whole hour and multiplying the decimal remainder by 60 for minutes and fractions of a minute and adding to the local time for west longitude. Thus, San Francisco at 122°17.9' W (122.298°) at 12 noon sun time would be 20 hours and 09.2 minutes Greenwich time. The time at San Diego would be 19 hours and 48.7 minutes or 20.5 minutes ahead of San Francisco time. This becomes important only when comparing times between the two localities or in calculating travel times between the source and point of observation when sun time is given. Time on the original marigrams is local time and for the early records this is sun time. In this century the records may have local time one hour ahead of standard time due to periods of "war time" and summer daylight savings time.

1.3.9 Arrival Time. This is the time of the arrival of the first wave of the tsunami at the location of the effects given in day, hour, and minutes. This is local time in the descriptive text and Greenwich time in the tables to facilitate calculation of travel times and comparison with other localities.

1.3.10 Travel time. This is the time in hours and tenths of hours that it took the tsunami to travel from the source to the location of effects. Figure 3 illustrates the wave height, amplitude, period, and arrival time.

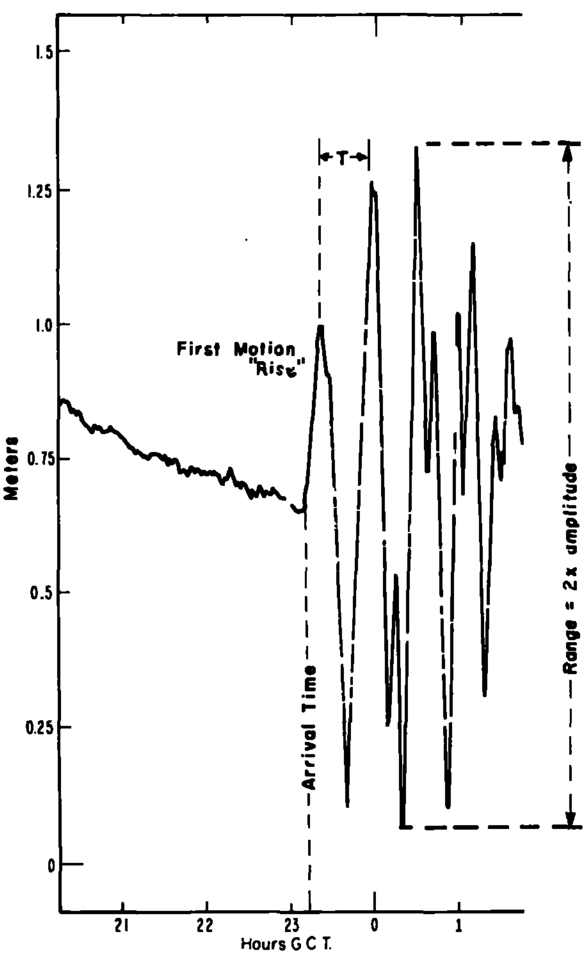


Figure 3. Marigram illustrating arrival time, first motion, period, range, and amplitude.

1.4 Tsunami Characteristics

Great tsunamigenic earthquakes are believed to elevate a block of the ocean floor which may be 600 miles in length and over one hundred miles in width. Once a displacement has occurred the water acts under gravity to regain its equipotential. The resultant displacement of the sea surface causes an outflowing (or inflowing) of water as it seeks to regain its level. The outflow has a velocity (v) which is proportional to depth of the water (d) and the gravitational constant (g) such that:

$$v=\sqrt{gd}$$

In 21,660 foot deep water and gravity at a constant of 32 feet/sec^2 the wave will be traveling at a speed of 568 miles/hr. Once generated, tsunamis can travel for great distances. Although in the deep ocean the speed may exceed 500 miles per hour they may travel for hours or more than a day before striking the distant shore. The May 28, 1960, Chile tsunami reached Japan, 10,680 miles away after traveling 23 hours. Waves with amplitudes of over ten feet struck the coast causing two hundred fatalities and extensive damage.

As the wave reaches the coast the velocity decreases since it is a function of the water depth. This causes the wave to increase greatly in height. This fact is the justification for evacuation of boats to deeper water where waves are lower—a good strategy if there is enough time to clear the harbor.

Tsunamis are strongly directional in their propagation away from the source. For tsunamis generated by great earthquakes the source region may be several hundred miles long parallel to the coast and some tens of miles wide. The tsunamis energy is directed both toward the adjacent coast and in the opposite direction. A consequence of the directionality is that the adjacent coast suffers the greatest effect. The effect may decrease quickly away from the epicentral area but areas diametrically opposite the epicentral area may also suffer greatly.

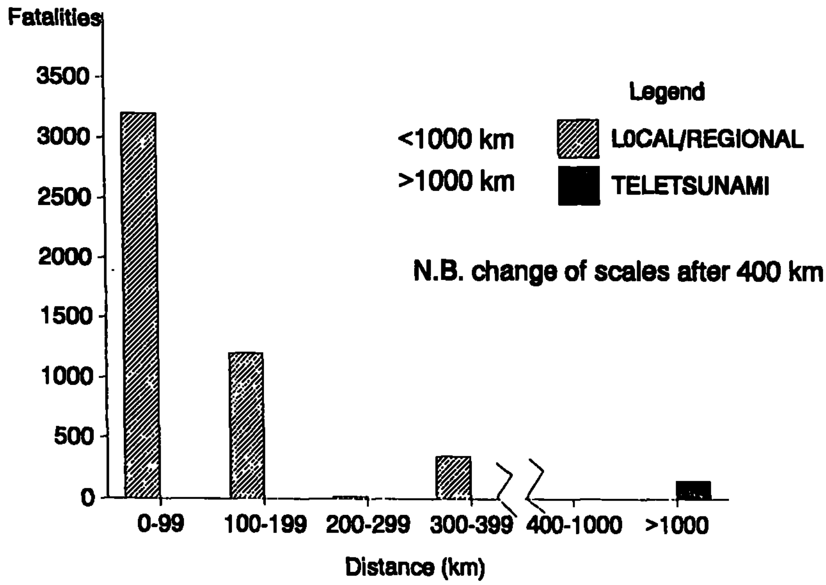


Figure 4. Fatalities caused by tsunamis in the last hundred years, as a function of distance from the source region. Note change in scale after 400 km and that most fatalities occur within 400 km of source.

Those far-ranging waves, called teletsunamis, may be steered by variations in depth including submarine ridges and focussed by convergence due to the spherical great circle paths the waves follow. Thus, waves generated by great earthquakes along the Alaskan peninsula (such as the 1964 event) are aimed directly at the west coast of the Unites States. Tsunamis generated along the southern Mexican coast are aimed to the sparsely inhabited South Pacific and away from populated areas.

The severity of the effects close to the source can be seen in Figure 4. Most fatalities occur within 250 miles (400 km) of the epicenter of a tsunamigenic earthquake.

Figure 5 (next page) shows the wave amplitude for the 1946, 1960, and 1964 tsunamis on the west coast. The directionality effect may be discerned in that Crescent City was nearly directly opposite the 1964 Prince William Sound, Alaska source while Half Moon Bay was opposite the 1946 Aleutian Island source. The 1960 event from Chile affected southern California relatively strongly.

The wavelength, (λ), the distance successive between peaks or troughs, is given by

$$\lambda = v \cdot t$$

where v is the wave velocity and t is the period. The initial period is believed to be related to the size of the original uplift and usually is between 15 minutes and one hour. Thus the wavelength would be 100 miles for a wave with a velocity of 200 miles/hour and a period of 0.5 hours (30 minutes). In the open ocean the wave's long wavelength and low amplitude make it invisible to the human observer but it is now detectable by sensitive ocean bottom pressure gages. Thus, knowing the depth of the ocean, it is possible to calculate the travel time of the wave between any two points. Figures 163 to 167 (Section 7.0, page 217) give the travel time charts for La Jolla, San Pedro, San Francisco, and Crescent City, California and Neah Bay, Washington. These maps can be used to compute the expected arrival times of tsunamis from distant origins if the earthquake epicenter and origin time are known. Approximate arrival times at other localities can be determined by interpolation between expected arrival times at mapped locations.

At Crescent City, California, in 1964 the first wave was 4.8 feet in height while the fourth and largest wave was 20.8 feet. The effect of the state of the tide is also an important factor. A smaller wave coming at high tide may have a larger runup than a larger wave at low tide. Waves arriving at high tide can cause more flooding damage, but waves arriving at low tide can also be dangerous, particularly where people engage in clamming, abalone diving, and bottom fishing.

Unusually low tides may attract people to the shores to gather shellfish. Unaware of an approaching tsunami, some may be tempted out onto the newly exposed sea bottom due to the retreat of the water (tsunami trough) to gather stranded fish or to explore the strange new landscape. The returning waves cannot be outrun.

In protected harbors such as San Francisco Bay the tsunami danger relates mostly to the change in the height of the water rather than to the tide stage as it is the currents in the harbor rather than flooding that cause damage.

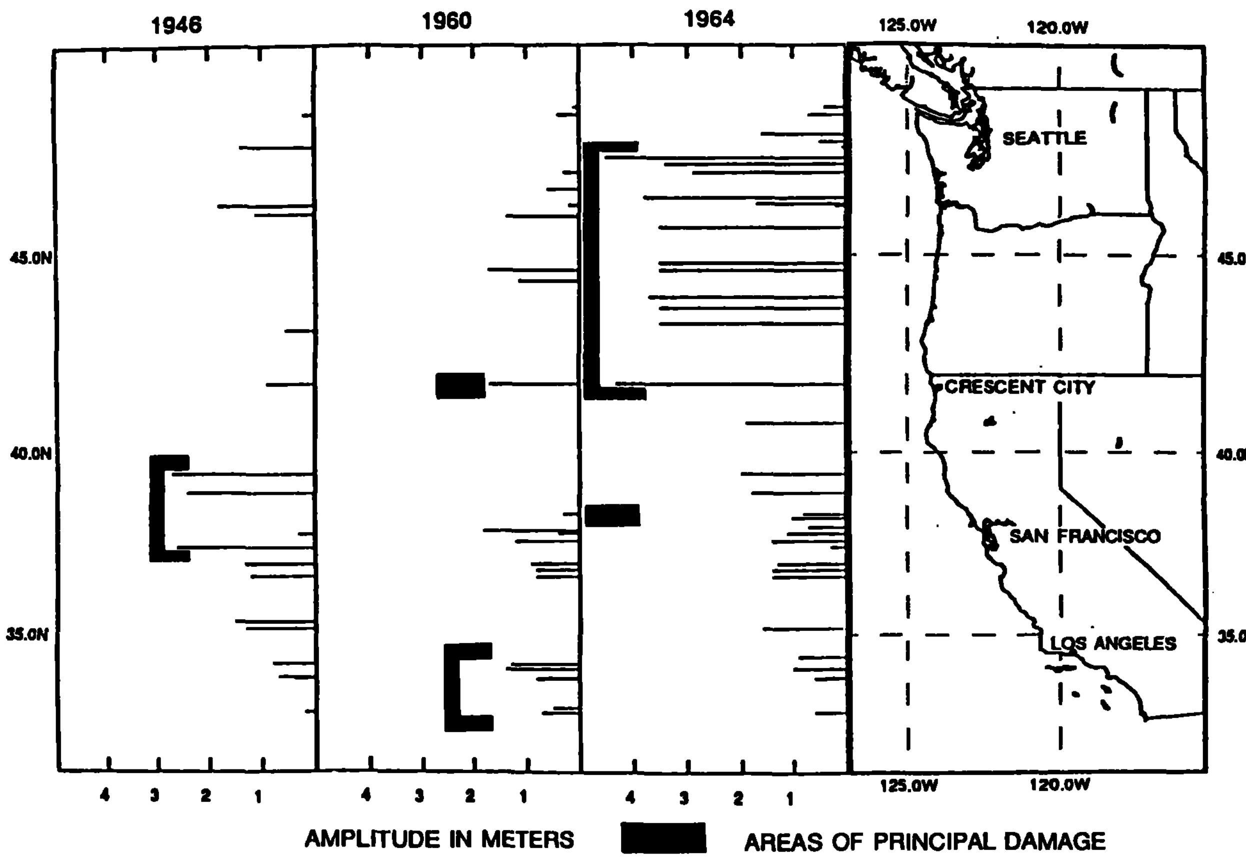


Figure 5. Tsunami amplitudes at selected localities along the west coast of the United States for the tsunamis of April 1, 1946, in the Aleutian Islands; May 22, 1960, in Chile; and March 28, 1964, in the Gulf of Alaska.

Many marinas and harbors are not designed for the currents which can be set up by the 15 to 30 minute period waves. Tides with 12 hour periods produce much lower currents. Storm waves with periods of less than a minute do not have time for the mass movements of water to set up strong currents.

The waves may travel miles up rivers often as bores with near vertical or stepped wave fronts.

Later arriving tsunami waves are more complicated. The earlier waves may set up resonances of several natural periods of the harbor or resonances between the coast and the continental slope. The sudden increase in tsunami velocity beyond the continental slope acts as a boundary and reflects the waves back. Waves with different periods may periodically coincide and reinforce each other.

There is nothing in the definition of a tsunami to restrict them to oceanic areas. Landslides into bays and reservoirs set up an identical phenomena. Their affects are usually limited to the immediate area. On Franklin D. Roosevelt Lake, formed by Grand Coulee Dam, landslides have continued since 1944 with waves reaching 65 feet on the opposite shore.

Many submarine landslides are associated with submarine canyons. The material for these slides may come from the capture of laterally transported sediments or may be part of the canyon growth process from collapses of eroded canyon walls.

Tsunamis may be generated by subaerial or submarine landslides which are triggered by seismic shaking or from non-seismic instabilities. It is usually impossible to determine a tsunami's

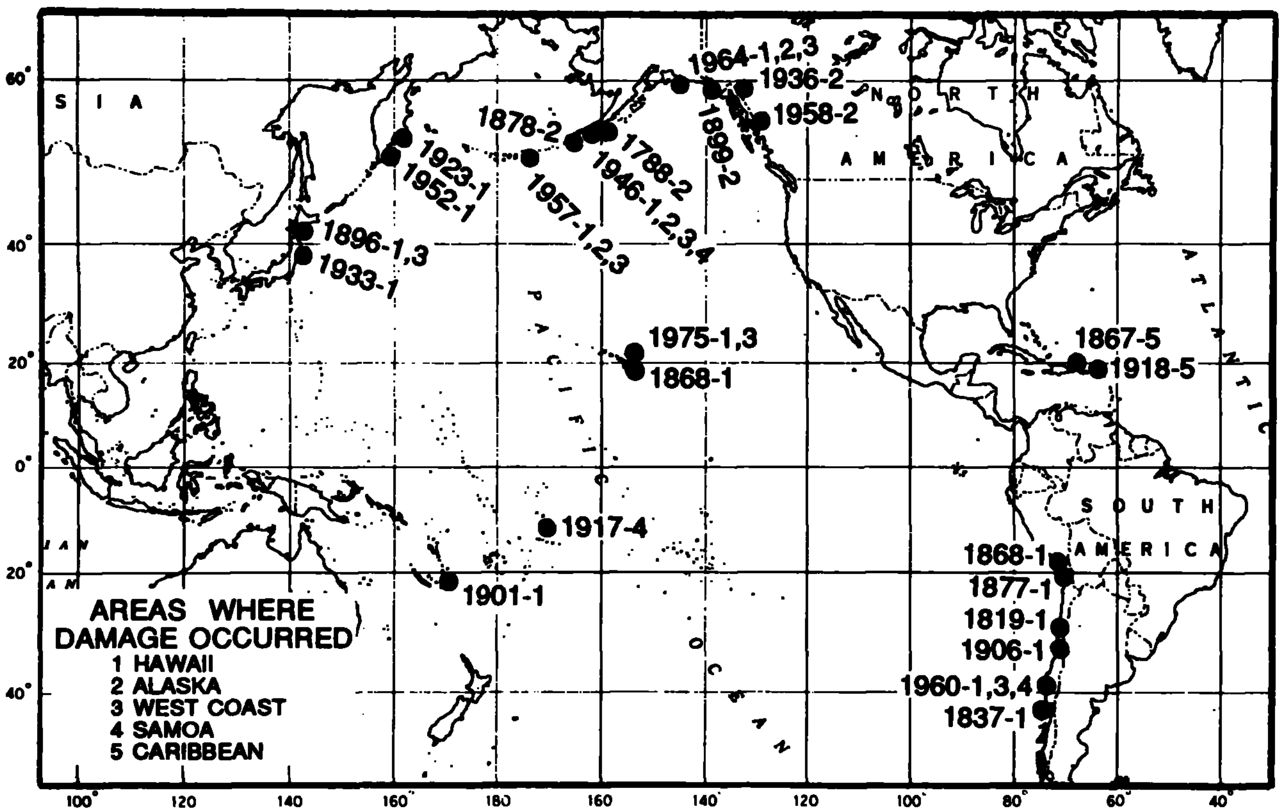


Figure 6. Location of tsunamis causing any damage to the United States and possessions. Only those with a "3" following the date affected the U.S. west coast.

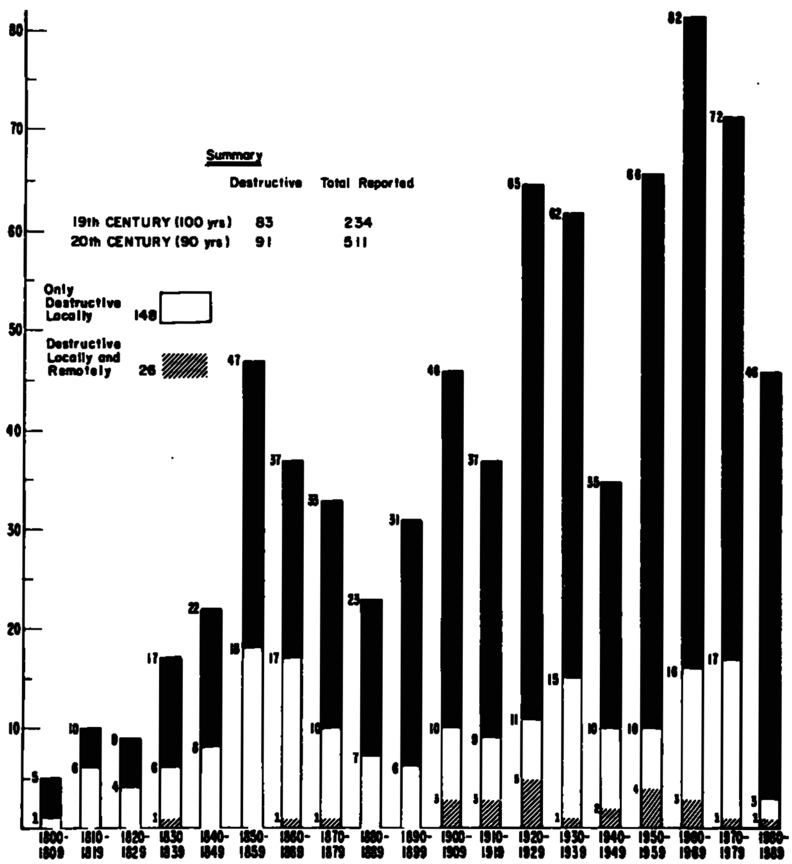


Figure 7. Number of tsunamis per decade reported since 1800. Increase following 1850 probably reflects beginning use of tide gages. Drops during 1910 and 1940 decades probably reflect decreased reporting during war years.

primary cause, particularly when an earthquake has occurred.

Some clues for a submarine landslide source include: earthquake epicenter on land or not near the waves, relatively low magnitude for a tsunamigenic earthquake, seeing the water flow out forming a mound, broken submarine cables, and the disappearance of sandy spits.

The combination of late arriving tsunami waves, and reflection, seiche resonance, and changing tides can keep a coastal area in a hazardous state for more than a day after a major Pacific-wide tsunami. In 1964 a man was drowned at Duxbury reef near Bolinas, California, thirteen hours after the first wave. These late arriving surges are also hazardous to the clean-up efforts. Two men were killed by crane failures probably due to over-loading caused by the sudden changes in sea level.

1.5 Occurrence

Figure 6 shows the distribution of tsunamis causing damage to U.S. territories. Note that only the 1946 and 1957 Aleutian tsunamis, 1960 Chile, 1964 Alaska, 1952 Kamchatka, and 1975 Hawaiian tsunamis caused any damage on the U.S. west coast and most of the damage was due to the 1964 tsunami.

Most tsunamis are generated in the near shore areas of lands bordering the Pacific. Earthquakes and volcanoes are common in the great "Ring of Fire" stretching along the coast of the Americas from Chile to Asia and southward from Siberia through Japan, and the Philippines to New Zealand. This "ring" marks the boundaries of plates of the Pacific Ocean where they are being subducted under the continental land masses. Tsunamis also occur in the Indian Ocean, particularly in Indonesia; in the Mediterranean and Caribbean Seas; and rarely in the Atlantic Ocean.

Figure 7 (previous page) shows the distribution of tsunamis and damaging tsunamis per decade. Tsunamis are a relatively rare phenomena even in the Pacific Ocean basin where one per year is observed (on the average) and only one per decade causes substantial damage in locations around the Pacific Ocean. Tsunamis are even more rare on any segment of the basin margin such as the west coast of the United States.

However, with the growing settlement and development of the ocean front it is important to have a long tsunami history in order to evaluate the tsunami hazard. Figure 8 shows the frequency of tsunamis affecting the U.S. west coast by decade. Note that the history essentially begins with the 1850's and the anomalous high number of local events in the early decades.

1.6 Warning Considerations

Teletsunamis, those which affect coasts more than an hour's travel time from their sources, offer some additional opportunities for mitigation. As a rule they are generated only by energetic sources such as major earthquakes which can be detected soon after occurrence. If the tsunami-generating earthquake can be located quickly, remote sites can be warned of the possibility of a wave being generated. Report of wave effects near the source can confirm the generation of a tsunami and there is time for warning and evasive action. Ships can leave for deep water where the tsunamis are harmless. Warning can be given to coastal inhabitants, workers, and visitors for evacuation to higher ground.

These mitigation possibilities led to the establishment of the Seismic Seawave Warning Center, now the Pacific Tsunami Warning Center, in 1948. Unfortunately, even at this stage (1993) in the development of a warning service, it is not possible to predict with high precision or certainty the height of the expected wave.

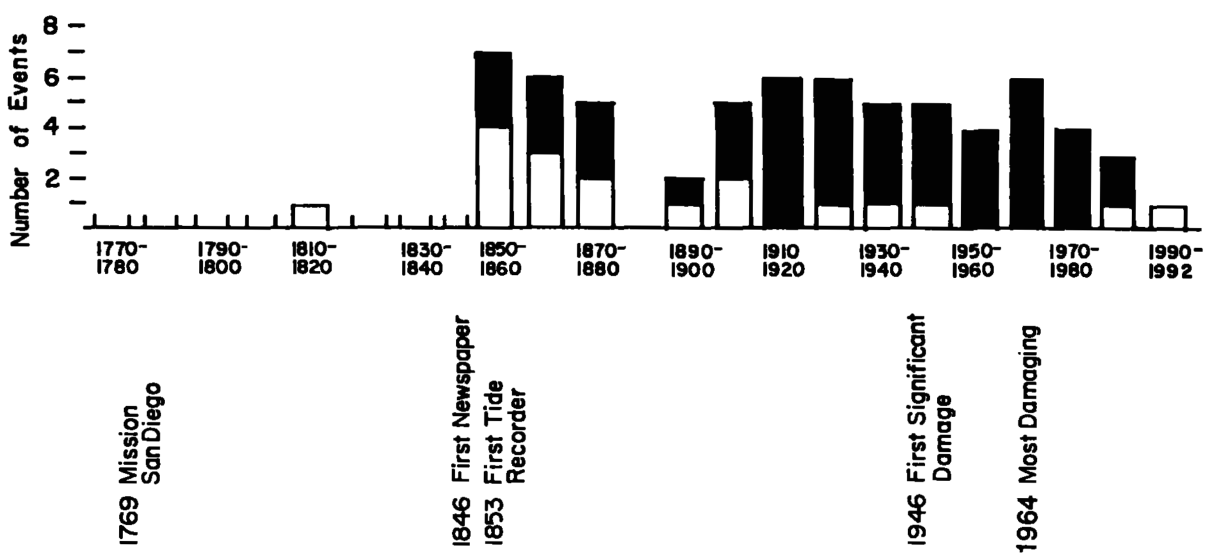


Figure 8. Frequency of occurrence of tsunamis observed on the U.S. west coast, per decade. Forty-six teletsunamis (black bar) are represented, and 18 local tsunamis (white bar), exclusive of Roosevelt Lake area tsunamis.

Since most tsunamis are small, this results in a high percentage of "false alarms." This is costly in terms of man hours of emergency personnel, business down-time, and evacuation expenses (especially for large ships). This also results in inappropriate action such as refusal to evacuate, returning to closed businesses to move stock or records, or just flocking to the shore in hopes of seeing this rare phenomena.

With the use of historical accounts of earlier tsunamis (such as this publication) and mathematical models, it should be possible to predict at least rough classifications of tsunami wave heights from a given source region, for given localities. This would be a most useful addition to the warning.

Local tsunamis, those adjacent to the generating area or generated by less energetic sources such as volcanoes or landslides, need to be treated separately as the effects may be quite severe locally but affect only a limited area. They may reach the coast in a few minutes, leaving little time for reaction. The prudent action is to leave a coastal area for higher ground immediately after feeling an earthquake. It is nature's warning. Similarly, if the water is seen to withdraw or to rise rapidly one should immediately seek higher ground. The returning wave or following waves could be much larger.

In 1958 a collapse of a fjord wall in Lituya Bay sent a surge of water up the other side clearing trees to a height of 1,725 feet and sending a 100-foot wave down the bay. Outside of the bay it was barely recorded at Hawaii. Since each locality has unique wave characteristics, effects, and reaction times, each must be separately studied.

1.7 The Tsunami Validity Scale

Reports of tsunamis and their effects may be more or less accurate. Errors may be introduced in later histories by simple transcription errors. Rewording of original reports also changes the interpretation.

For example the March 19, 1855, report states "*...in the vicinity of Buckport (Eureka) it having dried up the water in the branches and creeks for at least half an hour. At Angel's Ranch twelve miles north of Arcata, it shook the milk out of pans. Here, the water lying in holes was considerably agitated*," became "The water in Humboldt Bay was *agitated for an hour*" by the time it was reported by Soloviev and Go (1974) relying on an earlier report and repeated by Lander and Lockridge (1989).

There are several phenomena which may be confused with tsunamis including local storm waves, earthquake-induced seiches, remote storm-generated waves, astronomic tides, and meteorologic microbursts (see 1910 event, and also Section 1.2, Definition of Tsunami).

To quantify this uncertainty, a validity scale has been devised (Soloviev and Go, 1974; and Cox and Morgan, 1977). The continuum from almost certainly not a valid tsunami report (validity 0) to almost certainly a valid tsunami report (validity 4) is divided into five steps:

- 0 Not a valid tsunami report
- 1 Probably not a valid report
- 2 Possibly a valid report
- 3 Probably a valid report
- 4 Certainly a valid report

The criteria for assigning a validity are not fixed. Some factors include:

Validity 0: Date is proven to be in error; source of water disturbance is known to be from a meteorological or an astronomic tide source; reported tsunami effects shown to be in error in later documents which are based on primary references.

Validity 1: Duration of disturbance over several days without reports from distance locations; lack of clear report of wave activity, i.e. water "disturbed" or "shipping affected;" probable source not tsunamigenic; reports of winds, and/or waves at sea.

Validity 2: Insufficient information, single non-expert observation, descriptions not clear, i.e. shipping rolled, water agitated, etc.; source uncertain.

Validity 3: Reports associated with probable seismic or other cause; descriptions from several independent sources; descriptions of waves in the 10-30 minute period range.

Validity 4: Well-known source; well-recorded at more than one tide gage with a clear arrival at expected travel time, and/or observed at widely separated places.

In general, reports with validity 0 and 1 can be ignored for tsunami evaluations. They are included here so that it will be known that they were examined. Validity 2 can also be ignored unless the event is critical to the particular study where additional research may be needed. Validity 3 and 4 reports can be used with a fair degree of confidence although even those with a validity 3 may need a critical re-evaluation if they are key to a study. These validities are based on the authors'judgment of the available reports but other reports may be discovered or other evaluators may come to a different conclusion.

In this report the validity is for the material reviewed and referenced. The validity is usually for the tsunami event but occasionally the validity may be an evaluation of the authenticity of tsunami occurrence at a given location. A known tsunami in Japan, for example, (validity 4) may have a spurious report (validity 0) of effects on the west coast of the United States but this will be clear in the text.

1.8 Methodology

This compilation is based principally on the events identified in Lander and Lockridge (1989) which was based on earlier catalogs and regional studies, notably Soloviev and Go, 1974. From this list each event was researched for its earliest reference. This process occasionally led to new events such as the 1806, 1840, 1854, 1873, 1891, 1898, 1901, and 1949 events, but a general search for new events was not undertaken. Also while many analytic studies are referenced there are many others relevant to the study of tsunamis such as inundation modeling, coastal and harbor resonance, geology, tectonics, wave effects, submarine landsliding modeling, etc., which were not consulted. The objective of this study was to collect reports of tsunami observations and effects and to evaluate them for validity.

Additional reports were sought from contemporary sources, principally newspapers and marigrams. Most contemporary newspapers available were examined for the periods of interest. Undoubtedly, some accounts were missed as early newspapers often mentioned earthquakes and associated waves embedded in a long general news section some days after the event. Newspaper references are given at the appropriate places in the text and are deemed complete enough not to be repeated in the Reference Section. Other citations are carried in full in the Reference Section.

The substantive part of this report starts with Section 3.0 which separately considers local tsunamis, teletsunamis and reservoir tsunamis with a list of events, a brief description of effects for significant events, and general conclusions. A more complete description can be found in the Description of Tsunami Events (Section 4.0) which lists all events in chronological order.

Table 12, which summarizes all of the events in chronological order listing location and their reported effects given in meters, is in Section 5.0. Marigrams are displayed in Section 6.0, and Section 7.0 has travel time charts which have been published for west coast locations.

City and town place names are indexed following the References. This allows a user to find places in the text for west coast locations where a certain place name appears.

Damage values are for the dates of the event and not corrected to a common date.

2.0 History and Tectonics

2.1 History of Settlements

The coast was visited and explored by Cabrillo in 1542, and visited by Francis Drake in 1579 (Drake's Bay). Monterey Bay was explored for a possible settlement site in 1602 by Sebastian Vizcaino. The region was visited by other Spanish ships plying between Mexico and the Philippines and explorers searching for a northwest passage around North America. These early visits were so brief that there was only a remote chance that a rarely occurring tsunami would have been observed.

The first permanent settlement was the mission at San Diego established by Father Juniper Sierra in 1769. Twenty other coastal missions had been established by 1823.

The settlements usually consisted of the religious missions to minister to the local Indians, the military presidios for protection, civilian rancheros, and pueblos for traders and other civilians. Pueblos were established at San Jose in 1777, Los Angeles in 1781, and Yerba Buena (San Francisco) in 1776.

The mission period peaked shortly after the last mission was built in 1823. By 1834 the secularization of the mission lands had begun and was completed after 1840. Mexico become independent from Spain in 1810 but California did not officially become a Mexican province until 1822. Although there are numerous reports from this period, the sea was not a major concern nor would official or church reports likely deal with minor fluctuations of the sea.

The Russians had established their first permanent settlement in a Alaska by 1784 and established Fort Ross, north of San Francisco, in 1812 to supply its growing Alaskan fur enterprise. Fort Ross was located on a bluff with only limited access to the sea. Most shipping was handled at Bodega Bay to the south and hauled overland. Fort Ross was abandoned in 1841 with the decline of the fortunes of the Russian American Company. A search of Russian documents relevant to Fort Ross did not find any mention of tsunamis.

American trappers arrived in San Gabriel in 1828 and settlers began to arrive in 1841. California became a U.S. territory following the war with Mexico in 1848.

The discovery of gold at Sutter's Mill in 1848 led to a mass immigration of 90,000 people in 1849. San Francisco became a booming port of entry. Newspapers began publishing in 1846 at Monterey and in San Francisco. Their numbers expanded rapidly. By 1854 automatic tide recording instruments (tide gages or marigraphs) were installed at San Diego and San Francisco, California, and at Astoria, Oregon, the first on the Pacific Ocean basin. These events mark the real beginning of recording tsunami observations.

In Oregon, Lewis and Clark spent the winter on the site of Fort Clatsop at the mouth of the Columbia River in 1805–1806, and John Jacob Astor established a fur trading post at Astoria in 1811. Settlers began arriving in the territory in 1843.

The Spanish settled Neah Bay, Washington in 1791 but abandoned it five months later. Spain abandoned its claim to Washington and Oregon in 1818 which was jointly occupied by the United States and Great Britain until the present boundary with Canada was adopted in 1846.

The coast along much of northern California, Oregon, and Washington remains sparingly populated with most of the population in sheltered harbors such as Humboldt Bay, Grays Harbor, and Willapa Bay.

2.2 Tectonic Setting

In very broad terms the coastal tectonic framework of North America related to tsunamis consists of a young subduction zone comprising the Aleutian Islands arc and continuing into Prince William Sound. It has active volcanoes, a well-defined bathymetric trench with high seismicity, and earthquake focal depths of up to 170 km. In this zone typical tectonic tsunamis are generated which affect the whole Pacific Basin.

Eastward and southward is a seismically less active zone characterized by a normal fault system (including the Fairweather fault) capable of large magnitude earthquakes but with epicenters on land. Local tsunamis are typically generated by subaerial and submarine landslides within the fjords and coastal waterways.

From about the northern limit of the Puget Sound to the Mendocino escarpment is a unique zone in many ways typical of an eastern Pacific type subduction zone or perhaps a dying subduction zone. Off-shore is a series of spreading zone segments making up the Juan de Fuca fracture zone, ending to the south at the Mendocino escarpment. With the North American plate to the east this defines several small plates: the Gorda Plate and the Cascadia Plate which may be further subdivided.

There is considerable research on this feature regarding its potential to produce a great earthquake and great tsunamis. Spreading zone earthquakes historically have not produced tsunamis and the present day offshore seismicity is largely associated with the spreading zone. The zone lacks a bathymetric expression of a trench and significant associated seismicity.

On-shore seismicity is mostly concentrated in the Puget Sound area at focal depths up to 70 km and has caused several small subaerial and submarine landslide tsunamis within the sound. A recent (April 25, 1992) small tsunami was generated tectonically at the south boundary of this zone where the San Andreas system bends to form the Mendocino Escarpment. It appears to be unique in having been propagated parallel to the coast, with no visible waves on the adjacent coast.

A recently found report of a probable small tsunami near Port Orford, Oregon in 1873 may have had a tectonic or landslide origin.

South from Cape Mendocino to near Puerto Vallarta, Mexico, is a zone dominated by the strike-slip San Andreas fault system. It closely follows the coast through Tomales Bay and crosses the California coast at Mussel Rock, southwest of the Golden Gate. A branch, the Hayward fault, follows along the East side of the bay. There are many offshore faults south of Point Arguello where the coast swings eastward including those forming a basin with the Channel Islands as the Western edge. The San Andreas fault is offset by the Garlock fault before continuing south through Imperial Valley to the Gulf of California.

These faults are mostly on land and the major movement is strike-slip which usually does not produce tsunamis. However, some of the faults off the shore of Southern California are normal or thrust type which may be capable of producing small local tsunamis.

Figure 9 locates these features along the U.S. West Coast.

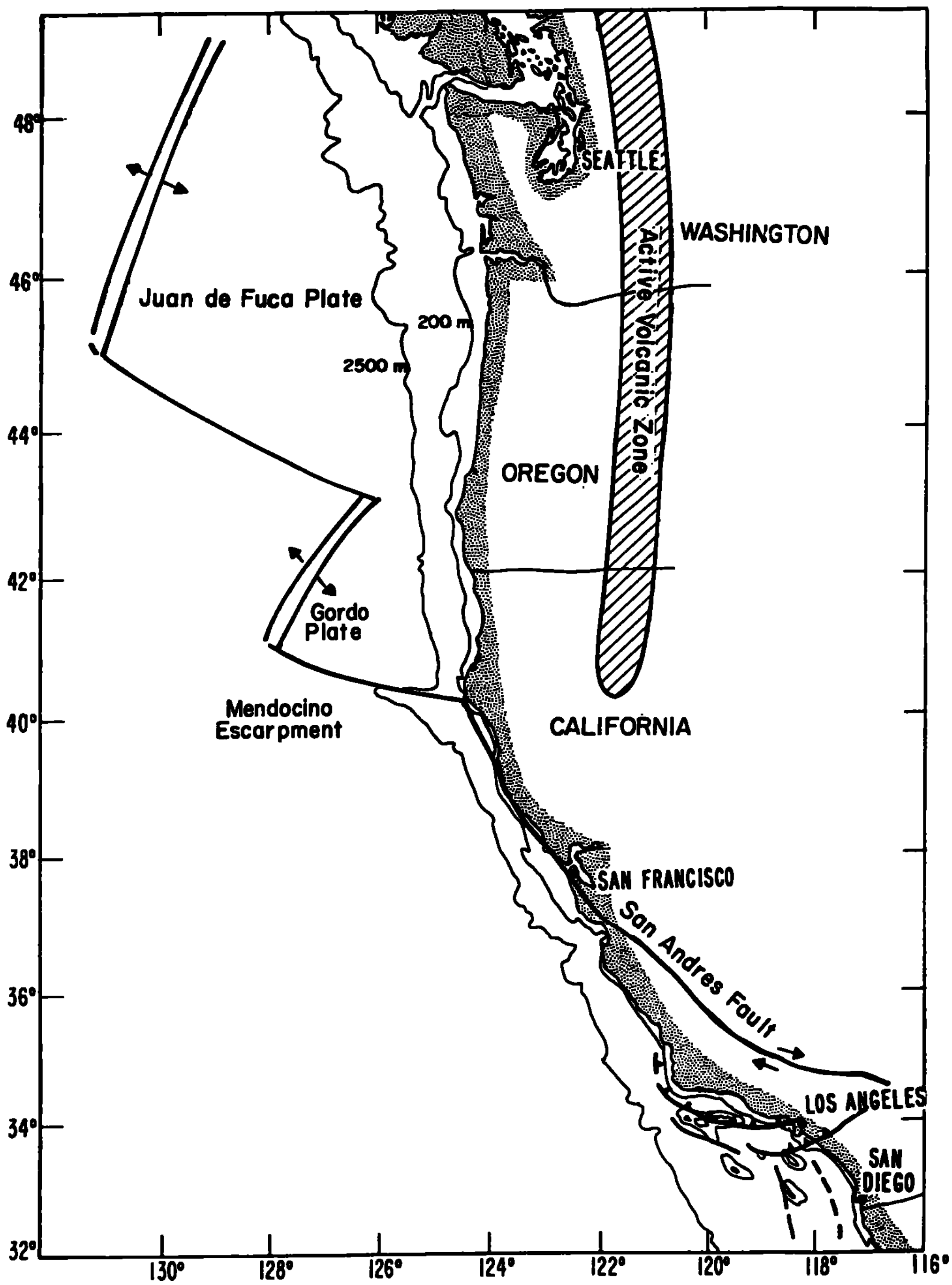


Figure 9. Major tectonic features of the U.S. west coast.

3.0 Summary and Evaluation

3.1 Local Tsunamis

Table 2 lists 52 events reported as local tsunamis or possible local tsunamis, exclusive of a long-term series of landslide tsunamis in Franklin D. Roosevelt Lake behind Grand Coulee Dam which are treated separately on page 30.

Of these listed events, 18 are judged to be of validity 3 or 4, probable or almost certainly true reports. Subaerial and submarine landslides were the cause of 12 to 16 of these. There was one tsunami with probable tectonic source—1992 (2.5 feet)—and three, 1873 (10 feet), 1906 (4 inches), and 1927 (six feet), for which a tectonic or landslide source seems possible. One event, 1989, probably had a mixed tectonic and submarine landslide source.

The 1812 event was the largest and effected a known length of 55 miles of coastline. It is the only validity 3 or 4 tsunami for the Mission Period of 1769 to 1850. The 1878 event caused the earliest reported fatality and the 1930 event also caused a fatality. (Neither of these fatalities were reported in earlier catalogs.) Damage occurred with the 1812, 1878, 1927, 1930, 1949, and 1992 tsunamis, but the damage was limited in amount and area.

Table 2. Local Tsunamis and Possible Local Tsunamis
[an asterisk (*) indicates a new entry—not in earlier catalogs]

Date	Location	Val.	Cause	Max. Amp. (ft.)	Comments
1806 Mar. 24-25*	Santa Barbara	2	?		Local earthquake Boats beached
1812	San Francisco	1			Plaza flooded? Erroneous report
1812 Dec. 21	Santa Barbara	4	Submarine landslide	8.5	Low areas flooded
1840 Jan. 16-18	Santa Cruz	0	Meteorologic		Material washed away
1851 May 15	San Francisco	1	Seaquake		Shipping rocked
1851 Nov. 12	San Francisco	1	Seaquake?		Unusual water movement
1852 Nov. 24	San Francisco	0			No wave reported Lake drained, bay disturbed
1854 May 31*	Santa Barbara	3	Landslide?		Light earthquake, sea swell
1854 Oct. 21	San Francisco	3	Landslide?		Vessel heaved

Date	Location	Val.	Cause	Max. Amp. (ft.)	Comments
1854 Nov. 1	San Francisco	0			Wrong date (Nov. 1) Waves at Angels Island
1855 Mar. 19	Humboldt Bay	1			No waves reported
1855 Jul. 10	Los Angeles	3	Submarine landslide		Earthquake on shore Two heavy swells
1855 Oct. 21	San Francisco	0			Duplicate of Oct. 21, 1854
1856 Feb. 15	San Francisco	3	Submarine landslide		Earthquake, water muddy Bay rose for five minutes
1859 Sept. 24	Half Moon Bay	2	Minus tide		Ship damaged
1861 May 4	San Francisco	0	Astronomic tide		Unusually low tide
1862 May 27	San Diego	4	Subaerial landslide	3	Earthquake generated wave on beach
1865 Oct. 8	Santa Cruz	3	Subaerial landslide		
1866 Dec. 20	Port Townsend, WA	0	Meteorologic	10-15	Flooding
1868 Oct. 21	San Francisco	3	Landslide?		15-20 foot runup
1869 Feb. 10	San Francisco	1			Storm noise on record
1872 Mar. 26*	San Pedro	0	Seaquake		Ship affected
1873 Nov. 22*	Port Orford, OR	3	Tectonic or landslide	10	Waves observed and debris above highest water mark
1875 Oct. 12-14*	San Francisco	0	Meteorologic		Waves on 12th, Earthquake on 14th
1877 Apr. 16	Cayucos	1	Meteorologic	6	High waves
1878 Nov. 22	San Luis Obispo	3	Submarine landslide		Damage, one fatality
1879 Aug. 10	Santa Monica	2	Submarine landslide		Earthquake and tidal wave
1887 Jul. 8	San Francisco	2	Landslide	0.2	Recorded
1891 Nov. 29*	Puget Sound, WA	3	Landslide		Two or more separate waves
1895 Mar. 9,30	San Miguel Island	2	Subaerial landslide		Wave uncertain
1895 July	San Miguel Island	1	Landslide		Wave uncertain

Date	Location	Val.	Cause	Max. Amp. (ft.)	Comments
1896 Dec. 17	Santa Barbara	0	Astronomic tide and meteorologic		Damage
1898 Mar. 30*	San Francisco Bay	2	Meteorologic		High waves at Oakland ferry houses; no damage
1899 Dec. 25	S. California	1	Meteorologic		Recorded surf noise
1901 Mar. 2*	Monterey	3	Submarine landslide		Epicenter near Parkfield
1904 Mar. 30	Washington coast	0	Meteorologic		River flooding
1906 Apr. 18	San Francisco	4	Submarine landslide or tectonic	0.3	Small recorded wave
1906 Aug. 7*	San Diego	2	?	0.07	Recorded
1906 Nov. 6	45 mi. off Washington coast	0	Meteorologic		Observed by ship at sea
1910 Nov. 21	San Francisco	0	Meteorologic		Local disturbance recorded, observed
1923 Jan. 22	Cape Mendocino	1	Seiche	0.1	Recorded
1923 Sept.	S. California	0	Meteorologic	20	Damage & fatality
1925 Oct. 4	Long Beach	1	Meteorologic	1.1	Very regular waves
1927 Jan. 1	San Pedro	1	Meteorologic	0.07	Damage & fatality Earthquake & storm wave
1927 Nov. 4	Point Arguello	4	Tectonic or landslide	6	Byerly field investigation Minor damage to railroad
1930 Aug. 30	Santa Monica	3	Submarine landslide	10	1 killed, 16 rescued
1933 Mar. 10	Long Beach	1	Meteorologic	0.1	3 killed on Recon plane crash, recorded
1934 Aug. 21	San Diego	1	Meteorologic	20	Damage, injured, recorded
1941 Feb. 9	N. California	0	Meteorologic		Recorded
1949, April 13 and April 16*	Seattle, and Tacoma, WA	3 and 4	Submarine-subaerial landslides	4	Minor damage 11,000,000 cubic yards
1989, Oct. 19*	Loma Prieta, CA	4	Tectonic and submarine landslide	3.3	Recorded
1992 Apr. 25*	Cape Mendocino	4	Tectonic	2.5	Recorded Minor damage

3.1.1 Summary of Validity 3 and 4 Local Tsunami Events

1812, December 21, Santa Barbara, California. The submarine landslide source is based on the report that "the sea was seen to retire and form a high hill and the people fled in fear of its return." A tectonic source of initial withdrawal (down dropped block) followed by an elevation (upward movement) is not reasonable. The intensity of VIII for Santa Barbara is low if they were very near to the epicenter. Wave amplitudes were judged to be about 8.5 feet at El Refugio (Gaviota) and three feet at Santa Barbara and Ventura after reducing the runup height for a three-foot tide at the time of the earthquake. Earlier reports had put the wave height erroneously at 50 feet at El Refugio. San Miguel Chapel at Santa Barbara located 15 feet above sea level (12 feet above high tide) may have been flooded. The total distance between Ventura and El Refugio—the extent of reported observations—is about 55 miles but given the height at these end points, the wave would have been observable over a greater range had there been more settlements. The wave was also probably observed in Hawaii. Validity 4.

1854, May 31, Santa Barbara, California. Heavy swell passed 30 feet (inundation) beyond an old wreck. Moderate earthquake felt. Trask (1856) is the sole source of the report. Submarine landslide source. Validity 3.

1854, October 21, San Francisco and Angel Island, California. An earthquake was followed by swells in the bay and vessels heaved. At Angel Island the sea rose several feet higher than previously observed (date uncertain but probably late October). Validity 3 when the Angel Island report is included for this date (subaerial or submarine landslide source).

1855, July 10, Dana Point, San Juan Capistrano, California. Two swells were observed following an earthquake that was damaging to Los Angeles; the epicenter was on land 60 miles from the wave site (Toppozada et al., 1981). Trask (1864) is the sole source of this report. Possible submarine landslide source. Validity 3.

1856, February 15, San Francisco, California. Magnitude 5.5 earthquake. "The water rose rapidly and maintained an elevation for five minutes when it sunk two feet lower than previous." Sediments in water. Not recorded on tide gage. Possible submarine landslide source. Validity 3.

1862, May 27, San Diego, California. A magnitude 5.9 earthquake caused landslides into the bay. Tide observer saw a wave run up on the beach three to four feet. Subaerial landslides. Validity 4.

1865, October 8, Santa Cruz, California. A strong earthquake caused a high flood tide and strong ebb tide. High cliffs crumbled into the sea at Soquel six miles south of Santa Cruz and as far as Castro Landing. Subaerial landslide source. Validity 3.

1868, October 21, San Francisco, California. A destructive magnitude 7.0 earthquake in the Hayward fault had a three foot horizontal displacement. Lawson (1908) reports commotion in the ocean sending a wave 15 to 20 feet above its usual mark at Cliff House. Three heavy rollers coming from NW observed off Fort Point. Source not directly associated with Hayward fault. Submarine landslide probable. Validity 3.

1873, November 22, Northwestern California and Oregon. A strong earthquake was felt over Northwestern California and Oregon. A loud noise was heard from the sea and the water rose and fell. Sand was thrown up to the highest water mark. Felt at sea by a schooner north of Cape Mendocino. Validity 3.

1878, November 22, San Luis Obispo, California. One fatality, and three wharfs damaged at Point Sal, and Avila. Observed at Surf and Port Hartford. No earthquake or wind reported. Probably submarine landslide. Validity 3.

1891, November 29, Puget Sound, Washington. Strong earthquake-generated waves eight feet high washed up on Lake Washington and boats rolled near Seattle and at Tacoma. Probably two or more subaerial or submarine landslides. Validity 4.

1901, March 2, Monterey, California. A magnitude 6.7 earthquake occurred near Parkfield. Monterey Bay was deeply stirred and waves dash on the rocks. Submarine landslide. Validity 3.

1906, April 18, San Francisco, California. A magnitude 7.8 earthquake was disastrous to bay area. A four inch wave was recorded. Tectonic or landslide source from San Francisco bar probable. Validity 4.

1927, November 4, Point Arguello, California. A magnitude 7 earthquake occurred off shore. Six foot waves washed out sections of railroad, and flooded stations at Surf and Pismo. Observed at Avila. Recorded in Hawaii and at Ft. Point and La Jolla. Tectonic source probably but effects also similar to 1878 submarine landslide event. Validity 4.

1930, August 30, Santa Monica, California. A magnitude 5.2 earthquake caused a 20-foot wave at Santa Monica, Venice, and Redondo Beach. Sixteen people were rescued from the surf. One drowned at Redondo Beach. Probably a submarine landslide source given the low magnitude of the earthquake and localized effect. Validity 4.

1949, April 13 and 16, Tacoma, Washington. A magnitude 7.1 earthquake near Tacoma triggered a subaerial landslide in the Narrows causing some damage. The landslide occurred two days after the earthquake which caused cracks in the bluff above. A small tsunami was generated at Cooper's Point, near Olympia on April 13 when a sandy spit of land collapsed during the earthquake. Validity 3 and 4.

1989, October 19, Monterey, California. A magnitude 7.1 earthquake at Loma Prieta caused extensive damage in the San Francisco Bay area and at Monterey. A small tsunami was recorded at Monterey and observed at Santa Cruz and Moss Landing. A submarine landslide source was verified by underwater photography. Probably two waves generated, one tectonically at Santa Cruz and one by landslide at Moss Landing. Validity 4.

1992, April 25, Cape Mendocino, California. A magnitude 7.1 earthquake which had its epicenter on land caused uplift along the adjacent coast of 4.6 feet. A small tsunami was apparently generated by uplift which propagated up and down the coast but was not seen by observers in the epicentral area or to the south. It was directly observed only at Clam Beach (1 foot), 40 miles north of the source, Trinidad (2.5 feet), 50 miles north of the source, and Crescent City (2 feet), 100 miles north of the source. Waves were recorded in Hawaii and on marigraphs on the west coast. Tectonic source. Validity 4.

3.1.2 Local Tsunamis Summary and Conclusions

1. All except the 1878 event were associated with earthquakes, but all of the earthquakes were below 7.2 magnitude or on land at some distance from the tsunami report except the April 18, 1906 event which was a strike slip fault event. No local tsunamis were observed on the Oregon and Washington coasts except 1873 observed at Port Orford, Oregon.

2. Most (14) were not recorded instrumentally although usually there were marigraphs in the area. This probably reflects the very local nature of these tsunamis and somewhat poor response of the instruments to shorter period waves associated with local tsunamis. Only the tsunami of 1906 and 1992, and the mixed 1989 event and the possibly tectonic tsunami of 1927 were recorded instrumentally.

3. Only the 1812 tsunami was directly observable beyond the source region and apparantly

it was observed in Hawaii. The 1927 and 1992 events were recorded in Hawaii.

4. None of the local tsunamis exhibited typical tectonic tsunami origins. The 1906 event may have been due to uplift associated with a bend in the San Andreas fault near the Golden Gate (Ma et al., 1991) or to inertia in the bay's water when the bottom moved laterally. It may have been due to submarine landslides from the San Francisco bar. A four-inch wave is a curiosity rather than a hazard. The 1992 Cape Mendocino event produced a wave consistent with an uplift on the Mendocino escarpment rather than subduction. The 1927 event is possibly of tectonic origin but the earthquake was of small magnitude and the effects are not unlike the non-seismic 1878 event.

5. Most were associated with submarine landslides or subaerial landslides. These were in the San Francisco and San Diego Bays and Puget Sound or were associated with off-shore canyons at Santa Monica, Redondo Beach, Surf, Monterey, and Dana Point and the Santa Barbara basin. At least three events, 1865, 1868, and 1906 may have been caused by landslides from the San Francisco bar.

6. Although damage probably would be larger if similar events occurred today, they would not be disastrous, since the waves from submarine landslides are small and the area affected is usually only one or several communities.

7. Most were observed at a single locality and all were confined to a small segment of the coast. The 1812 Santa Barbara event was observed along a 55-mile section of the coast and the 1992 Cape Mendocino event observed over a 60-mile section of the coast were by far the largest. The 1812 tsunami probably effected a somewhat larger segment of the coast but there were no reports due to the population distribution. The 1992 event was observed only between 40 and 100 miles from the source region due to the peculiar source region orientation.

8. There is an anomalous high concentration of reports, both among those judged valid and invalid in the two decades between 1850–1870 following the growth of the American population, newspapers, and tide gages. The evidence for some of the earlier events is weaker, and some of the seven events rated as validity 3 or 4 during this time may be overrated.

9. The addition of two sets of events affecting Puget Sound, and Lake Washington in 1891 and 1949 which were not included in any prior tsunami catalogs indicate that a minor hazard from landslide-generated waves exists there and that there probably have been additional events in that area which have not yet been identified. In sitting homes and facilities along the shore, thought should be given to the stability of the opposite shore as well as at the site.

10. The record of the amount of time between the shock and the wave arrival is incomplete, but generally the time is expected to be only a few minutes. In 1812 people reportedly observed the water retreat and form a "high hill" and they had time to flee to higher elevations. The July 10, 1855 event was reported to have arrived immediately after the shock of the earthquake. Other descriptions also indicate a very short time between the shock and the wave except for the 1992 event. Due to the peculiar generation of a wave parallel to the coast, the tsunami was first observed at Clam Beach about 40 miles from the source and reached Crescent City, about 100 miles away, about 47 minutes after the earthquake. An alert was issued and received before the waves arrived at Crescent City, but it is likely that this is the only local historical event for which a watch could have been issued before the event was completed. A watch or warning was not needed for mitigation purposes.

11. Byerly's work on the 1927 event illustrates

the importance of early field work. Without his report it is unlikely that this tsunami would have been known or important details recorded. The wave does not seem to have been mentioned except by some local newspapers. Similarly, work done for this catalog, including interviews with first-hand observers for the 1992 event, added to understanding that event.

12. Based on the historical record, and given the very local nature of the waves, their minimal damage, and the time between the earthquake and wave's arrival, a warning system for local tsunamis on the west coast may not be feasible or necessary. Education, including the past effects and the possibility of using natural warnings afforded by a shock or unusual behavior of the sea, for harbor officials, life guards, and emergency personnel particularly in areas with a history of effects, may be the more practical approach.

13. Evaluation of the current research on a possible future subduction zone earthquake and tsunami associated with the Gorda Plate is beyond the scope of this historical study. It is a proper research topic but it is probably premature for operational concern for hazard mitigation.

3.2 Teletsunamis

Table 3 (next three pages) lists 63 events as teletsunamis and possible teletsunamis. Forty-seven of these are validity 3 or 4 due to the existence of tide gage records (first installed in 1854). The December 23 and 24, 1854 teletsunamis from Japan are the earliest definite recordings of tsunamis in the world.

Thirty-two of the listed tsunamis were not reported as directly observed and only fifteen were directly observed as well as recorded. Two other tsunami events, 1883 Krakatoa and 1956 Kamchatka, were judged to be air waves from volcanic explosions, and not true tsunamis.

Seven events caused at least some damage: 1868 Chile (minor), 1896 Japan (minor?), 1946 Alaska (1 killed, $10,000 damage), 1952 Kamchatka (minor), 1960 Chile (injuries, $500,000+ damage), 1964 Alaska (16 fatalities, injuries, $17,000,000 damage), and 1975 Hawaii ($1,000 damage). The statistics are dominated by the 1964 event. Given the directionality of tsunamis and the orientation of the source regions, this probably represents the maximum possible teletsunami (remotely-sourced) for the west coast.

The most destructive events came from Alaska and Chile. On the west coast the 1946 Alaska tsunami was strongest in Central California. Sources further west along the Aleutian arc would effect Hawaii and Japan but would have less impact on the west coast. This was the first teletsunami to cause more than trivial damage. The April 1, 1960 Chilean tsunami was such a massive event that it caused damage widely around the whole Pacific Basin. The 1964 tsunami affected northern California, Oregon, and Washington most strongly due to its location on the eastern end of the Aleutian/Alaskan arc.

3.2.1 Summary of Damaging Teletsunamis

1868, August 13, 21:30 GMT. Two great earthquakes of magnitude of about 8.5 struck Arica, Peru (now Chile) generating 21-meter waves and causing more than 25,000 fatalities. A wave was recorded at San Diego with an amplitude of 2.6 feet. A loading dock was submerged and a residence flooded.

1896, June 15, 10:33 GMT. The great Sanriku earthquake in Japan produced a 38.2 meter wave locally that killed 26,000 people. Soloviev and Go (1974) report that a 4.9 foot wave destroyed a protected dike and did severe damage to a moored ship at Santa Cruz. The dike was a sand bag structure and the boat was likely a float being prepared for a local festival.

[summary continues on page 27]

Table 3. Teletsunamis and Possible Teletsunamis
[an asterisk (*) indicates a new entry; effects on U.S. west coast not in earlier catalogs]

Date—Greenwich Mean Time	Location	Val.	Mag.	Max. Amp. (ft.)	Comments for West Coast
1827 Jan. 18-21*	?	1			High coastal waves at San Francisco
1853 Nov.	Kuril Is.	0			Unsubstantiated report of recording at San Diego
1854 Jul. 24	?	2		0.2	Recorded at San Diego
1854 Aug. 18	?	2		<0.1	Recorded at San Diego
1854 Oct. 4*	?	3		0.2	Recorded at San Francisco
1854 Dec. 23	Japan	4	8.3	0.3	Recorded at San Francisco, San Diego, Astoria
1854 Dec. 24	Japan	4	8.4	0.2	Recorded at San Francisco and San Diego
1856 Aug. 23*	Japan	4	7.8	<0.1	Recorded at San Diego and San Francisco
1868 Apr. 3	Hawaii	4	7.5	0.3	Recorded at San Diego and San Francisco
1868 Jun. 13	Hawaii	0			Incorrect date for 1868, Apr. 3
1868 Aug. 13	Peru/Chile	4	8.5	2.5	Observed at Wilmington and San Pedro, and recorded
1869 Jun. 1	?	3			Traces recorded at San Francisco
1872 Aug. 23	Fox Is. Aleutian Is.	4		0.3	Recorded at San Francisco, San Diego, and Astoria
1872 Sept. 16	Fox Is. Aleutian Is.?	4		0.4	Recorded at San Francisco
1877 May 10	Chile	4	8.3	6.0	Observed at San Pedro, Wilmington and Gaviota and recorded
1878 Jan. 14	Aleutian Is.	0			Wharfs damaged at Carpenteria, Ventura, and Santa Barbara Meteorological waves
1883 Aug. 27	Indonesia	2			Krakatoa air waves
1884 Jan. 25	?	0			Possible long period seismic waves at San Francisco
1885 Nov. 12, Nov. 19, Nov. 24	?	1			3 separate reports of meteorological waves at Sausalito, San Francisco & Eureka
1895 Oct. 14		0			Storm waves recorded at Sausalito

Date—Greenwich Mean Time	Location	Val.	Mag.	Max. Amp. (ft.)	Comments for West Coast
1896 Jun. 15	Japan	4	7.6	4.8	Damage at Santa Cruz? Observed at Mendocino, recorded at Sausalito
1902 Feb. 26	Guatemala	0			Confusion in place name
1906 Jan. 31	Ecuador	4	8.2	0.2	Observed at San Diego and San Francisco? and recorded
1906 Aug. 17	Chile	4	8.6	0.2	Recorded
1917 May 1	Kermadec Is.	4	8.0	0.1	Recorded
1917 June 26	Tonga Is.	4	8.3	0.1	Recorded
1918 Sept. 7	Kuril Is.	4	8.3	0.2	Recorded
1918 Nov. 8*	Kuril Is.	4	7.8	0.1	Recorded
1918 Dec. 4*	Chile	4	7.8	emergent	Recorded
1919 Apr. 30	Tonga Is.	4	8.3	0.4	Recorded
1922 Nov. 11	Chile	4	8.3	0.7	Observed at Santa Cruz and Los Angeles and recorded
1923 Feb. 3	Kamchatka	4	8.3	0.7	Observed at Santa Cruz and Los Angeles? and recorded
1923 Apr. 13	Kamchatka	4	7.2	0.3	Shipping affected at Los Angeles, recorded
1928 June 17	Mexico	4	7.8	0.3	Recorded
1929 Mar. 7*	Aleutian Is.	4	7.5	0.1	Recorded
1931 Oct. 3	Solomon Is.	4	7.9	0.2	Recorded
1932 Jun. 3*	Mexico	4	8.1	0.1	Recorded
1933 Mar. 2	Japan	4	8.3	0.2	Recorded
1938 Mar. 22	Queen Charlotte Is.	0	6.3		Erroneous report
1938 May 19	Indonesia	0	7.6		Erroneous report
1938 Nov. 10	Shumagin Is. Alaska	4	8.3	0.7	Recorded
1943 Apr. 6	Santiago, Chile	4	8.3	0.7	Recorded
1944 Dec. 7	Honshu, Japan	4	8.0	0.4	Recorded
1946 Apr. 1	Unimak Is. Aleutians	4	7.8	5.0	Recorded 1 fatality at Santa Cruz, $10,000 damage

Date—Greenwich Mean Time	Location	Val.	Mag.	Max. Amp. (ft.)	Comments for West Coast
1946 Dec. 20	Nankaido, Japan	4	8.1	0.8	Recorded
1952 Mar. 4	Hokkaido, Japan	4	8.2	0.6	Recorded
1952 Nov. 4	Kamchatka	4	8.2	2.1	Recorded widely and boats sunk at Crescent City, minor damage.
1956 Mar. 30	Kamchatka	2	Vol.	0.7	Recorded, volcanic explosion
1957 Mar. 9	Aleutian Is.	4	8.3	3.3	Recorded, observed, minor damage at San Diego.
1958 Nov. 6	Kuril Is.	4	8.1	0.7	Recorded
1960 May 22	Chile	4	8.6	4.6	Boats sunk, injuries, $500,000 - $1,000,000 in damage, 1 fatality?
1963 Oct. 13	Kuril Is.	4	8.1	3.3	Observed at Crescent City and recorded
1964 Mar. 28	Alaska	4	8.4	15.8	$15,000,000 damage, 17 killed
1965 Feb. 4	Rat Is. Aleutian Is.	4	8.2	1	Observed at Santa Cruz and recorded
1966 Oct. 17	Peru	4	8.0	1	Recorded
1968 May 16	Honshu, Japan	4	7.9	2	Recorded
1971 July 26	New Ireland, South Pacific	4	7.9	0.2	Recorded
1974 Oct. 3	Peru	4	8.1	0.3	Recorded
1975 Nov. 29	Hawaii	4	7.2	4.6	Recorded, $1,000 damage at Catalina I.
1977 Jun. 22	Tonga Is.	4	7.2	0.3	Recorded
1986 May 7	Aleutian Is.	4	7.6	0.3	Recorded
1987 Nov. 30	Gulf of Alaska	4	7.6	<0.1	Recorded
1988 Mar 6*	Gulf of Alaska	2	7.6	<0.1	Recorded?

1946, April 1, 12:29 GMT. A magnitude 7.8 earthquake in the Aleutians produced a 115-foot wave which destroyed the Scotch Cap lighthouse killing five Coast Guardsmen. It was 56 feet high in Hawaii killing 173 people.

The wave was observed all along the west coast. At Tahola, Washington, boats were swamped by five-foot waves. At Seaside, Oregon, several boats and a log float were carried away.

In California boats broke free at Noyo Harbor. At Princeton homes were flooded and boats were left 1,000 feet from the shore. Fences were destroyed, land eroded, and a packing plant was damaged. At Half Moon Bay a shed was destroyed, a car floated into a house, boats were carried a quarter mile inland, rocks rolled onto roads, the Coast Guard barracks were damaged, and homes were flooded. At Santa Cruz, an elderly man drowned and minor damage was done by 10-foot waves. At Port Hueneme sand covered the railroad tracks. A small pier was washed away on Catalina Island. At San Pedro ships broke moorings. The total damage was at least $10,000.

1952, November 4, 16:58 GMT. A magnitude 8.2 earthquake in Kamchatka, USSR, produced a 13-meter wave locally. Logs broke from booms at several localities near Brandon, Oregon. Five small boats capsized and sunk at Crescent City, California, and 60-ton mooring buoys were moved. One boat was slightly damaged at Santa Cruz.

1957, March 9, 14:33 GMT. A magnitude 8.3 earthquake near Unimak Island, in the Aleutian Islands, generated a 12-meter wave there. At San Diego a late surge set up currents up to 30 miles per hour ripping out 60 feet of floating docks and damaging 125 feet of finger slips. Five large vessels were damaged slightly. A Coast Guard cutter broke mooring and damaged a 50-foot private craft. Damage was estimated at over $5,000.

1960, May 22, 19:11 GMT. A great magnitude 8.6 earthquake off the coast of Chile produced a 25-meter tsunami and caused $500 million in damages and 1,000 deaths locally. It created destructive waves throughout the Pacific Basin.

In Washington no damage was reported. In Oregon the boat landing and boats were damaged at Seaside and at Gold Beach. In Crescent City, California, three commercial fishing boats were sunk, and some damage was done to the dock facilities. A cafe and the sea scout building were damaged, a wood piling was carried away and many tons of debris was left in the lower part of the harbor. At Noyo Harbor almost every dock was damaged and boats were carried upstream. At Princeton a dozen pleasure and commercial boats were damaged. A concessionaire's cabin was damaged at Pismo Beach. One man was killed at Morro Bay when a boom broke and hit him. He was using the boom to remove a float left on the rocks by the tsunami.

In Santa Barbara, about a dozen boats broke their moorings, causing minor damage. Over $1,000,000 in damage was reported in Los Angeles. Forty boats were sunk and 200 were damaged. The ship-to-shore cable was cut and lumber was washed away. Docks and piers were damaged. One man, a skin diver, was lost. At San Diego, two boats broke their moorings and 165 feet of dock was destroyed. The Coast Guard cutter *4F* broke its mooring. A bait barge in Marina Bay broke in half, knocking out pilings and moorings. A 160 foot dock on Shelter Island was destroyed. A 100 ton derrick barge carried by late surges during clean-up rammed a bridge causing $3,000 in damage. Damage was also done to city docks on Shelter Island where three 50 to 100 foot concrete sections were overturned. A cabin cruiser was sunk at Dana Point.

March 28, 1964, 03:36 GMT. A massive 8.4 magnitude earthquake in the Prince William Sound area of Alaska generated a Pacific-wide tsunami that heavily impacted the United States west coast.

In Washington $80,000 damage was done to roads and bridges, sixteen homes were damaged including three that were destroyed. Nine trailers and at least three automobiles were lost. Bulkheads were destroyed. Debris was left behind, and at least two people were injured. In Oregon, four children were drowned and one woman suffered a fatal heart attack. Bridges, houses, trailers, cars, motel units, and sea walls were destroyed. Damage was estimated at between $750,000 and $1,000,000.

In California there were twelve drowning fatalities. One longshoreman was killed the next day when a crane failed. At Crescent City damage exceeded $15,000,000. Another $1,000,000 in damage occurred to marinas inside San Francisco Bay. Damage occurred all along the California coast but was heavier in the north.

1975, November 29, 14:48 GMT. A magnitude 7.2 earthquake on the south side of the Island of Hawaii produced a submarine landslide causing a 26-foot wave there. It caused $1,000 damage on Catalina Island (California) where a small floating dock at Isthmus Harbor was destroyed by nine foot waves.

3.2.2 Teletsunami Summary and Conclusions

1. Remote-sourced tsunamis are a relatively minor hazard for the west coast with sources in the eastern part of the Aleutian Islands Arc being the most hazardous. The Shumagin Island seismic gap may be a particular area of risk. Great tsunamis anywhere would be a hazard but the Chilean coast seems to be the most productive of these events. The 1964 source has released its energy and should not be a major hazard for a century or more.

2. The characteristics of tsunamis are not well known by the general public or by many officials. Breaking waves, as popularly envisioned, are almost impossible for the U.S. west coast where tsunamis appear as rapidly changing tides, swift currents in harbors, and bores on rivers.

3. Most fatalities occurred when people left places of relative safety to seek safer places during the brief calm periods at water reversal from incoming to outgoing or from low to high stage.

4. The number of fatalities has been remarkably low considering all the people who were at high risk by being in the water. Such luck may not always be the case.

5. Warnings given by local communities are spotty. Officials base their response more on their past history of such warnings rather than for the situation facing them. This is a consequence of too many "false alarms" for non-hazardous waves. Warnings need to carry at least a rough estimate of the expected amplitude if they are to be effective.

6. Television and radio are sources of information on expected tsunami arrivals for many people. Unfortunately, too many flock to the shore to see this rare phenomena creating problems for emergency personnel and putting themselves at some risk. Such broadcasts should include admonitions to stay away from the shore or directions telling them where to go for a safe, out-of-the way vantage point.

7. The state of the tide at the time of the tsunami is an important factor. The greatest inundation is likely to occur with a tsunami wave arriving at high tide. That wave may not have been the first or the greatest but the combination with the tide could make it the highest. Tsunamis at low tide may be a hazard for people fishing or clamming. Low water may entice people into gathering fish, shellfish, or just exploring in newly and temporarily dry land and into danger.

8. Strong currents in protected harbors such as San Francisco, Los Angeles, and San Diego cause most of the damage there. These have not yet been directly measured but may reach 20 miles per hour or more. This is a function

Table 4. Observed and Damaging Teletsunamis
[OBS = teletsunamis observed, but not measured]

Date—GMT	Source	Observed (ft.)	Location of Effects	Mag.	Damage/Effects
1868 Aug. 13	Peru/Chile	2.5 2.5	San Pedro Wilmington	8.5	Minor flooding
1877 May 10	Chile	3.4	San Pedro	8.3	
1896 Jun. 15	Japan	3.5 4.8	Mendocino Santa Cruz?	7.6	Damage?
1906 Jan. 31	Ecuador	OBS	San Diego	8.2	Ships turned
1922 Nov. 11 or 1923 Feb. 3	Chile Kamchatka	OBS? OBS? OBS? OBS?	Santa Cruz Los Angeles Santa Cruz Los Angeles	8.3 8.3	Currents?
1923 Apr. 13	Kamchatka	OBS	Los Angeles	7.2	Shipping affected
1946 Apr. 1	Unimak / Aleutian Is.	5.0 5.0	Charleston Santa Cruz	7.8	$10,000+ damage One fatality
1952 Nov. 4	Kamchatka	OBS 3.4 OBS	Brandon Crescent City Santa Cruz	8.2	Log booms broken 4 boats sunk Boat damaged
1957 Mar. 9	Aleutian Is.	1.5	San Diego	8.3	$5,000+ damage to ships and floating docks
1960 May 22	Chile	4.6	All areas	8.6	$1,000,000 damage, injuries
1964 Mar. 28	Alaska	15.8	All areas	8.4	17 fatalities + injuries $12,000,000 damage
1965 Feb. 4	Aleutian Is.	4.5	Santa Cruz	8.2	Rise in water
1975 Nov. 29	Hawaii	4.5	Catalina	7.2	$1,000 damage

of the short period of tsunami waves and seiches, usually 15 to 30 minutes. These currents do not depend on the state of the tide, just to the period and amplitude of the waves and harbor configurations.

9. There seems to be a special hazard with operating booms in clean-up after the main tsunami has passed. Late surges put additional stresses on both boat and shore-based cranes which have failed with fatal consequences at least twice.

10. Field studies are invaluable for both local and teletsunamis. Often attention is focused at the principal point of damage. For example; Hilo, Hawaii, in 1946 and Crescent City, California, in 1964 were studied extensively but little attention was paid to other affected areas.

11. If there is time for action, evacuation of boats to deep water seems useful and practical even if it is somewhat dangerous.

12. Damage estimates are not reliable. The amounts are reported in the values at the time and a lot of damage does not get reported in the total dollar amount.

13. Floating debris including logs, boats, and cars, propane tanks, gasoline from boats and storage tanks, toxic chemicals, and downed electrical power lines may add to the hazard.

3.3 Franklin D. Roosevelt Lake Tsunamis

Table 5 lists the water waves mentioned in Jones et al. (1961)—a sequence of landslide-generated tsunamis in Franklin D. Roosevelt Lake (Washington) beginning even as the reservoir behind Grand Coulee Dam was filling.

Landslides were common in the area before the dam but the raising of the water level contributed to an increase in slides by raising the ground water level. The reservoir provided the water for tsunami generation. While such waves are not generally thought of as being tsunamis they do not differ significantly from the landslide tsunamis generated in coastal bays. They are instantaneously generated gravity waves in water.

Such waves have occurred at other reservoirs such as at the Vaiont Dam, Italy in 1963 (Müller, 1964) and at Chungar, Peru in 1971 (Plafker and Eyzaguirre, 1979). At this writing landslides are still occurring but new wave reports are unavailable. This is partly due to the smaller size of the most recent slides as the shore line comes to equilibrium with the water level. However, slide areas along the 600 miles of the shore line are infrequently checked and the shore is mostly uninhabited.

During the Pleistocene a glacier advanced down the Columbia valley leaving thick glacial stream and lake deposits of silt, sand, and gravel. These deposits form bluffs on the rivers and reservoir shores and may collapse. If they fail rapidly and into the reservoir, waves may be created. There remains a probability of additional waves not reported here and of future waves. Other reservoirs may have similar problems not documented here.

3.3.1 Summary of Larger Reservoir Tsunamis

1944, April 8. A four to five million cubic yard landslide 78 miles upstream of Grand Coulee Dam created a 30-foot wave on the opposite shore, 5,000 feet across Roosevelt Lake.

1949, July 27. A two- to three-million cubic yard landslide near Hawks Creek about 35 miles upstream of Grand Coulee Dam created a wave destroying trees and shrubbery 65 feet above the lake on the opposite shore. It was observed 20 miles away.

1951, February 23. A 100,000 to 200,000 cubic yard landslide near Kettle Falls and about 104 miles upstream of the dam generated a wave which hurled logs through the Harter Lumber Company mill 10 feet above lake level causing $2,500 to $3,000 in damage.

1952, April 10-13. A 15,000,000 cubic yard landslide three miles below Kettle Falls bridge created a 65 foot wave on the opposite shore. These were noticed at the Laferty Transportation Company docks six miles upstream.

1952, October 13. A large landslide about 98 miles upstream of Grand Coulee Dam created a wave which broke tugboat and barge moorings at the Laferty Transportation Company. It swept logs, driftwood, and chunks of sod over a large flat area about at lake level.

1953, February 16. A series of landslides about 100 miles upstream from Grand Coulee Dam produced ten waves over sixteen feet high.

1953, August 19. A landslide near Kettle Falls beach produced a wave which dislocated a floating boardwalk at the National Park Service faculty.

3.3.2 Reservoir Tsunamis Summary and Conclusions

1. The landslide generated tsunami problem on Roosevelt Lake appears to be abating as the shore line bluffs reach equilibrium with the new hydrological regime. However, the record is probably far from complete given the length of shore and the few observers in position to report on waves.

2. Similar undocumented problems probably exist in other reservoirs.

3. Although these are not what is normally thought of as being tsunamis, they are the same physical phenomena. They are capable of being destructive.

Table 5. Reservoir Tsunamis in Franklin D. Roosevelt Lake, Washington

Local Date/Time	Location	Slide Volume 10^6 cubic yards	Max. Wave Height (ft.)	Comments
1944, April 8, 6:00 A.M.	Reed Terrace	4-5	30	On opposite shore 5,000 ft. away.
1949, July 27	Hawk Creek	2-3	65	Observed 20 mi upstream.
1951, Feb. 23, 8:45 A.M.	Kettle Falls	0.1-0.2	10?	$2,500-$3,000 damage to lumber mill.
1952, April 10-13,	Reed Terrace	15	65	On opposite shore. Observed six miles upstream. Many waves over several days.
1952, Oct. 13, 11:45 A.M.	Main Terrace			Tug boat and barge broke moorings 6 miles upstream. Logs, driftwood and sod carried above lake level.
1953, Feb. 14-19	Main Terrace			Many large waves created.
1953, Feb. 16, 3:43 A.M.	Main Terrace	16		10 waves at least 16 ft. on opposite shore.
1953, Aug. 19, 11:00 A.M.	Kettle Falls			Small waves displaced floating walkway at National Park Service.

4.0 Description of Tsunami Events

1806, March 24–25. An earthquake at midnight cracked the walls of the Mission Santa Barbara in three places (Toppozada et al., 1981, p. 134, citing Bancroft, 1886 and Geiger, 1965). Professor George D. Louderback of the University of California did considerable research on early California earthquakes (Louderback, 1944, 1947, 1948). Item 17 on page 21 of the index of his files as given in Annex A of "The California Tsunami of December 1812" (Grauzinis et al., unpublished manuscript) states "A page titled 'Earthquake of 1806' which mentions boats beached." The location and date of the beaching is not given in this brief account but the 1806 Santa Barbara event is the only earthquake listed. This may imply that a local tsunami occurred after this earthquake. However, Geiger (1965) p. 16, states, "An earthquake on March 24, cracked the chapel walls in three places, and on May 24, the same year, a violent storm almost destroyed what was left," which could also account for the boats being beached. Geiger cites the Provincial State Papers, IX, 85 in the Bancroft Library. Toppozada gives an epicenter with origin time of 08:00 UTC, on March 25, at 34.4°N, 119.7°W, and Intensity VI. Validity 2.

1812. Holden (1887) reports that several strong earthquakes in San Francisco generated waves which covered the ground now occupied by the Plaza. This information was communicated to him by J.R. Jarboe, Esq., citing Senora Juana Briones. This is a third-hand report of events that were supposed to have happened seventy years earlier and the report is attributed to a woman who was at least eighty-four years old (born in 1796). It is the only known report of a tsunami in San Francisco in 1812. There is no mention in the 1812 annual reports of Santa Clara, San Jose or Dolores (San Francisco) Missions of earthquakes in San Francisco in 1812 (Toppozada et al., 1981; Grauzinis et al., unpublished manuscript). Iida et al. (1967) suggested that this report is possibly a mistaken account of the same event that produced the December 21st waves at Santa Barbara, but Wood (1916) cited these waves as evidence for displacement on a fault across San Francisco Bay rather than a more seaward fault. This is a doubtful tsunami report with no contemporary mention and is probably a report of effects of the December 21st, Santa Barbara earthquake (Soloviev and Go, 1975, p. 200, 202; McCulloch, 1985). Validity 1.

1812, December 21, 11:00 A.M. A major earthquake on December 8 destroyed the Mission San Juan Capistrano. Jacoby et al. (1988) place the epicenter of the December 8, 1812, shock on the San Andreas fault. Two more earthquakes fifteen minutes apart on December 21, the second and largest with a magnitude estimated at 7.7, occurred at about 11:00 A.M. It destroyed the Mission La Purisima Conception, damaged the Mission and Presidio of Santa Barbara and the Mission San Buenaventura (Ventura) and other settlements (Toppozada et al., 1981).

Information on a tsunami from the December 21 earthquake has become distorted over the years to include exaggerated reports of waves of up to 50 feet at El Refugio (Gaviota), 30 to 35 feet at Santa Barbara, and ten feet or more at Ventura. The wave heights for Gaviota were derived from an account of "an old trader" in the *San Francisco Bulletin* of March 16, 1864, 52 years after the event, which reported "the sea was seen to retire all at once and return in an immense wave, which came roaring and plunging back, tearing over the beach fit to crack everything to pieces. This wave penetrated the lowlands of the gulches a mile from shore." This report, in turn, was converted into the fifty-foot height by Prof. Louderback apparently by using a topographic map and that value was accepted by Wood and

Heck (1951). Contemporary sources from the missions at Santa Barbara and Ventura make little mention of disturbances of the ocean. A letter written by Padre Senan to Bishop Rouset of Sonora in early January, 1813 states "The people are living huddled together in the area of the mission whither they repaired because the presidio is close to the sea which threatened to rise...In the Mission of San Buenaventura, the tower, the facade of the church and the front wall are about to fall. It has been necessary for us to leave here for the present at a distance of about half a league to the interior out of fear that the sea which we know had risen in two places, might engulf us" (Grauzinis et al., unpublished manuscript). The statement that the sea had risen in two places does not give specific times or places. However, they were experiencing numerous aftershocks, and had relocated since the mission was only 694 varas (1908 ft.) from the sea. Apparently their experience was such that they did not feel safe at that distance. Fr. Vitorio's entry in the Book of Missions for January 9, 1813, states, "The ninth day of January, of the year 1813, in the interim church of Xacal at a site called San Joaquin and Santa Ana, a distance very slightly less than three-fourths of a league from the mission, to where we retired ourselves because of the horrible tremors or earthquakes that we experienced very strongly and because the ocean was very agitated (literally, put into commotion) by the temblors above mentioned that, by chance, it was feared that its water would inundate the mission" (Grauzinis et al., unpublished manuscript, pp. 47–48).

While the "commotion of the sea" does not say that waves were observed and this term is often used to describe sea quakes as well, it seems unlikely that the effects of a sea quake would be observed from the shore.

Commandant Arguello of the presidio at Santa Barbara wrote, "In the Bay of the Presidio the sea has changed from its natural condition," which might suggest a change in elevation due to tectonic deformation or compaction. Fr. Senan, from San Buenaventura, wrote of Santa Barbara and the Rancheria de Mescaltitan: "People from the rancheria are living on the plains around the mission to where they withdrew since they were very close to the ocean which threatened to flood them." The only reasonable way for the "sea to threaten them" would be for some wave action to have occurred.

In 1948, Mr. Frank Orr, a Ventura lawyer, wrote that he had recently talked to Mrs. Myrtle Francis who had settled in Ventura in 1873, and she related an account provided by an old Indian who was living in Ventura at the time of the tidal wave. He reported that San Miguelito Chapel, located at the southwest corner of Palm and Mèta Streets, was damaged by the tidal wave of 1812. The chapel was 15 feet above sea level (Grauzinis et al., unpublished manuscript) and was a low adobe building—the earliest mission in the area. This accounts for the published wave height at Ventura.

Trask (1856) collected information from native inhabitants and older foreign residents on the earthquake and tsunami. He reported: "A Spanish ship which lay at anchor off San Buenaventura (Ventura), 38 miles from Santa Barbara, was injured by the shock, and leaked to the extent that it become necessary to beach her, and remove most of her cargo."

Later, regarding the Bay of Santa Barbara, Trask (1856) quotes an unknown source: "The sea was observed to recede from the shore during the continuance of the shocks, and left the harbor dry for a considerable distance, when it returned in five or six heavy rollers, which overflowed the plain on which Santa Barbara is built. The inhabitants saw the recession of the sea, and being aware of the danger on its return, fled to the adjoining hills near the town to escape the probable deluge."

Trask (1856) continues: "The sea, on its return flowed inland little more than half a mile, and reached the lower part of town, doing but trifling damage, destroying three small adobe buildings."

Donna Augustias de la Guerra (Mrs. Ord, daughter of the Commandant of the Santa Barbara presidio in 1815) states in April 1, 1878, that "Father Luis Gil Taboada told her of the very strong earthquake of 1812 while he was in Santa Barbara. He was at the presidio when there occurred an earthquake so strong that the sea retired and took the form of a high hill and he and all the people of the presidio departed running for the mission, singing the liturgies to the Virgin."

In an article regarding the history of earthquakes in the January 17, 1857 *Los Angeles Star*, a local authority reported that "on December 21, 1812, an American ship, engaged in smuggling, was laying anchored off a canyon at the Rancho Refugio, in Santa Barbara county. The sea became violently agitated by the earthquake, and the captain let go his cable, the vessel was drifted ashore and up the canyon, the receding waters bringing her back to her proper element."

The ship mentioned by Trask was probably not a Spanish ship nor was it at San Buenaventura. Instead it was an American ship at El Refugio near Gaviota that was collecting otter skins and was probably trading with the missions illegally. This illegal activity might account for the lack of mention of the ship in the contemporary mission reports. On the other hand there were several Indian encampments near the beach at Santa Barbara. The Padres kept careful records of Indian births and deaths, and the lack of any mention of effects at these sites is a strong limitation to the report of the height of any wave at Santa Barbara. Given the real and significant damage from the earthquakes it may be expected that little contemporary comment would have been recorded for the relatively small and nearly harmless sea waves.

Even though the contemporary record does not describe a tsunami or runup, and the later reports are possibly exaggerated and occasionally confused, it is likely that there was a moderate tsunami. Grauzinis et al. conclude that the data would be reasonably supported by runup elevations of about 15 feet above mean sea level at El Refugio where an American ship was anchored, and less than ten feet at Santa Barbara and Ventura (Grauzinis et al., unpublished manuscript; Soloviev and Go, 1975, p. 200; Marine Advisers, 1965; Iida et al., 1967). According to Long (1988) the predicted tide at Santa Barbara and Ventura was about three feet above mean sea level at 10:51 and 11:08 A.M. respectively which would make the amplitude of the tsunami at Santa Barbara and Ventura about 6.5 feet. The Marine Advisers' report, the Grauzinis et al. manuscript, and Toppozada et al. (1981) are sources for much more detailed information for this event.

Independent of this study and at the suggestion of one of the authors, Dr. Doak Cox undertook to clarify the date of the earliest report of a possible tsunami in Hawaii originally given as 1813 or 1814. His search through contemporary diaries and with information on the Hawaiian calendar and religious practice let him to conclude that the Hookena, Kona, Hawaii event occurred between December 18th and 23rd, 1812, exactly covering December 21st, the date of the Santa Barbara event. The wave run-up height at Hookena was estimated at between six and 14 feet. These events are most probably the same and the researches are mutually supporting (Cox, unpublished manuscript, 1989).

The Santa Barbara event was most probably due to a submarine landslide triggered by the earthquake. The Santa Barbara Basin is offshore almost opposite Gaviota which is shown by Field and Edwards (1980) to be accumulating landslide deposits. The description—"the sea was seen to retire and form a high hill and the people fled in fear of its return"—perfectly describes a submarine landslide generated wave and not one generated by a fault movement source. Also, if the people were able to observe this effect and it was due to a tectonic source, they would have been at the very epicenter of a magnitude 7.7 earthquake and the intensity given as VIII (Toppozada et al., 1981) should have been higher; probably interfering with their observations and subsequent flight. The range of the reported effects, approximately 55 miles of coastline, might have been larger if there were observers elsewhere along the adjacent coast. This event has variously been mis-dated as September, 1812, and even as 1811 and 1814. Validity 4.

1827, January 18-21. Capitaine B. Duhaut-Cilly, a French voyager, arrived by ship from Europe to the Golden Gate about noon on the 18th of January. A heavy fog set in about 2:00 P.M. preventing their entry. On the 19th they arrived opposite Sir Francis Drake's Bay in a very light wind when they suddenly discovered an enormous chain of breakers. He was mystified as his maps showed no reefs in the area. The wind had died away altogether, and a surge of formidable height was bearing the ship toward a steep and shoreless coast, where he saw the surge dash itself with a mighty roar. They anchored in ten fathoms of water much less than a mile from land. The coast was formed of vertical rocks whose base was fortified by scattered rocks; it seemed only with an effort to resist the violence of the waves lashed into torrents of foam. By 2:00 P.M. the sea had quieted down a little and the breakers were less noticeable. During the next four days they were enveloped in dense fog. On the 21st they again encountered breakers almost under the ship. The waves were three times higher than the ship in 3.5 fathoms of water. They encountered a Russian brig whose captain assured them that there was no danger of a reef. Duhaut-Cilly had difficulty reconciling what he had seen but finally concluded it was some sort of mirage.

The above description might be a description of a teletsunami or remote-sourced meteorologically-produced waves. There was apparently little wind. Fog is common on the coast at that time of the year. The statement that they saw waves three times as high as the ship (deck) over two days after encountering the first waves can not be reconciled with a single tsunami theory. There are no Pacific tsunamis reported for that date but the record is far from complete. This is possibly a remotely-generated meteorological event. He may have been observing waves which form over the Four-Falham shoals, part of the San Francisco bar (Duhaut-Cilly, 1834). High waves are known to form over the San Francisco bar, a depositional feature just west of the Golden Gate. Validity 1.

1840, January 16-18. Bancroft's *History of California*, (1886, Vol. 4, p. 78) states that "An earthquake at Santa Cruz threw down several houses and the church tower, besides causing a wave which carried away a large quantity of tiles which were 200 yards from the shore." This report was repeated and modified by Holden (1887; 1898) and the earthquake was given an intensity of IX. The earthquake intensity of IX was converted to a magnitude 6.3 in Hays et al. (1975). Louderback (1944) in examining the original reports (*Archives of Monterey County*, Vol. IX, p. 24) used by Bancroft, found "...that during the 16th and 17th of this month the sea did great damage. It came out more than 200 varas (550 feet) from the shore line and carried off the roofing material intended for the local community...On the 18th of the same month the tower of the church of Santa Cruz fell owing to the abundance of water in the ground. He believes that some of the houses of the settlement will fall." There is no mention of an earthquake. The three-day time span and the reversed sequence of first having the sea carry off the roofing materials followed a day later by the church tower collapse leads to the almost certain conclusion that the waves were of meteorological origin. Louderback (1944, p. 106) also quotes other accounts of an immense quantity of rain falling for the proverbial forty days and nights in the area. This is a classic example of how accounts can be distorted in later renditions. Validity 0.

1851, May 15, 08:00 A.M. Soloviev and Go (1975) quoting Perrey (1872) state that there were mild earthquakes in March, April, and on May 15th, 17th, and 28th at San Francisco and Salinas accompanied by marine flooding. Other sources only mention the May 15th event and do not mention flooding. The *Daily Alta Californian* newspaper (May 16, 1851) state "about eight o'clock yesterday morning the shock of an earthquake was felt through the city and harbor. In many parts of the city the shock was so marked as to cause for a short time great alarm. It is said that those on shipboard felt very sensitive to the throbbings and convulsions of the earth." The *San Francisco Herald* (16 May, 1851, p. 2) states, "The shipping in the harbor violently rocked producing great commotion on board. Fortunately, no accident as far as we can hear, occurred though many were greatly alarmed. Long Wharf rocked from side to side like a cradle while several old ships hard aground were moved perceptibly from their positions." "People ran out of the steamers which were lying near Long Wharf" (*San Joaquin Republican*, May 17, 1851, p. 2). "A great disturbance [was] produced among vessels in the Harbor" (*Sacramento Daily Union*, May 17, p. 2).

Trask (1856, p. 86) states, "May 15th—Three severe shocks in San Francisco. During the earthquake windows were broken and buildings severely shaken...The shipping in the harbor rolled violently." The contemporary reports seem consistent with sea quake effects or rolling due to the swaying of the wharf to which they were moored. The Perrey account is 21 years after the fact and the local accounts are numerous and consistent enough to effectively eliminate the existence of a tsunami. Validity 1.

1851, November 12, 06:45 P.M. The *Daily Alta Californian* (November 13, 1851) mentions an earthquake on the previous evening, November 12th at 6:45 P.M. local time, but does not mention any wave activity. Perrey (1856) states, "Again at San Francisco there in the port people on board ship felt an unusual movement of water." Iida et al. (1967) citing Perrey and Holden state, "motion of the waters of the bay. Perhaps a seiche. Probably not a tsunami." Holden (1898) quotes Perrey, and the Bancroft manuscript says only "1851, November 12th, 7:00 P.M., San Francisco, California." Perrey (1856) seems to be the source for the "unusual movement of the water" statement. This is probably a report of a sea quake. Iida et al. (1967) and Soloviev and Go (1975) use a date of November 13th but the local contemporary newspapers use the correct date. Validity 1.

1852, November 24, 11:00 P.M. "At a farm about eight miles west of San Francisco, a severe shock of an earthquake was experienced...which was so violent as to create a commotion among the domestic animals. On the next morning, it was discovered that a deep chasm, about half a mile in width and three hundred yards in length had been opened from Lake Merced to the ocean, and the lake was nearly dry." (*Daily Alta Californian*, 27 November, 1852, p. 2; Toppozada et al., 1981, p. 143, 144). Joy (December 26, 1967, personal communication) reports "an article of Mr. Alfred A. Green in the newspaper *Daily Alta Californian* for Saturday, November 27, 1852 (p. 2, col. 1, no. 43) entitled "Singular Freak of Nature" says that at 11:00 P.M. on Wednesday, November 24, an earthquake was felt and the next morning it was noticed that Lake Merced had been drained and great cracks had appeared; the bay was reported to be disturbed." Lake Merced would drain into the ocean and not into the bay. Toppozada et al. (1981) continues that "if an earthquake were responsible for the drainage of Lake Merced, it was small as no earthquake was felt in San Francisco." A subsequent article in the newspaper suggests that the winter floods may have cut the channel (*Daily Alta Californian*, December 6, 1852, p. 2.). (See also the *Daily Alta Californian* of November 28, 1852, p. 2, col. 2.) Validity 1.

1853 November. An earthquake in the Kuril Islands, Russia, produced a tsunami that penetrated far inland at Simushir Island (Soloviev and Ferchev, 1961). "Small waves possibly recorded on newly installed San Diego tide gage" (Joy, 1968, p. A3). Joy now believes it was a mistake to have listed this event (Joy, personal communication, January 24, 1992). Neither the San Diego nor the Presidio tide gages could be located for this date. If it were recorded, it would be the earliest recorded tsunami. In reference to the December 23rd and 24th, 1954 tsunamis, Lt. W.P. Trowbridge, U.S. Corp of Engineers in the Coast Survey San Francisco office, stated, "I have twice before noticed a similar appearance on the San Diego sheet and have noted the circumstances, in pencil, on the tidal sheets. Similar phenomena have been observed at Ft. Point on two occasions; once the tide observer felt the shock of the earthquake and made a note of it, if I mistake not, before the effect on the sheet was observed" (Bache, 1856, p. 99). Trowbridge does not identify the dates of any of these. A long period seiche is apparent occasionally on San Diego marigrams due to meteorologically induced resonance within the basin formed by the Channel Islands and the mainland. These seiches leave a marigram trace similar to that of a tsunami. Cassidy's (1862) excitement about the July 24th, 1854 tsunami and his lack of mention of having seen anything similar earlier also argue against this event having been recorded. Since there is no evidence that this event was observed at San Diego it is given a validity of 0 for this location.

1854, May 31, 04:50 A.M. Trask (1856, p. 89) reports "An earthquake at Santa Barbara ten minutes before five o'clock in the morning. There were three vibrations, the first of which was accompanied by a deep rumble; the second was preceded by a loud rushing sound like the approach of a strong wind. About four or five seconds elapsed between each shock. The sea was much disturbed and a heavy swell came in after the second shock was felt which passed some thirty feet beyond the old wreck near the embarcadero. The inhabitants left their beds in their night attire and sought the street, but little damage was done." Later, Trask (1864, p. 187) described as "surf" swell and "surf" waves the effect of which he had seen on the following July. No activity was seen on the marigrams recorded at Monterey, North Beach, or San Diego, all rather far away for recording a minor local tsunami. The *Los Angeles Daily California Chronicle* had no mention of an earthquake or wave activity for the period of May 31 through June 5th but Perrey (1856a, p. 548) says for May 1854 "the 29th again at Santa Barbara, a light shock," makes it possible that this event is slightly misdated. Validity 3, a possible local landslide event but depends entirely on Trask's reports.

1854, July 24. Activity with an initial period of 50 minutes, amplitude of about 3 inches and arrival time about 03:25 A.M. (120° meridian time) is seen on its marigram. Andrew Cassidy (1862) in his personal notes states, "The water in the harbor today seems to be in a confused state rising and falling very suddenly as will be seen by the tidal sheet. By observing the staff gage, the water rises and falls nearly a foot in ten minutes. This is not caused by heavy swells. The water in the harbor is calm. It therefore must be a rise and fall of the tide from the fact that the boats anchored in the harbor will tend in and out as the water rises and falls on the gauge." On the tidal sheet Lt. Trowbridge wrote, "It is possible that the rise and fall here noticeable is due to submarine earthquakes. Earthquake phenomena are common in this country."

Cassidy again noted on the record, "The very great vibration is caused by the tide. By observing the staff for two hours I find the water to rise and fall suddenly. There is no heavy swell—the water is calm." (See Figure 32, page 152, for marigram.)

This is the earliest recording yet found for a possible tsunami and is one of the two mentioned by Trowbridge (see November, 1853). There is nothing in Cassidy's notes to indicate an earlier or later similar event at San Diego. The longer duration of the activity and the long period indicates a remote but unknown source but it could be a seiche as the beginning is unclear and it was not observed at Fort Point which would have been expected from a large remote tsunami. The amplitude is 0.33 feet and the period is 36 minutes. Validity 2.

1854, August 18 (GMT). A series of waves beginning just before midnight local time (11:50 P.M.), on the 17th were recorded at San Diego with an amplitude of one inch. (See Figure 33, page 152, for marigram.) It was not noted on the record by the operator but may have been one of the two events noted by Trowbridge (Bache, 1856). There is no reported teletsunami for this date. Validity 2.

1854, October 4, 10:10 A.M. The tide gage at Fort Point recorded a wave with a period of about 24 minutes and amplitude of one inch beginning about 10:10 A.M. and continuing for 24 hours. (See Figure 34, page 153, for marigram.) It is a possible teletsunami but no source is known. The San Diego record was specifically checked for this time and date but no notes or obvious activity was seen. This event has not previously been listed. Validity 3.

1854, October 21, 07:35 P.M. The *Daily Herald* (October 22, 1854, p. 2, col. 1) reports, "Earthquake—At 25 minutes before eight o'clock last evening [October 21st] a shock of earthquake was felt in the city, the severest that has occurred since the morning of the 15th of May, 1851. The motion was horizontal and nearly East to West. There were five distinct vibrations occurring something like two and a half or three seconds. The shock was so violent that several in the lower portions of the city left their homes in alarm." The October 24th issue (p. 2, col. 1) continues, "The earthquake—A ship's captain informs us that on Saturday evening about half past seven o'clock his vessel commenced heaving to and fro, and for a few seconds he thought he would part the hawser. This was doubtlessly caused by the earthquake which was felt at about the same time." The weekly *Alta Californian* of October 28 (p. 6, col. 4) confirms the earthquake but makes no mention of effects on the water.

Trask (1864, p. 137) reports for October 26, "A smart shock at San Francisco near midnight. It was felt at Benicia. This shock was followed by a swell in the bay as vessels at the wharf swayed heavily at their hawsers." Earlier he (Trask, 1856, p. 87) reported, "a smart shock at San Francisco, felt also in Benicia. Vessels lying at the wharves worked heavily at their hawsers." Note the later additions of "near midnight" in conflict with the newspaper reports and "swells in the bay." Trask is probably in error on the date of this event and this description is for the event of the 21st.

Holden (1898), quoting Trask and Perrey, gives "1854 October 26; smart shocks at San Francisco and Benicia followed by a sea wave." Benicia is about 25 miles northeast of San Francisco between San Pablo and Suisun Bays.

The Ft. Point marigrams were checked for October, November, and December, 1854 with no identifiable tsunamis seen before the 23rd of December event except for the October 4th disturbance. The fact that a wave was not recorded does not entirely rule out the occurrence of a small local wave. The instruments are quite insensitive to short period waves and the traces were uniformly smooth with only minor short period storm wave activity noted at 10:00 P.M., October 22nd, continuing through October 24th. See also the following event. Validity 2–3 (see following event).

1854, October. "A gentleman who visited Angel Island on business related to us the following remarkable circumstances which happened just shortly before his arrival on the island in the morning about 10:00 o'clock. A sloop was lying along side the wharf at the east side of the island taking stone. The Captain relates that there was not a breath of air stirring at the time. The sea was as smooth as glass when suddenly an immense sea arose and commenced dashing the schooner about at a fearful rate. At the same time the tide rose several feet higher than it had ever been seen to rise before by people living on the island engaged in quarrying. The captain of the schooner became alarmed for fear his craft would be dashed to pieces, cast off the fasts and got under way as quickly as possible. This singular phenomena continued for almost half an hour. It was evidently the effect of submarine volcanic agency. Those who are residing on the island state that they have never witnessed such an occurrence before." *Daily Alta Californian*, November 1, 1854, p. 3, col. 1 and repeated verbatim in the weekly *Alta Californian* of November 4, 1854, p. 1, col. 5 and *Nevada Journal*, November 10, 1854.

This is given as November 1 in earlier catalogs, but it is clear that the November 1 date is incorrect since that is the date of publication of the newspaper. The phase shortly before his arrival on the island in the morning about 10:00 o'clock" is ambiguous. Ten o'clock could be his arrival time or the time of the event. The time period of about half an hour would seem to rule out a storm. Nothing was observed on the tide gage record. The account states that there was no breeze and that the sea was calm. These statements seem to rule out a period of time between October 22 and 24 or somewhat later when storm wave noise was present on the marigram. The wave action clearly was not due to any local submarine volcanic activity as there is none. A landslide from the Richmond area, (or perhaps Angel Island itself) is possible since there are several precipitous islands and points in the area, and the ship was on the east side of Angel Island. Torrential rains on the night of October 12, 1854 (*Daily Herald*, October 14th, p. 2, col. 2) and the sharpest earthquake in years on October 21 could have combined to cause a landslide which would also account for the rolling of the ships in San Francisco on that date. The hour of occurrence, though, at 7:30 P.M. would have been 45 minutes after twilight. If this description is for the October 21st events, as seems possible, then the validity would be 3 for a local landslide tsunami on that date.

1854, December 23, 00:00 GMT. About nine A.M. local time a magnitude 8.3 earthquake in Tokkaido, Japan, created a local tsunami 21 meters high at Osatsu, Shima Peninsula, Japan. The earthquake and tsunami destroyed 8,300 homes and killed 1,000 people (Iida, 1984). The new tide recorders at San Francisco recorded the event about twelve hours and 22 minutes later. It was recorded also on the San Diego and Astoria, Oregon gages. Lt. Trowbridge called attention to the waves and as the weather was normal concluded that they were caused by a submarine earthquake. This hypothesis was borne out when accounts of damage to the Russian frigate *Diana* in the Port of Simoda was received on June 20th. The amplitude at San Francisco and San Diego was 3.9 inches and 3.0 inches respectively. The arrival time at San Diego was one hour and 22 minutes later than at San Francisco or about 13:44 (120 Meridian Time). It was only observable at Astoria (Bache, 1856). This is the earliest certain recording of a tsunami. (See marigrams, Figures 35 and 36, on page 154.) Validity 4.

1854, December 24, 08:00 GMT. A magnitude 8.6 earthquake near Nankaido, Japan generated a maximum wave of 28 meters at Kochi, Japan, and the earthquake and tsunami killed 3,000 people. The tsunami washed 15,000 homes away. It produced a wave of amplitude three inches and 4.2 inches at San Diego and San Francisco respectively and was only weakly recorded at Astoria (Iida, 1984, Bache, 1856, Soloviev and Go, 1974). Validity 4.

1855, March 19, 04:30 P.M. The *Humboldt Times*, Union, California for March 24, 1855, p. 2, reports, "on Monday [March 19th] at 4:30 P.M., the good people of this county got a shaking "as was a shaking" from a young earthquake, whether gotten up exclusively for our benefit or not, we, on our part, decline an encore. It extended upwards of thirty miles but was more severe in the vicinity of Bucksport, it having dried up the water in the branches and creeks for at least half an hour. At Angel's Ranch, twelve miles north of this [Arcata] it shook milk out of pans. Here, the water lying in holes was considerably agitated, houses rattled and shook so much as to frighten occupants into the streets, some of whom have not yet recovered from the effects of it. On Tuesday, [20th] at 4:00 A.M., another shock was felt at

Bucksport." Union, California is now Arcata and Bucksport is now a section in the southern part of Eureka. Angel's Ranch, a rural mountain ranch, is twelve miles northeast of Arcata above Blue Lake (McCormick, personal communication). Soloviev and Go (1975) quoting Perrey (1856) and Holden (1898) state "...the discharge of water into the rivers were changed. The water in Humboldt Bay was agitated for an hour." Perrey (1856) states, "The water was agitated for an hour," without specifically mentioning the bay. This seems to be a combination of the Bucksport and Angel Ranch reports in the *Humboldt Times*. The editor of the *Humboldt Times* was located on the bay at Arcata, and he had adequate time to gather reports from a 30 mile area. Had there been agitation of the bay for an hour it is almost certain not to have been missed or ignored by him. There appears to be no contemporary report of observed wave activity. This does not eliminate the chance that a wave was generated but only that no contemporary reports of wave action have been found. If, for example, the April 25, 1992, event's effects were superimposed on this event, the results would have been similar and no wave would have been reported. (See also April 25, 1992.) Validity 1.

1855, July 10, 8:15 P.M. Extensive damage was done in the Los Angeles area by four earthquake shocks felt in about twelve seconds. Submarine origin is suggested by the sea waves (Coffman et al., 1982). Trask (1864) reports "At Point San Juan there was observed considerable commotion in the water, attended by a strong rushing sound and two unusually heavy swells immediately following the last shock." Joy (1968) states "almost every structure in Los Angeles [was] damaged." There is a report of a seiche or small tsunami occurring in Santa Monica Bay (Wood and Heck, 1951). Heck (1947) reports heavy waves at Point Sur. The San Diego marigram stopped recording about twelve noon on July 10th as noted on the record, "clock stopped due by shaking of the building." The clock was restarted at 2:00 P.M. and ran to 11:00 P.M. when the clock again stopped. The operator again started the clock at 6:00 A.M. on the 11th, and it ran to 11:00 A.M. It stopped and was restarted four more times before "the abatement on which the housing rests entirely gave way" and it was rebuilt by the 13th. Thus, there is a question on the date and time of this event. It was not recorded by the tide gage but the gage was working during the July 10, 8:15 P.M. period. The building was shaken earlier and later.

The report of the tsunami appears genuine although seemingly only from Trask. Point San Juan is now called Dana Point near San Juan Capistrano, south of Los Angeles. Toppozada et al. (1981) gives an epicenter on land and about 60 miles from San Juan Capistrano. Validity 3; probable submarine landslide local tsunami.

1855, October 21, 7:45 P.M. Trask (1856, p. 88) reports a strong earthquake in San Francisco felt particularly in homes near the shore. "There was much commotion in the water a few minutes *preceding* the shock [emphasis added], which caused several vessels to heave heavily at their hawsers and cables." There was no disturbance recorded on the Fort Point marigram or mention found in the San Francisco evening *Post Bulletin* for October 21, 22 or 23. The fact that the "commotion" (not "wave") was reported to have been observed *before* the earthquake is an additional problem. This report is almost certainly a mis-dated entry for October 21, 1854, 7:35 P.M. Validity 1.

1856, February 15, 05:25 A.M. A magnitude 5.5 earthquake caused some damage in San Francisco and threw some people down. "In the Bay the shocks were as severe as on shore. Vessels vibrated and shook as if striking on rocks. The officers of the steamers *Golden Gate* and *Uncle Sam* were aroused and went on deck apprehending that their vessels were injured, concerning that the shocks to have been caused by a collision with the docks. The water rose rapidly and maintained an elevation for five minutes when it sunk two feet lower than previous to the vibrations. A seaman described the effect on the surface to have resembled a whirling about" (*Sacramento Daily Union*, February 18, 1856). "The shock was felt by vessels lying in the harbor and the bay was much affected" (*Daily Alta Californian*, February 16, 1856, p. 2), "The water in the bay today is exceedingly thick, supposed to be caused by the throwing up of mud and sand in the bottom of the bay by the earthquake." (*Daily Evening Bulletin*, February 15, 1856, p. 3) Richter and McAdie (1908) state that "Prof. George Davidson [U.S. Coast and Geodetic Survey] has corrected a statement published in the description of the earthquake at San Francisco on February 18th, 1856, where one writer states that the water in the Bay of San Francisco rose, maintained its level for five minutes and sank two feet below its ordinary stage. Professor Davidson obtained a tracing of the marigram from the Coast Survey and it showed that the time of the water level was remarkably smooth on the date in question." The original marigram was re-examined and the above comment verified. However, as mentioned earlier, these records are relatively insensitive to short period disturbances. There was no sign of tide gage shaking from the earthquake either. The report that the bay was thick with sediment also would support a localized submarine landslide hypothesis as well as seaquake effects. Validity 3. Possible local submarine landslide source.

1856, August 23. A magnitude 7.8 earthquake generated a tsunami near Hokkaido, Japan. It was recorded at San Francisco and San Diego with amplitudes of about one inch. The arrival at San Diego, at 08:11 A.M. implies an origin time of about 4:30 GMT. (See marigram, Figure 37.) Validity 4.

A note published in the *West American Scientist* (vol. 2, p. 62, 1886) states "Mr. S. Haley, of Los Angeles, who was captain of the *Sea-bird* in 1856 mentions the occurrence in that year of an earthquake in Japan which caused a tidal wave that in less than three days struck the California coast destroying twenty-six vessels along our shore. The waters of San Diego Bay rose over twelve feet above high water mark." Clearly, these one inch waves did not cause these effects.

The *Los Angeles Star* (July 14, 1855) mentions the steamer *Sea-bird* arrived at San Pedro on Tuesday morning [10th]...seven days from San Francisco and New Orleans since the 7th of June. It also mentions reports from the steamer *Emile* just arrived at Santa Barbara which reported the loss of six vessels and 22 people in Mazatlan on June 1. Sanchez and Farreras (1993) do not mention a tsunami in Mexico in 1855.

There is a further report in Newmark and Newmark (1930) for January 9, 1857, as follows, "It was at this time, too, that a so-called tidal wave almost engulfed the *Sea-bird* plying between San Pedro and San Francisco as she was entering the Golden Gate. Under the splendid seamanship of Captain Salisbury Haley, however, his sturdy little ship weathered the wave, and he was able to report his awful experience to the scientific world." There is no report of a Pacific tsunami in January 1857.

These reports seem garbled and may include elements from December 1854 or August 23, 1856, Japanese tsunamis, a possible July 1, 1855, meteorological event in Mexico and perhaps some other events, such as 1877 Chile which caused twelve-foot waves at San Pedro and the January 15, 1878, storm but these reports do not relate to a known tsunami.

1859, September 24, 05:30 A.M. "Effect of the earthquake—The schooner *Black Warrior* was injured to such an extent while lying at anchor in Half Moon Bay on Saturday morning, [September 24] as to compel her to undergo repairs by going upon the ways. It appears that at about three o'clock a slight trembling of the earth was felt and the water of the bay receded a distance of nearly fifteen feet leaving the vessel aground and the water returned with equal suddenness injuring her keel as stated" (*Sacramento Daily Union*, September 28, 1859, p. 1, col. 7, and repeated verbatim in the *San*

Francisco Daily Herald, October 5, 1859). The *Herald* continues, "There is probably some mistake in the above as the earthquake occurred at ten minutes before six o'clock and not at three as stated. Again we have been informed by a gentlemen who was bathing in the Bay at the time that he observed no trembling of the water at all, and it is scarcely possible that they would have receded so much as fifteen feet at so short a distance from the city—about thirty miles—and produce no visible effect here." The *San Francisco Evening Daily Bulletin* reports "a shock of an earthquake and a pretty severe one, was experienced in the city this morning at a few minutes before 6:00 A.M." (September 24, 1859, p. 3, col. 6).

The Fort Point marigram shows a long period, one hour and 15 minutes positive deviation, at 5:30 A.M. and marked on the record as "earthquake." Nothing cyclic was observed on the marigram.

Iida et al. (1967) suggest the report may be a misplaced one for the October 5, Chilean tsunami and Perrey (1862) gives an October 18 date. Both are impossible given the verified newspaper date of September 24th. However, a plot of expected tides at Fort Point shows a minus six inch tide expected at 3:30 A.M. which could have caused the schooner's plight. This report could be for a local submarine landslide tsunami or a normal tide fluctuation unrelated to the earthquake. Validity 2.

1861, May 4. A light shock was felt near San Francisco. "It was noticed that during this week the ebb tide dropped 12–18 inches below the lowest mark below which it had previously stopped. The shoals in the bay between Chevres Island and the Oakland River dried up twice so that one could walk across without getting one's feet wet" (Soloviev and Go, 1975, p. 205). No wave action observed on Ft. Point marigram but unusually low tides were observed. Chevres Island is probably Goat Island (now called Yerba Buena Island). No reference to the Oakland River was found. Yerba Buena Island is in the middle of the San Francisco Bay between San Francisco and Oakland. The water could not have receded far enough to walk from Yerba Buena to Oakland. The authors may have been referring to another island in the Oakland Harbor area. The low tides are astronomical tides and no tsunami activity was involved. Validity 0.

1862, May 27, 12:00 Noon. A magnitude 5.9 earthquake at San Diego caused the only local tsunami observed there. The tide gage was being repaired at the time so no record was obtained. The gage operator, Andrew Cassidy, was on the beach at La Playa about 1.25 miles north of Ballast Point on the east side of Point Loma at the time of the earthquake. Cassidy (1862) states, "The water in the Bay did not appear much agitated not withstanding the sea run up on the beach between three to four feet and immediately receded to its level." This probably refers to the horizontal level (inundation) which would make the height much less. Cassidy also notes "falls" of earth (landslides) from the banks between Point Loma and La Playa which are a possible source of the wave (Agnew, 1979). Although Cassidy is the sole source of the reported wave his qualifications as the official tide observer validates the report. It is probably a minor sub-aerial landslide generated tsunami but Cassidy may not have observed the maximum run-up height. Validity 4.

1865, October 8, 20:46 GMT. A destructive earthquake occurred near Santa Cruz and caused a high flood tide then a strong ebb tide at the time of the earthquake. "Along below Soquel (6 miles east of Santa Cruz) the high cliffs crumbled into the sea and the tide rose and fell with convulsive throbs" (*Daily Alta California*, October 10th, 1865, p. 1, col. 4). The San Lorenzo River changed its course (Beach, unpublished manuscript, quoting from *Santa Cruz Sentinel*). (The San Lorenzo River runs through Santa Cruz.) "A fisherman (of Captain Davenport's Whaling Company now operating at that point) was out in a boat at the time, and he describes the motion as being very rough and cross cutting; immediately after the sea was calm as a mill-pond, no waves, surf or tide running while the bay was full of little bubbles rising to the surface; along the coast was one continuous cloud of dust rising way down to and below Castro's Landing and up towards Santa Cruz" (*Santa Cruz Sentinel*, 14 October, 1865, p. 2).

"Captain Josslyn of the schooner *Faraway*, from Monterey, reported experiencing the earthquake when about 25 miles from Point New Years (Point Ano Nuevo) at about half past twelve o'clock Sunday...The shock was heavy enough to jar the dishes on the table. The sea was very smooth at the time but in about half an hour it became very rough, more so than is generally experienced on that Coast" (*Petaluma Journal* and *Argus*, October 12, 1862, p. 2).

"Persons who were in small boats on the Bay (San Francisco) stated that they perceived no continuous wave of the shock but that the sensation to them was such as might be expected if their boat had been lifted out of the water suddenly and dropped again while the water was thrown in great commotion as if it had been subjected to great heat" (*Daily Evening Herald*, Stockton, October 12, 1865, p. 2).

"A resident enjoying a sail in a pilot boat off the heads on Sunday says just as the shock occurred the pilot boat was about two miles inside the bar, crossing which was a brig from Oregon. The sea was unusually smooth and the wind light. Just as the shock came, the brig on the bar was observed to plunge violently, the waves running mountainous high for a few moments. The sea swell abated considerably when it struck deep water where the pilot boat was but the pilot estimated the height of the first wave as ten feet" (*Sacramento Daily Bee*, October 11, 1862, p. 2). "The waters of the bay were greatly agitated as the ships lying in the harbor were twisted and turned like corks" (*San Francisco Examiner*, October 9, 1865).

"On Long bridge, extending across a slough of the bay (Mission Bay) the shock was exceedingly severe. Men who were crossing at the time remarked a peculiar bubbling and boiling of the water, as if some terrible commotion was going on beneath and the oscillation of the earth was so great that they could not retain a standing position but fell prone on their faces. Some were discovered immediately after the shock lying insensible, the fright and shock to their nervous systems having temporarily paralyzed them.

"On the Bay and Ocean previous to the earthquake the water was smooth and motionless as a sheet of glass. But succeeding the shock a sharp wind came up, the water became agitated and soon huge billows were rolling in. The sensation on shipboard was as if the vessel had struck a rock or bar" (Lloyd, 1876, p. 320).

There is no marigram for this time from Fort Point. The clock stopped for several hours when the earthquake began.

The account of collapsing cliffs and a high flood tide then a strong ebb tide is consistent with a subaerial landslide-generated tsunami. The account of the fisherman in Santa Cruz Bay would also be consistent with a small local tsunami. The account of the *Faraway* 25 miles (to seaward?) of Point Ano Nuevo is consistent with a seaquake, but the *Faraway* would have been in water too deep to have experienced a tsunami. The rough water half an hour later could relate to the report of sharp wind and huge billows reported in San Francisco Bay after the shock and of unrelated meteorological origin. The report of the "persons" in a small boat in San Francisco Bay also are probably due to a seaquake. It is not known where the "heads" were, but they probably were the Golden Gate and the "bar" is at the entrance into the Bay. The Oregon brig may have experience the same billow described above for the Faraway. The currents can be swift over the bar and storm waves can reach 25 feet over the shallows. A local collapse of part of a bar is also possible. Long bridge was a structure built across the mouth of Mission Bay, a former shallow inlet just south of the present Bay bridge. The bridge was approximately where Third Street is presently. These effects are due to the earthquake amplified by the unconsolidated sediments of Mission Bay. There probably was a small subaerial landslide tsunami at Santa Cruz and possibly a submarine landslide one was generated near San Francisco Bay. Validity 3.

1866, December 20. Camfield (1980) states that the *Puget Sound Weekly* reported that a tide, the highest ever recorded, occurred at Port Townsend, Washington, on December 20, 1866. "The main street was filled with drift logs, and the dwellers on lower floors were compelled to elevate to the next story." He concludes that since the accounts describe a gradual rise in water level the event was probably a tsunami of unknown origin. He later (1986) thinks it could have been a submarine slide. However, the *Daily British Colonial* and *Victorian Chronicle* (Dec. 21, 1866, p. 3) states, "The tide yesterday was higher than it had ever known to rise by the oldest inhabitants: They (pilots) say there were 20 feet six inches and upward on the bar and part of the Indian Rancheria in the vicinity of Bolton's ship yard was inundated. It remained high all day indicating the prevalence of heavy southerly gales outside the strait."

The *Petaluma, California Journal,* and *Argus* for Thursday, Dec. 27, 1866 reports a "storm which prevailed for ten days up to Sunday night (Dec. 23) may be classed among the heaviest that has visited this coast for years." The Russian River flooded washing away some bridges and the logs for a saw mill. The towns of Santa Rose and Bloomfield were flooded.

The marigram from Astoria shows two days of heavy storm activity. These are storm waves and not a tsunami. Validity 0.

1868, April 3, 02:24 GMT. A magnitude 7.5 earthquake in Hawaii generated a tsunami with waves up to 66 feet high that washed away 108 houses and drowned 47 people in Hawaii. It was recorded at San Diego with an amplitude of four inches, at Ft. Point with two inches, and at Astoria with one inch. (See marigrams, Figures 38 and 39, on page 155 and 156.) Validity 4.

1868, June 13. An earthquake-generated wave on the Pacific Coast was reported in the *San Francisco Evening Bulletin* of June 13 but there was no earthquake (Townley and Allen, 1939). The *San Francisco Evening Bulletin* (June 13, p. 2) states "An earthquake wave which followed the recent eruption in the Sandwich Islands (Hawaii) was transmitted to this coast and recorded on Government self-registering tide gauges at San Diego, San Francisco and Astoria in about five hours." This is clearly a late report of the April 3 tsunami mentioned above and is Validity 0 for this date.

1868 August 13, 21:30 GMT. Two great earthquakes with magnitudes up to 8.5 struck Arica, Peru (now Chile) at about 4:45 and 8:45 P.M. local time respectively and generated a 21 m wave locally. More than 25,000 people were killed locally and several cities and settlements along the Peru-Chile coast were destroyed. The *U.S.S. Wateree* was carried one quarter of a mile inland where it still remains.

The tsunami was observed at San Pedro and Wilmington beginning about 7:00 A.M. on August 14 as a wave bearing a perpendicular front of eighteen inches swept up the shipping channel. The captain of the steamer *Cricket* observed that the tide seemed to ebb and flood at intervals of 15–25 minutes, and that the water fell five feet (range) in eight minutes and then rose the same amount in the same time. At 11:30 A.M. the loading wharf was submerged under six inches of water." (*Los Angeles Star* Aug. 14–19, 1868, and *Alta California*, Sept. 12, 1868, as quoted by Grauzinis et al., unpublished manuscript, pp. 76 and 77). San Pedro is on the western end of San Pedro Bay at the external end to Los Angeles Harbor and Wilmington is the mainland area north of Terminal Island in Los Angeles Harbor.

Another account (unidentified by Grauzinis et al.) says "Mr. Timme's dining room and kitchen were flooded to a depth of two feet." The location or elevation is not known.

Proctor (1869) gives a height of "no less than sixty-three feet in height at San Pedro" which was subsequently repeated by Holden (1887). Gutenberg and Richter (1965, p. 96) cite a reported value of 59.4 feet indicating that it was probably a mistake. The local contemporary sources indicate a range of at least five feet (amplitude 2.5 feet) but nothing approaching the sixty-three feet value which must have been confused with the source region heights. Note that Proctor does not identify San Pedro as being in California, and it is a common place name. It probably refers to a location near the source. The 7:00 A.M. time was the observed time. The recording of the first tsunami arrival was about 2:00 A.M. at San Diego and the maximum occurred about 8:00 P.M. The second tsunami cannot be visually separated from the earlier one on the marigram. The maximum recorded amplitude at San Diego was 1.3 feet; at Fort Point, San Francisco, the maximum amplitude was 0.9 feet and at Astoria, 0.56 foot (Hilgard, 1869, p. 233). McCulloch (1985) lists tsunamis recorded at San Diego on August 13th with a height of 2.64 feet (after Agnew, 1979) and on August 14th with a height of 0.99 feet (after Iida et al., 1967). These are for the same event with confusion of dates of origin and observations and range and amplitude.

Andrew Cassidy, the tide observer at San Diego, wrote on the marigram, "This is the most extraordinary commotion of the water I have ever seen here. The tide will run in for a space of 15 to 20 minutes and immediately turn and run out with great velocity even against the ebb tide." (See marigram, Figure 40.) Validity 4.

1868, October 21, 7:53 P.M. A destructive magnitude 7.0 earthquake occurred on the Hayward fault producing a scarp 20 miles long with a three foot horizontal offset and apparently a slight downthrow on the southwestern side. It caused the following effects in San Francisco Bay as reported in the *Alta Californian*, October 22, 1868, and quoted by Lawson (1908).

"There was no 'tidal wave' so far as we can learn, accompanying this earthquake. Nevertheless, the passengers on a ferry steamer off Angel Island felt the shock and supposed for the moment that they were aground. Many other boats reported the same experiences. Two boatmen in a Whitehall boat off Fort Point reported scary rumbling sound coming from the water; their boat was shaken and wheeled rapidly around (before the rollers reached them), and shortly they met three heavy rollers coming from the northwest on a calm sea." Soloviev and Go (1975) report that the wave broke on shore. The Hayward fault would have been east of the two boatmen.

Lawson continues, "At Cliff House nothing unusual took place with the exception of a decided commotion in the ocean and an impetus given to the everyday wave which sent it well inland, say fifteen or twenty feet above the usual mark."

Holden reports that the ferry was the *Contra Costa* off Angel Island and that the *Pactola* anchored in deep water fifteen miles west of the heads also felt the shock. The *Sacramento Bee* (October 21, 1868) states, "Water in Sacramento River receded and returned in a wave at least two feet in height."

The *Santa Cruz Times* (October 24, 1868, p. 3) reports, "One of the hands working on the San Lorenzo bridge informs us that two or three seconds after the shock occurred the river commenced running upstream and continued to do so during the whole interval." The San Lorenzo River runs through Santa Cruz.

Soloviev and Go (1975) report that "other boats and ships, riding in the harbor reported no marked disturbance...The tide gage on Government Island registered an unusual rise of water." Government Island is now a small island in the channel between Alameda and Oakland but it was created much later when a channel was cut through to San Leandro Bay early in this century. Fort Point was the only tide station known to be in operation in San Francisco Bay area in 1868. There was no activity visible on the Fort Point marigram but the instrument there does not seem sensitive to short period waves. Holden (1898) reports "no waves noticed at Oakland."

This is a still confusing account of possibly three wave events. The event in the Sacramento River may have been a seiche or a local landslide-generated tsunami but could not be part of a tsunami from the San Francisco Bay. The account from Cliff House and the two sailors near Fort Point could possibly be a submarine or sub-aerial landslide-generated event near the Golden Gate, perhaps by a collapse of material on the San Francisco bar. The event reportedly recorded at Government Island could have been from the Golden Gate event but its existence and location are not known. The Lorenzo bridge report depends only on one observer. If this report is true then it would indicate another local event at Santa Cruz. The Cliff House event is judged to be probably a subaerial or submarine landslide generated tsunami given its height and possible support of the sailor's account. Validity 3. The Santa Cruz report on the Lorenzo River is independent and possibly a submarine landslide. Validity 2. The Sacramento River event is judged to be seiches generated by the surface waves from the earthquake. Validity 1.

1869, February 10, 4:50 A.M. Perrey (1872) reports, "The 13th at four hours 50 minutes in the morning at San Francisco a shock was felt. The marigraph at Fort Hornet indicated shaking at several unknown points." *The Mining and Scientific Press* (February 20, 1869, p. 114, col. 1) reports, "Oceanic Earthquake—The self-registering tide gauge at Fort Point, which never fails to record the slightest variation in the tide, indicated on the 10th instant an unusual disturbance in all probability caused by a submarine earthquake." The tide gage at Fort Point for the 13th does not show any activity and the record for February 10th shows short period and long period noise but no tsunami. Validity 1.

1869, June 1, 6:00 A.M. "Earthquake wave—a series of earthquakes waves were recorded on the earthquake indicator (tide gage) at Fort Point early on Tuesday morning last (June 1). Intelligence from Japan, the Sandwich Islands (Hawaii) and the South American coast is in consequence, eagerly looked for" (*Mining and Scientific Press*, p. 368, June 5, 1869). The marigram shows some activity at about 6:00 A.M. on June 1st. Source unknown. (See Figure 41, page 157.) Validity 3.

1872, March 26, 02:25 A.M. The magnitude 7.8 Owens Valley earthquake was felt over most of California and Nevada and with intensity VI in San Diego. "That the shock extended under the ocean is proven by the schooner *Beal* which was becalmed in the straits off San Pedro and was so much injured that she made port with difficulty" (Rockwood, 1876). The *San Diego Union* (March 28, 1872, p. 2) states, "Accounts from Wilmington and San Pedro that sharp shocks of an earthquake were felt at those points at about three o'clock this morning lasting about one and half minutes. No unusual disturbance of the sea was notable." The effects reported by the Beal were probably due to sea quakes effects. Validity 0.

1872, August 23, 18:02 GMT. A tsunami generated by an earthquake in the Fox Islands, Aleutian Islands was recorded at San Diego, San Francisco, and Astoria, all with amplitudes of less than three inches. (See Figure 43.) It was reported to have been recorded on the marigram at Honolulu which was installed there that year but the record has not been located. From the arrival times at the west coast stations and reported time from Honolulu, Cox (1984) was able to determine a source area in the Fox Islands. Lander recently found a marigram from St. Paul Island in the Pribilof Islands, Bering Sea, which confirmed the general location. This is the first instrumentally located earthquake and tsunami source.

Earlier, Professor Davidson had mentioned these waves recorded on the west coast and that they arrived two and three quarters of an hour earlier at Honolulu than Golden Gate. "He had made careful calculations from the data received and had determined that the immediate locality of the earthquake disturbance commencing on the 24th of August was about midway between the southern point of Kamchatka and the northern shores of the Japanese (Kuril Islands) Islands" (Yale, 1872, p. 268–269). The time difference between arrivals on the west coast and Honolulu seems to be ninety minutes too long from Cox's calculations and probably accounts for Davidson's error in location. Validity 4.

1872, September 16, 10:00 P.M. Davidson reported "On the 16th and 17th of September the tide gauge again indicated earthquake disturbances, and, from the character of the waves, it was determined that the location of the shock was not far removed from this coast" (Yale, 1872, p. 269). It is recorded at Fort Point San Francisco at about 22:00 local time with a maximum amplitude of four inches and a period of seven minutes. (See Figure 42.) It was not visible on the Astoria record and the San Diego record was not found. Joy (1968) mentions that it was noted on all three records and this is repeated by Soloviev. This is a mistake as Davidson (Yale, 1872), Joy's only source, mentions all three stations for the August 23, 1872, event but not for this event although both are treated in the same paragraph. This is possibly from a second and smaller shock from the Aleutian Islands or an other remote source but there is no other reports known from Hawaii or anywhere else for this event. The short period of the waves would support Davidson's conclusion of a regional source. Validity 3.

1873, November 22, 8:50 P.M. "I send you the following interesting item from the locality (Crescent City): We were visited on the 22nd instant at ten minutes before nine with an earthquake shock exceeding in violence anything ever before experienced here since the settlement of the country by the Whites. The vibrations were from the northwest to the southeast, and the duration was from 15 to 20 seconds. The shock was strong enough to ring the town firebell and to set all the door bells in the town ringing. The earth opened in several places, some of the cracks extending a distance of thirty and forty yards. Considerable damage was done. All the brick buildings in town and crockery-ware suffered considerable damage. The Indians here were very much frightened and took to the hills and highlands. It seems they have a tradition that such an occurrence took place here once before, followed by what, as they describe it, must have been an immense tidal wave. It is undoubtedly a true tradition, as there are indisputable evidence of it in the drift on the flat on which the town is located. Just immediately preceding the shock the air was strongly impregnated with the smell of sulphur. Yours, M." (*The Humboldt Times*, Eureka, December 1, 1873, p. 3).

"Earthquake at Sea—The schooner *Mariam* which arrived in San Francisco recently reports that when north of Cape Mendocino on the 23rd there was expressed a violent shock of an earthquake which made the vessel tremble as though dragging on the rocks."

"Port Orford, Oregon. The quiet of our town was somewhat disturbed last evening at 9 o'clock by a terrible earthquake, the first ever felt in this section. A rotary shock from Southeast to Northwest lasted a full minute. No noise accompanied it, no one was hurt, no buildings damaged, but had we brick structures in our town not a building would have been standing this morning. We hear it was felt about the same in all quarters within distances of ten miles from here."

"A loud noise was heard off at sea West of Cape Blanco. It appeared like the rush and upheaval of the waters; in fact the water was seen to rise and fall, boiling and hissing. This took place or was noticed immediately after the shock and the people in that vicinity were making preparations for climbing a tree or getting to higher ground.

No tidal wave followed and nothing unusual noticed on the beach. No signs of high wake. Light house and Tower still standing; at this time unable to learn if any damage was done to either. Yours truly, J.B.T."

"N.B. Mr. Deadmond who resides one mile north of here directly on the sea coast says that about ten minutes after the shake he heard a noise off to the westward, loud as the report of a hundred cannons, and that he noticed indications on the beach of very high water and sand being thrown up to the highest water marks. Lighthouse had little damage; plastering and putty slanted in many places. Vibrations in tower at least six inches. J.B.T." (*The Crescent City Courier*, November 29, 1873, p. 3).

Toppozada (personal communication, April 13, 1993) contributed this information on this important event and evidence of a prehistorical event from the Indian reaction and legend and the pre-existing debris line. As Toppozada concludes, the earlier tsunami must have been local in origin as the natives responded to the earthquake in seeking higher ground.

The cracks described probably were not fault lines as they were quite short. They probably were due to differential settling. The early smell of "sulphur" is not explained but could have been methane from compaction of the bay sediment.

The epicenter was near the coast. The loud cannon-like noise could have been due to landslides either in the hills or from the coastal cliffs, but no landslides were reported in this brief account. The rise and fall of the water could have been due to tectonic uplift if the faulting extended under the ocean, or to subaerial landslides considering the noise, whether the epicenter was on land or water.

This event is of considerable importance as the only one occurring in the Cascadia Plate region. It was not recorded by the Neah Bay, Washington, or Presidio tide gages but both were far from the source. An amplitude of 10 feet is estimated by computing the expected tide and the maximum tide level reached by the wave, -0.9 feet at 7:30 P.M. low tide estimated at about 9 feet, the highest of the month. Validity 3. Probably a subaerial landslide source as it was reported from only one place and loud noises were heard.

1875, October 14, 5:47 P.M. A sharp shock occurred at San Francisco and in the Santa Clara Valley with reports of heavy seas without wind from Santa Cruz to Cape Mendocino, rolling 100 to 300 feet beyond the usual tide. The waves continued for several days (Rockwood, 1876). Rockwood inferred that the earthquake had its origin somewhere in the Pacific Ocean. The *Santa Cruz Sentinel* (October 16, 1875, p. 2) states, "Wrecked by the waves last Tuesday (12th) morning. About 8:00 o'clock some 350 feet of the San Vicente Lime Company's new wharf at Davenport was totally destroyed by the force of the waves, which rolled in on the shore with almost relentless force." In a separate item on the same page "sharp shock—last Thursday (14th) evening at 5:47, the people of the town were shook up a little by an earthquake. The shock was the heaviest felt here since 1868. As far as we can learn it caused no damage in this vicinity." Obviously the waves of the 12th are not related to the earthquake of the 14th. The waves were probably meteorological in origin. Validity 0 for October 14. Validity 1 for October 12.

1877, April 16, 7:10 A.M. "A very slight shock of earthquake inflicting no damage was felt in San Luis Obispo about six o'clock on the morning on the 16th of April, 1877. A strange irregularity in the tides occurred at Cayucos. In the morning at ten minutes past seven, the peculiar freaks of old Neptune were observed. The sea had submerged the debris of extreme high water deposits, and on watching it for a few seconds found the water receding extremely fast. During the period of one half hour, three vibrations took place (10 minutes period on average), the sea rising and falling a perpendicular height of twelve feet (range) by actual measurement. The wave of 1868 as observed on the coast of California did not anywhere show greater fluctuations than on the 16th of April, 1877. At Anaheim, there was a rise of twelve feet in a few moments where as the ordinary wave rises only four feet in not less than three hours" (Angel, 1883, p. 330).

The *San Luis Obispo Daily Tribune* (April, 17, 1877, p. 3) states, "the tide was high in the morning. Steamer delayed due to winds and windstorm." The *San Diego Union* (April 19, 1872) reports 45 mph winds causing ships to seek shelter.

The *Santa Barbara Daily Press* (April 16, 1877, p. 1) reports "a very slight earthquake was felt here about six o'clock last Monday morning" (April 9) and on page two the *Anaheim Gazette* reports that the shock of an earthquake was plainly felt at Anaheim and Santa Ana about four o'clock, Friday morning (April 13th). The *Los Angeles Evening Express* (April 19, 1877, p. 3) states, "In a late issue of the *Los Angeles Evening Express* it was stated that the *Orizaba* on her last trip out from San Diego had to run into False Bay to get out of the wind and the sea had broken clear over her decks...This was not true as she laid in the harbor until the winds died down. That the sea was quite rough on the occasion alluded to is indisputable."

This appears to be accounts of minor earthquakes on the 9th and 13th, and a sea storm on the 16th. The 10 minute periods observed at Cayucos could be storm-generated seiches. Validity 1.

1877, May 10, 00:59 GMT. A magnitude 8.3 earthquake in Chile produced a 24-m tsunami that caused extensive damage along the Peru-Chile coast. The tsunami caused fatalities in Hawaii and Japan. It was well recorded at Fort Point and Sausalito with amplitudes of about 0.6 feet but not seen on the San Diego tide gage. (See Figure 44.) On page 990 of the *1877 Annual Report of the Chief of Engineers, U.S. Army*, is the following concerning San Pedro: "It may be well to notice here that an interesting and unusual phenomenon occurred on the morning of May 10th. Happily it did no damage of any amount. About seven o'clock in the morning, the tide being about four feet above low waters, the sea begun to rise, and in 2.5 minutes it rose 6.8 feet, submerging the work and a great deal of land on the shore which is little above high water. The wave retreated in a few minutes at a slower rate than it had advanced, falling five feet in nine minutes. There were a number of these oscillations during the day, but none so large as the one just described."

The *Santa Cruz Weekly Courier* (May 11, 1877, p. 3, col. 5) reports: "Tidal Waves. Yesterday morning two tidal waves visited us. The first occurred at 6:30 o'clock and the last at 7:30. The water in both cases receded sufficiently to lay bare the buoys stretched to the raft at Leibrant's bath house. The returning waves were high enough to reach half way up the pilings supporting the bath house. These phenomena are possibly caused by earthquakes agitating the ocean."

The *Santa Cruz Local Item* (May 11, 1877, p. 3): "Tidal Wave. We may look for tidings of some unusual commotion of some point on the Pacific Ocean if the unusual occurrences remarked on our Bay yesterday morning shall be counted as anything. Captain Sagar informs us that about five o'clock yesterday morning the water of the Bay gradually rose about nine feet running up on the beach to within a short distance of the bath house, stopped a moment and then gradually receded. The rise of the water was first noticed by the precipitable rising of the steamer which was lying at the wharf. There was no sea on and it seemed more like a gentle swell rolling in, then resting for a second and then receding in the same manner. The water was higher than on any occasion since the southeast storms of last winter."

The *Los Angeles Evening Express* (May 11, 1877), "The Ocean on a Bender" from the Anaheim correspondent on the 10th: "At half past six A.M. when the tide ought to have been rising regularly (at eight A.M. was to be high water) the water suddenly rose up to about five feet in the course of about five minutes. After being tossed and stirred up a few minutes it suddenly rushed out again and fell five or six feet in five minutes. The current was frightfully swift to look at in the creek. Two of the sailors, just then coming in, in a small row boat were suddenly carried far up into the creek beyond their destination. Then suddenly they were rushed back again and barely could make the shore before being carried out to sea. A lighter [boat] loaded with lumber was being brought up the creek at the same time and became also unmanageable. The tide rushed in and out every five minutes at such velocity it would at one time leave the lighter high and dry upon the beach and again it would be floating in six or eight feet of water. After having attempted a dozen times without success to bring in the lighter, the puzzled Captain Wilson gave it up in disgust and anchored the lighter out at sea. When the tide fell it would always leave a number of sharks and other fish on dry land, floundering and spluttering in sand only to be washed off again into the water within the next few minutes. At the same time the water in the creek seemed tossed and stirred up by some force."

"Gaviota, May 10th. A tidal wave was observed at this place from ten minutes past seven to thirty minutes past nine this morning. The ocean rose and fell three times to a height of twelve feet. No damage."

The *San Diego Union Weekly* (May 17, 1877, p. 3) reported, "The rise of the tide at Wilmington on Friday was eleven feet."

This tsunami apparently did not cause any damage but if a similar wave occurred again it could be quite destructive due to the development of the area. Validity 4.

1878, January 14. Cox and Morgan (1977) discuss observations of a possible tsunami in Hawaii on January 20, 1878 that they believed originated in the Aleutian Islands. They mention an item from the *Pacific Commercial Journal* (February 1, 1878) containing a report from San Francisco concerning "a great tidal wave or extraordinary swell" that was observed five days earlier (January 15th) at Los Angeles and destroyed or badly damaged wharves at Carpinteria, More's Landing, Ventura, and Santa Barbara.

The *San Diego Union*, (January 16, 1878, p. 1) published an article datelined January 15th entitled "The Storm" reporting that heavy waves tipped over and destroyed the outer 300 feet of the wharf at San Buenaventura (Ventura) the evening before (Jan. 14) at 6:00 P.M. The wharves at Carpinteria, twelve to fifteen miles east of Santa Barbara, and More's Landing, seven miles west of Santa Barbara, were carried away. At Santa Barbara, near Goleta, an old abandoned wharf was destroyed and its debris destroyed 300 feet of the new wharf near the surf line. The *San Luis Obispo Tribune* (January 19, 1878, "A Furious Storm") and the *Ventura Signal* (January 19, 1878, "The Great Storm at Sea") confirm the damage and the heavy winds and rain. The effects covered much of the state including a five foot flooding of the "Lovenze" River (Lorenzo) at Santa Cruz on January 25th (*Monthly Weather Review*, January 1878, p. 8).

There is no doubt that these affects were caused by meteorological waves and perhaps were the source of the waves observed in Hawaii five days later. Validity 0.

1878, November 22. The *San Luis Obispo Tribune* (Saturday, November 23, 1878) states: "Marine Phenomena. On Friday last (November 22nd) a tidal wave swept along this coast doing considerable damage to many of the landings. The full extent of the wave and the exact amount of injury inflicted is not known at this time. It was observed as far south as Wilmington where the water fell three feet below the breakwater and in half an hour rose as many feet above it. As near as we can ascertain the culmination of the wave was within a few miles of San Luis Obispo Harbor. The principal damage was done at Point Sal. About half the wharf at this point is reported to have been carried away, involving the loss of several hundred sacks of grain and the drowning of one man. The Point Sal wharf was a strong structure and in thorough repair."

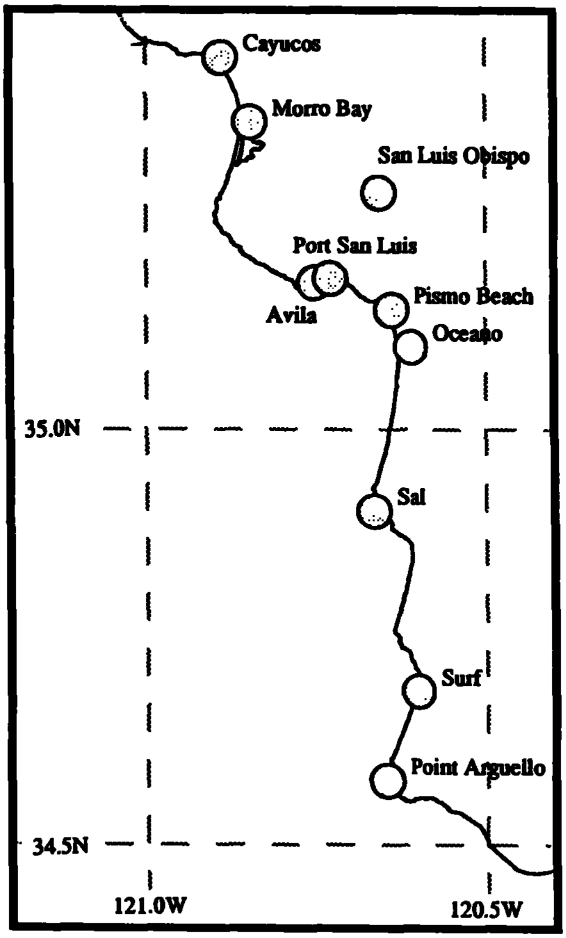


Figure 10. San Luis Obispo and vicinity.

"Captain Hanna of the *Gypsy* was at Point Sal taking on grain when the disturbance commenced and was obligated to put over to Port Harford, near Avila. The captain states he has not seen such heavy seas for years. The greater part of the old People's Wharf at Avila was carried away. This was not a very substantial affair, having been badly damaged last winter, since which time it has not been used and but partially repaired."

"Superintendent Haskins states that the reef which protects Port Harford presented a grand appearance during the raging of the waters. The waves would break against the rocks throwing the spray in clouds many feet above the highest rock. Port Harford was not affected."

"A gentleman who was driving along the beach in the vicinity of Price's Surf Landing (Pismo) reports an unusual commotion in the ocean early in the day. It was low tide at the time and the water would recede and then rush in with great force to above high water mark. At Morro the sea ran so high as to break over the sand ridge which divides the bay from the ocean. The Cayucos wharf was slightly damaged, losing about thirty piles. The new wharf at San Simeon was uninjured. The most remarkable features was the absence of wind. The disturbance was doubtless occasioned by a submarine earthquake."

The *Los Angeles Express* (November 22, 1878, p. 3) mentions a dispatch from San Luis Obispo reporting damage there to the wharves at Point Sal, the Peoples Wharf at San Luis Landing, the Cayucos Wharf. "While this destruction was going on it is a fact worthy of notice that there was no injury done to the wharf here at Santa Monica."

The *Santa Barbara Daily Press* (November 23, 1878, p. 2) states, "The *Los Angeles Express* thinks the recent tidal wave was doubtlessly caused by an earthquake shock finding its center in the Pacific Islands somewhere down on the Central and South American coasts."

Angel (1883, p. 329–330) essentially repeats the *San Luis Obispo Tribune* article above. Joy (1968) cites Angel in summary form adding that it was not noticed in San Diego. He notes there were no local earthquakes reported or other tsunami reports and concludes the event was probably mis-dated by Angel and refers to the

May 10, 1877 or August 13, 1868 Chilean tsunami. The dated quotes from contemporary newspapers make this impossible.

The *Los Angeles Express* article indicates the event must have happened fairly early in the morning for them to include it in their evening edition of the same day. Their mention of no damage to the Santa Monica wharf without commenting on effects reported by *San Luis Obispo Tribune* for Wilmington and the failure of the *Santa Barbara Daily Press* to mention local effects casts considerable doubt on the high waves reported for Wilmington.

The fatality is the first reported loss of life by tsunami action on the west coast and not previously reported.

This was probably a local submarine landslide tsunami near Surf and the report of effects at Wilmington are doubtful. See also November 4, 1927. Validity 3.

1879, August 10, 1:15 P.M. "Earthquake–On the 10th, (August) 1:15, very slight at Los Angeles, California. The motion was more precipitable at Santa Monica, about 13 miles distance and a tidal wave which followed was attributed to it. At San Fernando, the shock was quite severe" (*Monthly Weather Review*, August, 1879, p. 15). Possible local submarine landslide tsunami. Validity 2.

1883, August 27, 02:59 GMT. The explosion of the Krakatau Volcano in Indonesia generated a 30-m tsunami in the Sundra Strait that destroyed numerous towns and killed about 36,000 people. The explosion was heard about 3,000 miles away. It also caused an atmospheric pressure wave that was recorded on the tide gages at remote locations including South Georgia Island, Panama, France, England, Hawaii, Alaska, and San Francisco. Due to the shadowing by continents and island groups, a direct tsunami could not have reached most of these locations. Harkrider and Press (1967) show that the direct air waves (acoustic) are the first to be recorded. Atmospheric gravity waves with phase and group velocities nearer the oceanic gravity wave velocity ($\sqrt{gd}$) occurred and may have excited water waves (tsunamis) by transferring energy to the ocean. The longer the fetch, the more energy that would be transferred. These waves are the most energetic and are created beyond the land mass shadow zones. The initial acoustic waves, too, may create resonances in the coastal and harbor areas as seiches. To consider these to be true tsunamis is a stretch of the definition but atmospheric gravity waves are or may be a source for tidal disturbance which resemble tsunamis. (See also the events of November 21, 1910, and March 30, 1956. Marminer, 1930; McAdie, 1910; Wilson, 1954.) It was recorded with an amplitude of six inches at Sausalito. Validity 2 as a tsunami wave since the wave creation was not "instantaneous."

1884, January 25. A local tsunami was reported to have occurred on the coast near San Francisco (Soloviev and Go, 1975). This is due to a report in Holden (1898) citing Rockwood stating, "Professor George Davidson reported that at 19:24 on January 25th earthquake waves were indicated by the level of the astronomical instruments of Lick Observatory and they continued for twenty minutes." There is no mention of a local earthquake or any water disturbance. These may have been due to remote long period earthquake waves. Validity 0.

1884, November 12. Rockwood (1885) reports, "The self-registering tide gage at Sausalito, California recorded a series of waves probably due to a submarine earthquake." These are described in the *San Francisco Evening Bulletin* of December 12th. "They commenced at eight o'clock in the morning and ended at eleven. Here are nine well marked crests in two and a half hours or only seventeen minutes apart. They are only two or three inches in height but maintain their characteristic earthquake features in plain contrast with the breaking bar marks which are very sharp and frequent. It would appear from the height and length of the waves that this submarine earthquake took place near our coasts and was not violent." The area experienced stormy weather on these dates. The *Alta Californian* (November 19, 1884) reports 0.2 inches of rain in San Francisco on the 12th and 1.2 inches at Los Angeles. The *Monthly Weather Review* reports winds at Cape Mendocino of 68 mph on the 6th, 62 mph on the 9th, 54 mph on the 10th, and 58 mph on the 14th. The marigram shows short period noise on the 6th and again on the 8th. Longer period waves begin on the 12th and the operator notes "submarine disturbance."

There is no known remote source for a tsunami. The onset is emergent and given the known storm conditions this is probably a storm seiche. Validity 1.

1885, November 19. "Several great earthquake waves from the Pacific were observed at San Francisco on November 19 between one and eight o'clock P.M. at intervals of thirty-five minutes" (*Nature*, 1885). Holden (1898) mentions that the levels of astronomical instruments at intervals of 35 minutes also showed the waves. The *Monthly Weather Review* for November, 1885 (p. 279) reports, "On the Pacific coast the rainfall was remarkably heavy (for the month of November). Numerous stations reporting ten to nineteen inches...At San Francisco the departure (from normal) was also very marked amounting to 9.26 (inches). The rainfall at these stations was the largest recorded for any corresponding month."

The marigraphic record shows no clear beginning and there is a second amplification on November 24. (See Figure 45, page 159.) These are most likely storm-induced seiches. Validity 1.

1885, November 24. A tide at about 12:20 A.M. was reportedly 0.66 feet higher than any measured since Eureka was settled. At about 11:00 A.M. wind that had been blowing steadily and hard for several days stopped just before the sea began to rise. At about noon water began to pour into the foot of First, Second, Third, and Fourth Streets flooding many houses. Warehouses were flooded, destroying 32 tons of salt. Two feet of water flooded Vance's mill and people in low-lying areas were forced to evacuate. Damage to the Eel River and Eureka Railroad was estimated to be $20,000 (*Humboldt Beacon*). At Crescent City an unusually high gale had been blowing for several days, and it was near full moon. Tides were higher than normal. Much damage was done to the wharf, and many houses were flooded. A log 30 inches across and 29.7 feet long was washed inside a saloon. The above description was compiled by Evelyn McCormick in the *Humboldt Historian*, article of November-December 1985 and from transcripts she provided from the *Daily Times-Telephone* of Eureka, the *Weekly Times* of Eureka, and the *Humboldt Standard* of Eureka.

The effects are caused by high tides and a storm waves rather than a tsunami, although a series of minor earth tremors occurred in the area in the middle of November. The astronomical high tide was normal. The marigram at Sausalito showed longer period seiche on the 24th similar to those on the 19th. This event is almost certainly a continuation of the storm which probably caused the effects described for November 19. Validity 0.

1887, July 8, 04:00 P.M. Distinct waves were recorded on the tide gage at Sausalito beginning about 04:00 P.M. (See Figure 46.) The waves had a period of about twelve minutes and a maximum amplitude of about 2.4 inches and continued for about three hours. The exact time is not known as there was a failure of the hour marks by the tide record. Reports of an earthquake on July 6 at 10:15 P.M. by Townley and Allen (1939) are not related to this event.

An observer wrote "submarine disturbances or earthquake wave" on the record. A source is not known for this event but a local source is possible due to the short period. However, there was no report of an earthquake and earthquake faults in the area are strike slip in character, the type which do not produce tsunamis. A submarine landslide source usually has a longer initial period. A subaerial landslide source is possible but there are no reports to substantiate the occurrence. Validity 2. Source unknown.

1891, November 29. "Water in Lake Washington (vicinity of Seattle) surged onto the beach two feet above the mark of the highest water and eight feet above lake stage on that date" (Camfield, 1980, p. 217). The *Seattle Post Intelligence* (Dec. 1, 1891) reports, "The Rev. D.C. Garrett...said yesterday 'the *Flyer* had just pulled out from the wharf here when I looked at my watch to see how much later we were starting. The hands showed 03:17 and at that moment the ship careened so far to one side I feared for a moment she was going to upset.'" This presumably is on the Puget Sound side of Seattle as the *Flyer* was enroute to Tacoma.

The *Tacoma Daily Ledger* (November 30, 1891) states, "Lake Washington on the east side of town was lashed into foam and the water rolled on the beach two feet above the mark of the highest water and eight feet above present stage." This is repeated in Bradford (1935).

The Morning Globe (Tacoma, Nov. 30, 1891, p. 4) reports, "The Earthquake had its effect on the Sound also. Captain Sudlow of the brig *Quickstep*, which is lying at the end of the Northern Pacific dock being repaired, was at work in the cabin on some carpenter work, when his boat was lifted by a big swell, which broke on the bulkhead of the dock and splashed over the boat. The swell was so unusual that the captain made his way out of the cabin to see what steamboat was so close to shore, sending in swells. He could see no steamers and was puzzled until he heard about the earthquake." This effect probably was independent from the effect described for Seattle.

Two shocks of an earthquake lasting about five seconds each were felt. No damage was reported. Seismic waves came from the southeast to northwest. One building swayed so much that the elevator bumped against the side of the shaft.
This probably describes three separate events, one in Lake Washington, one on the Puget Sound side of Seattle and a third in the vicinity of Tacoma. These were probably subaerial or submarine landslide-generated tsunamis. Validity 3.

1895, March 9 and 30. "A strange seismic disturbance is reported from Costa Harbor, San Miguel Island. The land forming the high bluffs back of the boathouse is said to have sunk sixty feet perpendicular, forcing the beach and rocks strewn along it for a length of 1,800 feet some 30 feet upward and some 600 feet outward into the harbor. The change occurred on the 9th of March and the ground is reported to be still moving" (*Los Angeles Sunday Times*, March 17, 1895, p. 15, vol. 4). Joy (1968) describes events on these dates giving the dates as March 8, 10, and 30 as "A highly questionable series of events. A small schooner was wrecked while in the harbor on San Miguel Island, possibly a landslide triggered by an earthquake."

Townley and Allen (1939) cite an article in a newspaper of March 17 but did not identify it. They think the story was worked up by a newspaper reporter into a very sensational story. There was no mention of the events in the *Santa Barbara Free Press* of March 10 to 12 or March 31 to April 1. The *Santa Barbara Daily Independent,* the apparent source of these reports, could not be located for March.

The Daily Independent for April 2 states, "News must be very scarce in Santa Barbara when the correspondents of outside papers have to resort to fakes, pure and simple, to make their daily budget. The correspondent in yesterday's *Los Angeles Times*...gave the city the following undesirable advertisement: 'Santa Barbara has something to say about the wonders of the deep for it would seem the channel has some disturbing element beneath its surface. A Spanish captain declared to your correspondent that while his vessel was anchored in the channel directly on a line with the city he heard a tremendous explosion resembling a noise like thunder, only much louder. His vessel was visibly and very sensibly affected by the shock and the water in the immediate vicinity was also greatly disturbed.'"

The article continued labeling the report 'absolutely false.' In the same issue a writer refers to an article in the *Los Angeles Examiner* as being one of the few large daily newspapers to carry the story and that none had investigated the story on site.

Costa Harbor can not be located. The only harbor on the island is Cuyler's Harbor and has been known as that since 1852. The initial *Los Angeles Sunday Times* report seems like a very detailed description of a large coastal land slide of a rotational type, pushing its toe upward and outward. The account of the Spanish captain is not well fixed in time or place beyond being before April 1 and in line with Santa Barbara. Santa Barbara is the nearest mainland port for San Miguel and on the same latitude. The description of the noise, the visible and sensible effects of the shock on the vessel and the "disturbed" water would be consistent for a large subaerial landslide into the water with or without a triggering earthquake if the vessel were near shore. It could be a belated report of the event of March 9 or a continuation of the landsliding at a later date.

A landslide into the ocean could generate a local tsunami if it had occurred rapidly as the "noise" would suggest. However, there is nothing in these descriptions to suggest a wave beyond the "disturbance" of the water. Validity 2.

1895, July. A third disturbance is described by Townley and Allen (1939) as occurring in July at San Miguel when a ship was damaged by falling rocks at Flea Island (not Flag Island). Flea Island cannot be located. There is not anything in the description which would lead to a conclusion that a tsunami had occurred. Validity 1.

1895, October 14. Holden (1898) reports, "The tide-gauge of the U.S. Coast Survey at Sausalito shows evidences of a heavy storm or earthquake. The irregularities in the record begin at 8:20 A.M. on October 14th and lasted continuously for 18 hours" (*San Francisco Call*, October 19th). The *Monthly Weather Review* (October, 1895, p. 579) states, "The Great Storm of October 1896 [sic] in the Gulf of California began about midnight, September 30th. A hurricane at La Paz, B.C. [Baja California] destroyed La Paz." The marigram at Sausalito shows only 18 hours of short period storm waves. Validity 0.

1896, June 15, 10:33 GMT. The great Sanriku earthquake in Japan (magnitude 7.6) produced a 38.2 m wave at Sherahama, Ryori Bay. The earthquake and tsunami destroyed more than 11,000 homes and killed more than 26,000 people (Iida, 1984). A four inch wave was recorded at Sausalito near San Francisco at 12:52 P.M. local time. (See Figure 47, page 160.)

The *Mendocino Beacon* (June 20, 1896, p. 5) reports: "A tidal wave was experienced at this place [Mendocino] last Tuesday between two and four o'clock in the afternoon. The sea rose and fell some seven feet beyond its level in mighty waves gradually becoming less. The waves extended to the boon on Big River where the water rose ten inches. The log boom at the mill was in danger but stood the test. So there was no material damage done."

This account was repeated essentially in the *San Francisco Chronicle* of June 24, 1896, and Holden (1898). The *San Francisco Chronicle* of June 16, 1896 (p. 2) reported that a 9.5 foot wave arriving at low tide overtopped a temporary dike of sand bags protecting an area on the San Lorenzo River which was being used to build floats for a festival at Santa Cruz. It did not mention any ships being damaged. The Santa Cruz papers were filled with the preparations for the festival which included visits by the Cruiser *Monadnock* and Battleship *Philadelphia* which arrived on the 15th at 4:15 and 5:30 P.M. The tsunami would have arrived about 1:00 P.M. The ships were described as rolling in the currents by the *Chronicle*. The Santa Cruz papers did not mention any wave or damage to a ship whether from civic protectiveness for the upcoming festival or because it was minor news. As there were dozens of flimsy craft in the harbor especially built for the festival, the likelihood of damage was great.

No mention of the earthquake or effects were found in the *Santa Cruz Sentinel* for June 16 or 17 (June 15 missing) or in *Santa Barbara Morning Press* or the *San Diego Union*. Soloviev and Go (1974, p. 83) state that "at Santa Cruz a five-foot wave destroyed a protective dike. The wave rose far upriver and did severe damage to a ship moored to the pier." This account was not fully verified. Validity 4.

1896, December 17. "A tidal wave, the largest in the history of Santa Barbara, washed over the boulevard at 8:00 o'clock this morning [December 18] carrying back with it a large section of that beautiful and expensive driveway. The boulevard was built some five years ago and bulkheaded so securely that it was thought to be impervious to the action of the waves, but the bounding billows carried off a portion of asphaltum and solid masonry, heavy framework and iron in its receding grasp, nearly fifty square feet and eight feet deep. A large sand hill between the boulevard and ordinary high tide was carried completely out to sea" (*San Jose Mercury*, December 18, 1896). This was reported by most catalogues until McCulloch (1985) cited the *Santa Barbara Daily Independent* of December 17, as saying, "The flood tide this morning was one of the highest ever known in this city and the boulevard suffered considerable damage...The tide will be unusually high for the rest of the week."

This is a high astronomical tide with a strong meteorological component. The surf was described as very high from December 13 to 18. Validity 0.

1898, March 30, 11:43 P.M. A sharp and damaging earthquake occurred, centered in the east San Francisco Bay region. Mare Island was heavily damaged and damage occurred in San Francisco and elsewhere in the Bay area. The earthquake of magnitude 6.7 probably centered on the Rogers Creek fault which may extend under the San Pablo bay near Mare Island.

"The bark *Rufus E. Wood* felt it off Point Reyes, and the pilot schooner *America* was pitched about violently just outside the heads...and the ferry-boat *Encinal*, lying in the slip on this side of the bay danced merrily to the music of the temblor.

"The *Rufus E. Wood* was sailing for this port, and was some distance south by east from Point Reyes. So great was the shock that the vessel was struck aback. The second mate, who was in charge of the deck, thought that the *Wood* had run into a submerged rock or the hull of a derelict...

"The people on the *America* were greatly alarmed. Prior to the shock the sea had been perfectly calm, and when the schooner was suddenly thrown almost out of the water and then flung about like a plaything visions of submarine mines and everything but earthquakes disturbed the minds of all on board..." (*San Francisco Chronicle*, April 1, 1898).

"On board the pilot-boat *America* Captain Jordan and the pilots who were with him had almost a similar experience. The schooner was cruising off the Farallones when the concussion came, and everybody on board came to the conclusion that the powder works at Pinole Point had blown up" (*The San Francisco Call*, April 1, 1898, p. 2).

"Out on the bay a violent tidal wave lifted small boats high upon its crest..." (*The Evening Bee*, March 31, 1898, p. 2).

"The waters of San Francisco Bay rose in a tidal wave two feet high, but almost immediately subsided" (*The Record Union*, March 31, 1898, p. 8).

"The water off the Oakland mole was churned into a big sea, and the yachts were severely tossed about for several minutes. Large waves beat against the rocking ferry houses but did not damage them" (*The San Francisco Call*, April 1, 1898, p. 2).

"Down at Oakland mole the water of the bay was churned into an angry sea, and great waves dashed against the ferry houses" (*Oakland Tribune*, March 31, 1898, p. 1).

"The steamer *Napa City* was rounding Jacks' Point when the earthquake occurred and Captain Pinkham says the shock appeared to lift the boat out of the water...when he saw the water in agitation he knew that it was an earthquake" (*Nape Journal*, April 1, p. 2).

A "mole" is a breakwater. The Oakland mole extended east-west toward Yerba Buena Island. Jacks Point is probably Jack's Bend, a point over eight miles up the Napa River from Mare's Island. The origin of the waves is uncertain. The Rogers Fault is predominately strike slip but may have some vertical component. However, the path from the fault to Oakland is rather indirect having to pass through San Pablo Bay to get to the San Francisco Bay proper. Submarine landslides are problematic as there is little relief in the bay bottom. Subaerial landslides nearer Oakland are possible but there are no reports of any. The marigram for this event showed short period noise beginning about 11:30 A.M. and continuing for several days. Operators repeatedly noted "rough water." These were meteorological waves and nothing resembling a tsunami was observed. Validity 2, probably meteorological waves.

1899, December 25, 4:25 A.M. A magnitude 6.7 (Toppozada et al., 1981) earthquake in Southern California apparently was caused by a shift along the San Jacinto fault several miles south east of San Jacinto. Milne (1900, p. 84) relying on an abstract of local newspaper clippings sent to him by Professor F. Stupart reported "San Diego, California, December 25th—the most severe shock of earthquake experienced in this city in fourteen years took place at 4:25 A.M. today, and was accompanied by a loud rumbling noise. The tall buildings in the city were severely shaken, but no serious damage done. A high wave struck the beach ocean front but no damage was done."

The *Los Angeles Times* reports, "A high wave struck the beach on the ocean front soon after the shock but no damage resulted to shipping. At Redondo Beach the waves rolled in exactly as if the earth had not trembled." The *San Diego Union's* report on Ventura stated "the vibrations were from north to south, followed by a high wind and a heavy sea." The event was not recorded on the San Diego tide gage. The observer noted "rough water—strong north east wind" on the record which showed heavy short period noise continuing past the 25th.

The San Jacinto fault was 45 miles inland and could not have generated a wave directly. This is most likely a meteorologically-induced wave incidental with the earthquake. Validity 1.

1901, March 2, 11:45 P.M. Toppozada (1990, Draft manuscript) reports on a magnitude 6.7 earthquake near Parkfield with the following effects observed in the southern part of Monterey Bay: "Pacific Grove: the shock was the longest and heaviest in years and the tide was phenomenally high" (*Salinas Daily Index*, March 5); "the bay was deeply stirred" (*San Francisco Call*, 4 March). "Phenomenally high waves followed the temblor" (*Monterey Cypress*, March 10); "the bay was deeply stirred, and the waves dashed upon the rocks along the shore with unusual fury. The water marks this morning showed a phenomenal high tide" (*San Francisco Examiner*, *San Francisco Call* and others, March 4th). The event occurred several hours after the lower high tide astronomically and was ebbing.

The marigram at Presidio showed noise from "choppy water" but no tsunami signal. Validity 3.

1902, February 26. A great earthquake in El Salvador, and Guatemala generated a tsunami which killed 185 people in that region and was reported observed in San Diego according to Iida et al. (1967). There is considerable confusion surrounding several events in the area. On January 18, 1902, a large earthquake affected Guatemala. There was a third shock on April 18 of magnitude 8.3 which supposedly caused the Ocosa Coast to subside along a one mile segment. This was reputed to have caused damage at Quesaltenango and San Pedro, Guatemala, among other places (Sapper, 1902). Incorrect dates of 1912, and February 2 and 21 appear in the literature (Soloviev and Go, 1975). The mention of San Pedro with this latter event probably accounts for the San Diego report in Iida et al. (1967) and McCulloch (1985).

Tide gage records are not available for San Diego between 1878 and 1906 and nothing but occasional storm noise is seen on the Presidio records for this period. It is almost impossible that a wave large enough to be observed visually at San Pedro or San Diego could have been generated but not observed elsewhere outside of the source region. Sanchez and Farreras (1993) do not mention any tsunami affecting Mexico during this period. Validity 0 for U.S. observation.

1904, March 17, 04:20 GMT and March 30. Oddone (1907, p. 82) remarked, "March 30 an earthquake must have caused the floods of the rivers Queets, Quinault, Wishkah and Hoh at their mouths" citing newspaper reports. The *Hoquian Washingtonian* (March 17, p. 1) reports dishes rattled and nervous people frightened at 8:21 P.M. March 16, but there was no mention of water activity and no mention of earthquake or waves in the March 31 edition. The *Seattle Star* mentions the earthquake on March 16 but there is no mention of rivers on this date or on March 30 or April 2. The *Seattle Post* (March 30, 1904, p. 9) mentions a great scarcity of marine news for the last two or three weeks due to the severe weather and the strike of marine engineers. The March 16 earthquake apparently occurred in the Puget Sound area as it was felt at Victoria, B.C., Port Townsend, and on ships in Seattle but there is no mention of river blockage.

The *Aberdeen Herald* (March 21, p. 2) mentions that south Oregon had been suffering from disastrous floods and swollen streams but no mention of waves. The *South Bend, Washington Journal* states (March 25, p. 1), "The barkentine *Addenda* which loaded lumber at this port for San Francisco had a very rough trip down the coast from Willapa Harbor. Off Cape Blanco a storm struck her and heavy seas swept her fore and aft." The earthquake was felt by few, and kerosene sloshed in lamps, but nothing related to water activity was mentioned in the April 2 edition. Reid's Catalog (undated manuscript) for March 16 and 17 reports "Rivers west of Olympia said to have ponded up but this seem doubtful as no further news has been received."

The *Port Townsend Weekly Leader* (March 23, p. 2) reports the barometer dropped very low. There was no mention of wave activity in the March 31 or April 1 editions. The *Monthly Weather Review* (March 1904, pp. 105, 106) reports, "the severest storm of the month appeared on the North Pacific Coast on the night of the 9th and on the morning of the 10th the barometric pressure was below 29.00 inches on the Washington and Oregon coasts. The gales which attended this storm were severe from British Columbia to San Diego and heavy rain fell on the coastal districts. The storms that appeared on the north Pacific Coast on the 10-11th and 19th were sufficiently severe to prostrate trees...Aberdeen received 15.66 inches of rain and South Bend received 12.88."

This event perhaps was the result of landslides triggered by the March 16 earthquake and the torrential rains as Reid's dates seem to fix the time. There were no accounts of wave activity. Validity 0.

1906, January 31, 15:36 GMT. A magnitude 8.2 earthquake off the coast of Ecuador produced a five meter wave locally that destroyed 49 houses and killed 500 people in Colombia. A letter of February 3, 1906, to the Superintendent of the Coast and Geodetic Survey, from B.A. Baird, Assistant to the Superintendent of the Coast and Geodetic Survey from the files of the National Ocean Survey's Tidal Analysis Bureau states: "The work of establishing a tidal station at San Diego is complete and a full report will be made as soon as possible. Before making the regular report, however, there is a matter of great scientific interest in regard to the present record [for February] now going on.

"On Thursday, February 1st at about 8:00 A.M. it was noticed by several of the men at the U.S. Quarantine station that the tidal current then flowing out and not due to change till 10:06 suddenly changed its direction with enough force to swing all the boats around and make considerable commotion, and while everybody was wondering, it changed back again running with increased strength. These currents continue to oscillate for some hours and the tidal record for this period is intensely interesting. These were no doubt tidal waves started by some distant earthquake, as no shock was noted in San Diego. I do not know at exactly what time the disturbances commenced, as I did not see the beginning of the recorded effect." The actual first arrival was about 15 hours earlier. The observed effects were not reported in the *San Diego Union* or *San Diego Sun* newspapers.

Soloviev and Go (1975) report, "The tsunami arrived at San Francisco at ebb tide. The succession of the ebb current by a flood current occurred so suddenly that it was noticed immediately by sailors and fishermen on the shore. All the ships and boats were turned around 180°." This was not confirmed in local newspaper accounts examined. The tsunami had an amplitude of two inches on the tide gauge register at San Diego. It was also recorded at San Francisco with about a 2.4 inches amplitude. Validity 4.

1906, April 18, 05:12 A.M. A catastrophic earthquake on the San Andreas fault which with the resulting fire destroyed most of San Francisco and killed 700 to 800 people. Its magnitude has been given values ranging 7.8 (Abe, 1983) to 8.5 (Gutenburg and Richter, 1954). The rupture produced up to twenty feet of right lateral horizontal motion with the Pacific Plate moving northward. There were many landslides along the coast from Cape Mendocino to Point Delgado thirty-eight miles to the south on a rugged largely uninhabited coast. South of there from Shelter Cove to Point Arenas the coast is lower but bedrock and loose material slipped into the sea and the water was turbid for several days after the earthquake. At the mouth of the Navarro River, near Albion, a ten acre tract of low lying area was flooded. This was the only directly observed effect in the water. A four inch drop in the water level was recorded some seven to nine minutes after the earthquake on the Fort Point tide record and returned to normal in about 15 minutes. The travel time for a tsunami from the fault to the gage is about eight to nine minutes. There were several cycles of forty minute waves following which were probably seiches in the bay. (See Figure 48.) None of these would be noticeable to an observer. "No tidal wave or disturbance in the water of any character followed the earthquake. The waters were unusually calm throughout the forenoon of April 15th" (McAdie, 1907). Ma, Satake, and Kanamori (1991) calculate the effect of a bend to the east in the San Andreas fault offshore near the Golden Gate and show that such a bend could result in vertical motions of the order of four inches without any vertical component to the fault movement.

The actual height of the wave would be somewhat more than the recorded height as the gages dampen and delay the response to the wave. The seiches could have been set up by the seismic waves rather than the tsunami. One might expect a momentum effect on the water due to the rapid movement of the ocean floor which would lead to a drop in water level in the quadrant including the tide gage. The pulse recorded is somewhat odd as it is only a half cycle. The calculated travel time and the mechanism proposed by Ma et al. (1991) are plausible explanations of the recording as a small tsunami. A small submarine landslide from the San Francisco bar, a seventy foot high depositional feature reaching from Mussel Rock to Bolinas Bay and bowing several miles seawards, is also a possibility. Validity 4. Tectonic or submarine landslide source.

1906, August 7, 03:12 A.M. A small event was recorded by the San Diego tide gage with an amplitude of about .75 inch and period of 13 minutes. (See Figure 49.) There is not a seismic source for these waves in the *International Seismological Summary* or the *Bulletin of the Bureau Central International de Seismologique* or mention of waves recorded elsewhere. Source unknown. Validity 2.

1906, August 17, 00:40 GMT. The Valparaiso, Chile, earthquake of magnitude 8.6 generated a five-foot tsunami that was damaging locally and in Hawaii. It was recorded at San Diego with an amplitude of 2.4 inches and at the Presidio with 1.6 inches. (See Figure 50.) Validity 4.

1906, November 6, 08:00 A.M. The American schooner *Stanley* situated at the center of a cyclone at 46° 09'N, 125° 32'W felt a sudden shock at 8:00 A.M. which lasted two to three seconds. Soon afterwards the captain saw three mountainous waves approaching from the southwest. When they fell on the ship, the schooner began to pitch and roll violently; its bow dipping into the water, and the ship almost sank. The dangerous seas lasted one hour and thirty minutes (Soloviev and Go 1975, p. 216 citing Lawson, 1908, p. 373). "The mate felt certain the mountainous waves were caused by the earthquake shock. Another ship reported rough weather for eleven days. Nothing but gales from southeast around the southwest" (McAdie, 1907). "The first half of November was very stormy and this district (Portland, OR) was visited by a secession of gales of unusual severity" (*Monthly Weather Review*, November 6, 1906). Heavy rains, flooding and damage to bridges and saw mills was also reported.

This position is located 45 miles off shore opposite the Columbia River mouth in water about 6,500 feet deep. A tsunami would not have been observable in water that deep. The *Stanley* was also 150 miles from the zone of earthquake activity, and no earthquakes were reported at this time. These were meteorological waves. Validity 0.

1910, November 21, 4:45 A.M. "There was a marked disturbance in atmospheric pressure. The morning was comparatively quiet with light winds; suddenly without any of the usual preliminary signs of air movement, the wind rose and gusts varying in velocity it is estimated from ten to thirty miles, occurred. The barometer fell rapidly and then rose rapidly...

"Mr. F. Westdahl, in charge of the Coast and Geodetic Survey, discovered in examining the marigrams for November that unusual markings appeared on November 21 about 4:30 A.M. and ended at 12:30 P.M. It was at first thought that this record was evidence of some submarine disturbance such as the dislocation of the sea bottom. The water rose more than a foot, fell again and fluctuated as shown on the record. It seems, however, more consistent with our present knowledge, to regard the disturbance as atmospheric rather than submarine and to assume the water simply responded to the sudden and violent change in air pressure" (McAdie, 1910, p. 1740–1734). (See Figure 51.)

McAdie gathered data on this remarkable event recorded progressively on six microbarographs from Point Reyes Station to San Jose with a pressure drop of up to 0.15 inch. There was a large storm in the vicinity of Washington and British Columbia which the weather observers believe spawned this pulse. This event is an important illustration of how meteorological effects can create marigrams which look convincingly like tsunami records without accompanying storms. Wilson (1954) discusses a similar phenomena for Cape Town, South Africa. Apparently atmosphere gravity waves can be set up meteorologically and travel considerable distances from their source. Validity 0.

1917, May 1, 18:27 GMT. A magnitude 8.0 earthquake in the Kermadec Islands located in the South Pacific produced a 12-m tsunami in the Samoa Islands according to Heck (1947). Pararas-Carayannis and Dong (1980) do not mention a tsunami in Samoa on this date. Iida et al. (1967) state that the Samoa report was confused with the June 26 tsunami. However, a re-examination of the marigrams at Honolulu and San Francisco shows that both recorded the event clearly at the expected times. The waves were well defined at La Jolla and San Diego also. The amplitude at San Francisco was about 1.2 inches. (See Figures 52 and 53.) Validity 4.

1917, June 26, 05:50 GMT. A magnitude 8.3 earthquake in the Tonga Islands produced another 12-m tsunami in Samoa and destroyed several villages. The tsunami was recorded on the west coast at the Presidio with an amplitude of 1.5 inches and at San Diego. (See Figure 54.) Validity 4.

1918, September 7, 17:16 GMT. A magnitude 8.3 earthquake in the south Kuril Islands, Russia, produced a 12-m tsunami damaging locally and in Japan. It killed 24 people (Soloviev and Ferchev, 1961). It was recorded at the Presidio with an amplitude of 1 inch. (See Figure 55.) Validity 4.

1918, November 8, 04:38 GMT. A magnitude 7.75 earthquake occurred in the same area as the above shock. It is somewhat controversial as Iida gives it as a second tsunami while Soloviev and Ferchev (1961) believed it was a duplicate report of the September event. It was recorded at the Presidio with an amplitude of 1 inch and as a "trace" at San Diego. Validity 4.

1918, December 4, 11:48 GMT. A magnitude 7.75 earthquake near Caldera, Chile, produced a 5-m wave there. It was recorded at Honolulu and San Diego with 2.7 inch amplitude and was emergent at the Presidio at about 5:00 P.M. and at San Diego. It was not reported elsewhere in the Pacific. Validity 4.

1919, April 30, 07:17 GMT. A magnitude 8.3 earthquake in the Tonga Islands produced a 2.5-m tsunami there, and it was recorded at San Diego with an amplitude of 1 inch and at San Francisco. (See Figure 56.) Validity 4.

1922, November 11, 04:33 GMT. A magnitude 8.3 earthquake in north-central Chile produced a 9-m wave locally that inundated parts of several Chilean cities and killed more than 100 people. It was recorded with an amplitude of eight inches at San Diego and seven inches at San Francisco. (See Figure 57.) The *Santa Cruz News* of April 14, 1923, and the *Los Angeles Express* of April 17, 1923, both mentioned that the tide was more powerful for the April 13, 1923, event than the one several months earlier following the marine disturbances off the coast of South America. This could refer to this tsunami, five months before the April 14, 1923, event or to the February 3, 1923, Kamchatka event two months earlier with a confusion of location with the earlier event. Validity 4.

1923, January 22, 01:04 A.M. A magnitude 7.6 earthquake occurred offshore of Cape Mendocino, California. Bernard Zeller, Chief of the Tides Section of the Coast and Geodetic Survey writing in response to a inquiry from Dr. Robert W. Weigel, University of California on September 15, 1967 states, "I have examined the marigrams requested in your letter and the results are essentially negative...There was no evidence at all of a tsunami on the records of 31 January 1922 for San Francisco and Humboldt Bay. The San Francisco marigram for 22 January 1923, showed a small seiche (about 0.1 foot) beginning about 01:30 (120°W time) with a maximum range of about 0.2 foot between nine and ten A.M. of the same day." The apparent travel time of twenty-six minutes is too short for a tsunami wave but right for seismic surface waves. The operator noted on the marigram, "Surface a little choppy. Strong S.E. wind with a steady light rain." This is probably a seismic or meteorological seiche. Validity 1.

1923, February 3, 16:01 GMT. A magnitude 8.3 earthquake off the east coast of Kamchatka, Russia, generated an 8-m tsunami that caused damage in Kamchatka and in Hawaii. A eight inch wave was recorded at San Diego and a four inch wave was recorded at San Francisco. (See Figure 58.) The *Santa Cruz News* (April 14, 1923) and *Los Angeles Express* (April 14) both mention that the tide on April 13 event was stronger than the one several months ago following the marine disturbances on the coast of South America. This could refer to the November 11, 1922, Chilean tsunami or to a confused report of this Kamchatka event which occurred two months earlier. Validity 4.

1923, April 13, 15:30 GMT. A magnitude 7.2 earthquake off the east coast of Kamchatka, Russia, generated a 20-m tsunami that caused some damage there and in Korea. It was recorded at San Diego with an amplitude of two inches and at San Francisco with a six inch amplitude. (See Figure 59.)

The *Los Angeles Express* (April 14, 1923, p. 1) reports, "Five big freighters according to the port pilot entangled in a severe traffic mix-up in the narrowest part of the channel today and but for the splendid seamanship of those in charge of the vessels one or more severe collisions would have occurred. Ships also had difficulty holding their lines to the dock because of swirling tides. It was reported today that the freakish tide was first noticed about ten o'clock last night when the tide just ran one way and then another." The first waves would have been expected at about 4:30 P.M. so these observations must have been of the later waves.

Soloviev and Ferchev (1961) report that several vessels were set adrift in Los Angeles. The event was not found in the *San Diego Union*, the *La Jolla Journal*, or the *Santa Monica Outlook*. Validity 4.

1923, September. R. Montandon (1924) lists a September, 1923 "Tsunami at the United States (California); destruction of Jose de Cado." The *San Diego Union*, (September 4, 1923, p. 1) gives, "20-foot waves hit San Pedro; vessels rocked, swells break over light house and sweep lumber into sea; mooring broken. Ground swells twenty feet high, larger than any in the experience of mariners at San Pedro struck the southern California coast early today (September 3) and were believed to have been the result of the earthquake and tidal wave which devastated parts of Japan...The first great waves were seen at one o'clock this morning and continued to rush in with greater intensity all day long.

"The swells broke completely over the 15-foot breakwater and carried away all loose objects including a boat tender and the lighthouse and considerable lumber piled along the shore.

"Vessels arriving today from mid-ocean and from coast ports report the waves the highest in their experience. Naval observers said no storm of any size was reported anywhere on the Pacific and they believed the huge swells were the reaction on this coast of the cause of the Japanese catastrophe. Ten deep-water ships in the outer harbor broke from their moorings more than once during the day and the *U.S.S. Idaho* and the *U.S.S. Nevada* rolled badly."

One man drowned trying to save companions swept 200 yards to sea a few miles north of Del Mar. However, the *San Diego Union* reports that its harbor was unrippled. The terrific ground swells were reported from San Pedro to Point Arguello but the sea off San Diego was as smooth as ever, according to reports of fisherman on the banks Monday (September 3) afternoon and evening.

The location of Jose de Cado is not known and Lander and Lockridge (1989) speculate that it referred to San Jose de Cabo, Baja California, Mexico.

The San Francisco marigram shows long periods waves on September 1 for about ten hours beginning about 2:50 A.M. Waves from the Japanese earthquake and tsunami of September 1 would not have arrived before 6:00 A.M. This great earthquake's tsunami was observed beyond Japan only at Hawaii and there only as three centimeter waves. A second shock on September 2 produced a maximum wave in Japan of 0.3 m.

This could not have been a local tsunami as it continued for a long time. The San Diego marigram also shows only 18 hours of long period low amplitude seiches. These were meteorologically induced waves. Validity 0.

1925, October 4, 04:15 A.M. A wave was recorded on the Long Beach marigram with an amplitude of 1.1 foot. The period was regular at 63 minutes and it continued for five days of the record examined. There was some short period activity at 4:15 A.M. on the 4th. There were no operator comments recorded and the weather was calm. (See Figures 60 and 61.) It was not recorded at nearby La Jolla. The long period waves look mechanically generated. There is no earthquake to provide a source. At Honolulu waves with a period of 37 minutes and amplitude of two inches were observed beginning on October 3 at 20:19 Hawaiian time and continued for the next three days with similar periods and amplitude. This is probably a seiche from a remote meteorological source. Validity 1.

1927, January 1, 12:17 A.M. A magnitude 5.7 earthquake occurred in the Imperial Valley on the U.S.–Mexico border. An aftershock of about the same magnitude occurred fifty-seven minutes later and was followed by a multitude of lesser aftershocks. Montandon (1928) says, "at San Pedro, the port of Los Angeles, sea waves carried off part of the new embankment; the damage was estimated at three million dollars." The *San Diego Union* (January 2, 1927) states, "San Pedro, January 1. The death of George W. Antis of Los Angeles, who was swept from his feet and carried out to sea by a huge wave while surf fishing near Portuguese Bend this afternoon, may have been due indirectly to the earthquake which shook the Imperial Valley of California and Mexico, according to the San Pedro Police who were summoned by Antis' companion. High tides along the coast and a small tidal wave which struck the harbor here this morning were believed due to the quake. The tidal wave was of such a height as to lift bodily a 400 foot section of board walk on top of the government breakwater and deposit it on the inner slope of rocks. A heavy ground swell, strong currents, and a muddy condition of the water were reported."

At Scripps the trace noise was very high. The trace was 2.75 inches wide and continued for several days. A San Diego waves with periods of about seven minutes and amplitude of 0.75 inches continued more or less for one day beginning at about 7:00 A.M.

The earthquake could not have caused the waves directly as it is around 100 miles to the coast and about 140 miles to San Pedro. Earthquake generated seiches also seem unlikely given the relatively low magnitude and the waves continued on the marigram for one to three days. A possible submarine landslide may have occurred but it would have been of short duration. A coincidental meteorological source most probably was the source. Validity 1.

1927, November 4, 5:51 A.M. A strong earthquake (magnitude 7.3) occurred about 22 miles southwest of Point Arguello in water 1,000 to 2,600 feet deep which caused considerable damage on shore. It was strongly felt at sea (Pacific Gas and Electric Company, 1988).

The *SS Socony* was 27 miles from Point Arguello at 34° 54' 30" N and 121° 01' 00"W. The shock at 05:51 awakened the captain from a sound sleep. "The ship was shaking from stem to stem and pounding just as if she were ashore on the rocks, the masts and rigging were shaking so violently I though they were going to come down. The surface of the sea for miles around was trembling and broken with short chop"

(Byerly, 1930, p. 60, quoting the captain). The captain reported that a second shock at 6:10 A.M. was the more severe but as it was insignificant on the seismograph record Byerly concludes it must have be at a shallower focus. The *Alaska Standard*, 14 miles north of Point Arguello at 5:50 A.M. felt a shock very similar to the propeller striking a submerged object but lasting longer. They felt a similar quiver without the shock a few minutes later (6:10 A.M.). "The sea was smooth at the time."

The *S.S. Floridian's* captain a few miles from Point Arguello reported feeling aftershocks beginning at 10:28 A.M. "From 11:00 A.M. on, noted quantities of dead or stunned fish" (Byerly, 1930, p. 60, 61). Byerly (1930) investigated the earthquake in the field and reports the following regarding the sea wave, "The sea wave was observed by the Southern Pacific (railroad) agents at Surf and Pismo. The former reported it as about a six foot wave. The latter reported it as resembling a large storm wave. The first wave was reported as positive i.e. there was no first recession of the water. The Pacific Coast Railway agent at Port San Luis (Avila) reported a five-foot fall and rise (range) followed by motion for an hour. The lightkeeper near Port San Luis reported a four foot rise and then a similar fall followed by normal conditions."

The *Santa Maria Daily Times* (November 4, p. 1) reports "the worst of the temblors seemed to be at Surf, where a tidal wave washed in destroying the Southern Pacific railroad tracks for many yards and inundating the railroad station." The *San Pedro Daily Pilot* (November 4, p. 2) reports, "Avila, November 4th—No damage was reported here from a series of earthquake shocks occurring this morning with the heaviest about six o'clock. An hour after the main quake there was an exceptionally high tide for this time of the year although the water did not quite reach to the seawall along the beach and no damage resulted." The *Lompoc Record* (November 4) gives only "the ocean rolled in high at Surf during the time of the quake this morning and onlookers state that it splashed up on the sand dunes." No mention of the waves were found in the *San Diego Union, San Diego Tribune, La Jolla Journal, La Jolla Light* or other regional papers.

The tsunami was also recorded at Fort Point with an amplitude of 0.75 inches and a period of fifteen minutes and 1.5 inches and similar periods at La Jolla. (See Figures 62 and 63.) The records at Fort Point show a 25 minute half cycle low amplitude recession beginning about seven o'clock before the shorter period waves begin. The tsunami was also well recorded at Hilo and less well at Honolulu. Satake and Somerville (1992) have shown that the fault displacements and focal mechanism of the earthquake is adequate to explain the tsunami. McCulloch (1985) believes that the fact that the tsunami was recorded at oceanic distances would rule out a landslide and that the areas off Point Arguello lack areas which have had appreciable downslope movement. However, the 1975 Kalapana, Hawaii landslide tsunami was well recorded on the West Coast and the 1812 Santa Barbara tsunami is believed to have been landslide-generated and observed in Hawaii. The November 22, 1878, tsunami appears to have been a landslide tsunami that affected almost identically the same area.

This event is important in several respects. It is the second largest and the best observed of local west coast tsunamis. If Satake and Somerville (1992) are correct, it is the only one for which a tectonic origin can be claimed except possibly the equally odd April 1906 San Francisco event, and the April 25, 1992 event still being investigated. It illustrates the importance of early field work. Without Byerly's information this tsunami would have lacked important first hand reports of wave heights and effects.

The issue of its cause, whether directly by tectonic motion or indirectly by a submarine landslide is unsettled. The vertical motion of the earthquake could account for the tsunami directly but it is unknown if the faulting actually reached the surface. The fact that the seismically smaller aftershock was felt more strongly, which Byerly attributes to it having a shallower focus, could not be so explained if the main shock's faulting reached to the surface. The earthquake could have triggered a submarine landslide anywhere in the area of high shaking. The tsunami is nearby identical to the November 22, 1878 event in communities affected and size and that event was not associated with an earthquake. The initial long draw down on the Fort Point marigram is more suggestive of a submarine landslide origin. Submarine landslide tsunamis in California typically have waves with a maximum amplitude of 10 feet and a very restricted affected area. This tsunami affected about 35 miles of shore line. Validity 4.

1928, June 17, 03:19 GMT. A magnitude 7.8 earthquake off the coast of southern Mexico caused minor damage locally and killed four people. The wave was recorded at La Jolla with a four inch amplitude, at San Diego with 0.8 inch amplitude, and at San Francisco with an amplitude of less than four inches. Validity 4.

1929, March 7, 01:35 GMT. A magnitude 7.5 earthquake in the Fox Islands, Aleutian Islands, produced a tsunami which broke the mooring lines of a steamship in Hilo and was recorded at Honolulu, Hawaii. It was recorded at Presidio, California with an amplitude of six inches but not at San Diego or La Jolla. (See Figure 64.) Validity 4.

1930, August 31, 00:41 GMT. A magnitude 5.2 earthquake in Santa Monica Bay generated a 20-foot (range) wave at Santa Monica-not two feet as previously published (Soloviev and Go, 1975; Lander and Lockridge, 1989). The *Los Angeles Evening Express* (September 1, 1930) reported, "Terrible Waves, Riptide at Santa Monica Perils 16 Sunday Swimmers—Waves twenty feet high and the worst rip-tide reported on the Santa Monica beaches for years endangered the lives of the great holiday crowds yesterday and caused strict supervision of the Labor Day crowd today to avoid loss of life...Life guards rescued 16 people yesterday. Huge waves started at 11:30 A.M. believed to be caused by a tremendous disturbance of the ocean floor...A dead 500 pound seal was washed up shore."

In a report in *Seismological Notes,* Dr. Ford A. Carpenter (1930) states, "Effects of the earth tremor on ocean wave—The shores of Santa Monica Bay were nearer the epicenter than the Weather Bureau offices (center of business district of Los Angeles) and a careful observer was about to take his evening swim when he observed a wave, much larger than usual, rise to its maximum height and about to break. He was about to dive into it when he noted that the wave hesitated, shook violently, did not curl, but assumed a plateau shape. In a few seconds the water mass was augmented, rose to a far greater height than its original size and broke, gathering volume until it struck the shore with tidal wave-like intensity."

The *Venice Evening Vanguard* (September 2, p. 1) reported, "Bathing was not at its best yesterday [September 1] because of an unusually heavy sea and the only most daring ventured into the waves which at times reached a height of nearly 20 feet. No drowning or near drowning were reported." The weather was reported as sunny.

The *San Pedro Pilot* (September 1, p. 1) reported at Santa Monica "mountainous waves believed due to the earth tremor caused the death of one man near here Sunday [August 31] and scores were rescued from the surf by lifeguards. The temblor occurred late Saturday and caused damage in varying degrees throughout the Los Angeles metropolitan area. Seismologists reported the temblor centered in the Pacific Ocean about 15 miles off Santa Monica and held it responsible for the heavy seas.

"Extra lifeguards were stationed along the beach to protect the large week-end crowds and finally posted warnings ordering all bathers to keep out of the angry seas. Some waves were 25 feet high.

"Larry Tobin, 20-year-old dishwasher of Palos Verdes, California, was swept beyond his depth south of Redondo Beach and was drowned.

"W.K. Rolf, 22, Los Angeles, drowned in the surf at Newport Beach but his death was attributed to either heart disease or exhaustion.

"Beach Patrols were reinforced today in the event the surf again becomes heavy."

The *Los Angeles Times* (September 1) reported that Rolf was swimming with a friend when he signaled he was exhausted. His companion was unable to keep him afloat. The same issue of the *Times* reports on Tobin's death at Hollywood Riviera Beach where he was swimming with a companion when he was caught in a rip-tide.

The *Santa Monica Outlook* (September 1) also reports that a season-high twelve rescues occurred and that 20 foot waves and a dangerous riptide to 100 feet out was running.

The wave was not detected on the San Diego, La Jolla, or Santa Barbara marigrams.

The wave seems to have been confined to a 16 mile stretch of the coast from Santa Monica to Redondo Beach. Rolf's death was not associated with the unusual waves and no time was given for the drowning. As Newport Beach is not in the source area and the contemporary sources do not link the two drownings, Rolf's death is judged to be unrelated to the tsunami. This is probable a earthquake-generated submarine landslide tsunami. Validity 3.

1931, October 3, 19:13 GMT. A magnitude 7.9 earthquake in the Solomon Islands generated a 9-m tsunami locally and was recorded at Santa Barbara with an amplitude of 1.5 inches, at San Diego with a 1.2 inch amplitude and even smaller amplitudes at the Presidio, Balboa, and La Jolla. (See Figures 65 and 66.) Validity 4.

1932, June 3, 10:37 GMT. A magnitude 8.1 earthquake at Jalisco, Mexico produced a small local tsunami of about 16 to 30 inches in Manzanilla Bay. It was recorded at San Diego with an amplitude of about 1.2 inches and as traces at San Francisco and Los Gatos near San Diego. (See Figures 67 and 68.) Validity 4.

1933, March 2, 17:31 GMT. The magnitude 8.3 Sanriku, Japan earthquake generated a tsunami with run-up there of as much as 29 m, destroyed 5,851 structures in Japan, and 3,064 fatalities occurred. It was recorded at San Francisco (Presidio) and Santa Monica with amplitudes of 2.8 inches and at Los Angeles, La Jolla, Long Beach, Santa Barbara, and San Diego, with slightly lower amplitudes. (See Figures 69, 70, 71, and 72.) Validity 4.

1933, March 10, 5:54 P.M. The magnitude 6.3 Long Beach earthquake was reported in the *Annales de la Commission pour l'Etude de Raz de Maree* (Anon. 1933) as: "A tsunami March 11, 1933 at Nex [sic] Port Beach near Pasadena." Both the Long Beach and Santa Monica marigrams show wave activity beginning to emerge before the earthquake and continuing more than 36 hours later.

Wood (1933) states, "There are no reliable reports of any conspicuous disturbances of the sea. Some disturbances in the near neighborhood of the origin must have occurred but nothing of moment happened. Not withstanding radio announcements and rumor, there was no so-called 'tidal wave.'" The tsunami was not observed on the San Diego, La Jolla, nor the Presidio marigrams. The *Long Beach Telegraph* (March 1) reported that three people were killed when their plane crashed in takeoff. They were sent out to survey damage and particularly to search for a tidal wave rumored heading for the coast. The term "tsunami" used in the Commission Report followed the original Japanese meaning and would include storms.

The emergent nature of the two readings, the early arrival times, and the long duration of the waves of 36 hours at Long Beach and at Santa

Monica indicate a meteorological source with perhaps some seiches set up by the earthquake. This is probably not a tsunami. Validity 1.

1934, August 21. *San Diego Union* (August 22, 1934, p. 1) reports, "Sea Wrecks Apartment; Many Flee; Four Hurt When Trapped on Newport Beach; Street Inundated; San Diego Escapes Surf Fury—A strangely acting Pacific Ocean which has been running waves 30 and 40 feet high during the day, got out of bounds at high tide at 6:10 o'clock tonight and swept a two story apartment building from its foundation and damaged other buildings. Part of the city was inundated a few feet.

"The waves, which have been breaking with tremendous force along the southern California coastline from Malibu beach to below Laguna Beach, did damage in excess of $24,000 here [increased to $75,000 in the August 23 issue]. The wind was reported strangely calm along the shore where heavy waves were breaking."

Local scientists ascribed the oscillations to seiches in the basin formed with the Channel Islands and triggered by remote storms and aggravated by the high tides.

The *Santa Barbara Morning Press* (August 22, 1934, p. 1) reported expecting unusually high tides for the next several days. The tides coupled with the heavy seas sent water over the breakwater.

The *Santa Monica Outlook* reports that lifeguards rescued ten people and administered first aid to nine others despite small crowds on the beaches. Their new breakwater withstood the force of the breakers.

The marigram at Santa Barbara was extremely noisy with the trace on the record two inches wide and Santa Monica showed long period noise most of the month. On the 21st the operator noted eight foot ground swells but the record scaled only three inches of water motion with a nine-minute period. The waves were probably seiches due to a remote source storm. Validity 1.

1938, March 22, 15:22 GMT. A magnitude 6.3 earthquake off the coast of Queen Charlotte Islands was reported to have generated a tsunami that was weakly recorded at Santa Monica (Neumann, 1940). Iida et al. (1967) list this as a doubtful tsunami partly because the mistaken travel time of three hours given by Neumann as the arrival time. Cox (1982b) examined the marigrams for Santa Monica and concluded that the small oscillations recorded were not distinguishable from background noise. The marigrams from San Francisco and Honolulu similarly did not show unusual oscillations. There is no report of a tsunami from the source area or elsewhere and this is probably an erroneous report. Validity 0 for the U.S. west coast.

1938, May 19, 17:08 GMT. An earthquake of magnitude 7.6 generated a two to three-m tsunami in the straits of Macassar, Indonesia, that caused some damage locally and killed 16 people. It was reported to have been recorded at Santa Monica with an amplitude of less than 0.75 inches (Neumann, 1940). Cox (1982a) examined the original record and concluded that it represents only normal background noise for that station. He could not find evidence of tsunami activity on the marigrams from San Francisco, San Diego, Honolulu or King Cove (Unalaska). It is almost impossible for a wave generated in Indonesia to find a way through the island archipelago into the Pacific Basin. It is also unlikely that if one did so it would escape detection by other tide gages in the Pacific. This is most probably a real tsunami but the report of its being observed on the U.S. west coast is erroneous. Validity 0 for the U.S. west coast.

1938, November 10, 20:19 GMT. A magnitude 8.3 earthquake at Shumagin Island by the Alaska Peninsula generated a tsunami weakly recorded in Alaska, Honolulu, and Santa Monica (Neumann, 1940). It was also recorded at Crescent City with an amplitude of 7 inches and weakly at San Diego. (See Figures 73 and 74.) Santa Monica experienced a storm at the time with heavy swells and winds preventing a planned visit of townspeople to the *U.S.S. Mississippi*, in port for a few days at the time. A young man was drowned "last night in the surf north of Santa Monica." Neither of these were related to the tsunami which had a maximum amplitude of about two inches.

This event is important in that a portion of the Shumagin tectonic block is a seismic gap and the expected earthquake there could produce a tsunami of uncertain size directed toward the west coast of North America. Validity 4.

1941, February 9, 09:44 GMT. A magnitude 6.6 earthquake occurred off the coast of northern California. There was an overall intensification of seiches in San Francisco and San Diego 14 hours after the event and 36 hours later at Port Hueneme as seen on marigrams (Joy, 1968). There were no changes at La Jolla (*Marine Advisers*, 1965; Soloviev and Go, 1975, p. 224). *The Monthly Weather Review* (February 1941) reported gale force winds at sea between 150°W and 175°E and north of 40°N reaching forces eight and nine on the Beaufort scale on the 1st, 2nd, 11th, and 13th. "As the disturbance of the 11th was moving inland the American ship *S.S. West Kyska* had a south-south-west gale of force ten in the early morning a little south of the Golden Gate." The long time delay between the shock and the seiche, the absence of reports of waves nearer the source and the presence of a storm in the area are convincing evidence for a meteorological cause. Validity 0.

1943, April 6, 16:07 GMT. A magnitude 8.3 earthquake north of Santiago, Chile, generated a small tsunami that was damaging locally. It was reported recorded at San Diego and Terminal Island with an amplitude of 0.75 inches. It was weakly recorded at the Presidio with an maximum amplitude of 1.2 inches and as a trace on the Crescent City record. The instrument at San Diego malfunctioned and no record was obtained and it was not seen on the La Jolla record. Validity 4.

1944, April 8, 02:30 GMT. A four to five million cubic yard landslide occurred on the Main Terrace in the Reed Terrace area about 98 miles above the Grand Coulee Dam, Washington. The terrace was 210 feet above the lake level and 350 feet above the former Columbia River level. The terrace cliff had been submerged 40% by the impounding of the river. It generated a wave 30 feet high on the opposite shore 5,000 feet away across Roosevelt Lake (Jones et al., 1961). Validity 4.

1944, December 7, 04:35 GMT. A magnitude 8.0 earthquake near Honshu, Japan, produced a 10-m wave that destroyed more than 3,000 houses and killed nearly 1,000 people in Japan. It was recorded with an amplitude of 4.3 inches at Port Hueneme, 2.75 inches at Santa Monica, 1.6 inches at San Diego and Terminal Island, Los Angeles, 0.75 at Fort Hunt, San Francisco, and barely discernible at La Jolla. (See Figures 75 and 76.) Validity 4.

1946, April 1, 12:29 GMT. A magnitude 7.8 earthquake in the Aleutian Islands generated a 30-m tsunami on Unimak Island destroying Scotch Cap lighthouse and killing five Coast Guardsmen. The tsunami was up to 56 feet high in Hawaii where 173 more people were killed and it caused over $26 million in damage there. It was observed throughout the Pacific Basin.

This was the most important tsunami in recent history as it resulted in the creation of the Pacific Tsunami Warning Service, the development of tsunami travel time charts, and the promotion of research and international cooperation. On the west coast of the United States it caused one fatality at Santa Cruz, about $10,000 in damage and had maximum height of about ten feet at Coos Bay, Oregon, and Santa Cruz, and Half Moon Bay, California. The following discussion of effects by community is given in north to south order, beginning with the State of Washington.

WASHINGTON

Friday Harbor. A wave of about one inch in amplitude was recorded.

Neah Bay. A wave with a six inch amplitude was recorded.

Taholah. The *Aberdeen Daily World* (April 2, 1946, p. 1) reports, "Taholah Hit by Big Wave—Residents in this community were alarmed shortly after ten o'clock when a five foot wave surged up the mouth of the Quinault River swamping boats and damaging fishing nets. Robert Graham, Taholah Postmaster, said today "Jack McBride and Peter Bruce tending a net three miles up the river reported the wave churned the river well past that point. Graham was on the dock near the Post Office when the wave surged in."

Other local newspapers examined including the *Seattle Star*, the *Seattle Daily Times*, *Ilwaco Tribune*, *Long Beach Chinook Observer*, *South Bend Journal*, *Florence Suislaw Oar*, *Newport Yakima Bay News*, and *Newport Journal* did not mention local effects but there is confusion as to what was expected. "No large waves approaching tidal wave size have been reported along the Washington Coast according to the Weather Bureau and Coast Guard Headquarters here" (*Seattle Star*, April 1, 1946). This leaves open the possibility that minor effects were observed but not reported.

OREGON

Clatsop Spit. O'Brien (1946) gives the height as six feet or 12 feet above MLLW at Clatsop Spit south of South Jetty near the mouth of the Columbia River.

Point Adams. "Point Adams Coast Guard Station reported that no unusual tidal action had been reported in the area of the Columbia River entrance" (*Astoria Evening Budget*, Apr. 3, 1946, p. 1). Since Point Adams is essentially the same location as Clatsop above and in view of the effects as reported for Seaside to the south, this negative report is probably in error.

Seaside. The *Seaside Signal* (April 4, 1946, p. 1) "Report of Tidal Wave is Not an April Fool's Day Gag! It Really Happened...A wall of water perhaps four feet high had swept up the Necanicum River about 10:00 A.M. It did no material damage so far as reported except to carry away several boats and a log float...Mrs. William Elroy who resides at 1016 North Holladay along the bank of the river heard a roaring noise and saw a wall of water rushing swiftly up the river filled from bank to bank (a bore) and a whirlpool formed at the rear of the house. It was probably ten minutes before the river returned to normal conditions."

Depoe Bay. It was first noticed when practically all of the water in the bay rushed out to sea. It immediately returned in a wall of water some five to seven feet in height followed by 24 hours of very bad surge. None of the harbors in Southern Oregon area suffered any damage (Coast Guard District 13, 1946).

Newport. "At Newport, Oregon, due to its broad expanse of water no wave was noted but there was a rapid rise in the tide of five feet" (Coast Guard District 13, 1946). This illustrates the reluctance to identify even moderate wave activity as a tsunami due to the popular misconception that tsunamis and "tidal waves" must be high.

Suislaw. (Florence) The wave was from three to four feet in height (Coast Guard District 13, 1946).

Coos Bay. "Coos Bay, however, reported a minor tidal wave" (*Astorian Evening Budget*, April 3, 1946, p. 1). The *Coos Bay Times* (April 1, 1946, p. 1) however reports, "Ten Foot Wave Sweeps into Lower Bay—A 10-foot [height] wave appearing without warning caused consternation in the lower Coos Bay and South

Slough area about 10:30 A.M. today but resulted in no damage.

"The Coos Head Coast Guard Station said the initial 10-foot wave was followed by a number of smaller waves much larger than anything usually seen in the lower bay.

"For a time it was feared fishing boats anchored in South Slough would be damaged but they rode out the extra high water with little trouble."

Charleston. Water dashed higher than the old CCC Camp buildings at Charleston, the Coast Guard reported. A wave hit about 10:20 A.M. causing no damage but observers called it an unusual and interesting spectacle (Coast Guard District 13, 1946).

Gold Beach. *Curry County Reporter*, April 4, p. 1: "Tidal Wave Hits Here—No Damage—Many of the people who happened to be in the river and some of the dwellers along the shore were startled Monday afternoon when the tail end of the great tidal wave that swept the Pacific came swirling into the river.

"It is reported that there were two waves, the first a rather gentle swell followed a few seconds later by a higher one of much greater violence traveling at a high rate of speed. Observers said that the wave seemed to come from the northwest, entering the river at an angle, and hence was much higher on the Gold Beach side of the stream than on the Wedderburn side.

"Practically no damage was done though Joe Sidle and his helpers had to do some lively work to save a 60-foot float, which they were just putting into the river, from being wrecked. The heavy float, partly in the water, was thrown back upon the shore and the men using timbers were able to prevent its being drawn back into the river where it probably would have been wrecked. Some slight damage is reported from the Winchuck River where the wave is said to have risen to a considerable height."

Brandon. *Western World*, April 4, 1946: "Barely perceptible at the mouth of the Coquille River. Brandon waterfront occupants stated that the rise in the water was not more than two feet."

CALIFORNIA

Crescent City. A three feet amplitude and a twelve minute period were recorded.

Humboldt. Humboldt and Del Norte County coastline were virtually untouched (*Humboldt Standard*, April 2, 1946).

Noyo Harbor-Fort Bragg. *Fort Bragg Advocate*, April 3: "Here at Fort Bragg the first indication of anything unusual was noticed by a group of fishermen working on their boats. They thought the boats were going out but it was the rapid fall of water that gave them that impression. In a very few minutes a surge came in through the mouth of the river that hit a 5-foot mark. The rise was very swift and boats that were not securely moored broke from their moorings and started drifting up stream.

"The three big boats tied at Paladini's wharf, the *Dawn*, *Noyo Star* and *Northern Light*, broke from their moorings and started upstream. For a while it was thought the boats would reach the bridge and cause damage, but their owners started their engines and put the boats under control.

"Several light surges came in the Noyo but after the fishermen became alerted, all boats were made secure." The *Los Angeles Times* (April 2, p. 2) reported that 100 boats were picked up by the waves and thrown as high as six feet. A number of boats broke away from their moorings and headed out to sea but all were rescued.

The *Mendocino Beacon* (April 6, 1946, p. 1) reported, "There were several minor rises and falls Monday. (Two men) noted what they thought was an extremely low tide and hastened

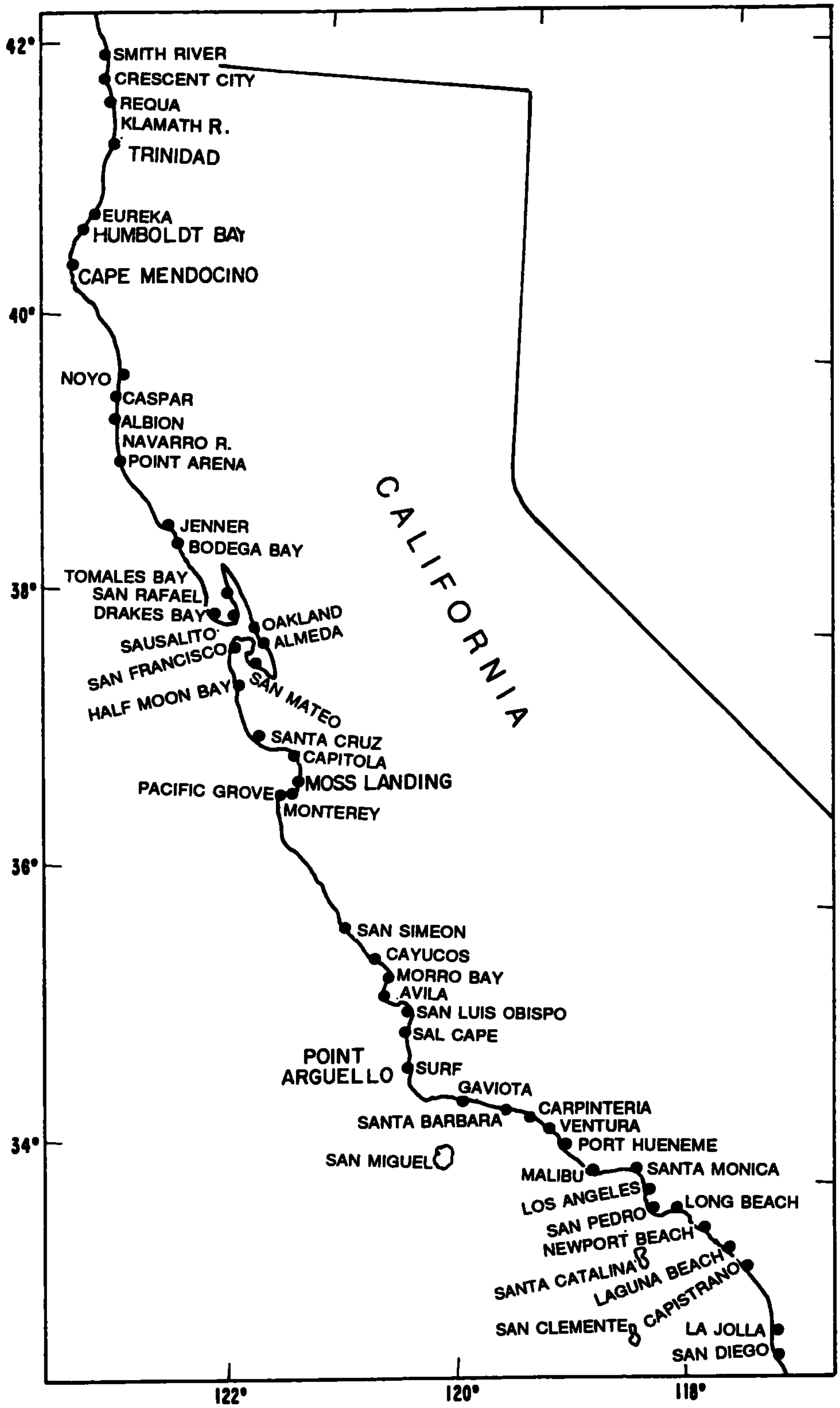


Figure 11. Location map for California.

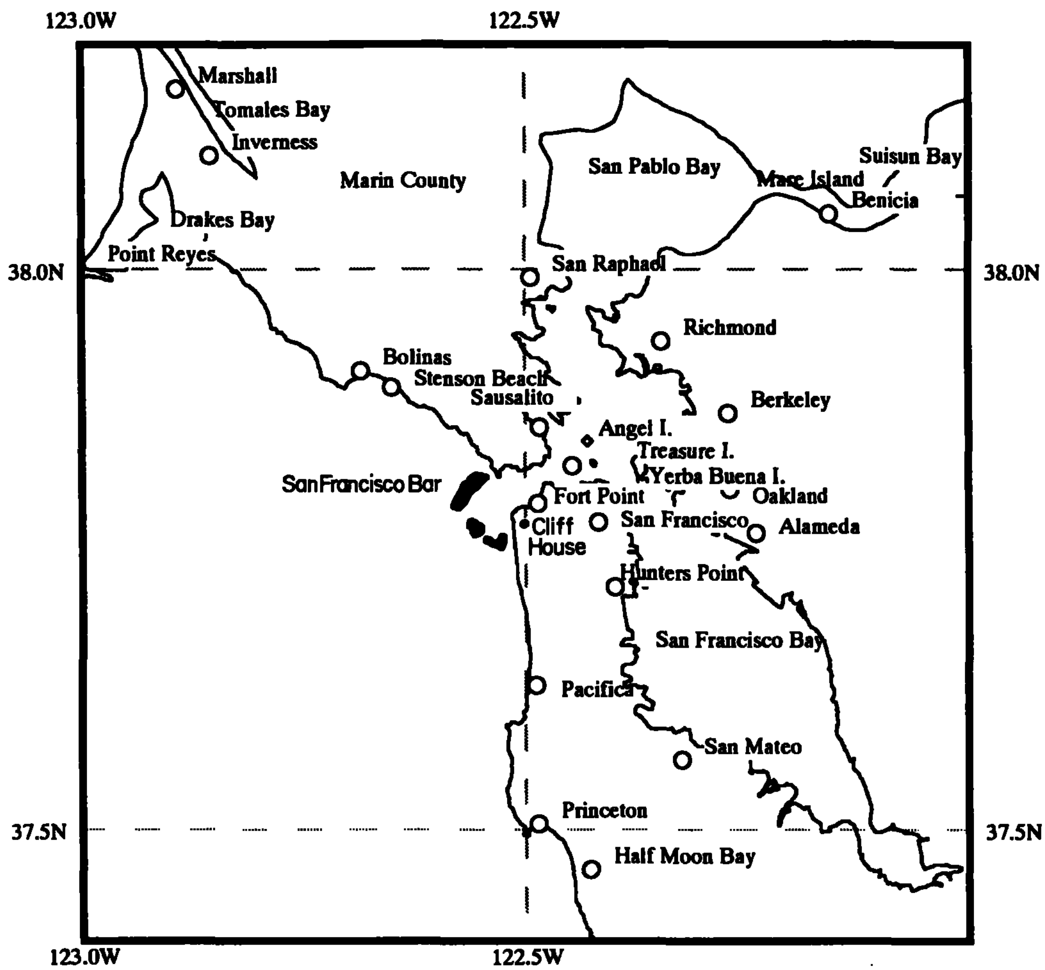


Figure 12. Location map for the San Francisco Bay area.

down on Agate Beach after abalones. They had just started to gather a few when the incoming surge started." One man had trouble beating the incoming wave to a place of safety and his partner saved him from drowning.

"Two other men driving down the coast from Fort Bragg looked out into the Caspar Bay and one remarked that he had never seen the tide so low there. The other could not understand it for there was no low tide scheduled at this time. The roadbed at the small bridge at this point showed that some driftwood had been washed across it not long before. It all looked fishy. They thought they might try for a few abalone at Jack Peter's Gulch. However, when they arrived there, high tide condition prevailed. Then they knew something was haywire. They stopped just above Agate Beach where the water was running out again and the rocks were showing an extremely low tide. It is said that there were about three of these rises in a short time. A number of people who attempted to gather abalones had narrow escapes." O'Brien (1946) gives a total height of 9.0 feet (range).

<u>Casper Beach.</u> A woman reported a flood passed under the bridge at Doyle Creek at 10:36 P.M. carrying big logs. An acre of pasture was covered with debris (Bascom, 1946).

<u>Arena Cove.</u> Magoon (1965) reports the maximum wave height as 14 feet above MLLW and 16 feet for the maximum wave height.

<u>Drakes Bay.</u> O'Brien (1946) reports a total height of 9.1 feet (range). Magoon (1965) gives a value of eight feet above MLLW. Crab traps

rolled over and moved and a small rowboat broke its line and capsized (Bascom, 1946).

Bolinas Bay. O'Brien (1946) gives the height above MLLW as 8.7 feet with a period of ten minutes and the character of a bore breaking in the entrance channel. Bascom (1946) gives the amplitude as 3.4 feet. A Coast Guard seaman who was in a row boat in Bolinas Bay observed a six foot wave that came in at great speed. A small island in the Bolinas area, which had not been touched with water for many years was submerged, the Bolinas Coast Guard Station reported.

Muir Beach. O'Brien (1946) gives a height above MLLW as 13.4 feet. The wave cut through the lagoon bar (Magoon, 1965). Bascom (1946) gives the amplitude as 8.4 feet.

San Francisco Bay Entrance. O'Brien, (1946) gives a height above MLLW as 6.8 feet, and period of five minutes. Magoon (1965) gives height above MLLW as 5.8 feet and the wave height as 1.7 feet at the Presidio. The range at Hunters Point was only 0.5 feet.

Alameda. The wave was recorded with a height of 1.4 feet at 18:23 GMT.

San Mateo. The wave was recorded with a height of 0.1 feet at 18:50 GMT.

Figure 13. Home at Half Moon Bay showing water height to its windows from the April 1 tsunami. Photo taken about 10:30 A.M. by Howard Anderson (Magoon, private collection).

Pacifica. The great waves were reported also at Sharp Park but there was no damage (*Half Moon Bay Review* and *Pescadero Pebble*, April 4, 1946, p. 1).

Princeton. *Half Moon Bay Review* and *Pescadero Pebble*, April 4, 1946, p. 1: "Several small tidal waves following in successive order a few minutes apart, Monday at Princeton flooded homes, shoved boats nearly 1,000 feet inland, uprooted fences, washed automobiles from their parking spots for distances of sixty feet and did damage along the coastside that may total $20,000.

"James Healy, owner of a number of boats, waded about the living room of his house in rubber boots. His residence is 400 feet back from the highest tide mark in Princeton's history.

"One of Healy's 26-foot-long power boats was washed inland more than 700 feet. Seven residences were flooded. The rear end of Hazel's Fish Stand on Patroni's Wharf had an estimated $500 in damage."

"A crew of United States Army Engineers making a survey for the proposed breakwater extending from Pillar Point...had to flee from a point near Romero Wharf as the second of the waves rolled in.

"Through it all there was no injury to persons, although several chickens were washed out to sea on the ebb of several of the waves.

"Several thousand dollars damage was done to affected areas near the Princeton Packers. The waves undid by erosion, what had taken weeks to do with bulldozers, trucks and hard labor.

"A.M. Patrick at the Princeton Packers plant telling of the waves said, 'a few more feet and it would have washed us right out of the office. It's all over the road. Debris, rocks, logs, crates, everything is piling up.'

Figure 14. Beached fishing boat at Half Moon Bay from the April 1 tsunami. Photo taken about 10:30 A.M. by Howard Anderson (Magoon, private collection).

"Waves washed completely over the piers at Princeton.

"The first wave washed away a ramp approach (to the Princeton pier)...succeeding waves...did considerable damage to the pier.

"A shed was picked up at the Half Moon Bay Coast Guard Station at Princeton and floated down the beach and the foundations of some other structures were washed out. Small boats used by this station were floated as far as a quarter of a mile inland. An automobile was hurled into the front of a house. Coast Guardsmen A.V. Peppard and Gilbert W. Lax said the first wave which swept in just as they arrived at the Coast Guard barracks, ripped boards off the building, shoved it half off its pilings and left five feet of water inside. Waves broke over the Half Moon Bay piers, but nominal damage was reported." (See Figure 15, next page.)

"First of the waves started at about 9:30. They continued until about 11:30.

"The seas also rolled rocks weighing as much as forty pounds onto the road and flooded the first floor of houses as far as 1,000 feet inland."

Observers in a boat estimated the water to be twelve or fourteen feet when it went over the shore line.

"Great waves were reported at Pigeon Point near the Santa Cruz—San Mateo County line. Roadways on the coastside near the surf all along San Mateo's coastside were inundated and debris strewn.

"The series of tidal waves started with a bright sun and from a sea calm and as smooth as glass.

"At Half Moon Bay...the first trough caused the surface to drop seven feet and then to rise seventeen feet to a height (amplitude) of ten feet above the original level" (O'Brien, 1946).

Santa Cruz. The *Santa Cruz Riptide*, April 5, pages 1 and 8 reported that there was no damage reported other than knocking a few boards from underneath the Casino caused by ten foot waves. One elderly man, Hugh W. Patrick, 74, was drowned. He had been walking on the beach with another elderly man, Cophus Smith, 73, at a cove at the west end of the beach where steps led down from West Cliff Drive when the two men were engulfed by a wall of water. The men were both knocked down. Smith tried to hold onto Patrick but a third wave pulled him free. Smith saved himself by holding on to a rock.

Figure 15. Rocks carried on to the road at Half Moon Bay pier. Picture taken by Manuel Sousa at about 11 A.M. Note continuing wave action. (Magoon, private collection.)

Another man, Ury Afanasief of San Francisco, was swimming when a surge dashed him against the rocks but he managed to fight his way out. Men on the municipal wharf reported the water receded at a terrific pace at a little after 10:00 A.M. and suddenly returned at an appalling speed and surged high on the beach. There were four surges, the last at 11:50 A.M. which all but topped the Espanade seawall. They were very frightened. The bay presented a weird sight as it seethed, boiled, and whirled. The water was dirty, and kelp, torn from its roots, whirled about. The rumor of the "tidal wave" spread fast and hundreds of people hurried to the beaches to see.

The *Watsonville Register-Pajaronian* (April 2, 1946, p. 1) reports that the wave covered the whole beach at Santa Cruz and was ten feet of water at Cowell Beach. One observer reported the sea rose ten feet above the normal level for the whole length of the wharf. He reported there were ten or more smaller waves.

Monterey. Some fishermen reported some slight turbulence in the local water. Many citizens rushed to the local waterfront but they were disappointed. Nothing much happened there (*Monterey Peninsula Herald*, April 1, 1946, p. 1). This would be about 2.1 feet lower than at Santa Cruz or a wave three feet in amplitude.

Pacific Grove. A single surge of water was observed at the municipal swimming pool which flooded the dressing room to a depth of three feet. A man on the dock fled up the steps ahead of the water. (This information is from the caption of photograph number B46D01-332 supplied by Magoon, Corps of Engineers in the NGDC photograph collection.) Magoon, (1965) reports a height of 10.3 feet above MLLW at Pacific Grove. See Figure 16.

San Simeon. O'Brien (1946) mentions that waves were large enough to be noticed at south facing shores including San Simeon.

Morro Bay. O'Brien (1946) gives a total height of 5.0 feet. Water threatened a trestle at the mouth of Morro Bay (*Santa Barbara News Press*, April 2, p. 1).

Avila. O'Brien (1946) gives a total height of 8.5 feet. The *Santa Barbara News Press* (April 2, p. 1) reports that the water was over the top of the breakwater and rose to within two feet of the top of the San Luis Obispo pier. It was also recorded.

Pismo Beach. The *Santa Barbara News Press* (April 1, p. 1) reported waves breaking high against the breakwater.

Point Arguello. The *Los Angeles Times* (April 3) reported that the Point Arguello tide "station showed a rise of three feet above normal though considerably below last Monday's seven foot rise."

Santa Barbara. The *Santa Barbara News Press* (April 1, p. 1) states, "Two separate waves surged into Santa Barbara Harbor Monday afternoon setting moored boats dancing and weaving but doing no damage. The tide was ebbing at 12:50 P.M. when the first wave raised the water level three feet and created a large whirlpool at the end of the breakwater. With a rush and a roar the water swirled out again dropping the level to a foot and a half minus tide. Ten minutes later a six foot (range) rise was recorded as a new wave surged in."

Figure 16. Municipal swimming pool at Pacific Grove, California, where high water from the April 1, 1946 tsunami reached the bottom of the word BOATS and flooded the dressing room three feet deep. A man fled up the steps ahead of the single surge. (Magoon, private collection.)

Carpinteria and Ventura. The *Ventura Star-Free Press* (April 2) states, "Police and Sheriff's Office observers reported a single wave that reached barely to the high water mark at Ventura and Carpinteria that occurred at 1:30 yesterday afternoon."

Port Hueneme. The *Port Hueneme Herald Express* (April 4, pp. 1, 8) reported that Port Hueneme and adjacent beaches were untouched except for a five foot rise in water. During the night this swept sand over the tracks of the Ventura County Railroad paralleling Ormond Beach which was being dugout Tuesday. Tuesday at low tide the water was at a point usually obtained at high tide. The tide gage recorded an amplitude of 2.75. O'Brien (1957) citing O'Brien (1952) states that there had been a ship berthing problem of a minor nature in 1946.

Santa Monica. A few hardy bathers at State Beach complained of "odd waves."

Los Angeles Harbor. Observers reported a regular rise and fall of a foot and a half (*Los Angeles Times* April 3, 1946, p. 1). An amplitude of 1.1 feet was recorded at Berth 174.

San Pedro. The *San Pedro Pilot* (April 1, 1946) reports, "Surging two to five feet above normal an unusual wave action this noon swept through the harbor...at 11:30 A.M. water in Fish Harbor rose an estimated five feet above normal and after ten minutes surged back. The phenomena was repeated at intervals...The surge lifted ramps at the ferry landing two feet above normal." The April 2 *Pilot* continues: "Surging harbor water today continued to reflect the oceanic quake-impelled uneasiness. Tide gauges at both the outer and inner harbor show a one-foot jump at irregular intervals after registering a peak of two and a half feet yesterday noon which broke ships from moorings at Bethlehem Shipyard and the General Petroleum Dock." It was recorded with an amplitude of 1.25 feet.

Long Beach. An undertow, such as has developed after earthquakes in Japan was reported by bathers, but so feeble it would not have been noticed if they had not been alerted to it.

Newport-Balboa. The *Santa Barbara News Press* (April 2, p. 1) reported that waves running in the opposite direction caused a furious eddy between Balboa and Little Isle dropping the tide five feet below normal, leaving boats high and dry.

La Jolla. The wave was first noticed about ten A.M. and peaked between 2:00 and 3:00 P.M. (*San Diego Union*, April 2, p. 1). These seem to refer to the tide gage measurements showing a maximum amplitude of about 0.7 feet.

Santa Catalina Island. The *Catalina Islander* (April 11, 1946) reports that the tide rose to a height of five feet and completely flooded the baseball diamond formerly used by the trainers of the U.S. Coast Guard at Catalina Harbor on the Pacific side of the isthmus. When the water receded it carried away a small pier that had been built on the west side for a motion picture set.

"One of the burned hulls of a vessel used in filming a Jack London picture was also carried out to sea and the hull of another vessel abandoned in 1937 was moved about one hundred feet. The debris on the beach indicated that the water had entered the harbor at four different levels, the first being about five feet and the others about three feet. There was no evidence of the water disturbance on its lee side of the island or at Bird Island in the entrance of the Isthmus Harbor."

The April 4 issue of the *Islander* reported a drop of six feet in the incoming tide with the water returning to normal "in a few moments" along the beach at Avalon.

San Diego. It was recorded with a maximum of seven inches. (See Figures 77–81, pages 176–178, for marigrams.)

Surprisingly, this important tsunami is largely unstudied. Several data gathering efforts were undertaken (O'Brien, 1946; Isaacs, 1946; Bascom, 1946; Carr, 1946; U.S. Army Engineering District, San Francisco, 1946; and Zerbe, 1953) but these were mostly unpublished reports and now unavailable. This is partly because the scientific and administrative organizations which would be established as a result of this event were not yet in place. Its neglect since, particularly for the west coast, possibly reflects the attraction of the more spectacular effects in Hawaii for the available scientific talent and the difficulty in capturing data years after the fact.

Warnings were issued to many communities through the Coast Guard although a formal system for doing so was not yet in place. Some communities took precautions in evacuating low-lying areas. The warnings triggered another phenomena which has plagued mitigation efforts in all subsequent events. They triggered a reverse response in attracting crowds to the beach.

This event happened on April 1, April Fools Day, and some mistook the warning and reports of a tsunami as a hoax. Validity 4.

1946, December 20, 19:19 GMT. A magnitude 8.1 earthquake at Nankaido, Japan generated a 6-m tsunami that swept 1,400 houses out to sea and killed about 2,000 people. It was recorded with a wave amplitude of nine inches at Crescent City and less than two inches at San Francisco. (See Figures 82 to 84.) It was also recorded at Avila and Los Angeles. Validity 4.

1949, April 13, 11:56 GMT. A magnitude 7.1 earthquake occurred near Olympia, Washington, causing $25 million in damage and eight deaths. At Cooper's Point one hundred fifty feet of a sandy spit northwest of Olympia jutting into Puget Sound disappeared during the night of April 13 leaving a small island (*Tacoma News Tribune*, April 15, 1949). There were reports of a large wave but no damage (*Daily Olympian*, April 13, 1949, p. 1). Validity 3.

1949, April 16, 2:55 A.M. An eleven million cubic yard landslide occurred on Point Defiance, at the Tacoma Narrows when a 400 foot high cliff gave way and slid into the water. "The water receded 20–25 feet from its normal tide line with an ominous sucking sound. Then an eight foot tidal wave rushed back against the beach smashing small boats, dock areas, a wooden boardwalk and other waterfront installations" (*Tacoma News–Tribune*, April 18, 1949, p. 1).

There was a row of homes at Salmon Beach at the foot of the cliff which was narrowly missed by the slide but sustained the damage listed above. The opposite shore from the slide was uninhabited (*Tacoma News–Tribune*, April 17, 1949, pp. 1, 2).

Although this event occurred three days after the earthquake, it is the result of weakening of the cliff from the shaking. A crack remained on top of the cliff above the homes.

This event has not been listed in previous tsunami catalogs. Most probably other waves have been generated by landslides caused by large earthquakes (or spontaneously) which have not been identified. Landslides are common in the Puget Sound area during large earthquakes and probably also occur without the impetus of an earthquake. (See also the 1891 events.) Validity 4.

1949, July 27. A two to three million cubic yard landslide occurred near the mouth of Hawk Creek about 35 miles above the Grand Coulee Dam, Washington. A 65 foot wave destroyed beaches and shrubbery directly across the lake. The wave was observed 20 miles away (*Colville Statesman–Examiner*, February 23, 1951, p. 6). Debris came down a slop averaging 30° and 380 feet high (Miller, 1960, p. 66). Validity 4.

1951, February 23, 8:45 A.M. A 100,000 to 200,000 cubic yard landslide occurred north of

Kettle Falls about 104 miles upstream of Grand Coulee Dam, Washington. It created a 300 foot spray upon hitting the water and generated a wave which picked up logs at the Harter Lumber Company mill and flung them through the sides of the mill ten feet above lake level. It caused $2,500 to $3,000 in damage there (*Colville Statesman–Examiner*, March 2, 1951, p. 1). Validity 4.

1952, March 4, 01:23 GMT. A magnitude 8.1 earthquake in Hokkaido, Japan, produced a 5.1-m tsunami that swept 90 houses away and destroyed 448 vessels. It killed 33 people in Japan. On the United States west coast it produced a tsunami of seven inch amplitude at Crescent City, two inches at Sausalito, 4.3 inches at Port Hueneme, 2.4 inches at San Diego, 0.8 inches at San Francisco and at Alameda, and five inches at Terminal Island, Los Angeles. (See Figures 85 and 86.) Note the values for San Francisco and Los Angeles scaled from the marigrams are less by more than an order of magnitude to those published in Iida et al. (1967) and subsequent catalogs. Validity 4.

1952, April 10–13. A 15 million cubic yard landslide three miles below Kettle Falls bridge on Franklin D. Roosevelt Lake, Washington, created a 65-foot wave on the opposite shore. Many waves were created on the lake during the first few days of landsliding. Many were noticed at the docks of the Lafferty Transportation Company six miles up the lake (Jones et al., 1961). Validity 4.

1952, October 13. A tremendous landslide about 98 miles upstream of the Grand Coulee Dam, Washington, created a wave which broke tugboats and barges loose from their moorings at the docks of the Lafferty Transportation Company six miles up the lake at 11:45 A.M. The wave swept logs, driftwood and chunks of lakeshore sod over a large flat area above full lake level. Validity 4.

1952, November 4, 16:58 GMT. A magnitude 8.2 earthquake off the east coast of Kamchatka generated a 13-m wave locally. On the United States west coast there were a variety of effects. Marigrams for this event are shown as Figures 87 to 104, on pages 181–189.

WASHINGTON

It was recorded at Neah Bay with a maximum height of nine inches, 2.4 inches at Friday Harbor and as a trace at Seattle.

OREGON

The *Brandon, Oregon Western World* (November 6, p. 1) reports, "The only effects reported locally—logs had broken loose from two Moore Mill log booms—one at Parkerville and one between Bullards and Prosper (up river). Logs had also been reported escaping from the Interstate Plywood boom and feeder logs at the Aberdeen log dump were reported surging. While no effect was in evidence near the mouth of the Coquille River, it was reported that a ground churning action at the bottom of the river was noticeable. The water seemed to be boiling from the bottom to the top." Other local newspapers in Washington and Oregon did not mention any effects. It was recorded at Astoria with an amplitude of five inches.

CALIFORNIA

Crescent City. "The wave described by Police Chief Veggo Hoyer, Crescent City, was described as a "high tide". The wave did not touch on any of the local harbors or beaches according to the Coast Guard" (*Humboldt Standard*, November 5, p. 8). The *Crescent City Triplicate* reported that four strong surges came in beginning at 8:00 P.M. with currents estimated at six miles an hour. When heavy swells came in, fishing boats tied fore and aft to their moorings would rise as high as the moorings permitted. The swift currents caught their keels and turned four boats completely over and sank them. A fifth boat was overturned but righted itself.

Table 6. Instrumental Data for the November 4, 1952 Tsunami

Location	Max. Amplitude/Feet
California:	
Alameda	1.2
Avila	4.2
Long Beach	0.8
Port Hueneme	2.3
Crescent City	2.3
Terminal Island	2.0
Los Angeles/Berth 174	2.0
Los Angeles	1.3
Hunters Point (San Fran.)	0.5
Santa Monica	1.8
San Diego	1.1
La Jolla	0.4
Washington:	
Neah Bay	0.7
Friday Harbor	0.2

Witnesses at the dock stated the water receded far beyond any low tide ever known and came back in with a swirling motion to within four inches of the top of the wharf. The Coast Guard radar spread the alert and fishermen rushed to take care of their crafts.

Massive 60 ton concrete moorings buoys were raked across the harbor floor and anchor lines were snarled. A few boats heeded the warnings and went to the outer harbor. The main wave arrived about 1:00 A.M. causing a 30-foot rise (range) in the water. This report in the *Crescent City Triplicate* is clearly too high given the recorded height of 4.7 feet. The Citizens Dock was undamaged and only minor damage occurred.

Santa Cruz. "The *Bruno Madre*, a fishing launch of the Cottardo Stagnaro Company, was damaged somewhat yesterday morning. It was being hoisted opposite the company's building when the hoisting rope snapped causing the boat to hang from one end in mid-air. Some damage was inflicted to one end of the boat because of the heavy ground swell.

"The ground swells which have been running for several days, continued at noon and caused the waves to roll high on the beach. Beyond Cowell's Point the waves were dashing and splashing against the bluff. The washing away of sand had caused the lower Saunder's steps to be ten feet above the ground. At the west end of the beach the sand rolled up to the bluffs and the receding waves left ponds of water. Along the beach there were piles of seaweed and kelp which had been broken loose by the swells.

"Water rolled up to the scaffolding along the front of the Casino whose interior was being remodeled" (*Santa Cruz Sentinel*, November 5, p. 4).

San Pedro. The *San Pedro New Pilot* (November 5) reports, "Effects of the seismic tidal wave which overnight swept across the Pacific this morning sent the harbor water surging up and down the channel." The ferry would alternately dock too high or too low for passengers to disembark easily. Validity 4.

1953, February 14–19. Beginning on February 14 and continuing intermittently until February 19 about 100 miles upstream from Grand Coulee Dam landslides fell into Roosevelt Lake, Washington. Many large waves were formed on the lake (Jones et al., 1961). Validity 4.

1953, February 16, 03:43 A.M. A series of landslides on Roosevelt Lake, Washington, near the February 14 slide site generated at least ten waves which crossed the lake and reached the maximum lake shore level 16 feet above the existing lake level. One exceeded the sixteen foot level. "A block of material was observed as it dropped into the lake and made a mound of white water one-fourth as high as the terrace.

The waves crossed the lake. The wave fronts were vertical walls of water; some had a dome-shaped surface just behind the vertical wall. On the average the waves crossed the lake in one and one-half minutes or at a rate of 4,000 feet per minute" (Jones et al., 1961). This is in good agreement for a lake depth of about 140 feet indicating the wave traveled as a gravity wave. Validity 4.

1953, August 19, 11:00 A.M. A landslide near Kettle Falls Beach, Roosevelt Lake, Washington created a small wave which dislocated one of the floating walkways at the National Park Service faculty. Since the part of the slide above the lake surface was small it must have been largely due to the collapse of the material below the surface (Jones et al., 1961). Validity 4.

1956, March 30, 06:11 GMT. A gigantic explosion of Bezymianny Volcano on Kamchatka, Russia, produced a shock wave or air wave that struck the coastal waters of Kamchatka (Gorschov, 1959). It created an air pressure wave that coupled with the sea and was widely recorded throughout the Pacific Basin. It was recorded at Avila, California, with an amplitude of eight inches (Iida et al., 1967). No signals were recorded on barographs operated by the U.S. Weather Bureau in the Pacific or on the west coast of the United States. Validity 2 as a tsunami wave.

1957, March 9, 14:23 GMT. The tsunami generated in the Aleutian Islands by a magnitude 8.3 earthquake generated a 12-m wave on Unimak Island that caused minor damage locally. It also caused extensive damage in Hawaii, and some damage in Japan. On the United States west coast the tsunami was both observed and recorded. The wave was barely noticed at Noyo Harbor (*Fort Bragg Advocate News*, March 14, 1957). It was unnoticed at Crescent City although it was recorded with an amplitude of 1.3 feet (see Figure 105). It was also unnoticed at Santa Cruz. The tide rose about two feet above normal at 12:30 P.M. at Monterey. A man and woman were swept off rocks at Point Lobos where they had been fishing Saturday afternoon. The man swam more than 100 yards in choppy, swirling water before reaching a cliff where he was rescued. He had been in the "stormy waters" for half an hour. His wife was also rescued after clinging to rocks. The newspaper account does not associate this rescue with the tsunami, but the time and water descriptions make it likely that it is related (*Monterey Peninsula Herald*, March 11, 1957, p. 1 and 2).

O'Brien et al. (1957) reports that the tsunami was just apparent on the Port Hueneme tide record at 12:59 P.M. as a recession with an initial amplitude of 0.4 feet at the ocean side recorder at Silver Strand and 0.9 feet inside the harbor. The maximum occurred about 7:16 P.M. with a 3.5 foot wave level change (range). A strong 12.5 minute period was present both in and outside the harbor.

The *San Pedro Pilot* (March 11) reported a 20 inch wave at Cabrillo Beach as measured on the tide gage.

The *Cambrian* (May 26, 1960) in reporting the effects of the Chilean tsunami stated, "Like the last tidal wave several years ago (1957) the one this week crossed the sand bar at the mouth of Santa Rosa Creek in only one place."

The first wave was noticed at San Diego at about 1:02 P.M. A late surge about 9:35 P.M. set up currents of 30 miles per hour ripping out 60 feet of floating docks and damaging 125 feet for finger slips at a commercial facility near the Bali Ha'i Club on Shelter Island. Damage was estimated at $5,000. Five large vessels were slightly damaged. At the Southwestern Yacht Club, Shelter Island Basin surges caused the 82 foot Coast Guard cutter *4F* to break its 1.5 inch cable and crash into the 50-foot *Sea Star* crushing a skiff on the *Sea Star's* stern. The waters dropped three feet (range) and rose again in three minutes (*San Diego Union*, March 10, 1957, p. 1). A family sleeping on the *Sea Star* was jarred awake but uninjured. Validity 4.

It was also recorded at Astoria and Newport, Oregon; Alameda, Anaheim Bay, Avila, Bodega Harbor, La Jolla (Figure 106), and Long Beach, California; Neah Bay, Washington; and Newport, Oregon.

1958, November 6, 22:58 GMT. A magnitude 8.1 earthquake in the south Kuril Islands, Russia, produced a locally damaging 5.0-m tsunami, and 5.0-m waves in Japan and an amplitude of less than four inches at Port Hueneme, eight inches at San Francisco and at Avila Beach. (See Figure 107.) Validity 4.

1960, May 22, 19:11 GMT. A great magnitude 8.6 earthquake off the coast of Chile caused 25-m runup there resulting in $550 million in damage and 1,000 deaths. It caused another $24 million in damage in Hawaii and 61 deaths and about $500,000 to $1,000,000 in damage on the U.S. west coast. In Japan the waves were more than 6-m high causing 199 fatalities and $50 million in damage. It is the most damaging tsunami recorded anywhere in the world.

Marigrams for this event are shown as Figures 108 to 123 (pages 192–198). Validity 4. It had the following effects:

WASHINGTON

Grays Harbor. The *Astorian Evening Budget* (May 23, 1960) quotes the Point Adams Coast Guard Station as having received reports of small waves at Grays Harbor.

Tokeland. The *Aderdeen Daily World* (May 23, 1960, p. 1) reports a two foot wave hitting Tokeland at about 9:45 A.M. but caused no damage. "An observer at Nelson Crab and Apples Cannery in Tokeland said the tidal wave as it crossed the Willapa Bar was foaming the width of the harbor opening. Repeated waves continued to roll across the bar.

"The north beaches were not visibly affected as the ocean surf had been running heavy" (*Aberdeen Daily World*, May 23, 1960).

Ilwaco Washington Tribune (May 27) states, "some rise above normal was reported about ten A.M. A two foot rise was reported by the Willapa Coast Guard."

This event was recorded at Friday Harbor with an amplitude of 0.3 feet, at Neah Bay at 1.2 feet, and at Echo Bay, Sucia Island as a trace.

OREGON

Point Adams. The *Astorian Evening Budget* (May 24, 1960) states the Coast Guard reported the wave rose and fell about three feet (range) without fully specifying the location. Presumably this was at the Point Adams Coast Guard Station.

Seaside. The *Seaside Signal* (May 26) reports, "Reaction to Chilean Quake Seen in Surges Here...brought surges of high water in the Necanicum River over a period of 48 hours. One bore described as being almost five feet in height damaged boat landings, swamped boats and knocked an unidentified man down. The first surges were noticed after 8:00 A.M., although there had probably been some earlier. It was not particularly spectacular but sufficient to cause comment. It was about 9:00 A.M. when the large bore shot up the river. Surges continued at about twenty minute intervals. There were more on Tuesday but later in the day they died down.

"The large bore covered the tidal flats, splashed water over the dike protecting the sewerage plant and smashed against the east shore of the river with a great roar."

Geese in Mrs. Lappla's yard at 434 North Holladay set up a clamor and she got to the river in time to see the wave. Emil Lappla at his plumbing business on Broadway saw the wave as being about one foot at that location.

Men working on a set of floats near the 1st Avenue bridge said the water was disturbed by a series of waves which kept the floats bouncing. (These locations are near where damage occurred in the 1964 tsunami.) (See Figure 21, page 96.)

Andy Brown observed the disturbance in the Ocean at the beach at Ocean Vista. There was a series of high waves which kept the sea in turmoil for several hours. Others did not notice anything unusual. Very few were on the beach. Late in the afternoon a wave probably five feet higher than usual swept the beach, drenching a number of clam diggers giving many a fright as they had difficulty keeping from being knocked down and swept into the surf.

There was very little damage as a result of the disturbances. Several boats were torn loose from their moorings, and a log float at Willard Court was torn from its anchorage.

Netarts Bay. The *Astorian Evening Budget* (May 23, 1960) reports that high waves at about 9:30 A.M. left debris on the beach.

Depoe Bay. The *Astorian Evening Budget* (May 24, 1960) reported a six-foot wave about noon which caught the trawler *R-Own* in the channel and tossed it out of control. It barely missed rocks near the channel as it was carried back out to sea.

Newport. The *Newport News* (May 26, 1960, p. 1) reported, "Richard Brown owner of the Deep

Figure 17. May 22, 1960 tsunami at Crescent City's Citizens Dock. (By permission, Wallace Griffin, Crescent City Printing Company.)

Six Marina and Tim McAdamo of the Coast Guard told of standing on the marine dock and watching the bay drop four feet (range) in a ten minute period around 11:30 A.M. Monday, May 23rd.

A spar buoy or channel marker attached to a chain and about 500 gallons in size was seen to bob up and down and to change with the tide three times at 20 minute intervals during a single hour. This occurred while the tide was supposed to be going out. Most of the surges were about two feet from ten A.M. to 1:30 P.M. after which the tide slowly returned to normal."

Gold Beach. The *Curry County Reporter* (May 26, 1960, p. 1) states that a section of dock and one boat was capsized about 10:30 A.M., Monday at the Rogue Boat Service. Several other boats were damaged and other boats were scattered.

Brandon. *Brandon Western World* (May 26, 1960, p. 1) reported, "Although there was a heavier than usual surge coming ashore the tide was at ebb and the effects were practically nil."

It was recorded at Astoria with an amplitude of one foot.

CALIFORNIA

Crescent City. The *Crescent City Triplicate* (May 27, 1960) reported a 13-foot tidal wave about noon flooding the southeastern part of the city following a number of 8.5-foot surges. Water again surged into the city shortly after midnight on a lesser scale. These times correspond to tsunami surges at high tide. Neither caused much damage on shore as the water failed to rise above curb level.

Front Street was flooded from H Street to the east, and Second and Third Streets were flooded from I Street to the east. The southern portions of J, K, and L Streets and the portion of Highway 101 coming into the city were also flooded. The water brought in and left thousands of tons of logs and debris literally covering Front Street.

The most severe damage was in the vicinity of Citizens Dock which also was debris laden. (See Figure 18, next page.) Three commercial fishing boats were sunk: the 50-foot *Ethyl G.*, the *Ida Mae*, and the *Andy N.* The *Andy N.* had been beached for repairs and was picked up from the beach by the wave and floated into the basin where it sank. Other boats suffered considerable damage. The *Ethyl G.* and *Ida Mae* were moored fore and aft and were swamped when they drifted crosswise to the retreating current. The *Ethyl G.* was raised the following week (*Triplicate*, June 2, 1960).

Most boat owners loosened their boats from the moorings and rode out the waves in the harbor.

There was some damage to the dock facilities. Water entered the Dock Cafe causing considerable damage and the Sea Scouts building was floated from its former location.

Preliminary soundings showed that twelve feet of sediments were deposited in some parts of the harbor.

Magoon (1962) reports a height of 12.5 feet above MLLW or 7.4 feet above predicted tide. A steel pile retaining wall at Citizens Dock parking lot partially failed caused by the scour of six to seven feet of sand from the seaward toe and increased hydrostatic pressure behind the walls during drawdown.

A wood pile mooring dolphin (for securing boats) located near the harbor side of the inner breakwater was carried away presumably due to the loss of sand at its base and the force of the currents.

The *San Diego Union* (May 24, 1960, p. 33) reports there were three injuries at Crescent City.

Figure 18. Flooding of the dock area at Crescent City from the May 22, 1960 tsunami. (By permission, Wallace Griffin, Crescent City Printing Company.)

Humboldt Bay. Magoon (1962) reported strong currents at the bay entrance and at the Eureka small boat harbor but there was no damage.

Shelter Cover. Magoon (1962) reported an estimated four-foot minimum waves based on only a very general description.

Noyo Harbor. The *Mendocino Beacon* (May 27, 1960, p. 1, 6) reported that surges began arriving at 6:15 A.M. raising the water four to seven feet above normal tide. Virtually every dock suffered loosened or broken pilings. A tier of six boats broke mooring from the south side pilings and still lashed together shot upriver unmanned with a high surge almost to Dead Man's Hole. A lone fisherman in a row boat caught up to the boats and tied them to a piling. Two of the six broke loose and ended on a mud bank. Half of the fishing fleet had put to sea following a warning.

Russian Gulch State Park, Van Damme State Park and Point Arena Light. Magoon (1962) reports that the wave was not observed.

Gualala River. Magoon (1965) reports two waves over the bar at the river mouth estimated at two feet.

Bodega Bay. Magoon (1965) reports a two foot rise in water reported inside the bay entrance.

Tomales Bay. Magoon (1962) reports a strong current at the bay entrance.

Stenson Beach. Shortly before 9:00 A.M. the sea rose ten feet with high waves foaming up to the pilings of beach homes. The water surged 50 feet up the beach at Seadowns, a section of Stenson Beach, leaving a line of drift wood and debris. *San Rafael Daily Independent Journal*, (May 23, 1960, p. 1).

San Rafael. The *San Rafael Daily Independent Journal* (May 23, 1960, p. 1) reports that a catamaran was torn from its moorings at Belvedere Lagoon and cast on pilings at the shore but was not extensively damaged. Belvedere Cove was filled with whirlpools with the water going out with the swiftness of a mountain stream.

San Francisco Bay. Magoon (1965) reports a height of 1.7 feet at the Presidio. Thirty-three tide recorders were in operation in the bay area and five recorded useful records. The *Santa Barbara News Press* (May 23, 1960, p. 5) reports that the San Francisco Ferry Service was disrupted by a current "running like the Mississippi River."

Berkeley. Boats bobbed at Berkeley Yacht Basin. Hugh W. Patrick, 68, was reported drowned. This was not confirmed in local accounts.

Pacifica. Magoon (1965) reports a height of 6.5 feet above MLLW which is identical with that at the Presidio and it probably had an amplitude of about 0.9 feet as did the Presidio.

Princeton. The *Half Moon Bay Review and Pescadero Pebble* (May 26, 1960, p. 1) reports that the northwest corner of the bay was drained nearly dry three times. A dozen or more pleasure and commercial fishing boats anchored in the bay suffered unusual damage as the drained bay left them on their sides. Two other salmon trawlers were driven on shore, heavily damaging one. Three men on board had to swim for their lives when heavy waves hit the craft and keeled it over. The craft was left 50 yards from the ocean's edge. The wave activity began about 5:30 A.M. and laid the ocean's floor bare for 600 feet or more beyond the main fishing pier. The water came back with a roar filling the bay up to nine feet. The water did not form a crest. The wave hit at low tide, sparing the community although a wave ran into the streets.

Magoon (1962) reports that the area was being subjected to thirty-knot southerly winds which may have contributed to the high waves and damage at Princeton. Based on visual observations he put the range at 14.5 feet (11.5 feet above MLLW). At Francis Beach State Park five miles to the south the tsunami was not observed.

Santa Cruz. The *Santa Cruz Sentinel* (May 23, 1960, p. 1) reports that "no damage was reported along the Santa Cruz County coast from the Pacific Ocean tidal wave but high wave action sent breakers up the steps of the Boardwalk Casino this morning at 10:35 o'clock and crashed over the sea wall at Capitola last night." An observer at the Municipal Wharf reported six-foot waves at 20 minute intervals continuing through the morning.

Moss Landing. Magoon (1962) reports a five-foot maximum wave observed with periods of 20–25 minutes and severe currents in the entrance channel.

Monterey. *The Monterey Peninsula Herald* (May 23, 1960, p. 1) reports waves surging into the bay. The partially completed frontal seawall was completely submerged but there was no damage. The water rose to within a few feet of the city beach parking lot. Heights based on visual observations by the Monterey Department of Public Works shows a maximum range of seven feet between 9:40 and 9:50 A.M.

Pacific Grove. Magoon (1965) reports six-foot maximum height at Pacific Grove.

Cambria. *The Cambrian* (May 26, 1960) states, "Like the last tidal wave alert several years ago

(1957) the one this week crossed the sand bar at the mouth of Santa Rosa Creek in only one place."

Pismo Beach. The *Arroyo Grande Valley Herald Recorder* (May 27, 1960) reports nine foot differential in tide (range) at Pismo Beach standing two feet on the seawall. The only damage was the unseating of a concession cabin on the beach.

Morro Bay. The *Sun* (May 29, 1960, p. 7) reports, "fresh tide here which followed earthquakes in another part of the world indirectly caused the death Monday morning about 10:30 A.M. of Earl Walker McCutcheon, 34. McCutcheon was hit on the head and killed by a falling boom from the hoist on his dock. He was on the lower level attempting to dislodge a float which had been lifted onto the rocks by the surging tides." A roof mooring broke loose allowing part of the equipment to fall.

One boat, the *Hornet*, broke loose from its mooring and floated to the end of the Embarcadero before its owner caught up with it. The harbor, which was nearly empty, was filled in a matter of minutes.

Avila Beach. The *Santa Maria Times* (May 23, 1960, p. 1) reports a higher than usual incoming tide and the outgoing tides went out farther. There was no damage. The Coast Guard reported surges of six or seven feet.

Oceano. The *Santa Maria Times* (May 23, 1960, p. 1) reports that a strong wave engulfed the Oceano ramp at about 9:00 A.M.

Santa Barbara. The *Santa Barbara News Press* (May 23, 1960, p. 1, 5) reports, "About 20 boats were torn loose from their moorings and the cables and chains of a dozen others were tangled. The highest swell washed the harbor at 9:30 A.M. and rose to a height of seven feet, eleven inches and then dropped nine feet all in less than ten minutes."

"A second series of high surges began again at 11:00 A.M. and had apparently subsided by 1:00 P.M. Boats were still breaking loose from their moorings and were being chased and caught by the city's harbor launch and local commercial boat operators.

"The water rushed in like an inland river, making swirls and eddies which pushed even moving boats about helplessly.

"The 125-foot oil exploration boat *Sand Dab* was pushed in circles breaking and snarling its mooring cables." Twice the *Sand Dab* rammed into the city dredge, both times cutting mooring lines which held the dredge in place. It ran aground but was pulled free and towed out to sea.

"The water rushed into, then out of the harbor again at speeds of five miles an hour, raising mud and debris from the ocean floor."

The first wave hit the harbor at 6:15 A.M. The Navy minesweepers roared out of the harbor at top speed and their wakes caused further difficulties for the men attempting to clear snarled cable and colliding boats.

The major damage was done to moorings and several boats were bumped and scratched. The damage was limited to boats on open moorings and not to mooring slip areas.

Two ships, the tanker *W.L.R. Emmet* and the 10,500 ton *Oneida Victory* collided off Santa Barbara Sunday night with significant damage and injury to the crew. This may relate to storm waves (see Port Hueneme and Half Moon Bay accounts) but was not related to the tsunami.

Port Hueneme. The *Ventura Star-Free Press* (May 24, 1960) reports that a charter fishing boat, the *Verna F.* returned to port when it encountered strange tides at the harbor entrance. After unloading its passengers, it noted a drop of eight feet within an hour.

The landing float and Dock No. 1 were damaged. Water swirled around the fishing pier as the tide swept in and out. The Navy portion of the harbor experienced some nuisance damage as some vessels were pushed under docks and others broke their moorings. The *Oxnard Press Courier* (May 23, 1960, p. 1) reports a six-foot surge moving in and out of Port Hueneme tore float loose at the Porter Bros. Dock.

A boat was run aground deliberately in the Piedmont Bay area at 7:30 P.M. Sunday due to heavy swells. This was not related to the tsunami but to a storm which may have aggravated the tsunami effects (see also Half Moon Bay and Santa Barbara).

Los Angeles. The *San Pedro News Pilot* (May 24, 1960) reports tsunami damage at over $1 million, and the harbor was closed on the 23rd. Losses were estimated at a quarter million dollars to small craft moorings and anchorages particularly in the Cerritos Channel area. More than 300 craft broke their moorings and small craft incurred well over three-quarters of a million dollars in damage there. Eight hundred small craft were torn from their moorings, 40 were sunk and 200 were damaged. Little or no damage was reported at shipyards—it was limited to lost loose lumber and the breaking of the ship to shore telephone lines at Todd shipyard. The tide were accompanied by extremely fast currents ripping loose numerous docks and finger piers.

The *Oceanside Daily Blade-Tribune* (May 23, 1960, p. 1) reports currents of up to eight knots raced through West Basin (Los Angeles) and the water was raised six feet in a few minutes.

Raymond Stuart, 30, a skin diver diving off Point Fermin was reported missing when he failed to keep a 9:00 A.M. appointment. His car and clothing were found, but his body was not recovered.

Other swimmers at Cabrillo Beach apparently enjoyed the freak waves. The Lifeguard Captain related seeing one man floating in water normally over his head when the water started going out. "The next thing he knew he was on his back in the mud."

He also tells of another swimmer signalling for emergency help when the current swept him away from shore. "We didn't bother sending aid because the next wave brought him back again."

Fish were left flopping in the mud. The draw bridges to Terminal Island were raised to prevent damage to them by the free-floating boats creating massive traffic jams complicated by many boat owners trying to get to their craft.

Docks to which clusters of as many as eighty boats were tied were torn loose and dumped into other docks, bridges, and the channel walls.

Gasoline from ruptured boats spewed into Long Beach and Los Angeles Harbors causing a fire hazard.

One dock broke loose at Sunset Beach, near Long Beach, but there was no damage to the boats.

Avalon, Catalina Island. The *San Diego Union* (May 24, 1960, p. 3) reports that boats moored at Avalon were riding out four foot swells easily.

San Diego. The *San Diego Union* (May 23, 1960, p. 1) reports that ten boats broke their moorings and 165 feet of dock was destroyed at the Southwestern Yacht Club at Point Loma causing $4,000 in damage to the docks. The boats suffered only minor damage. These included one large dock and four small slips. One of the boats was the 82-foot Coast Guard cutter *4-F* which was swept into the channel. (It had also broken its mooring in the 1957 tsunami.)

The surges broke in half a large bait barge in Mission Bay Park's Quivera Basin. Half of a 100-foot barge tore loose and smashed into the new Seaforth Landing fishing dock—knocking down five moorings, destroying pilings, and tearing away eight boat slips off the dock.

The ferry service between San Diego and Coronado was cut at 7:00 A.M. when the bay waters became extremely turbulent. Service was resumed shortly after noon. One of the ferries with a capacity of 75 cars was carried almost a mile off course during an early morning run. Other ferries had difficulty entering the slip pilings and at least two dolphin pilings clusters were damaged. (Dolphin pilings are a group of pilings lashed together, suitable for the mooring of boats.)

At 5:25 A.M., 140 feet of the Harbor Department's Operation Dock with three Port of San Diego patrol boats at Shelter Island tore loose under a swirling ocean surge. Damage was estimated at $3,500.

Five harbor crewmen were on board and were carried to sea. They finally docked the boats at Buoy Seven off the Navy's Sonar School. The Coast Guard dock of Shelter Island was damaged slightly.

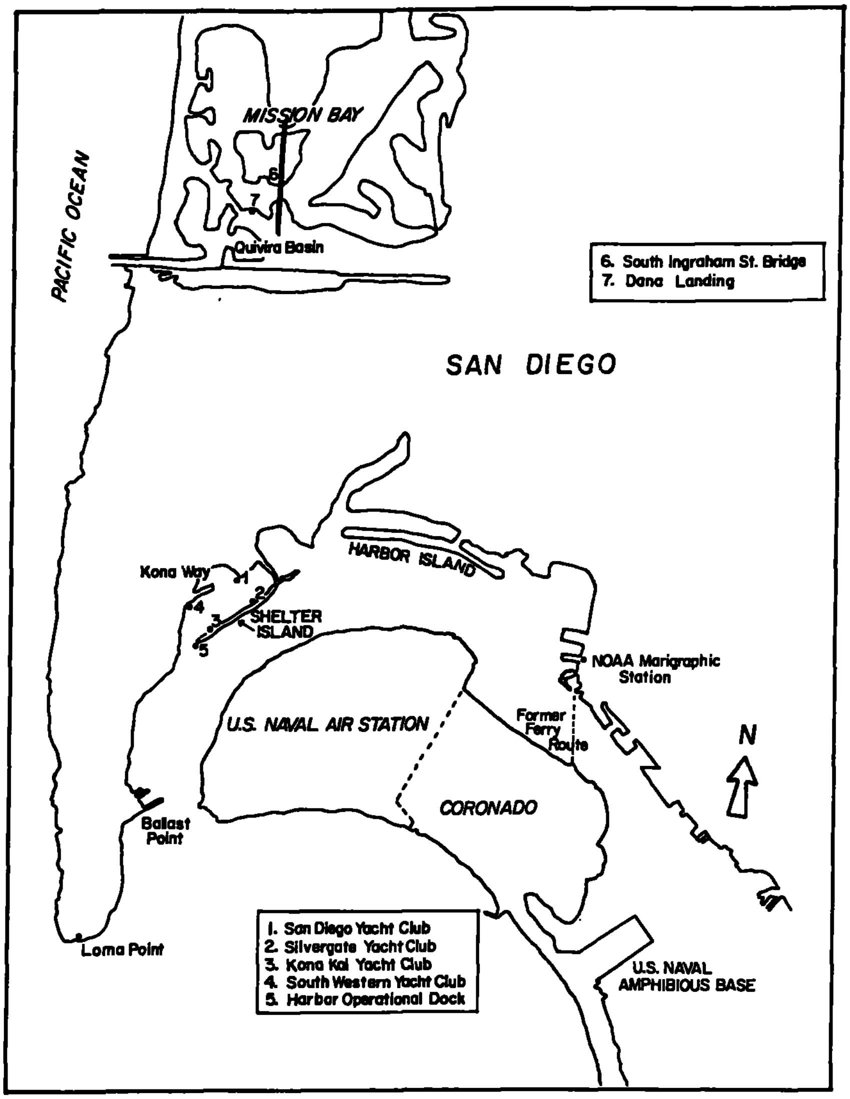


Figure 19. Location map for San Diego, California.

A 160-foot dock at Shelter Landings on Shelter Island was destroyed and twenty four boats were moved to other locations. Damage was estimated at $3,500 at this locality.

The waves swept into the San Diego harbor about every 15 minutes. There were no crests but rather the volume of water seemed to increase. It swirled in a thousand eddies with great whirlpools here and there. The channel was turned into a swift-moving river flowing in both directions. The water was muddy and sand was scooped up from the bottom and side of the channel. The Port Master estimated the water speed at 20–25 knots (23 to 28 miles per hour) with a maximum rise of seven feet.

A 106 foot schooner, *Marpatcha* broke loose from its mooring at Kona Kai Club on Shelter Island but was taken in tow by the Coast Guard. Two thousand dollars in damage was reported at Kona Kai Club.

Table 7. Instrumental Data for the May 22, 1960 Tsunami

Location	Max. Amplitude/Feet
California:	
San Diego	2.3
La Jolla	1.7
Wilson Cove, San Clemente Island	2.1
Alamita Bay	2.0
Long Beach	2.9
Terminal Island	3.1
San Pedro	1.5
Los Angeles/Berth 60	2.5
Santa Monica	4.6
Port Hueneme	4.4
Monterey	4.1
San Francisco	1.5
Alameda	1.0
Crescent City	5.5
Oregon:	
Astoria	0.5
Washington:	
Neah Bay	1.2
Friday Harbor	0.3
Echo Bay	trace

The *San Diego Tribune* (May 24, 1960, p. 1) reports that surges during the night caused a 100-ton derrick barge to ram a concrete piling supporting the South Ingraham Street bridge in Mission Bay Park. A 35-foot section of the 70 foot piling was broken off requiring a month and $3,000 to repair. The barge had been employed in cleaning up the damage in Quivira Basin caused by the earlier surges.

The *San Diego Union* (May 24, 1960, p. 1) reports waves eight feet above normal at 8:55 P.M. (high tide).

At 4:20 A.M. on the 24th, surges tore out more sections of the Harbor Department's docks on Shelter Island. One 100 foot section was turned over with the pontoons on top. Three 50 foot lengths were half turned over. Damage was estimated at $6,000.

At the Navy Electronics Laboratory docks the stern of the 87 foot Navy yawl *Saluda* was lashed against the small boat dock causing minor damage to the yacht and pier.

A 22-foot cabin cruiser was sunk near Dana Landing about 8:00 P.M. on the 23rd. The hull was punctured as the owner attempted to pull it aboard his trailer.

A crowd gathered on Shelter Island to watch the swirling whirlpools and see the damage caused by the currents. Police were needed to break up a traffic jam during the night.

The *San Pedro News Pilot* (May 26, 1960, p. 9) reported that a large shoal in front of the Harbor Master's headquarters was washed away, deepening the area by eight to twenty feet and saving a ordered dredging operation.

1963, October 13, 05:17 GMT. A magnitude 8.1 earthquake in the South Kuril Islands, Russia, produced a four-meter wave locally. It was reported observed at Crescent City's Citizens Dock where it rose and fell 2.1 feet (range) in three minutes at 8:22 A.M. Successive waves of 1.5 feet, 2.3 feet, 3.3 feet, and 1.9 feet were measured up to 9:40 A.M.

The stern mooring of one fishing boat was torn loose (*Del Norte Triplicate*, October 17, 1963, p. 1). The *San Diego Union* reported a 0.2 foot wave recorded at Scripps but otherwise the wave was not observed there. It was also well recorded at Avila. (See Figure 124.) Validity 4.

1964, March 28, 03:36 GMT. A massive magnitude 8.4 earthquake originated in Prince William Sound, Alaska, giving rise to a major tectonic tsunami affecting the entire Pacific Ocean Basin and also causing more than a dozen local landslide tsunamis in the epicentral area. They caused $84 million in damage in Alaska and 107 deaths. Run-up heights exceeded 200 feet. Due to the orientation of the generating zone the largest waves outside of Alaska were directed toward the United States and Canadian west coasts causing much more damage to the west coast, particularly at Crescent City, than all previous tsunamis combined and exceeding $17 million. There were 16 fatalities and a fatal heart attack and a fatal accident which may have been related to the tsunami. (Refer to Figures 125 through 140 for marigrams, pages 199–205) Validity 4.

WASHINGTON

Summary: Two people were injured and two more suffered heart attacks. Damage to bridges and roads was at least $80,000. One fishing boat was wrecked. Several skiffs and fishing nets were lost ($4,000). At least 16 homes were damaged including three destroyed. Nine trailers were damaged and three cars were lost. One mile of sea bulkhead was lost.

Friday Harbor. Recorded instrumentally with an amplitude of 1.15 feet.

Neah Bay. Recorded instrumentally with an amplitude of 2.35 feet. Considerable amounts of driftwood was deposited on the beach at Cape Flattery Lighthouse (Darling, April 22, 1964).

La Push. The second and highest wave occurred at 11:55 P.M. and was reported as 5.3 feet above predicted tide at the Patterson and Butts Dock. It was a gradual rise of the water and not a bore. Several boats and a floating dock broke loose from their moorings. The channel to the Coast Guard boat house may have decreased in depth. The first wave arrived at 11:25 as a three-foot rise. (Hogan et al., 1964) The Coast Guard at Quillayute River reported a maximum height of 7 feet (Darling, April 21, 1964).

Hoh River Mouth. The second and largest wave occurred at 00:10 A.M. on the 28th and was 1.7 feet above the predicted tide. No damage was reported. The amplitude was estimated by using the tsunami debris line and the predicted tide level (Hogan et al., 1964).

A grandmother in Seattle heard of the possible tsunami and called her daughter who was vacationing with her daughter, Patty (age 11), at Kalaloch Beach, Jefferson County. The daughter and an eleven-year old boy were camping on the beach. The mother reached them five to ten minutes before the wave. The boy went immediately to higher ground but the girl wanted to get her sleeping bag and pup tent. The mother grabbed the girl and headed for higher ground also as she could hear the water and logs coming. They reached a tree at the base of the 40-foot scrub covered embankment when the wave struck. The water reached their knees. After the wave receded, they attempted to climb higher. The second wave still reached to their ankles although they were five feet higher. All escaped without injury (*Seattle Daily Times*, March 30, 1964, p. 2).

Seattle. Earthquake waves generated seiches on Lake Union which caused minor damage to the gangway of the U.S. Coast and Geodetic Survey (USCGS) ship *Patton* and snapped mooring lines on the USCGS ship *Lester Jones*. Minor damage was also done to several pleasure craft, house boats and floats that broke their moorings. This earthquake phenomena was observed as far as the east coast and gulf coast of the United States and is not related to the tsunami. The tsunami was recorded with an amplitude of 0.4 feet at Seattle (Spaeth and Berkman, 1972).

Belfair. Tides were about three feet higher than normal at Belfair and the southern end of the Hood Canal. The water went over the highway at Beard's Corner and there was a lot of brush and trees floating in the canal (*Seattle Daily Times*, March 28, 1964, p. 1, 2).

Taholah. A wave of amplitude of 2.4 feet was reported to have occurred at 00:50 A.M. at the Indian village of Taholah at the mouth of the

Quinault River. Several fishing skiffs and fishnets valued at $1,000 were lost (Hogan et al., 1964). Four Tacoma men camping at Point Grenville south of Taholah were chased from their tents by the waves. One man was hospitalized for shock and their car and camping equipment were damaged (*Seattle Daily Times*, March 28, 1964, p. 2).

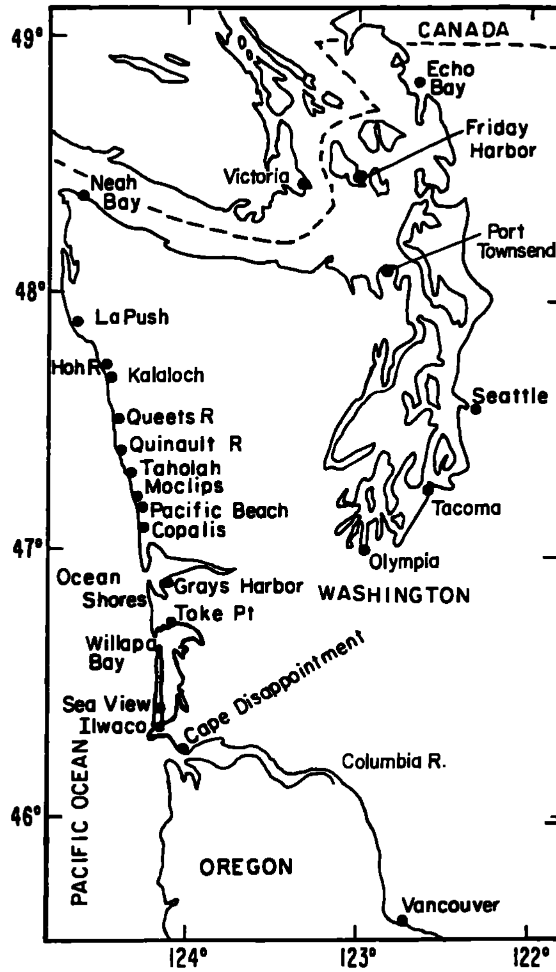


Figure 20. Location map for the State of Washington.

<u>Wreck Creek</u> (near Point Grenville). An amplitude of 14.9 feet was estimated at the highway bridge along the exposed ocean beach where $500 in damage occurred. The fill material at the bridge approach was eroded and debris was deposited on the bridge deck and nearby highway (Hogan et al., 1964).

<u>Moclips</u>. The second and highest wave occurred at 1:30 A.M. and was 11.1 foot high on the exposed beach south of town. Damage was done to eight beach houses there. An estimated $6,000 was caused to beach front houses, timber pile bulkheads, and the road. Damage to the houses was to the ocean side walls which were battered by floating logs. Houses were flooded to a depth of six inches to several feet and debris littered the yards. One house moved on its foundation (Hogan et al., 1964). Several cars were lost (Murphy, 1964).

<u>Pacific Beach</u>. Damage of $12,000 was reported to buildings at Pacific Beach and an additional $500 in damage occurred to a bridge over Joe Creek there. The amplitude of the first two waves at the Oceanographic Research Station was estimated at between 6.5 and 7.5 feet.

One medium-sized dwelling with four occupants, the Smiths and grandchildren, was lifted off its foundation, moved 40-feet to the northwest and partly torn apart. A second building was damaged and flooded, yards were eroded and covered with heavy debris.

The second wave was the highest. It was deflected by the south bank of Joe Creek and turned northwesterly inundating dwellings on the north bank. Damage to the bridge included the loss of three pilings and two 20-foot concrete spans. The wave was estimated to be eight feet high at the bridge (Hogan et al., 1964). One person at the Pacific Beach Navy Base injured his arm. Another person was reported to have suffered a broken foot but the community where the injury occurred was not identified. A private car of a member of the base personal was lost on the beach as he attempted to warn campers at Point Grenville (Murphy, 1964).

<u>Boone Creek</u>. About $500 in damage was done to a building at Iron Springs Resort. The foundation of one building was damaged and two

inches of water flooded the floor. Water was one foot above the floor level on the outside of the building. Heavy debris was left in the yard and low sections of the road near Boone Creek. The water was one to two feet above the road level at the Boone Creek culvert. A section of the road shoulder six feet wide, eight feet high, and 80 feet long was washed out and heavy debris was deposited causing $400 in damage (Hogan et al., 1964). About 75 guests were stranded at Iron Springs Resort by the bridge failures at Joe Creek to the north and on the Copalis River to the south. There was no warning (*Aberdeen Daily World*, March 31, 1964, p. 1).

Copalis. The first wave arrived about 11:30 P.M. Trailers were overturned and a car was washed into the Copalis River. The driver, Al Smith, was rescued but the deputy sheriff's car was washed over by the waves. Mr. Smith was attempting to reach his children at Pacific Beach (see above). The second wave arrived at 1:05 A.M., when two cars were lost. Two heart attacks were reported but the location of the victims is uncertain. Both survived. A third wave at 3:05 A.M. hit the sea wall hard, badly damaging about one mile of it. Two homes were wrecked, one beyond salvage and three others damaged by being moved from their foundations. The beach had been closed to clam diggers earlier due to the stranding of a barge there. Otherwise this beach would have a favorite camping area. Logs and driftwood had been left half a mile inland (Murphy, 1964).

The State Highway 109 bridge over the Copalis River consisted of a 4-piling timber bent and two timber spans near the center of the bridge. The height was estimated at six feet at the bridge. Mr. Leonard Hulbert, 50, stopped on the Copalis Bridge to watch the logs pile up against the footing. The bridge collapsed plunging him and the car into the river. He forced open the door against the current and escaped. His leg was pinned by the door, but he was able to pull loose. An area resort owner said the water swept nearly half a mile beyond its normal tide line carrying some trailers more than 100 feet. Damage to the bridges at Joe Creek, Boone Creek, and the Copalis River was estimated at $75,000, and $5,000 additional damage occurred there due to shoulder erosion and debris. These damage figures did not include the cost of building the detours around the damaged bridges (Hogan et al., 1964).

Grays Harbor Ocean Shores (0.75 miles south of Oyhut). A 9.7-foot wave was reported for the exposed ocean beach at the Central Motel office at the west end of Chance a la Mer Street at 11:32 P.M. Debris was deposited in the streets and on the beach (Hogan et al., 1964). A ranger at Ocean City pulled a woman immobilized by fear out of the surf (*Daily Olympian*, March 30, 1964, p. 1).

Aberdeen. Seiches set up by the earthquake waves caused 5,000 gallons of water to spill from the reservoir washing over a five block area of Aberdeen. It washed out a gravel road and flooded the basement of one home. Four lawns were covered with gravel and a $6,000 sunken garden was damaged. A sun deck and other gardens were damaged. These were not tsunami effects (Murphy, 1964).

Three log rafts at Saginaw Shingle Company on the Chekalis River broke loose and were recaptured without further damage (*Aberdeen Daily World*, March 31, 1964, p. 2). The Boat Club mooring area located about ten miles upstream from the bay was apparently silted up. Boats were left high and dry on the mud even at a plus tide. The Boat Club is located just south of the South Montesano bridges (Murphy, 1964).

On a beach north of Aberdeen, a woman was awakened by the rocking of her trailer. She stepped out into waist deep water. On reaching higher ground she needed hospitalization for a rapid heart beat. "We were up to our waist one minute and tumbling head over heels the next," she said. Four trailers were toppled at Redfield Trailer Camp after their occupants had fled. Some autos were reportedly overturned on the sand (*Daily Olympian*, March 30, 1904, p. 1). About 250 guests were evacuated at 11:30 P.M. at Ocean Shores at the suggestion of the Navy Hydrographic Station at Pacific Beach. Water ran up the access road and into the motel office and units to a depth of about two feet. It receded without doing significant damage (*Seattle Daily Times*, March 28, 1964, p. 1 and 2).

Westport. A fishing boat was wrecked and there was debris on the beaches (Murphy, 1964).

Willapa Bay. The Bone River bridge about eleven miles south of South Bend was damaged when an oyster plant building was swept against it (*Ilwaco Tribune*, April 3, 1964, p. 1). Losses to the oyster beds in Gray's Harbor and Willapa Bay were estimated at $900,000 over the several years needed for recovery (Thorsen (1988) quoting The *Aberdeen Daily World*, April 30, 1964). Unestimated losses also resulted from loss of tourism.

Sea View. A maximum wave amplitude of 12.5 feet was reported but no damage was observed (Hogan et al., 1964).

Ilwaco. A four to five-foot wave was reported at a dock south of Eides Warehouse, Ilwaco, which caused minor damage (Hogan et al., 1964). The *Ilwaco Tribune* (April 3, 1964, p. 1) and *Chinook Observer* (April 3, 1964, p. 1) report that a man and woman were going beach combing after hearing of the tsunami alert. As they crossed Holman Creek in their jeep, a wave stopped the motor. They jumped free but the jeep rolled over.

Four youths were camping at Beards Hollow when the first wave hit at 11:35 P.M. filling their old car. The car was shoved 60 feet. There was an undetermined amount of damage to the oyster beds. Particularly hard hit was Stony Point where oysters were washed up on the beach and new seed oysters were swept out to sea. Damage may have reached $100,000 to $200,000. The channel was deepened but no other damage was reported. No warning was received until a few minutes before the waves arrived.

Cape Disappointment. The U.S. Coast Guard Station at Cape Disappointment on the north shore of the mouth of the Columbia River reported a 5.7 foot wave at its boat moorage and fueling dock at 11:35 P.M. No damage occurred.

Columbia River. The tsunami was recorded at Astoria, Oregon, 14 miles from the river mouth with an amplitude of about 15 inches. At the Beaver tide gage 41 miles upriver the amplitude was about seven inches and at Vancouver, Washington, the amplitude was about two inches (Wilson and Tørum, 1968).

OREGON

Summary: Four children were drowned and one woman suffered a fatal heart attack. Bridges, houses, trailers, cars, motel units and sea walls were destroyed at communities along the length of the coast. Damage estimates are uncertain but appear to be between $750,000 and $1,000,000. Most of the communities did not receive any warning.

Astoria. A wave was recorded with an amplitude of 1.3 feet.

Point Adams. The Coast Guard reported a first arrival at 23:55 and a maximum height of 5.5 feet with the second wave (Darling, April 21, 1964).

Warrington. The waves did damage to a large area along the Warrington waterfront. Residents had been alerted. Log rafts were torn loose and broken up at the Warrington mill. An estimated $20,000 in damage was done to the mill docks and rafts. Two boats were floating attached to large logs but were rescued. The Skipanon River was at the highest level ever known.

Sunset Beach area was not damaged (*Seaside Signal*, April 2, 1964, p. 11).

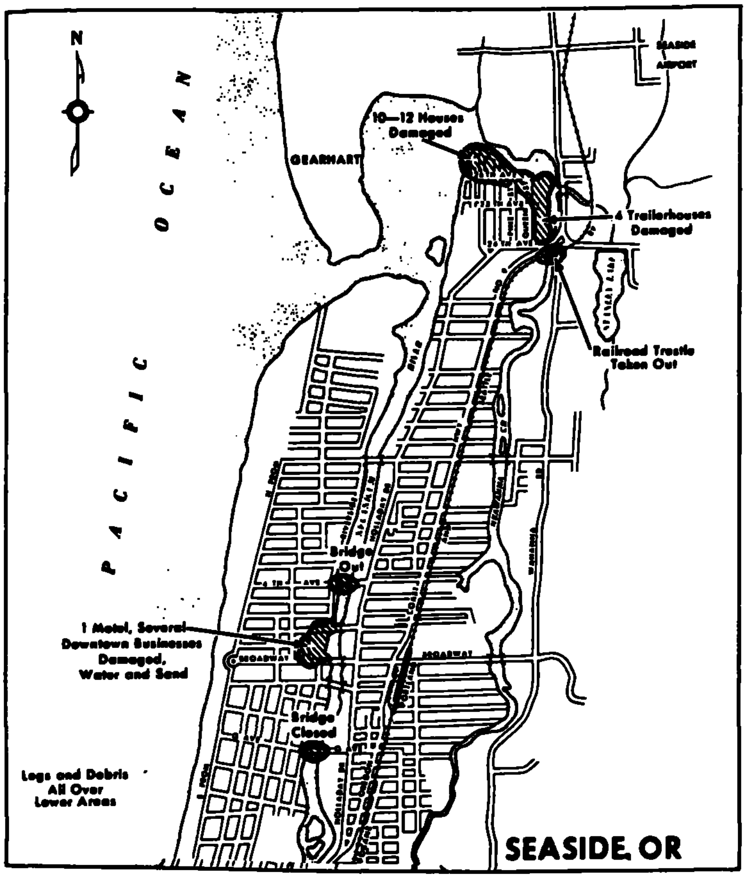


Figure 21. Location map for Seaside, Oregon, showing major damage from the March 28, 1964 tsunami. (Spaeth and Berkman, 1976)

Gearhart. One home next to the Neacoxie Creek at Fourteenth Street was heavily flooded. The residents awoke to find water ankle deep. The water filled the room halfway to the ceiling, leaving one to three inches of sand on the floor. A grand piano was full of water. A small cabin was left in the middle of the road 100 feet from its former site. Logs were thrown on the yard of a home on Thirteenth Street, and fill dirt around the water main washed away (*Seaside Signal*, April 2, 1964).

Seaside. Waves which followed the Necanicum River and Neawanna Creek caused $276,000 in damage ($235,000 to private property). The Fourth Avenue bridge was destroyed, a motel and several downtown business between First Avenue and Broadway were damaged and the Avenue C bridge was closed. At the north end of the harbor ten to twelve houses and four trailers were damaged, and the railroad trestle over the Neawanna Creek was destroyed (Spaeth and Berkman, 1967). It is notable that here as in several other places on the Oregon Coast the damage occurred well away from the coast.

A wall of water ten feet high raced up the Necanicum River damaging the Twelfth Avenue bridge, knocking out the condemned Fourth Avenue Bridge, passed the Broadway bridge without damaging it, knocked in the railing of the Avenue A bridge and severely damaged the Avenue G bridge. It took out a new rock wall facing the Necanicum Boulevard embankment. With the water came tons of dirt, logs, tree stumps, and marine life. Broadway was flooded. The water reached as far as the golf course leaving it strewn with small debris. Damage to the city property was estimated at $46,000.

Mrs. Mary Eva Deis, 50, died of a heart attack when the wave struck her home (*Seattle Daily Tribune*, March 30, 1964, p. 2). The Venice Trailer Court was hard hit. Automobiles in the city parking lot were swept into the river (*Olympian*, March 28, 1964, p. 2).

The heaviest damage occurred along the Neawanna Creek. Homes along the creek were flooded far up Bear Valley. The area from the creek bank to Queen, Pine, and Oregon Streets and 35th Avenue were severely damaged with no homes in that area escaping damage. The residents did not get an advanced warning and some awoke to find water under their beds (*Seaside Signal*, April 2, 1964, p. 1).

Cannon Beach. A bridge and motel unit moved about 2,000 feet inland causing $150,000 in private and $50,000 in damage to city property. The water penetrated Elk Creek washing out the old Highway 101 bridge and damaged the new bridge (Spaeth and Berkman, 1967). No warning had been issued. The first wave struck at 11:34 P.M. and swept the 200 foot long Elk Creek bridge a quarter mile upstream past the Sea Ranch stable. One of the houses of the Buoys and Gulls Motel was also swept away into a swamp. The other cottage and home at the motel were twisted from their foundations and flooded.

Water forced open doors and broke windows at the Bell Harbor Motel leaving a log in one unit, ruined furniture, and left salt and silt deposits. The water reached the height of the kitchen sinks, and some mattresses and portable TV sets were swept away.

The store at Driftwood Trailer Camp and one summer home were damaged. Some houses were knocked from their foundations. Several other houses were flooded to a depth of three or four feet. A family car was washed 75 feet away into a small creek. Several families escaped by wading in water up to two feet deep. A family asleep at the trailer camp was awakened by the lurching of the trailer and found the floor flooded. They waded out but their car was swept away.

A sewer line attached to the bridge and power lines were severed to the north shore of Elk Creek. The Sea Ranch lost three bridges to a pasture and some large objects smashed the barn wall and cracked the concrete flooring. The house was flooded. Logs also punched a hole through a beach front rental.

The water poured down the street carrying logs, debris, and sand everywhere between the buildings and littering the street. Several sections of sea walls were washed away (*Seaside Signal*, April 2, 1964, p. 1).

"At Cannon Resort utility poles were knocked down and a two-story dwelling swept into Elk Creek" (*Seattle Daily Tribune*, March 28, p. 2).

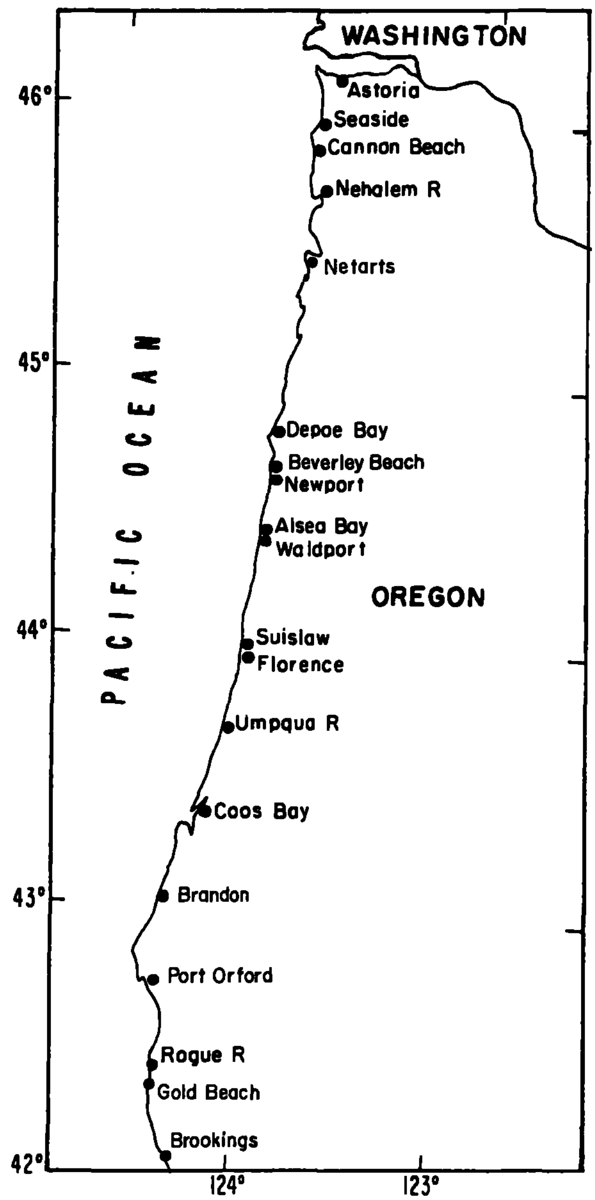


Figure 22. Location map for the State of Oregon.

Nehalem River. Water was 10–11.5 feet in height (Spaeth and Berkman, 1967).

Tillanook Bay. The Coast Guard reported a maximum height of three feet and first arrival at 23:45 (Darling, April 21, 1964).

Depoe Bay. Five thousand dollars in damage was done. The wave appears to have been about 10–11.5 feet high (Wilson and Tørum, 1968).

Newport. The McKinzie family from Tacoma was camping at Beverly Beach State Park, located between Newport and Depoe Bay. Mrs. McKinzie was a Red Cross Senior Life Saver and the children—ages three, six, seven, and eight—could swim. As they slept on the beach, a wave swept over them without warning. The first wave was small, and Mr. and Mrs. McKinzie gathered up the soaked children. Mrs. McKinzie was holding two of the children's hands when the second wave hit and battered them with logs and debris. She was knocked unconscious and found 400 yards from the camp. Mr. McKinzie climbed a cliff for help. The adults were able to reach an air pocket about one foot below the roof of their driftwood lean-to but all four of the children were lost. Only one body was recovered. The adult McKinzies were treated for shock. The family dog was also lost. (Story compiled from: *San Diego Union*, March 24, 1964; *Seattle Daily Tribune*, March 28, 1964, p. 2; and, *Aberdeen Daily World*, March 31, 1964.)

A log hit the retaining wall in the bay at Newport breaking off six feet at the end. Driftwood and logs were scattered over the highway near Waldport and Beaver Creek. About $6,000 in property damage was reported by Spaeth and Berkman (1967) and the waves were apparently about ten to 11.5 feet high at Yaquina Bay.

Waldport–Alsea Bay Area. $145,000 in damage was reported for the port facilities and another $15,000 in damage was done to private property (Spaeth and Berkman, 1967). Damage was evident in photographs of a picnic area at Ona State Park and to a small pier on Waldport Bay. (Schatz, 1965, figs. 1 and 2) The city docks were washed out to sea and the channel filled with sand. A lumber bridge drifted from the dock and onto the beach. A motel south of Waldport had driftwood in five of its units and a log in one. The grounds were littered with about two feet of driftwood (*Newport News*, April 2, 1964, p. 1). The Waldport dock held two restaurants and many boats; nothing survived but a few crumpled planks. Two motels at Yachats were damaged by water (*Newport Graphic–Review*). This report of two motels damaged probably includes the one given above.

Florence. $50,000 in damage was done. Waves reached heights of twelve feet (Spaeth and Berkman, 1967). The initial wave was about eight feet above mean high water at the Coast Guard station near the mouth of the Suislaw River and was only sightly dissipated when it reached Florence on the South Slough and surrounding tidal flats at the river mouth (Schatz et al., 1964).

The first wave noticed at the Coast Guard station was about midnight when the water appeared to act erratically. An eight foot wave at 12:25 A.M. knocked out floating stalls and a 24 x 60 foot floating dock and broke loose a pile driver. A float house on the Suislaw River was broken loose as well as an undetermined number of skiffs and small boats along the bank.

The next large wave at ten to eleven feet arrived at 1:22 A.M. and came up the river as a series of white capped waves, each succeeding wave higher than the other. It washed out a major portion of the bulkhead at Bay Bridge Marina. It knocked over pilings, tore apart the boat house, broke, and smashed and twisted the loading ramp into an unrecognizable shape. A new fueling station was ripped apart. Damage there was estimated at $30,000.

A third large wave only three feet over normal high tide arrived at 2:15 A.M.

Between the first and second wave it seemed almost possible to walk across the river which was choked by trees, logs, lumber, etc. Prior to the second wave, the water drained out so fast that logs were shooting down the river like water-borne arrows.

The second wave came in with a roaring sound knocking out power lines on the west side of Florence. The commercial boats bobbed like corks but were securely tied down (*Florence Suislaw News*, April 2, 1964, p. 1).

House trailers at the Bay Bridge Marina were pushed from their parking stalls and smashed together. Houses along Second Street had their yards covered with roots, logs, pilings, and other flotsam. Bay and Juniper Streets were also littered.

Figure 23. Boat owner and fireman flee the second and largest wave at Florence, Oregon. Photo published by permission of the *Suislaw News*.

Umpqua River (Reedsport). Waves reached 11 feet in height (Darling, April 21, 1964) and caused $5,000 in damage but was negligible at Reedsport, ten miles from the river mouth (Spaeth and Berkman, 1967). Two drag boats were broken loose from their moorings at Winchester Bay's Salmon Harbor. The bait stand also broke loose. The Salmon Harbor manager tried to evacuate his family and trailer but their car was swamped (Coos Bay *The World*, March 28, 1964).

"The tidal current hit Winchester Bay area at approximately 11:45 P.M. on March 27, 1964. The tidal current entered the small boat basin with great speed due to the fact that the boat basin is protected on one side by a break water, and a boat must enter and leave through a small opening at one (end) of the basin. This attributed most of the damage to the harbor due to the fact that the water poured through the opening with great speed (of) approximately 20 to 30 Kts.

"During the first surge of water into the harbor the tide rose to a plus 14′ at which time most of the damage was done in the harbor. The second tidal current entered the harbor at 1:00 A.M. at this time the tide rose to a plus 11′ and took 30 minutes to return to normal. The third surge hit at 2:00 A.M. and rose to a high of 11½′ at this time part of the breakwater slid into the harbor. The fourth surge hit at approximately 2:45 A.M. and the tide rose to a high of 7′.

"The tidal currents continued through the night occurring approximately every half hour and were reduced in height and speed gradually until late in the morning around eleven o'clock. The only real damage other than a few fishing boats breaking their moorings was the breakwater slide at 2:00 A.M." (Letter of April 13, 1964, from Douglas A. Pearce, Officer in Charge, U.S. Coast Guard Umpqua River Lifeboat Station, to John Darling, Corps of Engineers, U.S. Army).

Coos Bay. The first wave at 23:40 reached 9 feet (Darling, April 21, 1964) and caused $20,000 in damage (Spaeth and Berkman, 1967). It was negligible by the time it reached Pony Point about seven miles up the channel having been dissipated as it traveled over the large mud flats (Schatz et al., 1964). The wave arrived shortly before midnight. The maximum range was 14 feet. Damage was done by the first two waves and the sucking action of the surge. Charleston Hanson's Landing and the Charleston small boat basin took the brunt of the damage. Hansen's large charter boat was torn from its mooring, flipped over and sunk. The boat was salvaged but damage to the boat and floating dock was estimated at $21,500. In the small boat basin several boats were torn from their moorings. Nineteen pilings were damaged, four 40 foot floats, six pontoons (4 x 4 x 12 feet) and ten fenders were ripped out. Damage here was estimated at about $17,000. A fishing boat was tipped over and sank north of the bridge.

At funnel-shaped Sunset Beach, debris and sand were swept across the road and up into the picnic and camping areas. Picnic tables and benches were tossed about and two bridges were ripped out. Three skin divers camped at the north end of the beach escaped but their car was almost covered by the water. A panel delivery truck was carried 100 feet from the parking area, ending with its front end on a picnic table. A woman sleeping inside was uninjured. A new jeep about 100 feet from the ocean near the top of the sea wall was picked up, rolled and destroyed by big logs crashing into it.

At Empire, the biggest waves reached the edge of the highway and eroded fill and damaged outflow pipes at a new sewage plant (*North Bend News*, April 2, 1964, p. 1).

At Sunset Beach water marks were left eight feet high on the rock wall and rest rooms were filled waist deep with water.

Parts of the stiff boom at the south end of the basin was torn loose. A wing of the Charleston draw bridge was damaged and a navigation light was destroyed.

North Bend. No damage was incurred at North Bend.

Brandon. Negligible damage (Spaeth and Berkman, 1967). Wave appears to have reached 10–11.5 feet. The first wave struck at 11:40 P.M. and rose four feet above normal high tide. It caused little damage except to break free a 100-log boom at Moore Mill and Lumber Company on the Coquille River and to destroy numerous piles. Most of the logs were recovered on the beach. One man in a small boat had a harrowing experience among the crashing logs but escaped unharmed. Fifteen piles were broken and 25 additional pilings were pulled up and floated away. Most of the logs ended up on the beach along a three mile stretch from Table Rock to Crooked Creek. The wave came over the bank along Front Street leaving much debris behind but not flooding any of the buildings. An outboard motor boat moored to a floating dock at Randolph on the Coquille River was carried several miles down stream to the Bullards bridge (*Brandon Western World, April* 2, 1964, p. 1).

Port Orford. Negligible damage (Spaeth and Berkman, 1967).

Rogue River (Gold Beach). There was $3,000 in damage (Spaeth and Berkman, 1967). Damaged were several small boats and docks, especially on the Wedderburn side. No damage reported at Port Orford (*Humboldt Standard*, March 30, 1964, p. 17). Damage was estimated at $30,000 to $40,000 according to the sheriff. The first wave arrived at 11:43 P.M. and major surges continued for three to four hours. The heaviest damage occurred at the Rogue River Boat Service. About 400 feet of floating dock was torn apart and scattered along the river. There was no warning except a mention on television. Every piling was broken. The dock was salvaged but expensive to repair. Parts were found 2.5 miles upriver at Elephant Rock. Boats torn loose from the dock made circles around a large island in front of the boat service as the water ebbed and flowed. One jet boat was ruined and another small boat badly damaged. All boats had some damage. The damage here was estimated at $3,500.

At Del Rogue a 35-foot vessel was ripped loose and suffered $1,000 in damage. Four other boats including a new jet boat were lost along with fishing gear and another was damaged. The height was determined by a level to be 9.4 feet above the tide level (*Gold Beach Curry County Reporter*, April 2, 1964, p. 1).

Chetco River (Brookings). Negligible damage. Water rose to within a foot of the top of the dock. The south bank of the Chetco River was overflown flooding a field. The Coast Guard motor life boat struck some rocks from the jetty while leaving to assist Crescent City. The propeller shaft was bent but the boat was able to continue its mission (*Brookings Harbor Pilot*, April 2, 1964, p. 1).

Maximum range was 11 feet, with the first arrival at 23:52 being the largest (Darling, April 21, 1964).

Winchuck River. Three homes were damaged and a half a foot of water was left in one home in the low lying farm areas on the Winchuck River. A garage extension was damaged, mud left in the house, and extensive damage was done to the yard (*Humboldt Standard*, March 30, 1964, p. 17). Damage was estimated at $2,000 (*Brookings Harbor Pilot*, April 2, 1964, p. 1).

The *Coos Bay World* (March 28, 1964, p. 1) reports minor damage to the Winchuck bridge and five families along the river were evacuated.

CALIFORNIA

Summary: There were twelve fatalities excluding the death of a Wilmington longshoreman killed when a cable on a crane broke and dropped a loaded pallet on him. Twelve were injured in Crescent City during the early part of the disaster. Damage in California probably exceeded $17,000,000. Crescent City was the worst affected with about $15,000,000 of the damage occurring there. About $1,000,000 occurred inside San Francisco bay due to currents, a major source of damage on the southern California Coast. Late arriving surges also caused one death and considerable damage. Because of its proximity and source region orientation, this event is perhaps the most damaging tsunami to be expected for northern California and can serve as a design tsunami.

Smith River. Magoon (1965) reports $6,000 in damage to floating structures; strong currents on the river 0.3 miles above the mouth and a maximum wave height of 13.3 feet above mean lower low water level. A dock was washed away. No effects were reported for nearby Pelican State Beach.

Crescent City. The disaster at Crescent City exceeded all the combined effects in historical time from tsunamis on the United States west coast. Estimates of damage were: $11 million (Magoon 1965); $15 million (*Triplicate*, March 28, 1984); $16 million (Griffin et al., 1984).

These estimates substantially increased the earlier estimate of $7.4 million made shortly after the disaster. In Crescent City there were ten fatalities due to drowning. In the early hours of the disaster twelve people were hospitalized and twelve others were treated as outpatients. These numbers probably do not reflect the injuries sustained in the clean up. The port facilities and 29 city blocks containing 172 business, twelve house trailers, and 91 homes were damaged or destroyed. The businesses and homes on Highway 101 South were particularly hard hit and eight of the fatalities occurred there. Twenty-one boats were sunk, due in part to their being moored at both ends. The Coast Guard cutter *Cape Carter*, a lumber tug and a few fishing boats managed to escape the harbor and ride out the waves in the open sea.

A tsunami advisory bulletin was issued at 9:30 P.M. PST by the Seismic Sea Wave Warning System in Honolulu and was followed by a warning at 10:37 P.M. These gave an expected arrival time of midnight. There was nothing special about the warning to distinguish it from the many such warnings received over the years which were mostly for harmless waves, since the system does not attempt to predict the wave heights. Low lying areas were being warned when the first wave arrived at 11:39 P.M., just after high tide.

The first rise exceeded the gage limit but was estimated to have been 14 feet above mean lower low water (MLLW) (Kent, 1964), or about nine feet above the tide level. The wave period was about 29 minutes and it flooded the lower parts of town to 2nd Street. The second wave was smaller, at six feet above tide beginning about 12:10 A.M.

Believing the worst was over as had always been the case in the past, many merchants and sightseers converged on the area having been alerted by television, radio, and friends. Officials attempted to limit access to the area by sightseers to prevent looting, but businessmen and residents were allowed to pass.

The third wave also exceeded the limits of the gage which failed altogether at this time. It was

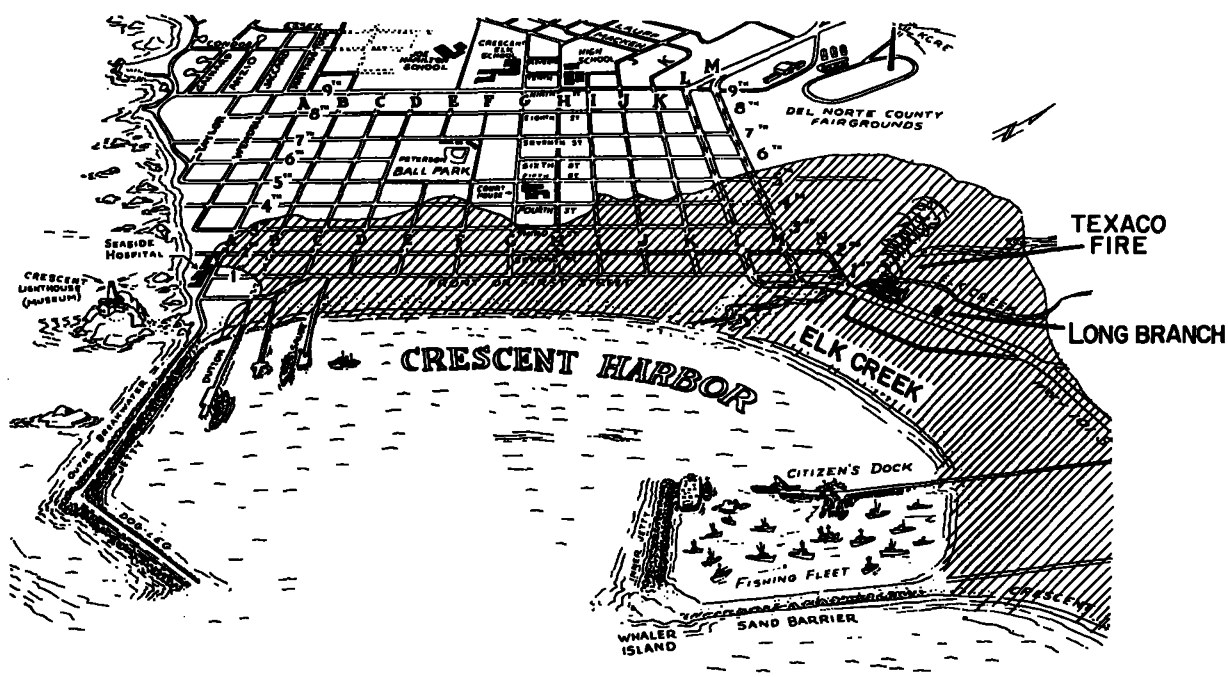


Figure 24. Inundation map for Crescent City for the March 28, 1964 tsunami. (Used by permission of Wallace Griffin, Crescent City Printing Co.)

estimated to have been sixteen feet above MLLW (Kent, 1964). It was at least a foot over Citizens Dock. A fire started at Nichols Pontiac and houses on the lower end of town floated off their foundations. The draw down after the third wave was exceptional. The curator at the Battery Point Lighthouse reported that it receded 0.75 of a mile beyond the end of the outer breakwater (Webber and Webber, 1991, p. 77). Boats were left on their sides in the mud.

Most of the damage and fatalities were caused by the fourth and largest wave beginning about 1:40 A.M. and peaking about 2:00 A.M. It reached a height of 20.78 feet above MLLW (Magoon, 1965) or about 15.7 feet above the expected tide. (It was not 28 feet as given by Magoon, 1965. Magoon added the height of the tide to the wave height rather than subtracting it.) There is some confusion in the various accounts on the timing and count of the waves. The beginning wave arrival times given here are basically from the rise above the expected tide from the tide gage record. Most popular accounts refer to times near the wave maximum. Some accounts missed the second wave, which was smaller, and treat the largest wave as the third wave.

The third and particularly the fourth waves picked up logs, cars, trucks, and other debris which acted as battering rams against buildings. One log penetrated the Post Office. The mail was sucked out but later most of it was painstaking recovered. Fallen electrical wires posed additional hazards and at least one person was burned by contact with the wires while in the water.

Many people were at high risk: swimming for their lives; wading in deep and swift flowing water; floating on car and trailer tops; standing on furniture and on roof tops in flooded homes, motels, and places of business; and floating in moving homes and cars. Ten were drowned—a relatively small number considering the large number of people in the water or in out-of-control situations. Many people were helped to safety by use of heavy equipment such as road graders and log loaders.

Mrs. Mabel Violette, 75, had remained at home in bed unaware of the tsunami. She awoke as the house began to jerk and heave. The roof fell, pinning her in bed. The house traveled three blocks. She was not found until 10:30 A.M. the next morning when her cries for help were heard by a passerby (Griffin et al., 1984, p. 80).

Of the ten people who drowned, five were at the Long Branch Tavern on Highway 101 South. They had been at home celebrating the 54th birthday of the owner of the Long Branch, Bill Clauson. On hearing of the tsunami they went to the tavern to empty the cash register which had gotten wet from the first wave. As everything appeared normal they continued their party.

A few minutes before the third wave, a Coast Guard car stopped and shouted a warning. Water came in the back door and everyone jumped on pieces of furniture. The floor buckled and the west wall collapsed. The lights went out. The room flooded until there was just head room to breath. The wave crested and become calm. The son, Gary, and M.D. McGuire, a patron, helped Mr. Clauson, his wife (Agatha), Joan Fields (Gary's girl friend), Juanita Edwards (an employee), her husband, Earl, and Bruce Garden (the bartender) to the roof. Gary and McGuire swam to dry land and got a boat that McGuire had. When Gary returned with the boat he rowed to the Long Branch. The water was calm (4th crest?) and all seven got into the boat to row about 75 feet. When the boat was about two or three boat lengths from dry land, the water started to recede, pulling them into Elk Creek. Bruce Garden managed to grab the Highway 101 bridge and saved himself as the boat passed underneath. Gary, a good swimmer, saved himself with difficulty but the other five perished (Griffin et al., 1984). The Long Branch was moved from its foundation almost into Elk Creek.

Figure 25. Nielsen's Hardware at 3rd and I Street, Crescent City, where water was four to six feet high. (Used by permission, Wallace Griffin, Crescent City Printing Co.) Note car intruding through the window. Damage is increased by floating projectiles such as automobiles, logs, and boats.

Figure 26. Magruder's store on 2nd Street, Crescent City, with tsunami in progress, probably the first or second wave. The second wave flooded the store to a depth of 16 inches and the third was three to four feet deep. (Used by permission, Wallace Griffin, Crescent City Printing Co.)

Three other fatalities occurred in the same area. Mrs. Wright, who lived near the Frontier Cafe, tried to escape with her three children. Her ten-month old son, William, was pulled from her arms and her three-year old daughter, Bonita, was also drowned.

Joyce London, who lived behind the Del Norte Ice Company on Highway 101, had just made a pot of coffee when her friend Lavella Hillsburg of Hammond Hill Road and her boyfriend arrived to warn them of the tsunami. The London's television was not working, and they were not aware of the danger. She, her husband, and their friends tarried to have a cup of coffee just after 1:00 A.M. and before the arrival of the largest wave. They got into their car but the wave shut it off. They tried to walk out arm-in-arm but were separated. Lavella, 49, was killed. Joyce was badly battered, with her hand, legs and seven ribs broken, and blows to the back of the head and face, requiring three months hospitalization. The men were unhurt.

Figure 27. Office and motel unit from Van's Motel block Highway 101. These structures floated from their foundations and damaged units in the next door Breaker's Motel. (Photo credit: U.S. Army)

There were two casualties in the downtown area. Adolph Arrigoni, 65, a bootblack from Italy who lived on "B" Street was found covered with debris on Third Street (Cates, 1984). James Parks, who had a combination home and shoe repair shop in a trailer on Front and Battery, was drowned when his trailer was swept away and overturned.

Oran Magruder, 73, died of a heart attack and is sometimes mentioned as a casualty. However, he died peacefully in his sleep.

Fire started in Nichols Pontiac Automobile Agency from a shorted fuse box and soon thereafter the Union Oil and Hussy Texaco oil bulk plants tanks ignited and exploded one after the other. The fire burned for several days. Another home burned when the owner could not report it due to loss of telephone service and fire fighters could not respond in time. Floating and hissing butane tanks were a potential fire hazard.

Mr. Stockman's (operator at the Texaco station) reactions are instructive and representative of others. He reported in Griffin (1984, p. 62–63), "At 11:45 P.M. a tourist and I heard news that a tidal wave was due to hit Crescent City about midnight. I told him we have had false alarms before...I laughed at several customers that asked me if I intended to close the station and get to safety...

"About midnight I looked down the street toward Elk Creek and water was coming down the highway...I began to get worried as the water came right to the edge of the station drive but it soon began to subside..."

He called his boss, Sonny Hussy, but since the water did not get up into the driveway he was not too concerned, thinking the worst was over. Mr. Hussy and his wife came down to check the gas tank lids. When another wave started about 1:00 A.M. they put Hussy's car on the rack. Water rose six inches deep in the station. They worried about the possibility of fire and electrical shock but calmed down when the water began to recede again.

Then the "big one" began to arrive and he raised his boss' car with them in it to the top of the service rack. The water reached eight feet inside the station and the car on top of the rack was being moved about. Then the lights went out. Luckily they survived and escaped the station before the fire began.

The retreating waves left a huge amount of debris behind: timbers, 2.5 million board feet of lumber (Miller, 1964), perhaps 1,000 automobiles, shattered buildings, silt, and fish from the bay. Fish were found everywhere: in hanging flower baskets, rafters, desk drawers, in walls, and in large piles. Sand was not notably left behind as tsunamis have strong draw back currents which clean up such deposits. Telephone and electrical lines were destroyed. The harbor was silted up in places and needed dredging. Many of the old buildings were built of sturdy redwood timbers but floated from their foundations.

There is now a sculpture and plaque commemorating the ten killed in Crescent City and one killed at the mouth of the Klamath River mouth.

Figure 28. Cars stacked up at Harbor Motors, Second and L Street, Crescent City. Note that the lighter trunk end of the cars floated up onto the heavier motor ends. (Used by permission, Wallace Griffin, Crescent City Printing Co.)

Three additional people were listed as missing by Griffin et al. (1984), but these have now been accounted for (Griffin, personal communication, Feb. 17, 1993). *Crescent City's Dark Disaster* (Griffin et al., 1984) is a source of numerous first hand accounts of experiences during the tsunami and includes photographs of its effects. It is a useful reference for those interested in disaster responses.

Crescent City Harbor has a history of being unusually susceptible to tsunamis from all directions, more so than most other west coast communities. This characteristic has been ascribed to the effects of the Cobb Seamount, 400 miles to the northwest (Roberts and Chien, 1964) and to the shape of the coast. It is a crescent shaped embarkment from Point St. George to Patrick's Point, forty miles to the south (Wilson and Tørum, 1968, p. 111, 112). The facts that the largest wave was the fourth wave and that Crescent City is affected disproportionately by waves from the south as well as the north supports the concept of a harmonic resonance of the coast shelf with a mode of the common tsunami periods between 15 and 60 minutes.

Klamath River. Sgts. Donald McClure and Stuart Harrington were fishing for eels at the mouth of the Klamath River when suddenly at about 11:30 P.M. a wall of water about twelve feet high crashed over the sand bar without warning. They and the surrounding driftwood were picked up and carried about half a mile up river. With difficulty they climbed on a large log and shed their fishing boots. A second surge again pushed them back up river. When the water began going out, they swam for the north shore near the Requa boat dock. Sgt. McClure did not make the shore and drowned. His death is generally counted with the ten from Crescent City as the eleventh victim. Magoon (1965) reports from interviews that the water was about two feet above normal at Deans Camp, 0.7 miles south of the entrance, and three feet above normal high tide at Panther Creek Lodge, one mile from the mouth. The dock and boats at the

Figure 29. Second Street looking west from L Street. Note typical debris in the foreground and buildings moved into the street in the background. (Used by permission, Wallace Griffin, Crescent City Printing Co.)

Chinook Trailer Court, 1.6 miles above the river mouth, incurred $1,200 in damage. Four thousand dollars damage was done to the Requa Boat Dock and boats, and strong currents occurred 0.7 miles above the river mouth.

Trinidad. The *Humboldt Standard* (March 28, 1964, p. 1) reports no damage to the dock at Trinidad and a five-foot rise in water. Magoon (1965) reports on 18-foot rise above MLLW, (considerably more than a 5-foot rise). Wiegel (1965b) reports a height of about 17.5 feet elevation above MLLW, a probable tide level of between 4.2 and 5.3 feet for a probable wave amplitude of about 12.2 to 13.3 feet. The town is located on the hillside well above the sea.

Humboldt Bay and Eureka. The Eureka Boat Basin suffered little damage but the water rose over the ten-foot seawall and eight feet into the street at the height of the rise. The tide was six feet. The bay was filled with logs and debris. Half of the sea and channel markers were moved off their stations by the surge. Nine changes in the tide were reported between midnight and 4:30 A.M. with an eight to nine feet tide at the channel entrance. "It was like someone pulled the cork out of the bay. The velocity was tremendous. It came back in just as fast and kept repeating" (*Humboldt Standard*, March 28, 1964, p. 11).

Wiegel (1965a) reports maximum run-up elevations above the tide stages as probably 3.1 feet at the Coast Guard Station on North Spit, about 4.7 to 5.1 feet at the Municipal Marina, Eureka, about 4.5 feet at the entrance to King Salmon Slough, and 3.8 feet at the Pacific Gas and Electric Power Plant intake (0.6 miles upstream on the King Salmon Slough.) Magoon (1965) reports 14 knot currents in the channel opposite the Coast Guard Station. Professor Gast, Humboldt State College, estimated the maximum height as 14 feet (7 foot amplitude based on water lines on docks and structures) (Darling, April 22, 1964).

The *Ferndale Enterprise* (April 10, 1964, p. 1, 4) estimated that just past midnight the wave at the boat ramp was one foot above normal tide.

Noyo. The first wave arrived shortly before midnight. The sheriff had tried to alert boat owners, and some had heard of the threat from radio and television. The Coast Guard cutter *Pt. Ledge* cleared the harbor after the first surge. The *La Paz*, a 42-foot drag boat with three tons of fish in its hold was hit by another boat and shot upstream in full reverse slamming into other boats near Casa del Noyo. The crew tried to tie it up but another surge sent it upstream another quarter of a mile and aground against the *Mary R*. It was later salvaged and towed to San Francisco for refitting (*Fort Bragg Advocate–News*, April 2, 1964).

There were four major waves. The first crashed over pilings normally ten feet above high tide. Six larger boats sank. Pilings supporting the dock and boardwalk were snapped off. Three or four skiffs or drays were washed out to sea. The Coast Guard's initial report listed extensive damage to ten vessels and a float. There were about twenty boats in the harbor (*Santa Rosa Press Democrat*, March 29, 1964).

Damage was estimated at $250,000 to $500,000 (*Fort Bragg Advocate News*, April 2, 1964) or $250,000 to $1 million by the California Disaster Office in 1964. Magoon (1965) reports a maximum height above MLLW of 12.6 feet, damage of $124,000, and that second and third waves were bores proceeding upriver at 35 miles per hour as a series of step-like jumps. The *Fort Bragg Advocate News*, April 2, 1964, reports that ten to twenty boats were sunk, half of them commercial fishing boats and another 100 were damaged from slightly to demolished.

Caspar. Waves surged over Highway 1 at Doyle Creek near Caspar but caused no damage (*Santa Rosa Press Democrat*, March 29, 1964).

Albion River. Magoon (1965) reports a maximum water elevation of nine feet above MLLW. The wave was observed as four or five low bores traveling up the river and making a loud noise. It was observed at least 1.25 miles upstream. Currents scoured out the river mouth. About $500 in damage occurred due to delays to fishing vessels.

Russian Gulch State Park. A maximum height above MLLW of 11.3 feet was reported by Magoon (1965).

Van Damme State Park. A wave with a maximum height above MLLW of 8.8 feet progressed about 500 feet up Little River (Magoon, 1965).

Point Arena Light Station. An estimated maximal height of twelve feet above MLLW was reported at Point Arena Light Station (Magoon, 1965).

Arena Cove. A maximum wave height of twelve feet was reported for Arena Cove (Magoon, 1965). Point Arena had four foot waves on top of the high tide but no damage (*Santa Rosa Press Democrat*, March 29, 1964).

Jenner Beach. An estimated maximum height above MLLW of ten feet was reported by Magoon (1965) with no effect on the Russian River.

Bodega Bay. Campers were evacuated from nearby Wright's Beach and Duran Park (*Santa Rosa Press Democrat*, March 29, 1964). About $2,000 in damage was done to navigational aids.

Eight knot currents were reported. The maximum wave height was five feet inside the harbor entrance and one foot on the northeast side of the bay (Magoon, 1965).

Tomales Bay. A 25 mile-per-hour current was reported at the mouth of the bay. Six thousand dollars in damage was done to Lawson's Pier. The maximum height of 6.5 feet at the bay entrance was reported by Magoon (1965) and eight feet (above MLLW) at Drakes Beach. Inside the bay at Marshall and Jensen heights of two feet were reported and at Inverness at the far end of the bay one foot was reported. About one-third of the Lawson's Pier was lost as well as four large boat hoist poles (*Santa Rosa Press Democrat*, March 29, 1964).

Bolinas. Isaac Dirksen, 34, was drowned about 3:00 P.M. on March 29, 1964, about 13 hours after the arrival of the first tsunami wave. He was caught by a late surge at high tide while wading across a channel at the end of Maple Avenue at Duxbury Point wearing rubber fishing waders. The surge was about three feet high filling his waders and he was about 30 feet from shore (*San Rafael Independent Journal*, March 30, 1964, p. 4). Duxbury Reef had been exposed four times during the night by the main tsunami waves (*San Rafael Independent Journal*, March 28, 1964, p. 3).

Muir Beach (near Golden Gate). Magoon (1965) reports a maximum water height of nine feet above MLLW.

San Francisco Bay. A maximum water height of 3.7 feet (amplitude) was recorded on the Presidio gage at 1:35 A.M. The first wave arrived at 12:42 A.M. with a rise of 2.3 feet on the high tide and was the highest wave about MLLW as the tide was falling.

San Rafael. Damage centered on the marina on the Marin County Bay shores. In Loch Lomond Marina at San Raphael about 2:30 A.M. the largest wave of about five foot height broke the end off of the dock with about 20 boats still moored to it. It crashed into a neighboring dock bending it into a crumpled "S". A 32-foot cruiser sank but was later raised and repaired. "F" Dock with 30 boats attached was lifted over a levee and deposited a quarter mile away. The greatest damage occurred to other docks where several craft tore loose from their moorings, crashed into others, and parts of the dock were torn loose. Four or five boats sank including a new, $30,000 36-foot boat. Gasoline spilled, raising the possibility of fire. Sparks from parting electrical lines looked like the 4th of July. The water had a strong current and rose about four feet. One fishing boat reportedly sank at Kappas Yacht Harbor at the Chris Craft sales. One boat was holed and sank. Damage was done to the docks' floats.

A fireman reported the water level dropped seven feet at Tiburon before the largest wave. Only minor damage occurred there. A few garages and driveways were flooded at Strawberry Circle.

The Coast Guard sent its vessels to sea after the first wave. Harbors were left partly filled with silt and mud. There were four major crests.

Sausalito. The old ferryboat *Berkeley*, being used as a floating store "Trade Fair," was loosened of all but one of its moorings and a large section of pilings were torn loose by the old ferry and they floated in the bay (*San Rafael Independent Journal*, March 28, 1964).
Magoon (1965) reports maximum wave heights of four feet at the Marinship Yacht Harbor and Clipper Yacht Harbor at Sausalito. One hundred thousand dollars damage occurred at the Clipper Yacht Harbor to floating structures and boats. Water reached about 6.5 feet (eight feet above MLLW) at the San Rafael Yacht Harbor with $7,500 in damage to floating structures and boats. Water reached five feet at Lowrie Yacht Harbor and caused $10,000 in damage. He reports only $100 damage at the Berkeley Yacht Harbor and boats touching the bottom of the Red Rock Marina. The wave heights and locations are also given in Table 8. Total damage to

Marin County was put at $1 million by the California Disaster Office.

Table 8. Wave Amplitudes in San Francisco Bay; March 28, 1964 Tsunami (Magoon, 1965)

Location	Max. Amplitude/Feet
Belvedere	
San Francisco Yacht Club	2.5
Point San Pablo	
Standard Oil Company	2.2
San Pablo	
Yacht Harbor	3.2
Richmond	
Yacht Service	0.8
Yacht Harbor	3.5
Channel Marina	4.5
Oakland	
Jack London Marina	3.5
Norwalk Yacht Harbor	3.7
Embarcadero Yacht Harbor	4.0
Alameda	
Naval Air Station	2.7
Alviso Sough (bay entrance)	0.6
Benicia	0.2
Collinsville & beyond	<0.1

Pacifica. Magoon (1965) reports a maximum wave of nine feet.

Half Moon Bay. Magoon (1965) reports a maximum height above MLLW as 10.1 feet. Four boats at the Pillar Point breakwater were damaged. An abalone boat was sunk but later raised with $500 damage to it. An 18-foot craft was swept to sea but was recovered. Two other small crafts were forced onto the rocks of the western arm of the breakwater but pulled off without serious damage. Before the second wave at 2:00 A.M. the water dropped precipitously returning as an eight to twelve foot wave. It reached the top of the banks but did not spill over. A late surge at 7:00 A.M. created currents of ten to twelve knots. Extensive evacuation had moved 2,000 people away from the beaches and low areas (*Half Moon Bay Recorder and Pescadero Pebble*, April 2, 1964, p. 1).

Martins Beach. Magoon (1965) reports a maximum wave height of about 20 feet above MLLW which seems unusually high.

Santa Cruz. Frank Monnich, the owner of the 38-foot *Big Boy II*, and Jim Adams, a passenger, set out for open water after being warned of the tsunami. On the way out he hit something and about half a mile from shore he realized he was in trouble. He tried to beach the boat but at about 200 yards from shore their boat disintegrated. They jumped into the water and were rescued by another boat.

A 10-by 35-foot dredge sank immediately and may have been the object the *Big Boy* hit. Thirty of its floats were in the bay and were sunk by shooting holes in them as they were navigational hazards. The waves caused a ten-foot rise, then left the harbor dry and boats on their side when they went out. Damage to the boats was slight. An auxiliary platform was broken up, a small boat overturned, and several others were scratched. The water reached the steps to the boardwalk but caused no damage (*Santa Cruz Sentinel*, March 29, 1964). The *Watsonville Register–Pajaronian* (March 28, 1964) reported the first wave at 1:15 A.M. as being eight feet and that two waves followed. Magoon (1965) reports $100,000 in damage and a maximum wave 12.4 feet above MLLW (10 foot height).

Capitola. Water surged over the Esplanade seawall, a common happening at high tide (*Santa Cruz Sentinel*, March 29, 1964). Magoon (1965) reports a 14-foot wave at Capitola. He also reports a maximum of five feet and minimum of minus one foot MLLW for a total height of six feet at Seacliff.

Rio del Mar. Hundreds of people lined the cliffs and jammed the roads to see the tsunami, creating a problem for police. The retreating sea revealed the crumbling wreck of a cement ship at Seacliff. It then advanced to the shore end of the jetty from the river mouth (*Watsonville Register–Pajaronian*, March 28, 1964).

Moss Landing. Magoon (1965) reports a maximum wave height of five feet, a damaged skiff and strong currents.

Monterey. Waves 8.5 feet high surged into the bay. A finger float was broken off, and some utilities were cut. After the warning, about a dozen skippers took their boats out of the harbor. The waves came at about 20 minute intervals beginning at 12:15 A.M. as measured on a tide gage on Pier 2 (*Monterey Peninsula Herald*, March 28, 1964). Magoon (1965) reports losses of $1,000 and a maximum elevation of 7.5 feet. Whirlpools were formed at the seaward end of Monterey breakwaters.

Pacific Grove. Magoon (1965) reports a maximum elevation of seven feet above MLLW and a maximum wave height of six feet.

San Simeon. Campers and trailers were evacuated from San Simeon State Park, Cambria, and Cayucos Beaches. No damage was reported to the beaches, but campers were drenched as the waves struck high on the beaches.

Cayucos. The most obvious result of the wave which arrived at 1:20 A.M. was the mud and debris left in the parking lot by the Cayucos Memorial Building. Many stranded fish provided dinner for some. Observers reported that they could have walked around the end of the Cayucos Pier when the water went down. At Moro Strand, residents reported seeing rocks not previously seen when the water withdrew with a sucking sound ("Cayucos By the Sea," *Sun*, April 2, 1964).

Morro Bay. Worst hit was the Morro Bay Marina which lost its fuel dock. It broke free and hit several boats. Damage was reported to floats, pilings, and one boat. The Morro Bay Yacht Club lost its house boat which had been moored near the south Embarcadero boat launching ramp. It broke free along with the walkway and sailed down the bay on a 20 mile-per-hour outgoing tide. It rammed into the end of the C&L dock splintering the houseboat completely and it sank. Brown's oyster barge also broke loose, came down the bay at a great speed and took out two lumber pilings at the same pier.

The barge ran into another boat. Possibly $10,000 damage was done to the newly planted oyster beds by silting and washing oysters to sea. The early warning helped save much equipment. Two boats which had broken their moorings were saved (*Morro Bay Sun*, April 2, 1964). The trestle was in danger of being washed out (*San Luis Obispo Telegram Tribune*, April 1, 1964).

The tide changed about ten feet in ten minutes. The current carried away an 18 foot inboard motor craft after first swamping it at the dock. Many small boats broke loose from the dock and were known to be lost. Others were in "dry dock" having been washed aground on a sand spit inside of the harbor. One boat, the 44-foot *Adventure* was just clearing the harbor when the large surge came at 12:45 A.M. Although making nine knots speed it was pushed back into the breakwater (*San Luis Obispo Daily Telegram*, March 28, 1964).

Avila. Waves came to within two feet of the top of the pier (*San Luis Obispo Telegram Tribune*, April 1, 1964). A few boats broke loose from their moorings (*San Luis Obispo Daily Tribune*, March 28, 1964).

Pismo Beach. Waves washed up against the sea wall (*San Luis Obispo Telegram Tribune*, April 1, 1964).

Oceano. Water rose to the dunes but did not reach the community. Heavy surf action was reported along a three mile strip (*San Luis Obispo Daily Telegram*, March 28, 1964).

Santa Barbara. Five-foot surges on 20-minute cycles continued into the day making boat handling hazardous. Two boats caught in the harbor entrance slammed into a piling on the slip nearest the entrance and snapped it off. One walkway was damaged. Several big mooring drums ended up in the middle of the channel and several boats dragged their anchors (*Santa Barbara News–Press*, March 28, 1964). The gage dropped from 5.4 feet to 2.7 feet in ten minutes (*Santa Barbara News–Press*, March 30, 1964, p. 5).

Oxnard. Large swells reported after daylight (*Oxnard Press Courier*, March 28, 1964).

Ventura. Tide said to have dropped eight feet to an all time low tide.

Santa Monica. One 16-foot outboard motor boat was damaged, capsized and sunk, and a fueling station and floating anchorage damaged at Marina del Rey. Eight surges hit the marina between 1:45 A.M. and 7:00 A.M. with the last one tearing the oil company fueling float loose. It was quickly caught and caused no damage. Several other of the 800 boats in the marina were damaged.

A maximum 52-inch change in water (26 inch amplitude) generated 15 mile per hour currents. Damage estimates were as high at $100,000 (*Santa Monica Evening Outlook*, March 30, 1964, p. 7). Tides changed from minus one foot to plus six feet within half an hour (*Santa Monica Evening Outlook*, March 28, 1964, p. 1).

Los Angeles. Most damage occurred to berths 206, 207, and 208 of the Fellows and Stewart Yacht Harbor on the Terminal Island side of Cerritos Channel. The damage occurred around 6:00 A.M. when a high swift surge entered the channel wrenching boats and finger piers loose from their moorings. At one time about 75 to 100 boats were floating free. Three boats were sunk. A surge of about six feet moved through the channel at 10:20 A.M., about the same size as the 6:00 A.M. surge, but caused no apparent damage (*San Pedro News Pilot*, March 28, 1964).

A longshoreman was killed at Wilmington Saturday when a boom with a pallet was being swung back on board the *Philippines Presidential Magsaysay*. A cable snapped and went out of control, crushing him. Also, the Union Oil tanker *Santa Maria* ripped out a 175-foot section of dock when it was suddenly pushed against it while being moved by tug boats. The backlash from the tanker propeller racing to prevent the crash swamped an 18-foot boat and sank it. The *Santa Maria* incident was blamed on continuing surges in the channel and the longshoreman's death may also have been caused by stresses in the cable due to the ship's motions. The press did not report the time of either event. (*San Pedro News Pilot*, March 29, 1964)

Santa Catalina Island. Spontaneous waves as high as ten feet hit Santa Catalina Island but caused no damage. The first wave was four feet high (*San Diego Union*, March 29, 1964, p. 2).

San Diego. The channel into Shelter Island Yacht Harbor looked like a rapid flowing river. Water rushed in and out of Mission Bay Channel but the effect was less noted. Water rose 6.5 feet in ten minutes. Surges continued through the night with one surge breaking the mooring at the Bali Ha'i restaurant on Shelter Island and another wrenching the 60-foot schooner from its moorings. The currents were strong enough at 4:00 A.M. to move two sections of a floating concrete pier at the Navy Amphibious Base on the Silver Strand. The sections were anchored by 5,000 pound anchors. One was dragged 100 yards by the current (*San Diego Union*, March 29, 1964, p. 2).

SUMMARY

This tsunami illustrates several factors. Recent past tsunamis were poor indicators of the tsunami threat from great tsunamis. Crescent

City businessmen who returned to their businesses too early, placing themselves at risk to later and larger waves could have saved risking their lives if they had a better knowledge of the continuing tsunami hazard. Waves of destructive size or causing swift currents can occur more than twelve hours after the initial arrivals.

Table 9. Instrumental Data for the March 28, 1964 Tsunami

Location	Max. Amplitude/Feet
California:	
Alameda	2.7
Alamitos	1.4
Avila	5.2
La Jolla	1.1
Los Angeles, Berth 60*	1.6
Monterey	4.7
Neah Bay	2.4
Newport Bay	0.9
Rincon Island	3.0
San Diego	1.9
San Francisco	3.7
Santa Monica	3.3
Oregon:	
Astoria	1.2
Washington:	
Friday Harbor	1.2
Seattle	0.4

* Spaeth and Berkman, 1972

In protected harbors, such as Loch Lomond in San Francisco Bay, the potential for damage depends on the wave height almost independent of the tide stages, as it is the current which is the main hazard and not flooding. Marinas are often not designed for the currents which can occur during major tsunamis. Sightseers obstruct necessary movement in the hazard area as well as putting themselves at risk. Radio and television broadcasts should stress that non-emergency personal should evacuate and remain out of the area. While it is inherently dangerous, actions to evacuate boats to the open water before the arrival of large waves and strong currents seem to be beneficial. Tending to boats in the harbor during tsunamis was successful in this case but also hazardous.

Most of the fatalities would have been avoided if the people had not left the buildings during quiet periods in the wave activity. These periods are brief and soon give way to strong currents as the water reverses its flow. Data gathering, particularly for the Washington and Oregon coasts was completely inadequate. This is the largest event to have happened to the west coast and is probably the design event for tsunamis in this area. The few available reports concentrated on maximum runup heights and dollar damage without detail.

1965, February 4, 05:01 GMT. A magnitude 8.2 earthquake in the Rat Islands, Aleutian Islands, generated a wave that was widely recorded throughout the Pacific Basin. On the west coast it was observed directly only at Santa Cruz where the water rose two feet at 4:00 A.M. and dropped back to normal (*Santa Cruz Sentinel*, February 4, 1965). It was recorded at Crescent City with an amplitude of one foot, and at Santa Monica with an amplitude of three inches (Von Hake and Cloud, 1967; Soloviev and Go, 1974). Validity 4.

1966, October 17, 21:42 GMT. A magnitude 8.0 earthquake near Peru generated a 1.5-meter amplitude wave locally. On the west coast it was recorded as a one-foot wave at Crescent City and at less than four inches elsewhere. (Iida et al., 1967) (See Figures 141, 142, 143, and 144, pages 205–207.) Validity 4.

1968, May 16, 00:49 GMT. A magnitude 7.9 earthquake east of Honshu, Japan generated a 5-meter wave locally that flooded houses. It destroyed more than 100 ships. On the west coast it was recorded with amplitudes of two feet at Crescent City, eight inches at Santa Monica, California and Newport, Oregon, four inches at

Long Beach, and less elsewhere (Coffman and Cloud, 1970). (See Figures 145, 146 and 147.) Validity 4.

1971, July 26, 01:23 GMT. A magnitude 7.9 earthquake occurred near New Ireland in the Bismarck Sea. The maximum wave amplitude at Rabaul was estimated at 2.5 to three meters. It was recorded at Crescent City with an amplitude of 2.4 inches and at Los Angeles with an amplitude of two inches (Coffman and Von Hake, 1973; Soloviev, et al., 1992). (See Figures 148 and 149.) Validity 4.

1974, October 3, 14:21 GMT. A magnitude 8.1 earthquake near Lima, Peru, caused a tsunami with an amplitude of 0.9-m. It was recorded at Crescent City, California with an amplitude of three inches (Coffman and Stover, 1976; Soloviev et al., 1992). Validity 4.

1975, November 29, 14:48 GMT. A magnitude 7.2 earthquake in Hawaii generated a submarine landslide and a 26-foot tsunami at Halape on the southern coast of the Island of Hawaii killing two people and injuring 19 more. It caused $1,000,000 in damages in Hawaii. In California the damage was estimated at $1,000 on Catalina Island where a small floating dock was destroyed by waves with a nine foot range at the Isthmus Harbor, and another floating dock was broken free. Several boats were stranded on the bottom but refloated with the returning wave without damage (*San Pedro Pilot*, December 1, 1975). A small tidal surge was reported at Marina del Rey near Santa Monica (*Santa Monica Evening Outlook*, December 1, 1975; Spaeth, 1977; Soloviev et al., 1992). (See Figures 150 through 157.) Validity 4.

1977, June 22, 12:09 GMT. A magnitude 7.2 earthquake in the Tonga Trench area generated a 0.8-m wave at Pago, Samoa. It was recorded at Port San Luis and Long Beach with amplitudes of 4.7 inches, at San Diego with an amplitude of three inches, and at Los Angeles with an amplitude of two inches. Validity 4.

Table 10. Instrumental Data for the November 29, 1975 Tsunami

Location	Max. Amplitude/Inches
Port San Luis	15.5
Bodega Bay	8.5
Imperial Beach	7.3
Los Angeles	5.9
La Jolla	5.9
Long Beach	2.8
San Diego	2.4
San Francisco	2.4

1986, May 7, 22:47 GMT. A magnitude 7.6 earthquake in the western Aleutian Islands generated a tsunami with the highest runup of eight inches recorded at Adak, Alaska. It was widely recorded throughout the Pacific Basin. The amplitude was 2.7 inches at Crescent City, 3.5 inches at Neah Bay, Washington and 1.8 inches at Toke Point, Washington. Validity 4.

1987, November 30, 19:23 GMT. A magnitude 7.6 earthquake about 45 miles south of Cape Yakatanga, Alaska, on the Pacific plate produced a ten-inch wave locally. Small waves were recorded at the Presidio with an amplitude of one inch (U.S. Geological Survey, November, 1987). Validity 4.

1988, March 6, 22:36 GMT. A magnitude 7.6 earthquake in the Gulf of Alaska generated a tsunami with a maximum amplitude of four inches at Yakatat. It was reported recorded at the Presidio, San Francisco, with an amplitude of 0.5 inches (Carte, 1987). None of the other sources which would have been expected to report on it such as the *ITIC Newsletter*, the *Bulletin of the Seismological Society of America*, "Seismological Notes" section, Gonzales and Kulikov (1991), nor Gonzales et al. (1991) mention any recording at San Francisco. The original San Francisco marigram was not found and it was not recorded at Alameda, Monterey, or Port San Luis (Avila). Validity 2.

1988, April 30, 3:42 P.M. A magnitude 3.9 earthquake about 46 miles west northwest of San Diego generated some minor swells (*San Francisco Examiner*, May 2, 1988). "An intense storm over Nevada and Utah sent strong winds into San Diego County last night [April 30] kicking up heavy surf along the coast that created concerns about possible flooding. Waves eight to fourteen feet were expected along the west facing beaches with possible wave sets to 20 feet. The Mission Street jetty was closed to small vessels, city life guards said" (*San Diego Union*, May 1, 1988, p. B3). Meteorological waves. Validity 0.

1989, October 18, 00:04 GMT. A magnitude 6.9 earthquake on the San Andreas system with its epicenter near Loma Prieta about 15 km northeast of Santa Cruz caused extensive damage in the area and in San Francisco. It also generated a small tsunami or tsunamis in Monterey Bay with a maximum recorded amplitude of about 15.7 inches. (See Figure 158.)

The tsunami with a nine minute period was recorded on the Monterey tide gage about 20 minutes after the earthquake origin time. This travel time is consistent with a source in the north part of the bay. The signal continued for about 24 hours with periods matching natural modes of the harbor. Due to the instrumental response which is insensitive to shorter periods, the actual amplitude may be twice as much as shown on the record.

Stephen Scheilblauer, harbor master at the Santa Cruz Yacht Harbor, reported that several docks had become stuck to the piers and had to be lifted manually or broken which implied that water level fell below the usual low tide level. Several boats were lying on the harbor floor, implying a permanent change in the water level. Also, a small tidal wave was observed rushing out of the harbor following the earthquake that continued for 15 to 20 minutes (McNally et al., 1989).

The sudden water level adjustment was probably due to a vertical uplift of 0.1 to 0.2 m (four to eight inches) over a ten second interval according to W. Thatcher (Schwing et al., 1990).

At Moss Landing, about ten minutes after the main shock, the water suddenly drained from the Old Salinas River exposing large portions of its bed. The harbor water level fell by one or more meters in a few minutes before rising again (Gardner-Taggart and Barminski, 1991).

Numerous lobate features 1.65 foot thick and 0.9 to 1.8 miles long were seen on side scan sonar records in the bay at the head of Monterey submarine canyon (Schwing et al., 1990).

Increased wave activity in the mouth of Moss Landing Harbor was also observed a few minutes following the earthquake. A video camera had providentially been set up and began operating two minutes before the shock. The water was flat and calm. Camera shaking marked the beginning of the earthquake. Large waves entered the harbor shortly after this and the cameraman commented it looked like a wake from a large boat passing. The period was about two seconds and began 138 seconds after the shock, indicating a source about 1,419 feet distant.

Fathometer records indicate a slump scarp three to six meters high and one hundred meters long in the wave-generating area. A concrete outfall pipe was offset vertically 18.1 inches due to slope failure under the pipe. Other areas of slumping were found by scuba divers and remotely-operated vehicles. A 412.5 foot block of unconsolidated material was found about 0.6 mile west on the canyon axis by fathometer soundings (Gardner-Taggart and Barminski, 1991). They conclude that the waves seen early by the video camera and the waves which drained the tidal wetlands were of different origin with the latter due to the uplift near Santa Cruz.

Ma et al. (1991) show that modeling of an uplift source for the tsunami does not yield a synthetic marigram matching the observed periods of the waves, but does match the travel time, polarity, and initial amplitude. Postulating an additional landslide source near Moss Landing beginning about nine minutes after the earthquake and involving 1.3 x 10^6 m^3 of sediments gives good agreement with the observed record.

It would appear that a compound event explanation would fit the facts. At the time of the earthquake, and uplift occurred near Santa Cruz generating a small tsunami, and probably some minor slumping occurred near the head of Monterey Canyon. About nine minutes after the shock, as the Santa Cruz tsunami arrived at Moss Landing, a larger submarine landslide occurred, triggered by the tsunami pressure wave on weakened canyon walls or by the water current drawing down on Moss Landing's tidal wetlands. This combined wave was what was recorded at Monterey nine to ten minutes later. Validity 4.

1992, April 25, 18:06 GMT. A magnitude 7.1 earthquake occurred about 11:06 A.M. PDT near Petrolia and about six miles inland of the shore. It injured 95 people and caused $61 million in damage, particularly at Ferndale, Del Rio, Fortuna, Petrolia, and Scotia.

A minor but interesting tsunami was generated. It was observed directly at Trinidad, 60 miles north of the epicenter where a fisherman was attempting to launch his boat from his car trailer for fishing at low tide. When he arrived, the tide was exceptionally low. Before he completed unloading his boat a six-foot wave ran up under his car. Another fisherman on the same beach was attempting to load his boat onto his trailer when the wave returned, filling the stern with water. Both vehicles became bogged down in the sand and had to be pulled out.

Crab fishermen off Clam Beach 20 miles south of Trinidad observed changes in the water of several feet while tending their pots.

Waves were also observed in the Crescent City Harbor where a man had driven down the boat launch ramp and found the water rapidly rising up under the cab of his vehicle. He quickly left. It was observed by harbor officials and fishermen as oscillations of ten to fifteen minute periods and a maximum height of 35 inches to 48 inches in the protected inner harbor by about 3:30–4:00 P.M. (Thompson, personal communication, 1992).

Strangely, it was not observed in the source area. A group of hikers were on a narrow beach along the base of the sea cliffs north of the Mattole River. When the earthquake struck, the cliffs began to crumble. They were forced to retreat to the ocean standing in waist deep water for a time. They did not report any wave activity. Another couple could see that the road out from the beach was hazardous due to crumbling cliffs so they decided to wait near the ocean. The ocean became rough but remained at the same level—neither rising nor lowering for several hours (Fortuna, *The Humboldt Beacon*, July 9, 1992, p. 3).

Two young men were diving for abalone before planning to join others looking for mussels at low tide. One left the water and a few minutes later the other encountered short period waves six feet high, making his return to the beach quite difficult. Shortly after reaching the beach, the main shock occurred, tossing them into the air. As soon as they could, they retreated to higher ground fearing a tsunami. The sea receded 50 yards. Rocks normally barely visible were twelve feet out of the water. The water returned only with the tide. They saw no wave activity. (Shinn, personal communication, 1992)

At Shelter Cove checks with the Fire Station, Eureka Civil Defense Office, operator of an ocean side campground, an abalone diver, and a store owner failed to turn up reports of unusual wave activity. One resident near the area of uplift said the water did not go out but that the land rose.

The *Triplicate* (April 25, 1992) reports that the Coordinator of the County Office of Emergency

Services stated that tides in Crescent City harbor fluctuated from two to four feet between 11:20 A.M. and 4:30 P.M., "but no tsunamis were generated." This illustrates the widely-held misconception about what tsunamis really are even by people in official positions. Unfortunately it is not an isolated or rare situation.

Obvious uplift occurred along the coast between Punta Gorda and Cape Mendocino over a 16-mile length of coast. Carver et al. (1992) surveyed the area measuring the height of killed sessile marine plants and animal life. They found the maximum uplift to have been at Mussel Rock almost due west of the epicenter and with an uplift of 4.6 feet. The uplift was relatively flat topped over a 7.4 mile stretch. It tapered off over a length of 1.86–3.1 miles to the north of Cape Mendocino where the height was 1.3 to 1.6 feet.

Figure 30 shows Angela Jayko, U.S. Geological Survey, estimating the height of the die-off zone characterized by bleached algae and dead or dying intertidal organisms. This photo was taken June 2, 1992, at Devil's Gate, about 10 km west-northwest of the epicenter. Initial measurements at Devil's Gate indicated about 1 m of uplift.

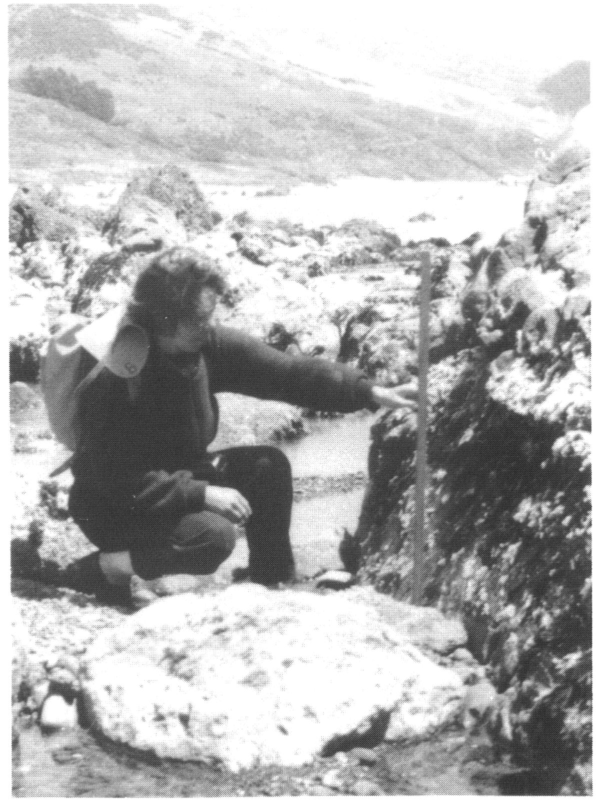


Figure 30. A scientist measures uplift caused by the Cape Mendocino mainshock of April 25, 1992. (Photo by Gary Carver, Humboldt State University.)

To the south the uplift decreased over a 6.2 mile length to Sea Lion Gulch, 3.1 miles south of Punta Gorda. There were no surveys to determine how far seaward along the Mendocino Escarpment the uplift continued.

The tsunami was recorded at Crescent City with a maximum height of 3.9 feet, the largest range of any of the recordings. This highest reading occurred about 3.5 hours after the onset. The initial arrivals were emergent so that reliable travel times are difficult to measure. (See Figure 159, 160, 161 and 162.) The event was also recorded in Hawaii.

Note that the largest amplitude and all of the directly observed reports are well to the north of the epicenter. (See Table 11, next page.) Crescent City's larger amplitude with respect to North Spit may reflect the partial shadowing of the latter by Cape Mendocino.

This event is important as it may bear on the possibility of a large subduction zone type earthquake and tsunami involving the Gorda Plate. The focal mechanism of the earthquake is of a thrust to the northeast. Major "aftershocks" of magnitude 6.6 and 6.7 occurred on April 26 at 12:42 A.M. and 4:15 A.M. (PST) but had strike slip focal mechanisms. Both were offshore; no tsunamis were formed by them. The geology in this region is complex with the San Andreas fault bending into the Mendocino fault and escarpment.

The tsunami resulting from the main earthquake is not what would have been expected from a

Table 11. Instrumental Data for the April 25, 1992 Tsunami

Location	Max. Amplitude/Inches
California:	
Crescent City	21.0
North Spit	7.8
Arcadia	4.5
Point Reyes	4.2
Fort Point	1.3
Alameda	1.4
Monterey	1.1
Arena Cove	4.8
Port San Luis	2.8
Washington:	
Port Orford	1.8

typical subduction type event. The epicenter was inland. The earthquake magnitude at 7.1 is small to have tectonically generated a tsunami. Normally, the main local tsunami effects would be near the source area where no wave was observed. The waves discussed by Shinn (1992) arriving before the main earthquake are not explained. There was a foreshock of magnitude 2.4 at 40.17° N, 124.17°W at 17:06 GMT which is offshore. Clearly there was uplift with the main shock which could have and probably did generate the tsunami recorded at the tide station and observed at Trinidad and Crescent City.

At this writing the event is still being actively studied. It is likely that this is a tectonic tsunami. A plot of the aftershocks shows conclusively that the rupture zone extended west-northwest from the epicenter along the Mendocino escarpment. The tsunami resulted from an uplift from the collision and over-thrusting of the northward moving Pacific plate and the static or east-moving Gorda plate, and not as an eastward subducting thrust towards the North American plate.

The pattern of wave heights suggests a source on the Mendocino Escarpment with the waves being generated parallel to the coast and predominantly to the north. If so, this is a unique source mechanism for tsunamis. Validity 4.

5.0 Summary of Events

Table 12 (on the following pages) summarizes the events listed in the previous pages of text and observations and lists the quantitative data for each event. The times are given in Universal Time and the amplitude data are in meters. The key to the "Cause" (of event) column is:

L = Landslide (subaerial or submarine)
M = Meteorological
A = Astronomical tide
E = Earthquake
V = Volcano

References are occasionally given for the origin data. The abbreviations are as follows:

Abe	Abe (1983)
BRK	Berkeley Seismological Observatory
Cox	Cox (1984a)
DNAG	Decade of North American Geology Seismicity Data (1991)
G&R	Gutenberg and Richter (1954)
Iida	Iida (1984)
ISC	International Seismological Center
ISS	International Seismological Summary
PAL	Lockridge (1985)
PCT	Iida et al. (1967)
PDE	Preliminary Determination of Epicenter, Monthly Listing
S&C	Stover and Coffman (1993)
T&A	Townley and Allen
Top	Toppozada et al. (1981)

The data on Table 12 and data for other areas of the world are available in digital form from the National Geophysical Data Center. For more information, please contact:

National Geophysical Data Center
NOAA, Code E/GC1
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Telephone: 303-497-6221
Fax: 303-497-6513
Internet: info@mail.ngdc.noaa.gov
Telex: 592811 NOAA MASC BDR

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1806 03 24		S. Calif.	2	E ?		Santa Barbara, CA	OBS?					Boats beached.
1812		N. Calif.	1			San Francisco, CA	OBS?					Possible misdated report of December 21 waves at Santa Barbara.
1812 12 21	19:00 34.2N 119.7W [DNAG] 7.7	S. Calif.	4	L	1.0 1.5	El Refugio, CA Santa Barbara, CA Ventura, CA	3.4 2.0 2.0	 F				Ship at anchor drifted to shore and up canyon. Estimated runup. Estimated runup.
1827 01 18–21		N. Calif.	1	M		Golden Gate, San Francisco, CA						Huge waves on coast.
1840 01 16–18		S. Calif.	0	M		Santa Cruz, CA	OBS					Church tower collapsed, flooding of probable meteorological origin.
1851 05 15	16:10 37.8N 122.4W [Top]	N. Calif.	1	E		Salinas, CA San Francisco, CA	OBS OBS					Mild shocks March, April, and May 15, 17, and 28; marine flooding, ships, wharf rocked.
1851 11 13	02:51	N. Calif.	1	E		San Francisco Bay, CA	OBS					Unusual water movement felt on ship. Possible seiche.
1852 11 25	07:09	N. Calif.	1	E		San Francisco, CA	OBS					Lake Merced drained.
1853 11		Kuril Is.	0	E		San Diego, CA	OBS?					Marigrams not found.
1854 05 31	12:59	S. Calif.	3	L		Santa Barbara, CA	OBS					Sea agitated. Heavy swell came in. Not recorded.
1854 07 24		S. Calif.	2	?	-2.0	San Diego, CA	<0.1		36.0			Currents set up in a calm harbor.
1854 08 18		S. Calif.	2	?		San Diego, CA	<0.1					Unidentified source.
1854 10 04	18:19	N. Calif.	3	?		San Francisco, CA	<0.1		15.0			Waves recorded for 24 hrs.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1854 10 22	03:45	N. Calif.	2-3	E		San Francisco, CA	OBS					Probably correct date for 10-26. Vessels swayed.
1854 11 01 ?		N. Calif.	0	?		Angel I., San Francisco, CA	0.6					The water rose 0.6 m (several ft.) with high waves in calm weather in the vicinity of Angel Is., San Francisco Bay. May be misdated effect of Oct. 21 event above. Nov. 1 is the date of publication of report.
1854 11 10		N. Calif.	0									Erroneous date for 1854, Nov. 1
1854 12 01		N. Calif.	0									Erroneous date for 1854, Nov. 1
1854 12 23	00:00 34.0N 137.9E 8.3 [Iida]	Enshunada, Japan	4	E	4.0 3.0	Astoria, OR San Diego, CA San Francisco, CA	OBS <0.1 0.1		35.0	23-12:22	13.8 12.6	Earliest known tsunami recording.
1854 12 24	08:00 33.1N 135.0E 8.4 [Iida]	Nankaido, Japan	4	E	4.0 3.0	Astoria, OR San Diego, CA San Francisco, CA	<0.1 <0.1 <0.1			23-21:55	12.0	
1855 03 20	00:30 41.0N 124.2W [T&A] 6.0	N. Calif.	1	E		Humboldt Bay, CA	OBS					No contemporary reports of waves in bay.
1855 07 11	04:15 34.1N 125.1W 6.3 [DNAG]	S. Calif.	3	L		San Juan Capistrano, CA	OBS					Two large waves surged on shore.
1855 10 22	03:54	N. Calif.	1			San Francisco, CA	OBS					Doubtful tsunami. Probably misdated for October 22, 1854.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1856 02 15	13:25 37.6N 122.3W 5.5 [Top]	N. Calif.	3	L	-1.0	San Francisco, CA	0.6					Water rose and stayed high for 5 minutes.
1856 08 23	04:30 40.5N 143.5E 7.8 [Iida]	SE Hokkaido Is., Japan	4	E	2.0 2.0	San Francisco, CA San Diego, CA	<0.1 <0.1		37.0 42.0	 23-16:11		
1859 09 24		N. Calif.?	2	A	1.5	Half Moon Bay, CA	4.6	F				Schooner damaged. Minus tide at 3 A.M.; small earthquake at 5:50 A.M.
1861 05 04		N. Calif.	0	A		San Francisco, CA	OBS					Tide dropped 30–45 cm below lowest low tide during the week.
1861 05 05		N. Calif.	0									Alternate date for 05-04.
1862 05 27	20:00 32.7N 117.2W 5.8 [Top]	S. Calif.	4	L		San Diego, CA	1.2	R				0.9 to 1.2 m runup. Possibly inundation rather than runup.
1865 10 04		San Francisco, CA	0			Santa Cruz, CA	OBS					Alternate date for 10-08 below.
1865 10 08	20:46 37.2N 121.9W 7.0 [DNAG]	San Francisco, CA	3	L		Santa Cruz, CA	OBS	R				High flood tide and strong ebb tide following collapse of cliffs into bay.
1866 12 20		Port Townsend, OR	0	M		Port Townsend, OR						Flooding at Port Townsend and Victoria due to storm surge.
1868 04 03	02:24 19.2N 155.3W [Cox] 7.5	Hawaii	4	E	4.1 3.4 	San Diego, CA San Francisco, CA Astoria, OR	0.1 <0.1 <0.1		30.0 40.0 	03-08:37		

ORIGIN DATA		VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km) / Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1868 06 13 ?	S. Calif.	0			Pacific coast	OBS					"Earthquake wave" reported by San Francisco paper misdated for Apr. 3, 1868.
1868 08 13	21:30 18.6S 71.0W 8.5 [PAL] N. Chile	4	E	4.3	San Diego, CA	0.3		16.0		11.9	45.7 cm bore. Wharf submerged.
				3.5	San Francisco, CA	0.3		21.0	13- 10:30	12.9	
					San Pedro, CA	0.8					
					Wilmington Beach, CA	0.8		20.0			
1868 08 14	01:30 18.6N 71.0W 8.5 [PAL] N. Chile	4	E		Astoria, OR	0.2				14.8	Incorrectly associated with first tsunami by Iida et al.
1868 10 21	15.53 37.7N 122.1W [DNAG] 7.0 N. Calif.	1			Government Island, CA	OBS	R				Registered on tide gage?
		1	L		Sacramento, CA	OBS	R				0.61 m wave observed.
		3	L		San Francisco Bay, CA	4.5	R				6.0-m surge on shore at Cliff House.
		2			Santa Cruz, CA	OBS					Water rushed up river.
1869 02 10	12:59 N. Calif.	1	M ?		Fort Point, CA	OBS					Earthquake recorded on tide gage?
1869 06 01	N. Calif.?	3			Fort Point, CA	OBS					Earthquake waves recorded on tide gage.
1872 03 26	10:19 37.7N 118.1W 7.8 [Top] S. Calif.	0	E		San Pedro, CA	OBS					Ship damaged.
1872 08 23	18:02 52N 170W [Cox] Fox Islands, Aleutian Is.	3	E	0.5	Astoria, OR	<0.1					First instrumental location for a tsunamigenic earthquake.
					San Diego, CA	<0.1					
					San Francisco, CA	<0.1					
1872 09 16	Fox Is., AK (?)	3			San Francisco, CA	0.1					Oscillations recorded.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1873 11 23	05:09 42.0N 124.0W 6.7 [Top]	N. Calif.	3	E ?		Port Orford, OR	3.0					Waves observed and debris at highest tide mark.
1875 10 12–14		N. Calif.	0	M		Davenport, CA	OBS					Wharf destroyed, waves on 12th, earthquake on 14th.
1877 04 16		N. Calif./ S. Calif.	1	M		Anaheim Landing, CA	1.8		10.0			Small earthquakes reported for 9th and 13th and sea storm on 16th.
1877 05 10	00:59 19.6S 70.2W 8.3 [PAL]	N. Chile	4	E	4.0 3.5	Anaheim, CA	0.9					Swift currents.
						Gaviota, CA	1.8					Observed.
						San Francisco, CA	0.2	F		10-14:04	13.1	Recorded.
						San Pedro, CA	1.0					Observed.
						Santa Cruz, CA	OBS					2 waves observed.
						Sausalito, CA	0.2					Observed.
						Wilmington, CA	1.7					
1878 01 14		Calif.	0	M		Carpinteria, CA	OBS					Wharves damaged by met. waves.
						More's Landing, CA	OBS					Wharves damaged by met. waves.
						Santa Barbara, CA	OBS					60-m of new wharf damaged by met. waves.
						Ventura, CA	OBS					90-m of new wharf damaged by met. waves.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1878 11 22		S. Calif.	3	L		Avila, CA	OBS					Some damage, wharf destroyed.
						Cayucos, CA	OBS					Wharf damage.
						Morro Bay, CA	OBS					
						Pismo Beach, CA	OBS					
						Port Harford, CA	OBS					Near Avila.
						Sal Cape, CA	OBS					1 killed, half of wharf destroyed.
						San Luis Obispo Bay, CA	OBS					
						Surf, CA	OBS					
						Wilmington, CA	1.0					Doubtfully same source.
1879 08 10	21:07	S. Calif.	2	L		Santa Monica, CA	OBS					
1883 08 27	02:59 6.7S 105.4E [PCT]	S. Java Sea (Krakatau)	2	V		Sausalito, CA	<0.1					Air pressure wave recorded on marigram.
1884 01 25		N. Calif.	0			San Francisco, CA	OBS					Observed on astronomical instruments.
1884 11 12		N. Calif.	1	M	-3.0	Sausalito, CA	0.1					Oscillation recorded on tide gage. Probably part of storm continuing on 19th & 24th.
1885 11 19		N. Calif.	1	M	1.0	San Francisco, CA	OBS					Record on tide gage. Major storm in progress.
1885 11 24		N. Calif.	0	M		Eureka, CA	OBS					Some flooding.
						Crescent City, CA	OBS					Meteorological waves and high tides but not a tsunami.
1887 07 08		N. Calif.?	2	L ?		Sausalito, CA	OBS					Distinct waves. No source known.
1891 11 29	23:21 48.1N 123.4W [DNAG]	Puget Sound, WA	3	L		Lake Washington, WA	2.4					Water 2.4-m above lake level.
			3	L		Seattle, WA	OBS					Boat almost overturned.
			3	L		Tacoma, WA	OBS					Boat rocked, 3 separate events.
1895 03 9 and 30		S. Calif.	2	L		San Miguel I., CA	OBS					Bluffs collapsed into bay. Wave reports doubtful.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1895 07		S. Calif.	1	L		San Miguel I., CA	OBS					Small schooner wrecked by falling rock. Continuation of above.
1895 10 14		N. Calif.	0	M		Sausalito, CA	OBS					Irregularities continued for 18 hours. Great storm in progress.
1896 06 15	10:33 39.5N 144.0E 6.8 [Iida]	Sanriku, Japan	4	E	4.0 3.8	Mendocino, CA San Francisco, CA Santa Cruz, CA Sausalito, CA	1.0 0.2 1.5 0.1	 R	 19.0	 15-21:54	 11.3	Log booms threatened. Sand bag dike overtopped & festival float destroyed.
1896 12 17		Santa Barbara, CA	0	M	1.5	Santa Barbara, CA	2.5					Wave was a true "tidal wave" and not a tsunami.
1898 03 31	07:43 38.2N [Top] 122.4W 6.2 [Top]	N. Calif.	2	M		Oakland, CA	OBS					Strong earthquake at 11:43 P.M. Marigraph recorded storm waves at 11:30 A.M. No tsunami. Great storm waves at Oakland Ferry House. No damage.
1899 12 25	12.25 33.8N 177.0W 7.0 [DNAG]	S. Calif.	1	M		S. California	OBS					Large wave; high winds, earthquake far from coast.
1901 03 03	07:45 36.0N 120.5W [DNAG] 6.7 [Top]	N. Calif.	3	L		Monterey, CA	OBS					Earthquake near Parkfield. High waves.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1902 02 26	13.5N 89.5W [PCT]	El Salvador -Guatemala	0	E		San Diego, CA	OBS					Date probably inaccurate, as large earthquakes occurred in this region on Jan. 19 & Apr. 19, 1902, but not on this date.
1904 03 17 and 30		Washington -Oregon	0	M		Grays Bay, WA Hoh River, WA Queets River, WA Quinault River, WA Wishkah River, WA	OBS OBS OBS OBS OBS					Water rose in the bay. Water rose in mouth of river. Water rose in mouth of river. Water rose in mouth of river. Water rose in mouth of river. Possibly refers to Mar. 15, 1904 earthquake felt strongly at Victoria, B.C. & widely over western Washington & storms in the area. No waves reported.
1906 01 31	15:36 1.0N 81.5W [DNAG] 8.2 [Abe]	Colombia -Ecuador	4	E	1.0 3.0	San Diego, CA San Francisco, CA	<0.1 OBS					Currents observed. Boats turned.
1906 04 18	13:12 37.7N 122.5W [DNAG] 7.8 [Abe]	N. Calif.	3	E	0.1 -2.0	Navarro River, CA San Francisco, CA	OBS <0.1	 F	 16.0		 0.8	Flooding of low-lying areas. Slight drop in water level.
1906 08 07		Unknown	2	?		San Diego, CA	<0.1					Recorded
1906 08 17	00:40 33.0S 72.0W [PAL] 8.6 [Abe] 25	Central Chile	4	E	2.0 2.0	San Diego, CA San Francisco, CA	<0.1 <0.1		22.0 28.0	17- 14:28	13.5 15.0	

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1906 11 06	46.0N 125.0W	Washington - Oregon	0	M		off Washington-Oregon coast	OBS					Ship nearly lost to large waves; waves of probable meteorologic origin.
1910 11 21	12:45	N. Calif.	0	M	-1.5	San Francisco, CA	0.3	R	53.0			Waves recorded at San Francisco; probably meteorologically induced.
1917 05 01	18:27 29.2S 177.0W [ISS] 8.0 [G&R]	Kermadec Is., South Pacific	4	E	1.0	La Jolla, CA San Francisco, CA San Diego, CA	OBS <0.1 <0.1		 20.0 17.0	 02-07:04 01-07:00	 12.6	
1917 06 26	05:50 16.0S 171.0W [ISS] 8.0 [G&R]	Samoa Is.	4	E	3.0 3.0	Presidio, CA San Diego, CA	<0.1 <0.1		17.0	06-17:00	11.2	
1918 09 07	17:16 45.5N 152.0E 8.0 [Iida]	Kuril Is., Russia	4	E	3.6	San Francisco, CA	<0.1	R	14	08-02:25	09.2	
1918 11 08	04:38 44.5N 151.5E 7.75 [G&R]	Kuril Is., Russia	4	A ?		San Diego, CA Presidio, CA	<0.1 <0.1			 08-14:15	 09.5	Recorded.
1918 12 04	11:48 26.0S 71.0W 7.75 [G&R]	Chile	4	E		Presidio, CA	OBS					Emergent.
1919 04 30	07:17 21.2S 172.5W [ISS] 8.3 [G&R]	Tonga Is.	4	E	1.0	San Diego, CA San Francisco, CA	0.1 OBS	R		07-18:41	11.4	

ORIGIN DATA			V A L I D I T Y	C A U S E	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1922 11 11	04:33 28.5S 70.6W 8.3 [PAL] 25	N. Central Chile	4	E	3.0	San Diego, CA	0.2	R	30.0	11-17:19	12.8	
					2.5	San Francisco, CA	0.2	R	30.0	11-18:15	13.7	
						Santa Cruz, CA	OBS?		15.0			
						Los Angeles	OBS?					
1923 01 22	09:04 40.8N 124.1W [DNAG] 7.2	N. Calif.	1	E	-2.0	Cape Mendocino, CA	<0.1					Recorded on tide gage. Probably a seiche.
1923 02 03	16:01 53.0N 161.0E 8.3 [Iida]	Kamchatka Pen., Russia	4	E	3.0	San Diego, CA	0.2		10.0		10.0	
						San Francisco, CA	0.1	R	16.0	04-00:30	08.5	
						Santa Cruz, CA	OBS?					
						Los Angeles, CA	OBS?					
1923 04 13	15:30 56.5N 162.5E 7.2 [Iida]	Kamchatka Peninsula, Russia	4	E	4.0	Los Angeles, CA	OBS					Vessels set adrift in harbor.
						San Diego, CA	<0.1		43.0			
						San Francisco, CA	0.1	F	20.75	05-00:58	09.4	
1923 09		Calif. (?)	0	M		Jose de Cado, CA (?)	OBS					Sudden rise in water caused destruction. Location of Jose de Cado is unknown but possibly refers to San Jose del Cabo in Baja, California, Mexico. Possibly meteorologic in origin or associated with Kanto, Japan, earthquake and tsunami of September 1.
1925 10 04		Calif.	1	M	-1.0	Long Beach, CA	0.3					Wave of possible meteorological origin.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1927 01 01	08:17 32.5N 115.5W 5.7 [S&C]	Calif.	1	M		San Pedro, CA	OBS					Sea wave carried off part of embankment, damage estimated at $3 million. 1 killed. Uncertain connection to inland earthquake.
1927 11 04	13.51 34.9N 120.7W 7.3 [DNAG]	N. - S. Calif.	4	E ?	1.0	La Jolla, CA	<0.1	R	15.0	04- 15:10	1.3	Registered on tide gage.
					1.0	Pismo Beach, CA	OBS					
						Port San Luis (Avila), CA	0.8	F	15.0			
						San Diego, CA	OBS	R				Registered on tide gage.
						San Francisco, CA	<0.1	R	12.0	04- 15:00	1.1	Registered by tide gage.
						Surf, CA	1.8	R				
1928 06 17	03:19 16.3N 97.7W [DNAG] 7.8	S. Mexico	4	E	1.0	La Jolla, CA	<0.1					
					1.0	San Francisco, CA	<0.1					
						Los Angeles, CA	<0.1		15.0			
1929 03 07	01:35 51.0N 170.9W [DNAG] 8.6 50	Fox Islands, Aleutian Is.	4	E		Presidio, CA	<0.1		15.0	08- 07:34	05.9	Recorded.
1930 08 31	00.41 34.0N 118.6W [S&C] 5.2 5	S. Calif.	3	L ?	-1.0	Santa Monica, CA	6.1					16 rescued.
					-0.5	Venice, CA	6.1					High waves.
						Redondo Beach, CA						1 drowned.
1931 10 03	19:13 10.6S 161.7E [ISS] 7.9 [G&R]	Solomon Is.	4	E	1.0	San Diego, CA	<0.1					
					2.5	Santa Barbara, CA	<0.1					

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1932 06 03	10:37 19.8N 104.0W 8.1 [DNAG]	Jalisco, Mexico	4	E		Long Beach, CA	0.1	R	41.0	03-14:13	03.7	
						Los Gatos, CA	trace					
						San Diego, CA	<0.1					
						San Francisco, CA	trace		22.0			
						Santa Barbara, CA	<0.1					
1933 03 02	17:31 39.1N 144.7E 8.3 [Iida] 10	Sanriku, Japan	4	E	3.0	La Jolla, CA	<0.1		11.0			
					3.5	Long Beach, CA	<0.1					
						Los Angeles, CA	<0.1		14.0		11.5	
						San Diego, CA	<0.1					
						San Francisco, CA	<0.1		12.0		10.5	
						Santa Monica, CA	0.1			03-04:26		
1933 03 11	01:54 33.6N 118.0W 6.3 [DNAG] 16	S. Calif.	1	M	-2.0	Long Beach, CA	<0.1		19.0			Uncertain recording.
						La Jolla, CA	OBS					Questionable recording. 3 killed on reconnaissance flight crash.
1934 08 21		S. Calif.	1	M		Balboa, CA	OBS		25.0			Flooding and $75,000 in wave damage, probably not related to earthquake of same date, but to storm seiches and high tides. No wind.
						Laguna Beach, CA	OBS					
						Long Beach, CA	OBS					Questionable damage reports.
						Malilbu Beach, CA	OBS					
						Newport Beach, CA	12.0					High waves and damage reported probably not due to true tsunami.
						Santa Monica, CA	OBS					10 people rescued from high surf.

DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
ORIGIN DATA					TSUNAMI DATA							
1938 03 22	15:22 52.2N 131.9W 6.3 [DNAG] 16	Canada	0	E		California coast	OBS					Doubtful recording. Probably only background oscillations.
1938 05 19	17:08 0.5S 119.2E [ISS] 7.6 [G&R]	N. Molucca Islands, Indonesia	0	E	1.5	Santa Monica, CA	<0.1					Doubtful recording. Probably only background oscillations.
1938 11 10	20:19 55.5N 158.0W 8.3 [DNAG] 25	Alaska Peninsula	4	E		Crescent City, CA San Diego, CA Santa Monica, CA	0.2 <0.1 0.1		45.0 55.0 35.0	12-00:32 12-03:11 12-01:20	04.2 06.9 05.0	
1941 02 09	09:44 40.5N 125.4W 6.6 [DNAG]	N. to S. California	0	E		Port Hueneme, CA San Diego, CA San Francisco, CA	OBS OBS OBS					Seiches observed 36 hours after the earthquake. Harbor seiches 14 hours following the earthquake. Seiches in harbor 14 hours following earthquake. No tsunami was observed.
1943 04 06	16:07 30.8S 72.0W [PAL] 8.3 33	N. Central Chile	4	E		Crescent City, CA San Francisco, CA San Diego, CA Terminal Island, Los Angeles, CA	trace <0.1 0.1 0.1					
1944 04 09	02:30	Columbia River Valley, Washington	4	L		Franklin D. Roosevelt Lake, WA	9.1					First of series of landslides from April 8, 1944 to August 19, 1953. Wave on opposite shore 5,000 feet away.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1944 12 07	04:35	Ryukyu Trench,	4	E	3.0	La Jolla, CA	trace					
	34.0N	Japan			2.5	Port Hueneme, CA	0.1					
	137.1E					San Francisco, CA	<0.1					
	8.0 [Iida]					San Diego, CA	<0.1		14.0		13.9	
	30					Santa Monica, CA	<0.1					
						Terminal Is., Los Angeles, CA	<0.1		16.0			
1946 04 01	12:29	E. Aleutian	4	E		Alameda, CA	0.2		13.0	01-18:23	05.9	
	52.8N	Islands				Arena Cove, CA	2.4					Given as height by O'Brien (1946) and also as 4.3 m above MLLW.
	163.5W					Avila, CA	1.3		18.0	01-18:05	05.6	Water over top of breakwater.
	7.8 [DNAG]					Bolinas, CA	OBS		10.0	01-18:50		Height above MLLW given by O'Brien (1946) as 2.6 m. Small island submerged and several row boats sunk. Part of wharf broken and pier loosened at Coast Guard Station.
	25					Brandon, OR	OBS					Barely perceptible
						Carpenteria, CA	OBS					
						Caspar Beach, CA	OBS					Minor damage.
						Catalina Island, CA	1.8					Small pier washed away.
						Charleston (Coos Bay), OR	1.5			01-18:20		
						Clatsop Spit, OR	1.8					Mouth of Columbia River. Height given by O'Brien (1946). Also given as 3.7 m above MLLW.
						Crescent City, CA	0.9	R	12.0	01-17:07	04.6	

ORIGIN DATA		VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km) — Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1946 04 01 (cont.)					Depoe Bay, OR	0.9	F				Bay drained; water returned as a wall. High surf for next 26 hours.
					Drakes Bay, CA	2.6			01-19:00		Height (runup?) given by O'Brien (1946). Also given as 2.5 m above MLLW.
					Friday Harbor, WA	trace					
					Gold Beach, OR	OBS					Heavy float beached on Rogue River.
					Granada, CA	OBS					10 m boat washed on highway.
					Half Moon Bay, CA	2.6		11.0	01-18:45		Wave swept into unoccupied Coast Guard barracks and loosened it from its foundation. $1,000 in damage.
					La Jolla, CA	0.2		10.0	01-18:40		
					Long Beach, CA	0.2				06.2	Undertow reported by swimmers.
					Los Angeles, CA	0.4		06.0	01-19:10		
					Monterey, CA	OBS				06.7	
					Morro Bay, CA	1.5			01-20:30		
					Muir Beach, CA	OBS			01-19:45		Height (runup?) given by O'Brien also given as 2.4 m above MLLW. Wave reported by O'Brien (1946) as 4.8 m above MLLW.
					Navarro River, CA	OBS	R				Water rose to top of pier.
					Neah Bay, WA	0.2	R	10.0	01-17:00	04.5	
					Newport, OR	1.5			01-18:00	04.5	
					Noyo, CA	1.4			01-18:00		100 fishing boats thrown 1.8 m up bank & some damage to pier. Height given by O'Brien as 3.4 m above MLLW.

ORIGIN DATA		VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Area Latitude Longitude Magnitude [authority] Depth (km)			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1946 04 01 (Cont.)					Pacific Grove, CA	OBS					Dressing rooms in municipal swimming pool on beach flooded 1 m. (3.1 m above MLLW)
					Pacifica, CA	OBS					
					Pismo Beach, CA	OBS					
					Point Arguello, CA	1.1					
					Port Hueneme, CA	0.8		14.0	01-18:23	05.9	Sand deposited on railroad tracks.
					Princeton, CA	OBS					Large boulders washed as far as the highway. Houses flooded 1,000 feet inland. $20,000 damage.
					San Diego, CA	0.2		07.0	01-19:15		
					San Francisco, CA						
					Presidio	0.3		15.0	01-18:00	05.5	
					Hunters Point	0.1	R	15.0	01-18:12		
					San Luis Obispo, CA	1.2		11.0	01-18:05	05.6	Tanker torn from mooring lines.
					San Mateo, CA	<0.1		16.0	01-18:50	06.3	
					San Pedro, CA	0.4					One tender and two cargo ships broke mooring lines.
					San Simeon, CA	OBS					
					Santa Barbara, CA	0.9					
					Santa Cruz, CA	1.5			01-18:15		Man drowned; cars pushed against houses. Garages, chicken house, and cow shed swept inland; 8 m boat washed 300 m off beach and into lagoon. Fisherman terrified. Wave height given as 4.6 m by *Santa Cruz Sentinel* and as 3.8 m above MLLW by O'Brien (1946).
					Santa Monica, CA	OBS					Observed by swimmers.

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1946 04 01 (Cont.)						Seaside, OR	1.2					A wall of water swept up Necanicum River carrying away several boats and a log float.
						Suislaw River, OR	1.0					
						Taholah, WA	1.5					1.5 m wave surged up Quinault River swamping boats and damaging fishing nets. Wave visible more than 5 km up river.
						Ventura, CA	OBS					
						Winchuck River, OR	OBS					Slight damage.
1946 12 20	19:19 33.0N 135.6E 8.1 [Iida] 20	Nankaido, Japan	4	E	2.4	Avila, CA Crescent City, CA San Francisco, CA Terminal Is., CA	0.1 0.2 <0.1 0.1		3.0 14.0 12.0 52.0			
1949 04 13	19:56 47.2N 122.6W 6.9 70 [S&C]	Puget Sound, WA	3	L		Olympia, WA	OBS					Cooper's Point collapsed causing large waves.
1949 04 16	10:55	Puget Sound, WA	4	L		Tacoma Narrows, WA	OBS					11 million cubic yards of Point Defiance collapsed. Wave smashed boats, docks and boardwalks. Delayed effect of above event.
1949 07 27		Columbia River Valley, WA	4	L		Franklin D. Roosevelt Lake, Washington	19.7					Debris slide at Hawk Creek from 103 m above lake level. Largest wave rose 19.7 m on opposite side of lake.
1951 02 23	16:45	Columbia River Valley, WA	4	L		Franklin D. Roosevelt Lake, Washington	3.0					Debris slide on east side. Logs caused $2,500 - $3,000 in damage to mill.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1952 03 04	01:23 42.2N 143.9E 8.1 [Iida] 45	SE Hokkaido, Japan	4	E	2.0	Alameda, CA	<0.1					
					2.0	Crescent City, CA	0.2		25.0			
						La Jolla, CA	<0.1		10.0			
						Long Beach, CA	0.1		52.0			
						Los Angeles, CA	0.1		33.0			
						Neah Bay, WA	<0.1		32.0			
						Oceanside, CA	<0.1		10.0			
						Port Hueneme, CA	0.1		15.0			
						San Diego, CA	<0.1					
						San Francisco, CA	<0.1		27.0			
						Sausalito, CA	<0.1					
1952 04 10–13		Columbia River Valley, WA	4	L		Franklin D. Roosevelt Lake, WA	19.8					Many waves created.
1952 10 13		Columbia River Valley, WA	4	L		Franklin D. Roosevelt Lake, WA	OBS					Noticed at docks 6 mi. away; logs, driftwood and soil washed up opposite shore.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1952 11 04	16:58 52.8N 159.5E [Iida] 8.2 30	Kamchatka Peninsula, Russia	4	E	4.0	Aberdeen, OR	OBS	R	34.0			Logs escaped and surged.
						Alameda, CA	0.4		31.0	05-02:09	09.2	
						Astoria, OR	0.1					
						Avila, CA	1.4		18.0	05-01:35	08.6	
						Brandon, OR	OBS					Logs broke loose at Parkersburg and between Bullards and Prosper.
						Crescent City, CA	1.0	R	18.0	05-00:55	08.0	4 boats overturned, concrete buoys moved.
						Friday Harbor, WA	<0.1					
						Hunters Point, CA	0.2	R		05-02:05	09.1	
						La Jolla, CA	0.1	R	32.0	05-02:13	09.3	
						Long Beach, CA	0.3	R	19.0	05-02:08	09.1	
						Los Angeles, CA	0.3		17.0	05-01:00	08.0	
						Neah Bay, WA	0.2		12.0	05-01:59	09.0	
						Port Hueneme, CA	0.7	R	20.0	05-02:32	09.6	
						San Diego, CA	0.4		18.0	05-01:38	08.7	
						San Francisco, CA	0.5	R			09.5	
						San Pedro, CA	0.3		28.0	05-02:08	09.2	
						Santa Cruz, CA	OBS					One boat damaged; sand washed away.
						Santa Monica, CA	0.5					
						Seattle, WA	OBS					
1953 02 14–19		Columbia River Valley, WA	4	L		Franklin D. Roosevelt Lake, WA	OBS					Many waves observed.
1953 02 16	11:43	Columbia River Valley, WA	4	L		Franklin D. Roosevelt Lake, WA	4.8+					At least 10 waves, 4.8 m runup.

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1953 08 19	19:00	Columbia River Valley, WA	4	L		Franklin D. Roosevelt Lake, WA						Floating walkway dislodged at Kettle Falls Beach.
1956 03 30	06:11 55.0N 160.5E [PCT]	Kamchatka Peninsula, Russia	2	V		Avila, CA	0.1		23.0			Explosions of Bezymianny volcano induced wave. May not be a true tsunami.
1957 03 09	14:23 51.5N 175.7W 8.3 [DNAG] 33	Central Aleutian Islands	4	E	3.5	Alameda, CA	0.2		12.0	09-20:32	06.2	
						Anaheim Bay, CA	0.4		24.0	09-21:05	06.7	
						Astoria, OR	<0.1					
						Avila, CA	0.5		18.0	09-20:08	05.8	
						Bodega Harbor, CA	0.3		30.0	09-19:42	05.3	
						Cambria, CA	OBS					Water crossed creek sand bar.
						Crescent City, CA	0.7	R	14.0	09-19:33	05.2	
						La Jolla, CA	0.3		14.0	09-20:58	06.6	Minor damage.
						Long Beach, CA	0.3		40.0	09-21:00	06.6	
						Los Angeles, CA	0.3		28.0	09-21:20	07.1	
						Monterey, CA	0.6					2 people swept off rocks.
						Neah Bay, WA	0.2		13.0	09-19:21	05.0	
						Newport Bay, CA	0.1		21.0	09-21:00	06.6	
						Noyo Harbor, CA	OBS					
						Port Hueneme, CA	0.5	R	15.0	09-20:54	06.5	

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1957 03 09 (Cont.)						San Diego, CA	0.2		18.0	09-21:15	06.9	Pier, moorings, and ship damage estimated at $5,000. Wall of water 1 m high reported at Shelter I.
						San Francisco, CA	0.3		11.0	09-20:18	05.9	
						San Pedro, CA	0.2		13.0	09-21:20	07.0	
						Santa Monica, CA	0.5		11.0	09-20:59	06.6	
1958 11 06	22:58 44.3N 148.5E 8.1 [Iida] 80	S. Kuril Islands, Russia	4	E	2.0	Port Hueneme, CA	0.1		12.0		10.5	
						San Francisco, CA	0.2					
						Avila, CA	0.1					
1960 05 22	19:11 39.5S 74.5W 8.6 [PAL] 33	S. Central Chile	4	E	4.5 4.0	All West Coast						$500,000-$1,000,000 damage. 2 killed
						Alameda, CA	0.3	R	36.0	23-19:50	15.6	
						Alamitos Bay, CA	0.6	R	90.0	23-09:34	14.4	
						Astoria, OR	0.2	F		23-12:40	17.5	
						Avalon, Catalina I. CA	0.6					
						Avila Beach, CA	0.9					Surges
						Berkeley, CA	OBS					Surges, boats bobbed.
						Bodega Bay, CA	0.3					
						Brandon, OR	OBS					
						Cambria, CA	OBS					Wave crossed Santa Rosa Creek sand bar.
						Capitola, CA	OBS					Wave over sea wall.
						Crescent City, CA	1.7	R	84.0	23-10:40	15.5	Two ships were destroyed ($30,000). Others were damaged.

ORIGIN DATA		VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km) / Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1960 05 22 (Cont.)					Depoe Bay, OR	1.8					Trawler in channel tore out of control but was undamaged.
					Echo Bay, WA	OBS			23-17:05	21.9	
					Friday Harbor, WA	0.1	R	33.0	23-16:30	21.3	
					Gualala River, CA	0.6					
					Gold Beach, OR	OBS					A section of dock destroyed, a boat capsized and others damaged and scattered.
					Grays Harbor, WA	0.3					
					Humboldt Bay, CA	OBS					Currents at bay entrance and at Eureka.
					Ilwaco, WA	OBS					
					La Jolla, CA	0.5	R	21.0	23-08:50	13.6	
					Long Beach, CA	0.7	R	40.0	23-09:27	14.3	$500,000 – $1,000,000 in damage in Long Beach and Los Angeles harbors. 300 small craft ripped from moorings and 30 sunk. 24 m yacht smashed into bridge loosening its superstructure.
					Los Angeles, CA	0.8	R	46.0	23-09:18	14.1	One drowned at Cabrillo Beach and one injured.
					Monterey, CA	1.1					Waves surged. 1 killed, boat broke mooring.
					Morro Bay, CA	OBS					Severe currents.
					Moss Landing, CA	0.8					
					Neah Bay, WA	0.4		20.0			
					Newport, OR	0.6	R	52.0	23-12:25	17.2	Observed for about 4 hours.
					Noyo Harbor, CA	OBS				20.0	6 boats broke mooring. Piers damaged.
					Ocean Vista, OR	OBS					High waves observed on beach.
					Oceano, CA	OBS					
					Pacifica, CA	1.2					Ramp engulfed.
					Pacific Grove, CA	0.9					

DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km) / Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
	ORIGIN DATA				**TSUNAMI DATA**						
1960 05 22 (Cont.)					Pismo Beach, CA	1.4					Concession stand dislocated.
					Port Hueneme, CA	1.3					Landing float and dock damaged, ships broke mooring.
					Princeton, CA	2.2					Boats beached, 3 men swam ashore when boat overturned.
					San Diego, CA	0.7	R	57.0	23-09:12	14.0	80 m of dock destroyed, bridge damaged, barge sunk, 8 slips destroyed.
					San Francisco, CA	0.4	R	72.0	23-10:13	15.0	Strong currents.
					San Pedro, CA	0.5	R	26.0	23-09:18	14.1	
					San Rafael, CA	OBS					Catamaran torn from moorings.
					Santa Barbara, CA	1.4					Total of $20,000 damage to 40 small craft & dredge.
					Santa Cruz, CA	0.9		20.0			High wave action.
					Santa Monica, CA	1.6	R	46.0	23-09:22	14.2	8 small craft snapped lines, innundation 91 m, parking lot flooded.
					Seaside, OR	1.5				20.0	Bore on Necanicum River damaged boat landings and swamped boats. One man was knocked off his feet by the waves.
					Shelter Cove, CA	0.6	R				
					Stenson Beach, CA	1.5					
					Terminal I., Los Angeles, CA	0.9		45.0	23-09:30	14.3	
					Tokeland, WA	0.6					
					Tillanook, OR	OBS					Some damage also observed at Netarts, seven miles south of Tillanook on the beach.
					Tomales Bay, CA	OBS					
					Willapa Bay, WA	0.6					Strong currents at bay entrance.
					Wilson Cove, CA	0.6	R	38.0	23-08:54	13.7	

DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
ORIGIN DATA					TSUNAMI DATA							
1963 10 13	05:17	Kuril Islands,	4	E	2.0	Avila, CA	0.3					*Fishing boat broke mooring.*
	43.8N	Russia				Crescent City, CA	0.5					
	150.0E					Los Angeles	<0.1					
	8.1 [Iida]					La Jolla, CA	0.1					
	60					San Francisco, CA	<0.1					
1964 03 28	03:36	Gulf of Alaska-	4	E	4.5	All West Coast	OBS					16 deaths and $20 million total damage including $105,000 damage in Washington and $734,000 in Oregon.
	61.1N	Alaska Peninsula										
	147.5W											
	8.4 [DNAG]											
	23					Aberdeen, WA	OBS					3 log rafts broke loose, trailers flooded.
						Alameda (NAS), CA	0.8	R	42.0	28-09:06		
						Alamitos Bay, CA	0.4	R	36.0	28-09:36	06.0	
						Albion River, CA	OBS					2.7 m above MLLW. Bores observed 2 km up river from mouth.
						Arena Cove, CA	1.8					
						Astoria, OR	0.4	R	20.0	28-07:56	04.3	
						Avila, CA	1.6	R	15.0	28-08:44	05.1	Boats broke mooring, $2,000 damage.
						Belfair, WA	OBS					Water flooded highway.
						Bodega Bay, CA	0.8					1 drowned.
						Bolinas, CA	OBS					
						Boone Creek, WA	OBS					Bridge damaged, $500 damage at Iron Springs Resort, $400 damage to culvert.
						Brandon, OR	OBS					Log boom and boats broke free.
						Brookings, OR	1.7					Coast Guard boat damaged.
						Cannon Beach, OR	OBS					Bridge and motel unit moved 0.3 km inland, $230,000 damage.
						Cape Disappointment, WA	1.7					
						Capitola, CA	2.1					
						Caspar, CA	OBS					Highway 1 flooded.

ORIGIN DATA		VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km) / Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1964 03 28 (Cont.)					Cayucos, CA	OBS					Parking lot flooded.
					Charleston, OR	OBS					Chartered boat & fishing boat sank.
					Coos Bay, OR	1.4					$20,000 in damage.
					Copalis, WA	OBS					Small bridge destroyed and $5,000 damage in town. Four mobile campers overturned. Debris in the streets.
					Crescent City, CA	4.8	R	29.0	28-07:39	04.1	$15 million damage; 54 houses destroyed, 172 businesses damaged or destroyed, 21 fishing boats lost, 10 deaths and 35 injured. Runup was 6.3 m above MLLW.
					Depoe Bay, OR	3.5					$5,000 in damage, 4 children killed while camping at Beverly Beach.
					Drakes Beach, CA	OBS					2.4 m above MLLW.
					Florence, OR	0.6					$50,000 in damage.
					Friday Harbor, WA	0.4	R	19.0	28-08:30		
					Grays Harbor, WA	OBS					8 automobiles lost, 9 trailers damaged, 5 houses destroyed or damaged.
					Gearhart, OR	1.4					Home flooded; cabin left in road.
					Half Moon Bay, CA	OBS					3.1 m above MLLW. Boat sunk; 4 others damaged.
					Hoh River Mouth. WA	0.5					
					Humboldt Bay, CA	1.9					Street flooded; strong currents.
					Ilwaco, WA	1.4					Minor damage.
					Jenner Beach, CA	OBS					3.0 m above MLLW.
					Joe Creek, WA	OBS					Bridge damaged.
					Kalaloch Beach, WA	OBS					2 children rescued.

ORIGIN DATA		VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km) Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1964 03 28 (Cont.)					Klamath River, CA						1 killed, $4,000 damage to boat dock & boats at Requa 1.1 km above mouth. $200 damage to dock & boats 2.6 km above river mouth at Chinook trailer court.
					La Jolla, CA	0.3	R	33.0	28-09:24	05.8	
					La Push, WA	1.0					Boat wrecked.
					Long Beach Harbor, CA	OBS	R	29.0	28-09:24	05.8	8 docks destroyed with value of $100,000.
					Los Angeles County Harbor, CA	0.5				05.8	$75,000 damage to harbor sides.
					Los Angeles, CA	0.5		39.0	28-09:24	05.8	$200,000 damage to six boat slips, fuel dock damaged. Longshoreman killed.
					Marin County, CA	OBS					$1 million damage.
					Martins Beach, CA	3.0					
					Moclips, WA	3.4					Bulkhead washed out, $6,000 damage to 8 houses, road damaged.
					Monterey, CA	1.4					Small boats broken loose; $1,000 damage.
					Morro Bay, CA	OBS					Fuel dock lost. $10,000 damage.
					Moss Landing, CA	1.4					2.7 m above MLLW.
					Muir Beach, CA	OBS					
					Neah Bay, WA	0.7	R	22.0	28-07:18	03.7	
					Nehalem River, OR	3.5					
					Newport, OR	0.3					1.9 m of retaining wall destroyed.
					Newport Bay, CA	0.5	R	24.0	28-09:26	05.8	
					Noyo, CA	2.0					100 fishing boats damaged, 10 sunk, $250,000–$1,000,000 damage.
					Oakland, CA	OBS					

ORIGIN DATA				TSUNAMI DATA							
DATE (GMT)	Time (GMT) Area Latitude Longitude Magnitude [authority] Depth (km)	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1964 03 28 (Cont.)					Oceano, CA	OBS					Heavy surf.
					Ocean Shores, WA	2.9					Debris in streets & yards.
					Oxnard, CA	OBS					
					Pacifica, CA	1.4					$200 damage.
					Pacific Beach, WA	OBS					$12,000 damage to houses, 1 injured.
					Pacific Grove, CA	0.9					
					Pebble Beach, CA	OBS					4.5 m above MLLW.
					Pismo Beach, CA	OBS					
					Point Adams, OR	0.8					
					Point Arena, CA	OBS					3.7 m above MLLW.
					Port Orford, OR	OBS					
					Rio Del Mar, CA	OBS					Negligible damage.
					Rincon I., CA	0.9	R	17.0	28-09:17	05.7	
					Rogue River, OR	OBS					$30,000 damage.
					Russian Gulch, CA	OBS					3.4 m above MLLW
					Salmon Creek Beach, CA	OBS					3.6 m above MLLW. Fisherman lost catch.
					San Diego, CA	0.6	R	69.0	28-09:50	06.2	Floating restaurant mooring broke.
					San Francisco, CA	1.1	R	39.0	28-08:42	05.1	
					San Rafael, CA	1.5					$77,500 damage to boats and berthing facilities.
					San Simeon, CA	OBS					
					Santa Barbara, CA	0.8					Minor damage
					Santa Catalina I.	OBS					
					Santa Monica, CA	1.0	R	39.0	28-09:15	05.7	Boat sunk, others damaged.
					Sausalito, CA	1.2					$100,000 damage to floating structures & boats at Clipper Yacht Harbor.
					Seaside, OR	OBS					1 died of heart attack, damage in city: $41,000; Private: $235,000. 4 trailers, 10-12 houses, 2 bridges damaged.
					Seattle, WA	0.1	R	48.0	28-09:12	05.6	

ORIGIN DATA					TSUNAMI DATA						
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1964 03 28 (Cont.)						Sea View, CA	3.8					
						Smith River, CA	OBS					4.1 m above MLLW, $6,000 damage to floating structures.
						Taholah, WA	0.7					$1,000 damage, skiffs destroyed, fish nets lost.
						Tillanook Bay, OR	0.5					
						Tomales Bay, CA	1.0					$6,000 damage to pier.
						Trinidad, CA	OBS					5.4 m above MLLW.
						Umpqua River, OR	1.7					$5,000 damage.
						Vancouver, WA	<0.1					Amplitude recorded at about 2 cm 160 km from out of Columbia River.
						Van Damme State Park, CA	OBS					2.6 m above MLLW, wave progressed 450 m up Little River.
						Ventura, CA	OBS					
						Waldport-Alsea, OR	OBS					$?0,000 damage done to rafts and docks.
						Warrington, OR	OBS					One boat was wrecked.
						Westport, WA	OBS					Bridge damaged.
						Willapa Bay, WA	OBS					3 homes flooded, $2,000 damage.
						Winchuck River, OR	OBS					Debris deposited on bridge, $5,000 damage.
						Wreck Creek, WA	4.5					$5,000 damage.
						Yaquina Bay, OR	3.5					
1965 02 04	05:01 51.3N 178.6E 8.2 [DNAG] 36	W. Aleutian Islands	4	E	3.0	Crescent City, CA	0.1					Recorded.
						Los Angeles, CA	<0.1					Recorded.
						San Francisco, CA	<0.1					Recorded.
						San Diego, CA	<0.1					Recorded.
						Santa Cruz, CA	<0.1					Observed.
						Santa Monica, CA	<0.1					Recorded.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1966 10 17	21:42 10.7S 78.8W 8.0 [PAL] 40	Peru	4	E	1.0 1.5	Avila, CA	<0.1					
						Crescent City, CA	0.1		15.0	18-09:45	12.1	
						Long Beach, CA	<0.1					
						Los Angeles, CA	<0.1					
						Neah Bay, WA	<0.1					
						Newport Bay, CA	<0.1					
						Rincon Island, CA	<0.1					
						San Diego, CA	<0.1					
						San Francisco, CA	<0.1		33.0	18-07:49	10.1	
1968 05 16	00:49 40.7N 143.6E 7.9 [Iida] 0	Honshu, Japan	4	E	2.0 -0.5	Alameda, CA	<0.1					
						Avila, CA	<0.1					
						Crescent City, CA	0.6					
						La Jolla, CA	<0.1					
						Long Beach, CA	0.1					
						Los Angeles, CA	<0.1					
						Neah Bay, WA	<0.1					
						Newport Bay, CA	<0.1					
						Newport, OR	0.2					
						Rincon I., CA	<0.1					
						San Diego, CA	<0.1					
						San Francisco, CA	<0.1					
						Santa Monica, CA	0.2					
1971 07 26	01:23 4.9S 153.2E [ISS] 7.9 [PDE] 43	New Ireland	4	E		Crescent City, CA	<0.1					
						Long Beach, CA	<0.1					
						Los Angeles, CA	<0.1					
1974 10 03	14:21 12.3S 77.8W [PAL] 8.1 13	Peru	4	E		Crescent City, CA	<0.1					

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1975 11 29	14:48 19.3N 155.0W 7.2 [Cox] 8	Hawaii	4	E		Bodega Bay, CA Imperial Beach, CA La Jolla, CA Long Beach, CA Los Angeles, CA Port San Luis, CA San Diego, CA San Francisco, CA Santa Catalina Island, CA Santa Monica, CA	0.2 0.2 0.1 <0.1 <0.1 0.4 <0.1 <0.1 1.4 OBS					$1,000 damage to two docks. Surge observed.
1977 06 22	12:09 22.9S 175.7W [ISC] 7.2 [BRK] 69	Tonga Trench	4	E		Long Beach, CA Los Angeles, CA Port San Luis, CA San Diego, CA	0.1 <0.1 0.1 <0.1					
1986 05 07	22:47 51.3N 174.6W 7.7 [S&C] 37	W. Aleutian Islands	4	E		Crescent City, CA Neah Bay, WA Toke Point, WA	0.1 <0.1 <0.1					
1987 11 30	19:23 58.7N 142.8W 7.6 [S&C] 10	Gulf of Alaska	4	E		Presidio, San Francisco, CA	<0.1					
1988 03 06	22:36 57.0N 143.0W 7.6 [S&C] 10	Gulf of Alaska	2	E		San Francisco, CA ?	<0.1					Report not confirmed.
1988 04 30		S. California	0	M		San Diego, CA						Storm waves.

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1989 10 18	00:04	N. California	4	E		Santa Cruz, CA	OBS					Wave rushing out of harbor.
	37.0N					Monterey, CA	0.4	F	09.0			Recorded.
	121.9W					Moss Landing, CA	1.0					Water drained from Salinas River.
	7.1 [S&C]											
	19											
1992 04 25	18:06	N. California	4	E		Arcadia, CA	0.1					
	40.4N					Arena Cove, CA	0.1					
	124.3W					Alameda, CA	<0.1					
	7.1 [PDE]					Clam Beach, CA	OBS					Water level changed several feet.
	15					Crescent City, CA	0.6					Oscillations in harbor.
						Ft. Pt., San Francisco, CA	<0.1					
						Monterey, CA	<0.1					
						N. Spit, Humboldt Bay, CA	0.2					
						Point Reyes, CA	0.1					
						Port Orford, WA	<0.1					
						Port San Luis, CA	<0.1					
						Trinidad, CA	0.9					Cars stuck on beach.

6.0 Marigrams for West Coast Tsunami Events

The following figures are marigrams from West Coast tide stations. The time is local time, unless otherwise marked as Universal or Greenwich time. Before 1883 local time was "sun time" and varied from community to community. (See section 1.3.8 for the method of converting local sun time to Universal time.) After 1883 Standard times were used with the West Coast being in 120°W Meridian time or eight hours behind Universal time. A further complication is the introduction of Daylight Savings Time in 1918, effectively moving the Meridian time to 105°W. It was gradually adopted by individual states but not the West Coast until February, 1942, when year around Daylight or War time was adopted lasting until September 1945. Usually the time used is clear but for critical events near a date of conversion some extra precaution should be taken.

The marigrams typically record at speeds of one inch per hour and with a convenient amplification factor to keep the trace on the width of the paper. A typical scale is 1:12 such that one inch on the record equals one foot of water change.

The dates are the dates of origin of the event in all but a few cases. Records reproduced from earlier sources carry the date as they give them. Thus, the records from the November 4, 1952 tsunami are dated as November 4, 1952 with local hours for the records copied for this study, and as November 5, 1952 GMT for the records from Zerbe (1953). It should be clear enough what time and date are being used from the figures.

The tide gages were first installed on the West Coast in 1854 with long term stations at San Diego, San Francisco, and Astoria and three other instruments moved about frequently to determine local tidal parameters. The instruments are designed to record the approximately 12 hour tide and perform less well at lower periods. The instruments' performance at the shorter periods can be effected by partial plugging of the hole bringing water into the stilling well by marine animals or by deliberating reducing the hole size in noisy sites.

Figure 31 illustrates the reductions of amplitude and shift of the peak by the instruments.

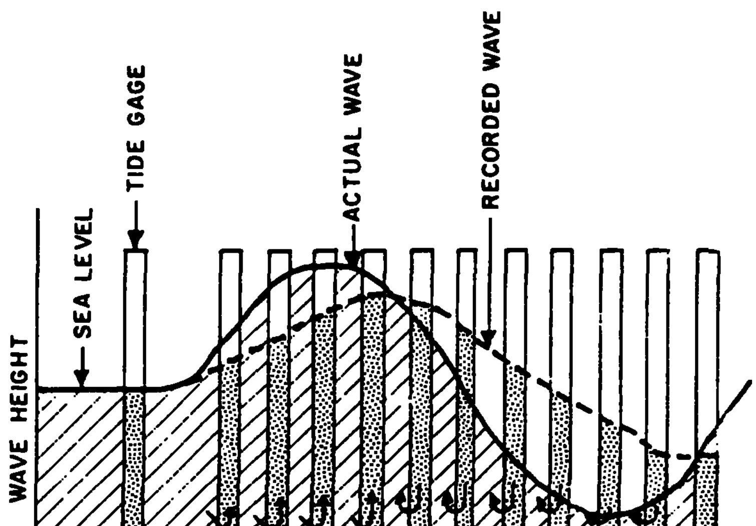


Figure 31. Schematic illustrating how the stilling well in tide gages results in a decrease in recorded wave height and a delay in recorded peak height with respect to the actual wave.

These figures are meant to give a general sense of the record. Where a high degree of accuracy is needed, the user may need to refer to the microfilm collection at the National Geophysical Data Center or the original records at NOAA's National Ocean Survey.

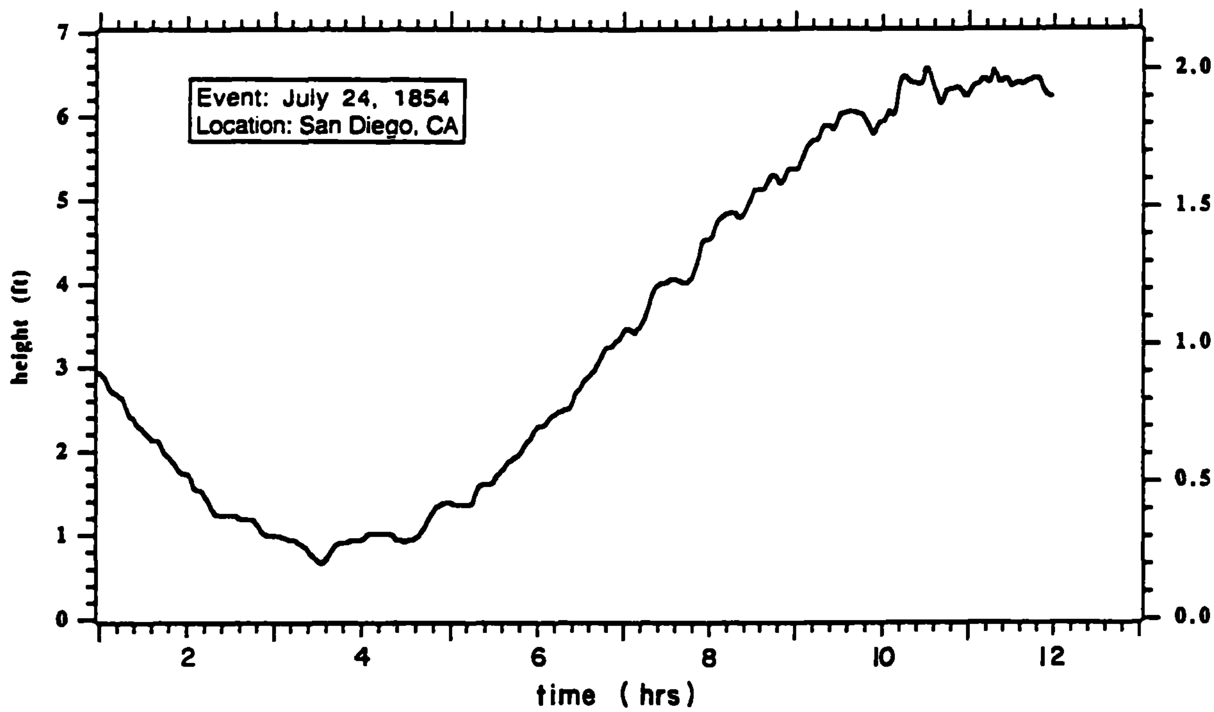


Figure 32.

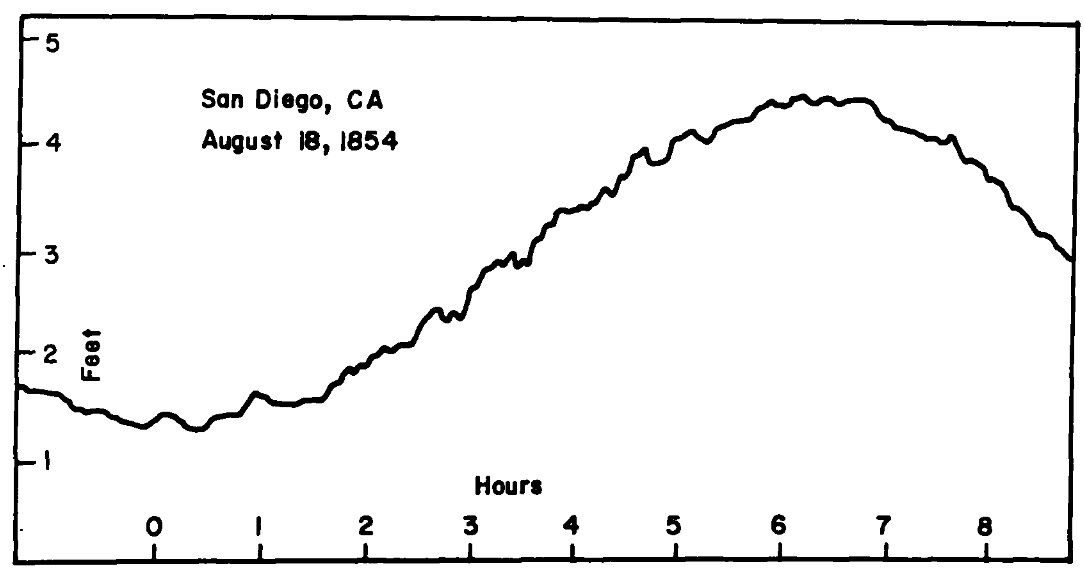
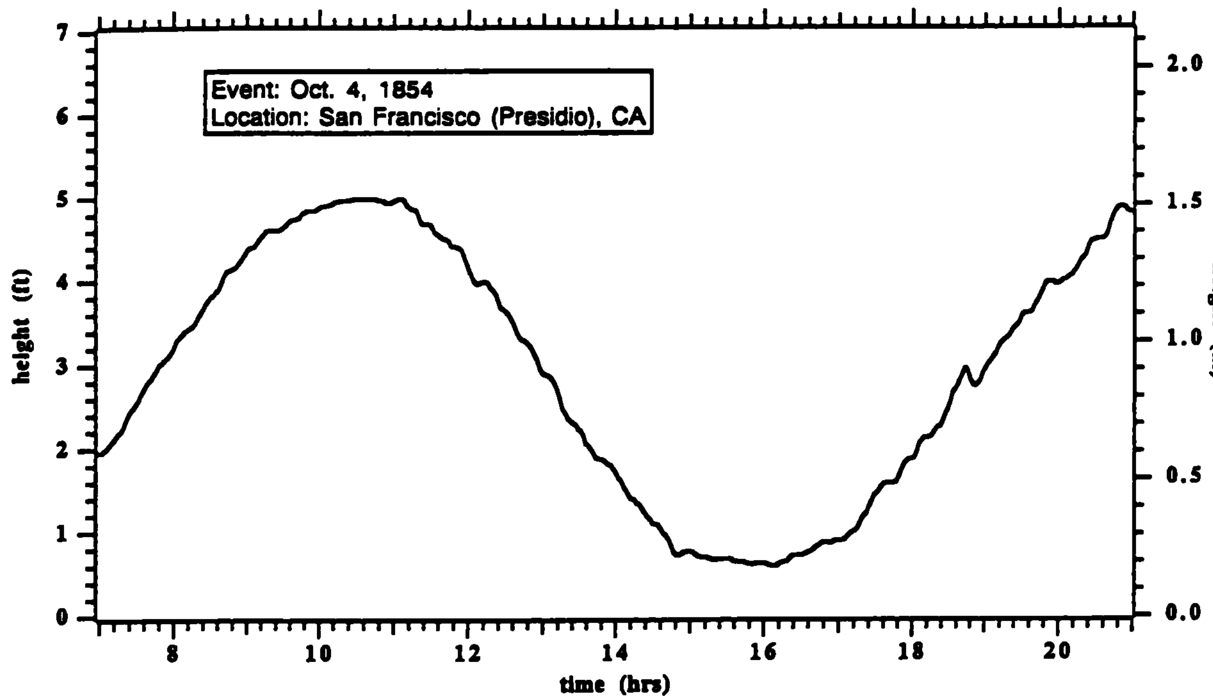


Figure 33.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height (m)
time (hrs)
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2
3
4
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6
7
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0.5
1.0
1.5
2.0
8
10
12
14
16
18
20

Figure 34.

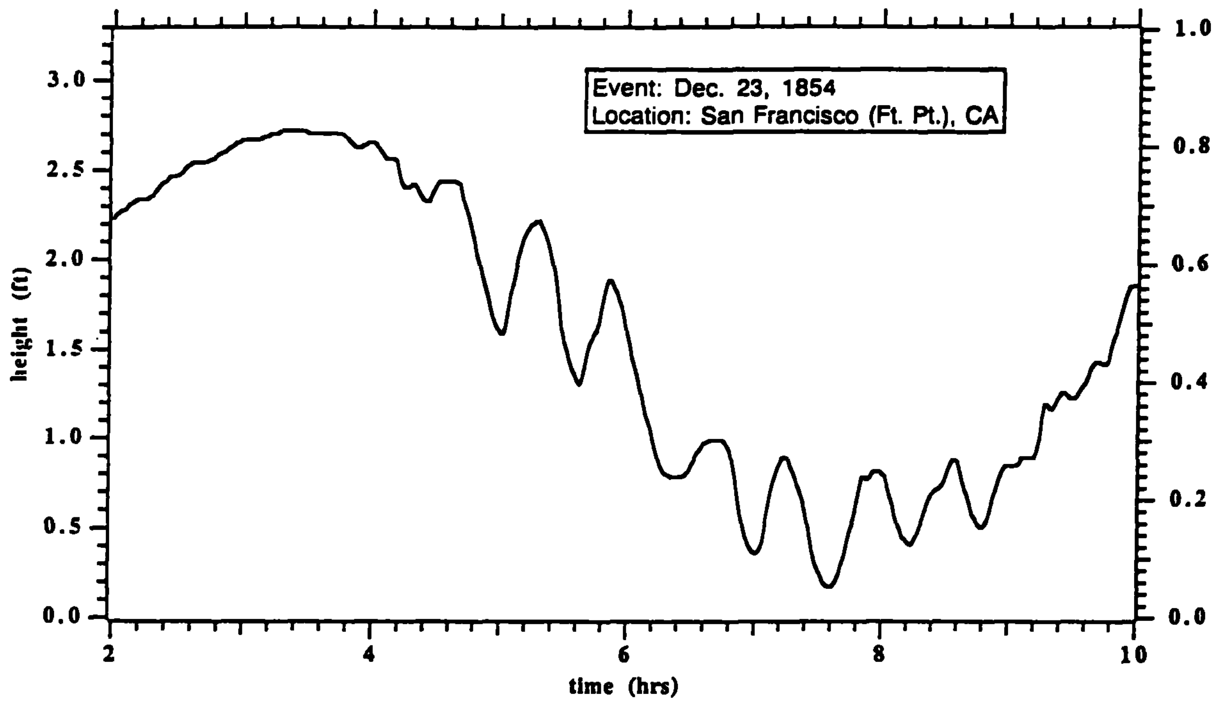


Figure 35.

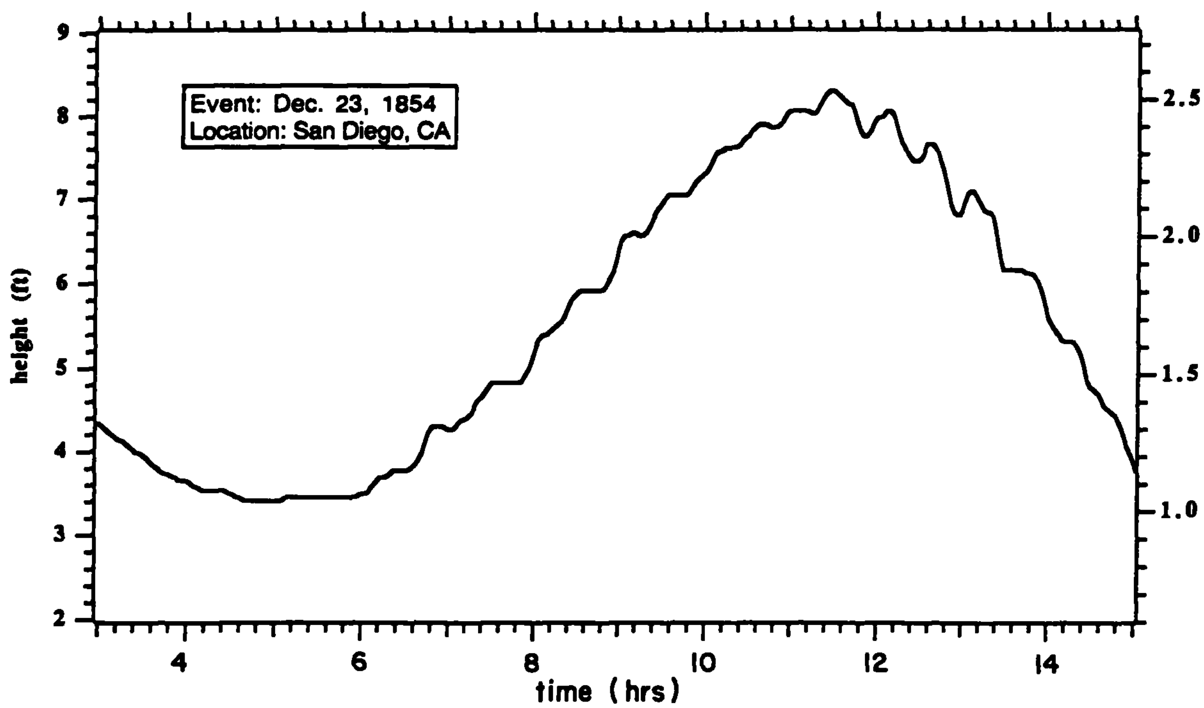


Figure 36.

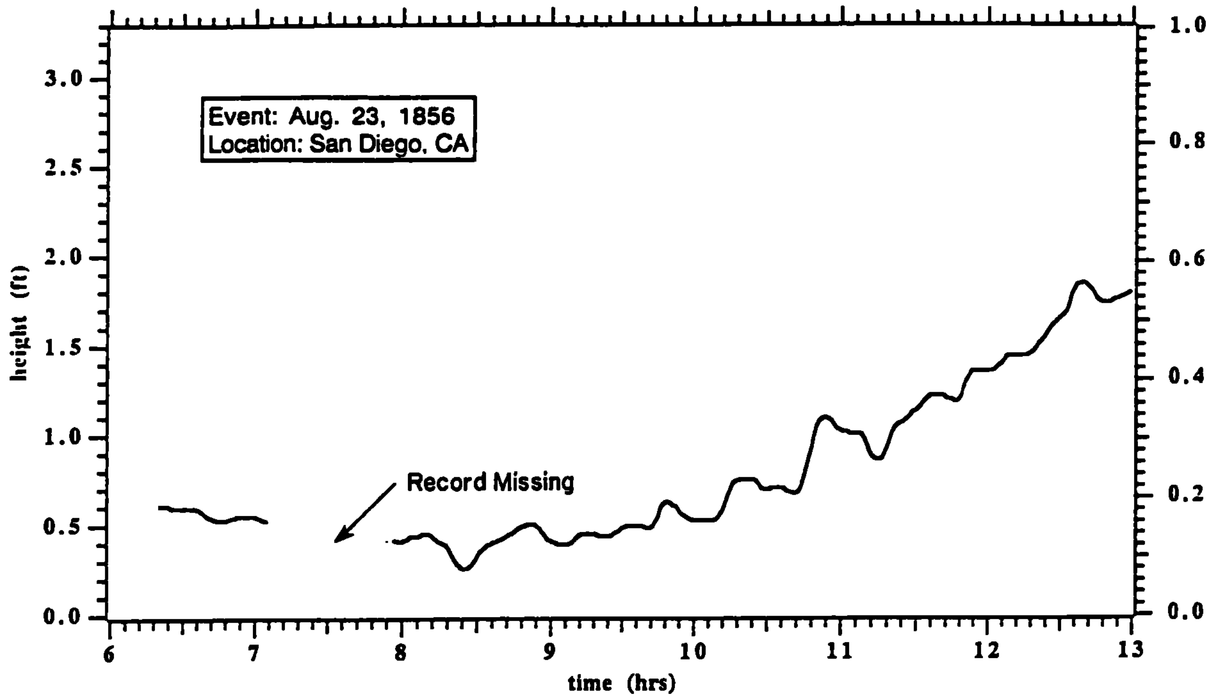


Figure 37.

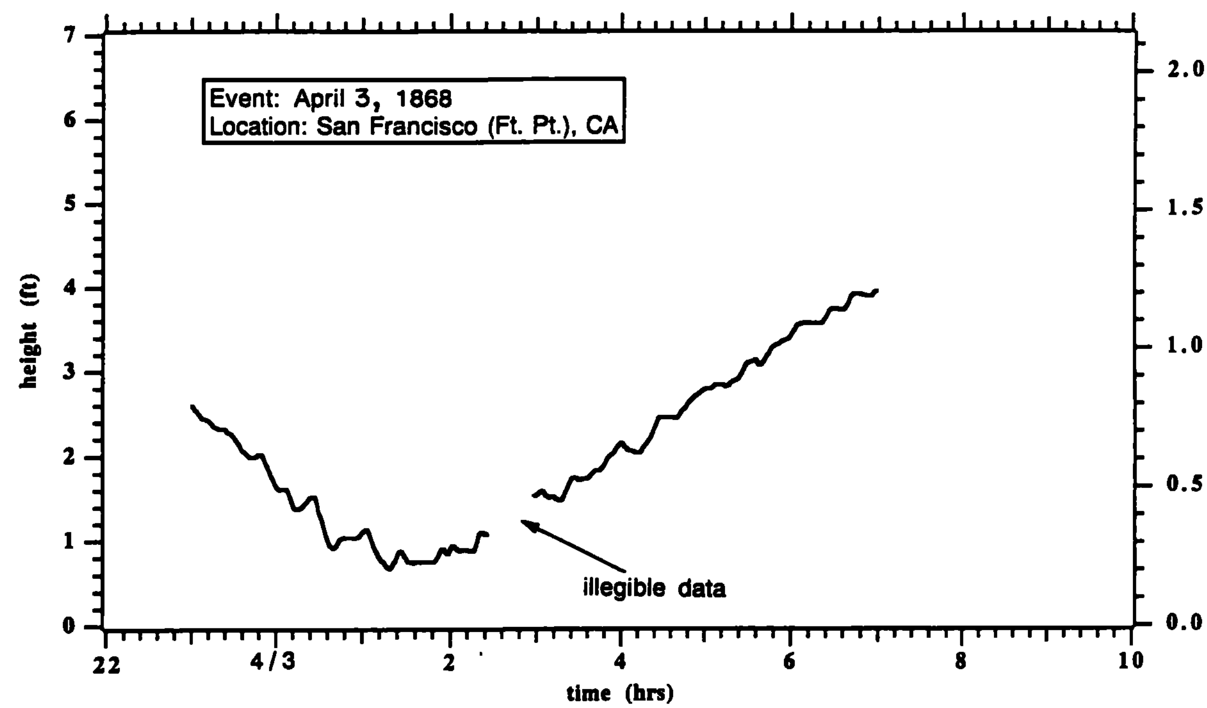


Figure 38.

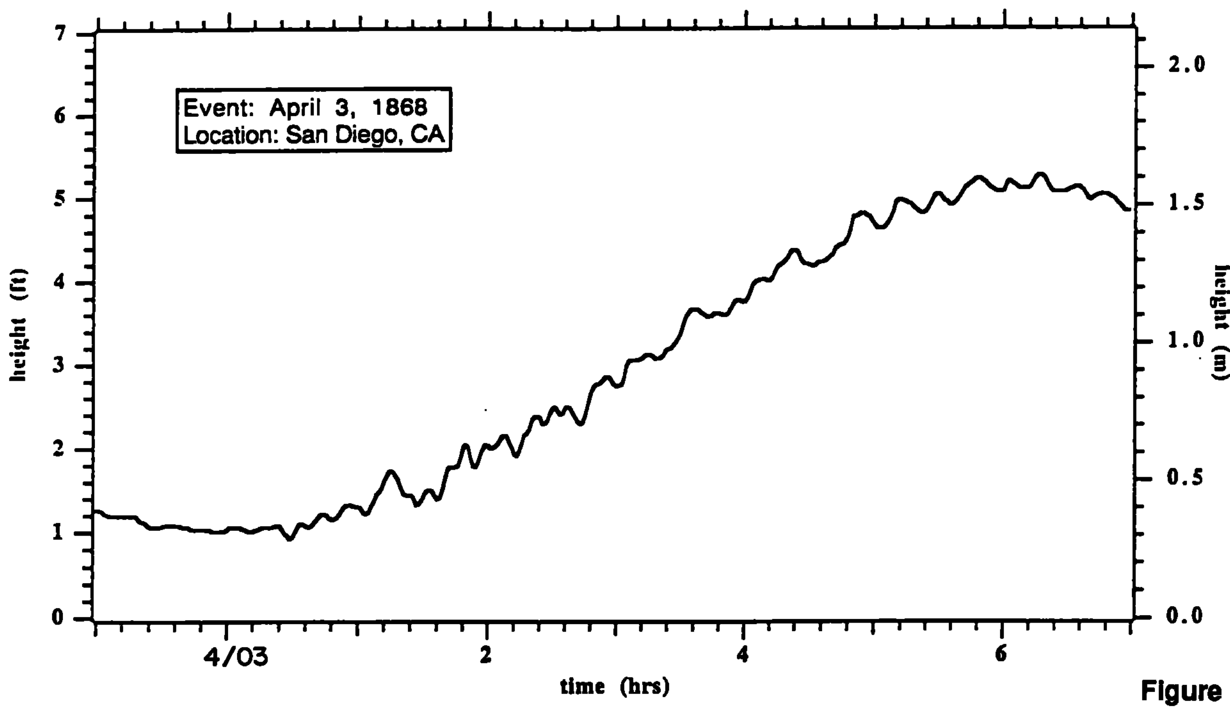
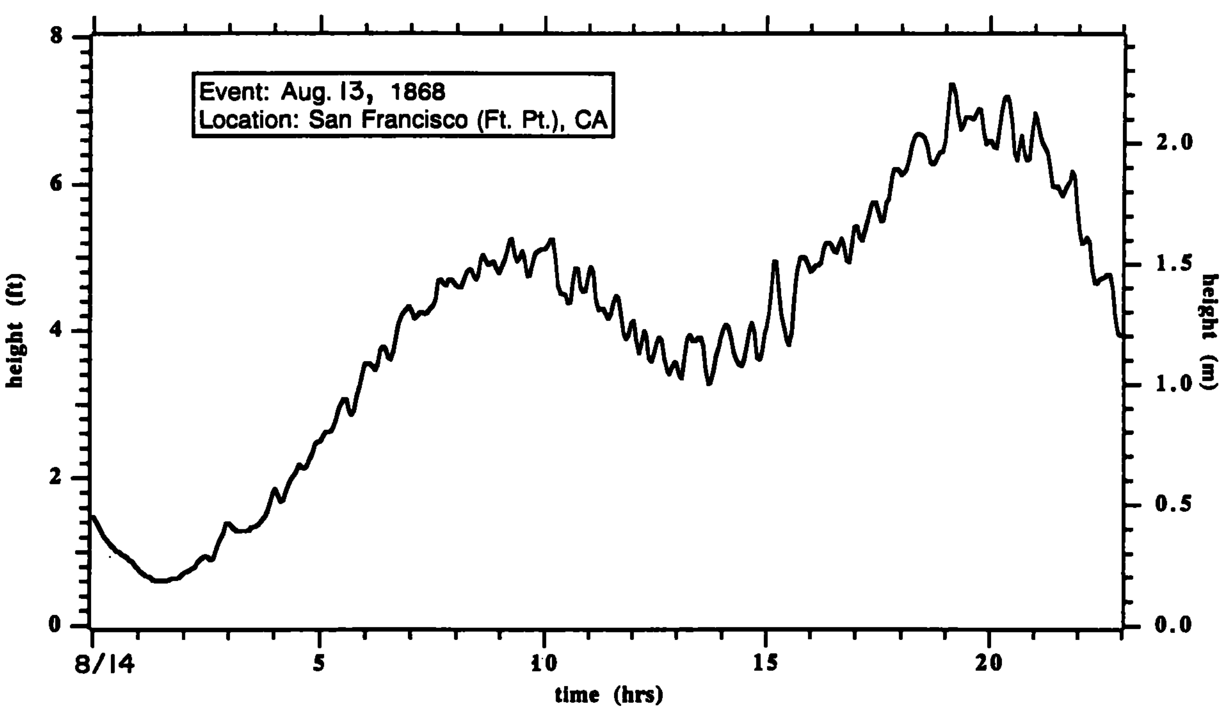


Figure 39.



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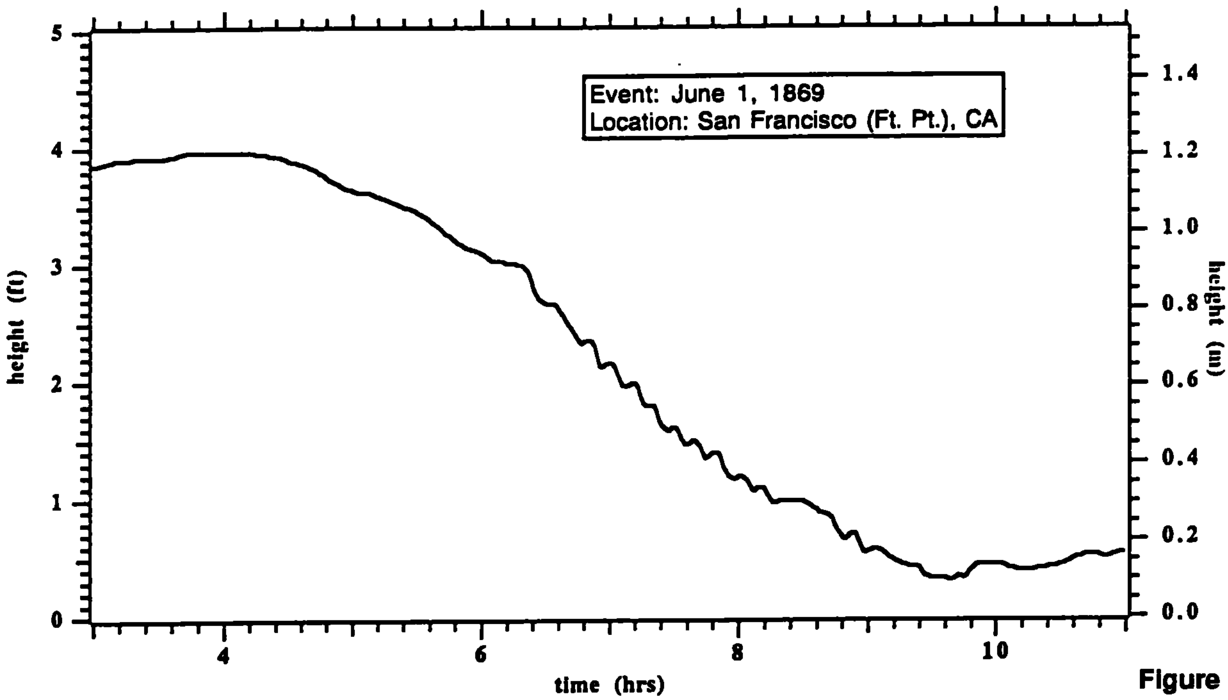


Figure 41.

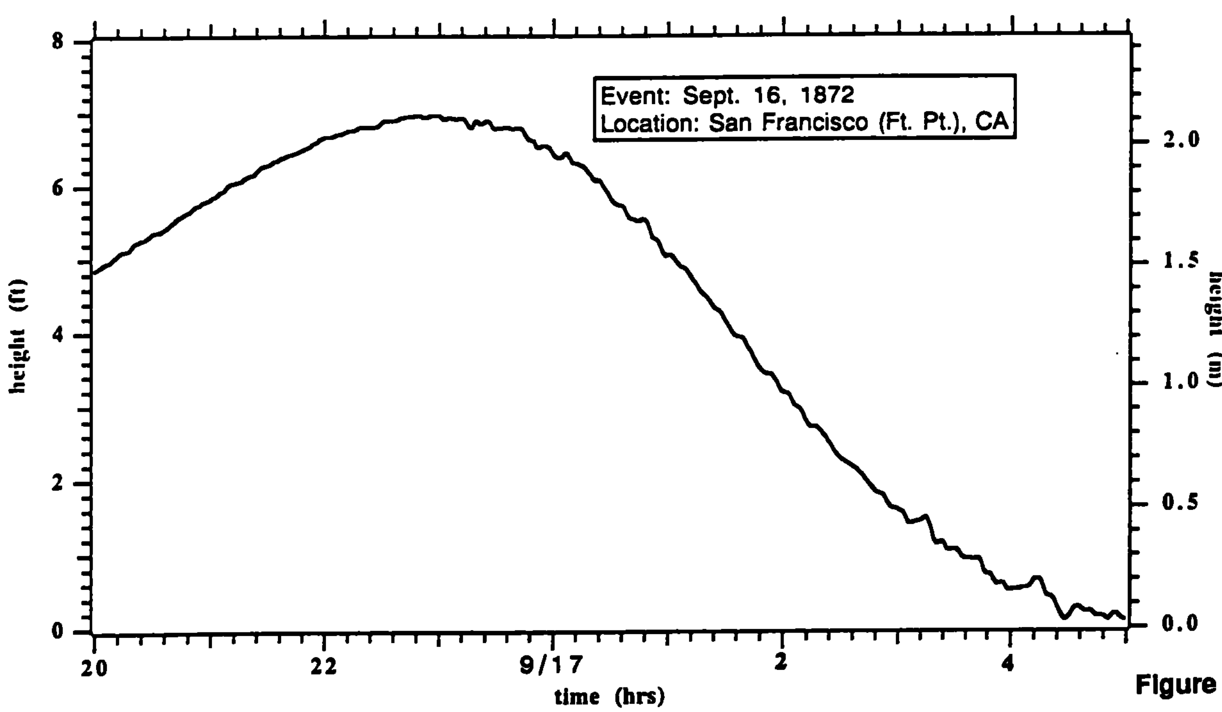
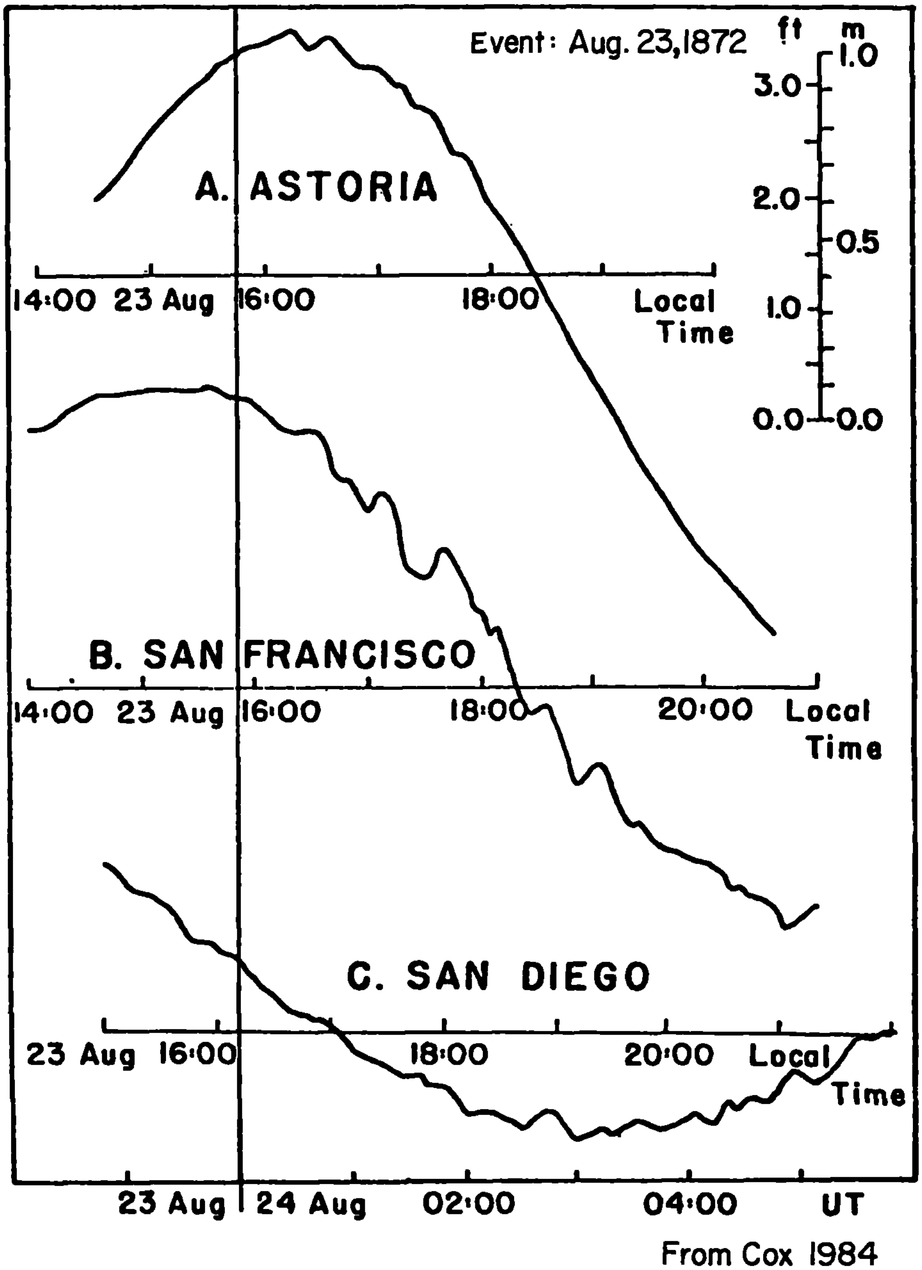


Figure 42.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ft
m
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2.0
0.5
1.0
0.0
0.0
A. ASTORIA
14:00 23 Aug 16:00 18:00 Local Time
B. SAN FRANCISCO
14:00 23 Aug 16:00 18:00 20:00 Local Time
C. SAN DIEGO
23 Aug 16:00 18:00 20:00 Local Time
23 Aug 24 Aug 02:00 04:00 UT
From Cox 1984

Figure 43.

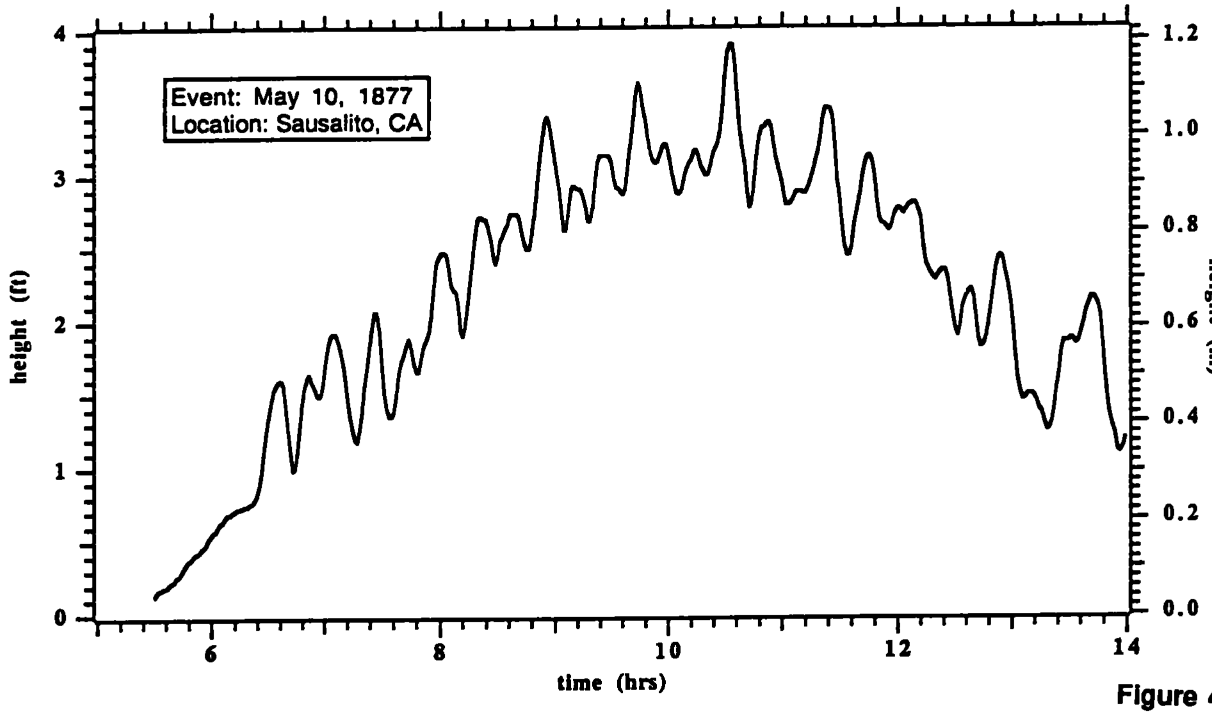


Figure 44.

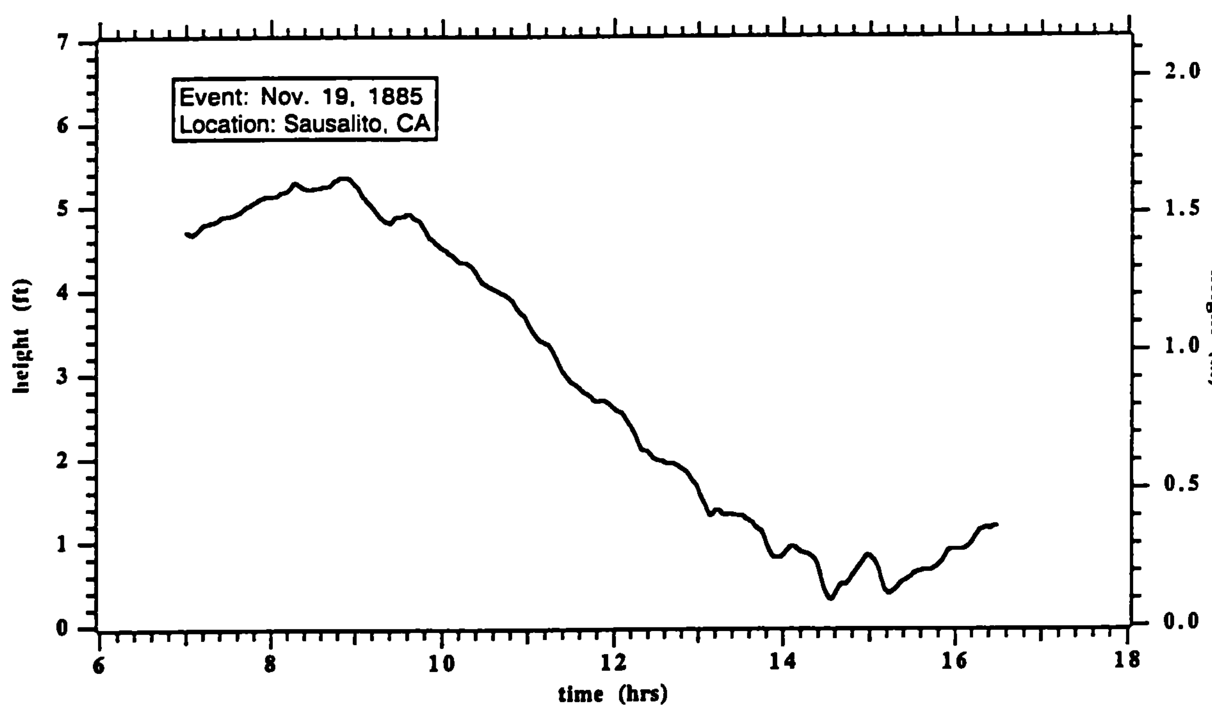


Figure 45.

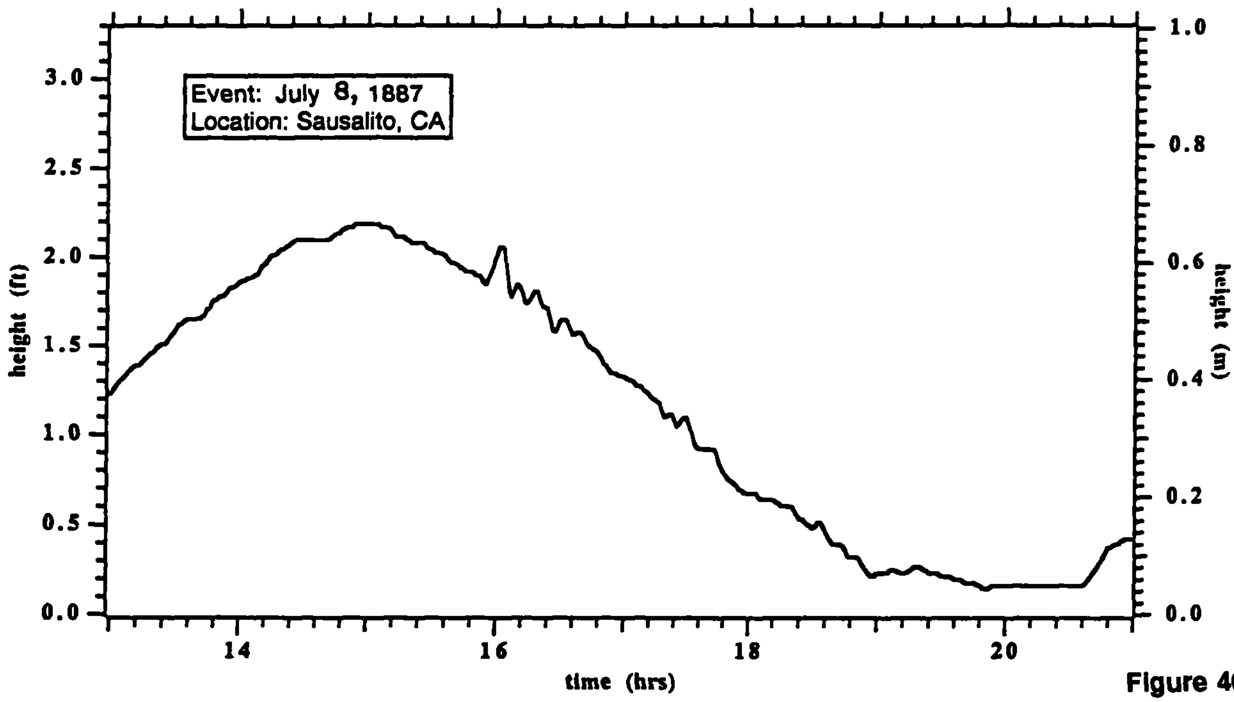


Figure 46.

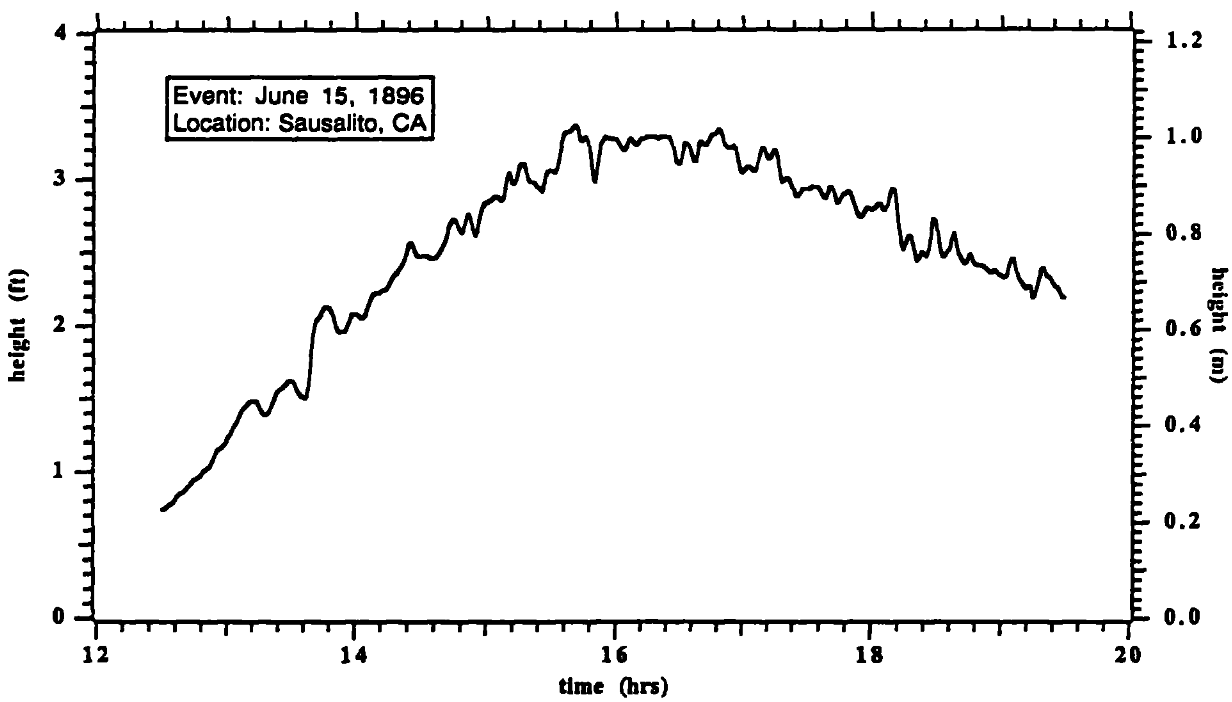


Figure 47.

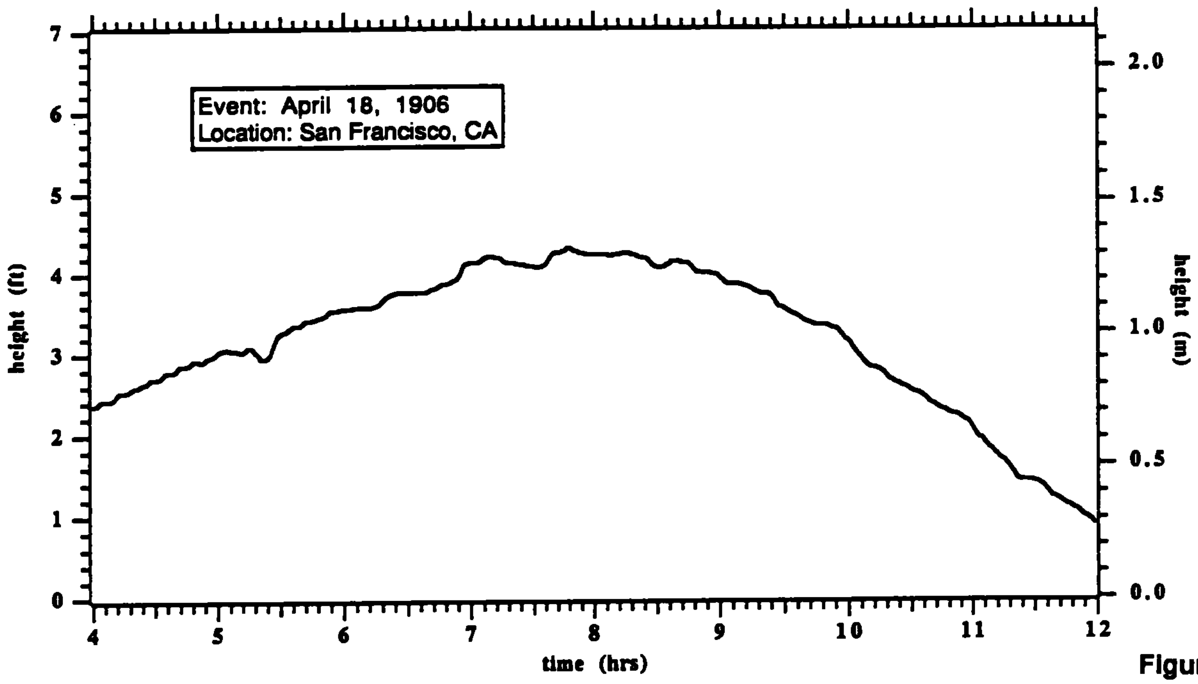


Figure 48.

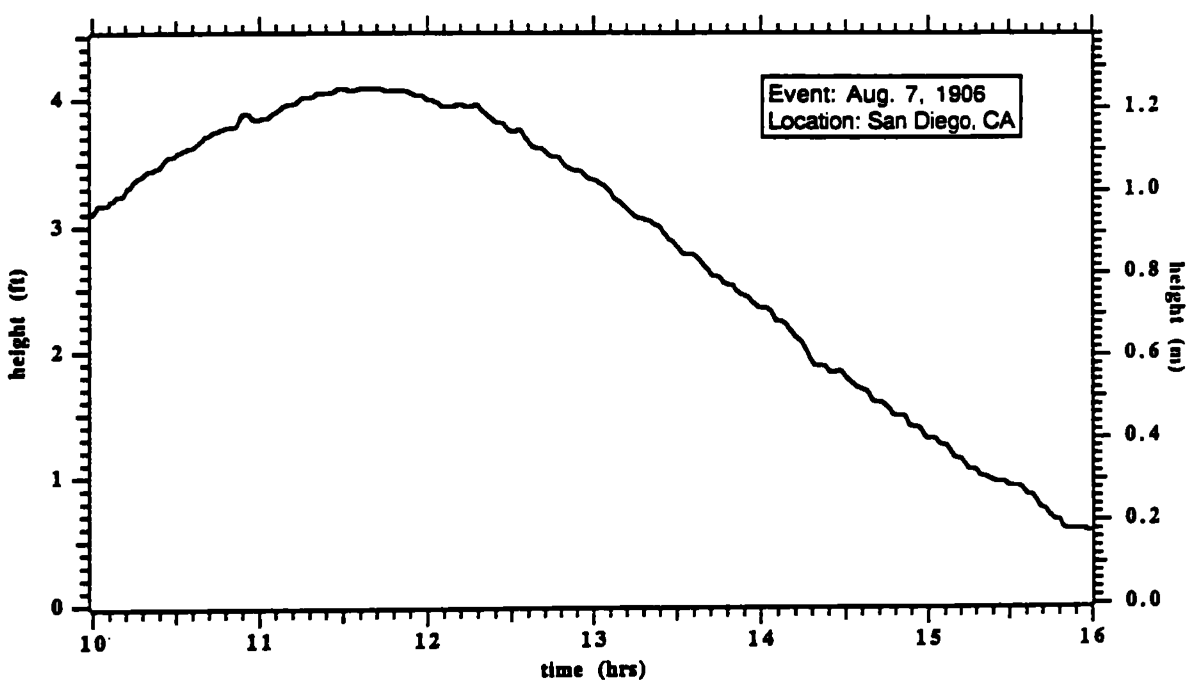


Figure 49.

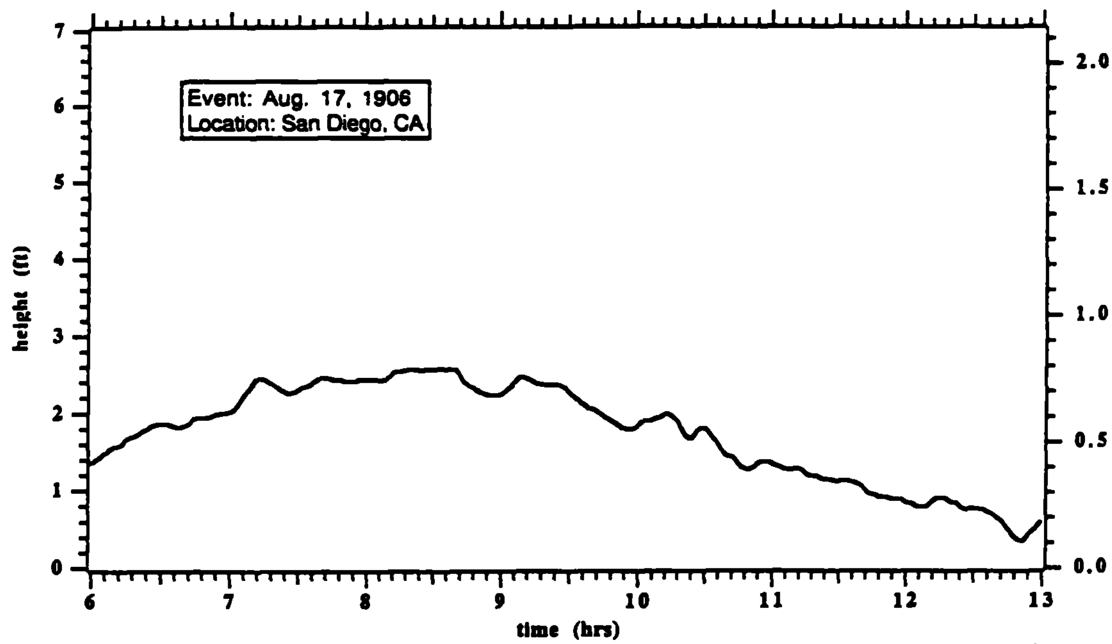


Figure 50.

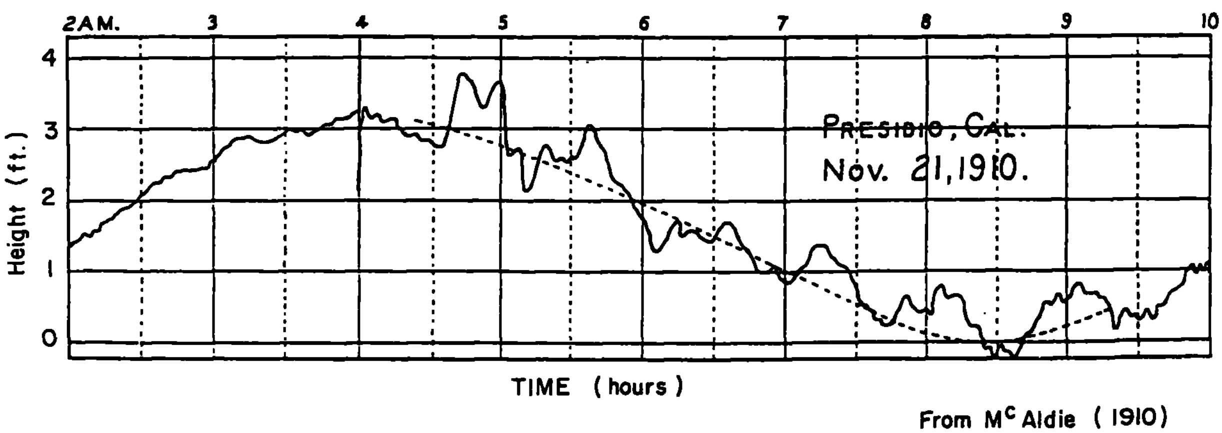


Figure 51.

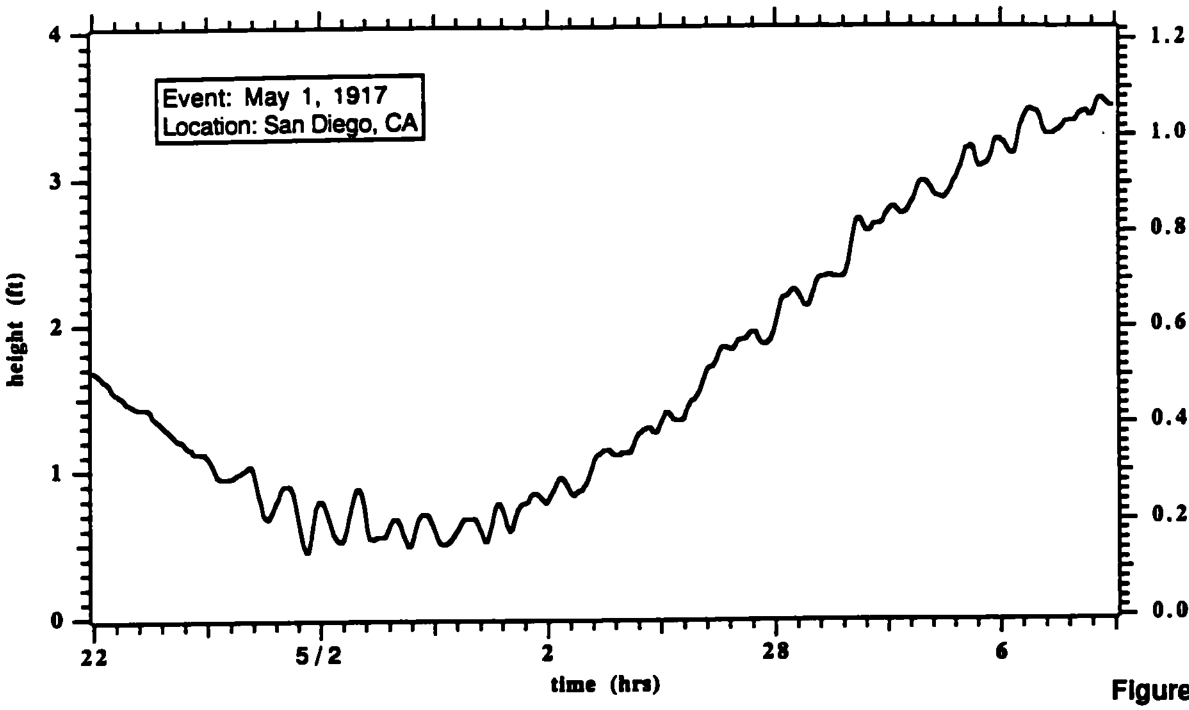


Figure 52.

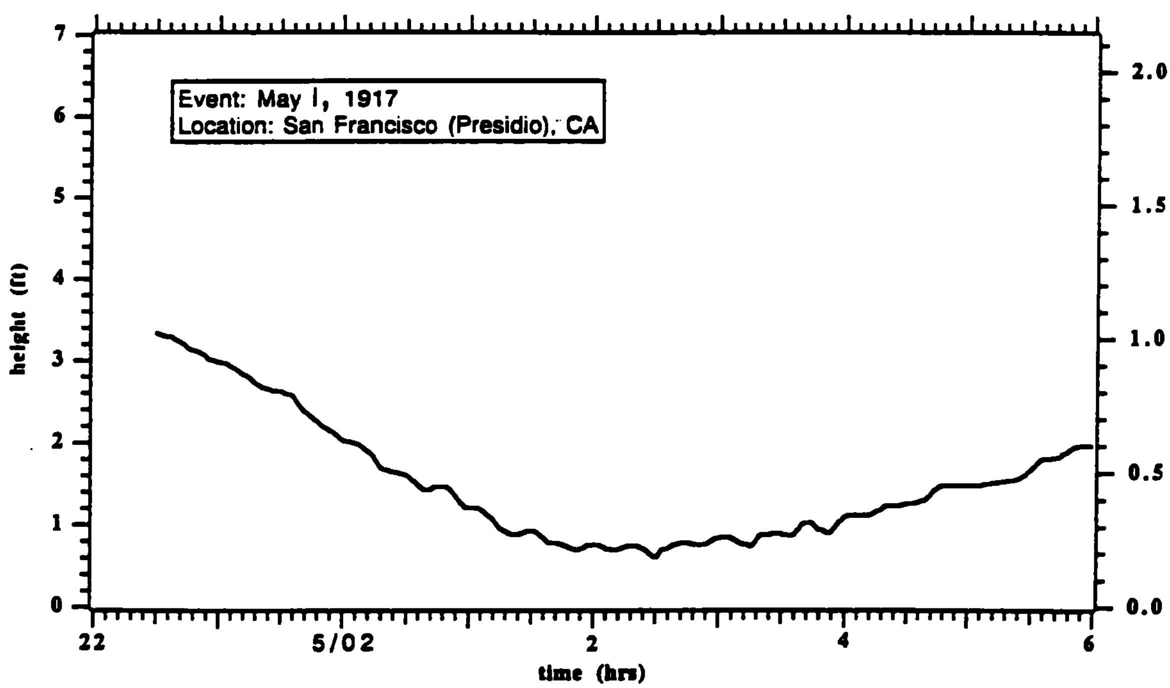
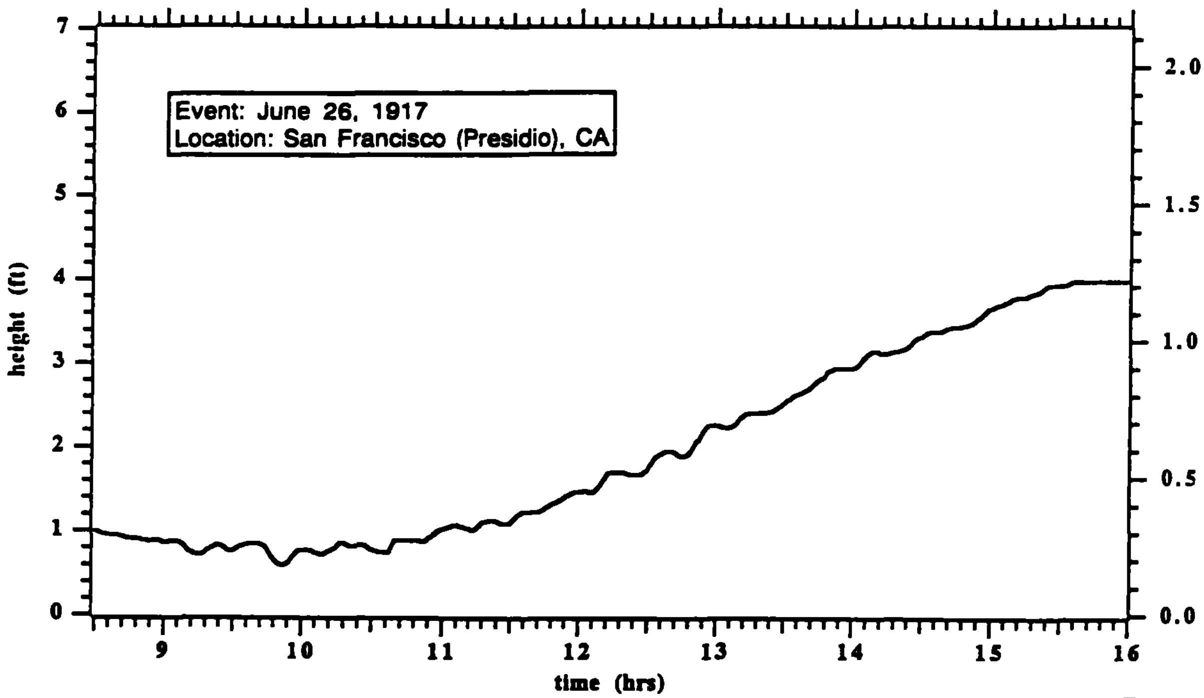


Figure 53.



Event: June 26, 1917
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height (ft)
height (m)
time (hrs)
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7
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1.0
1.5
2.0
9
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11
12
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15
16

Figure 54.

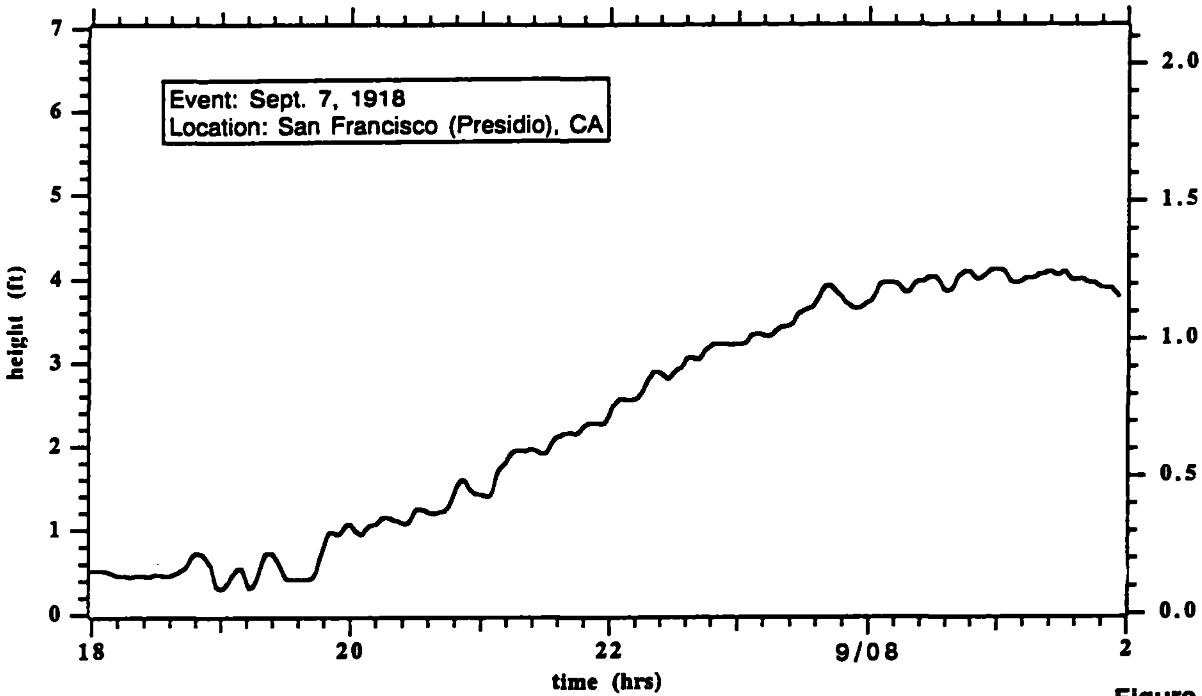


Figure 55.

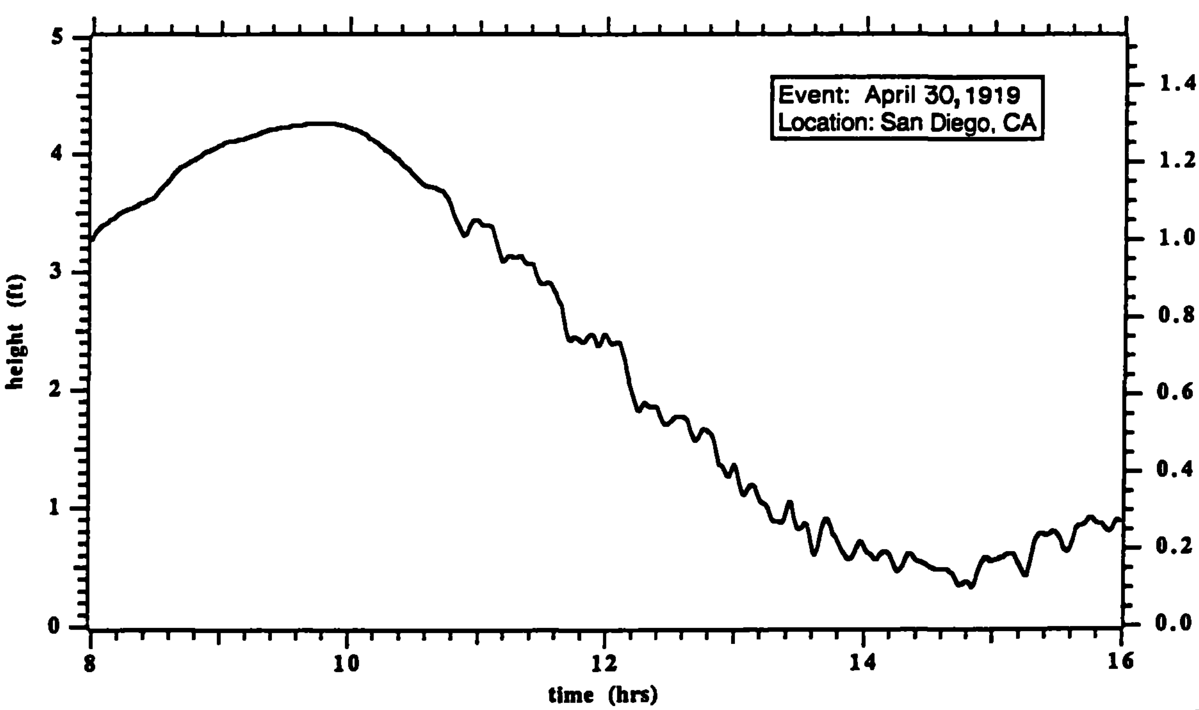


Figure 56.

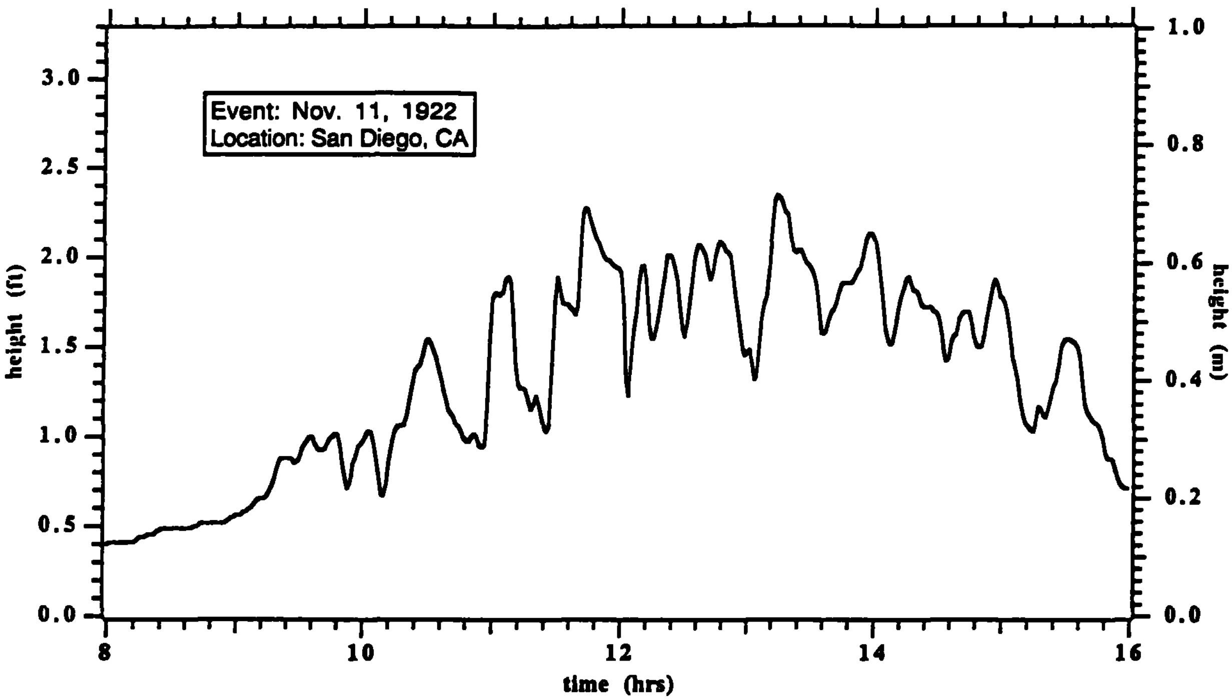


Figure 57.

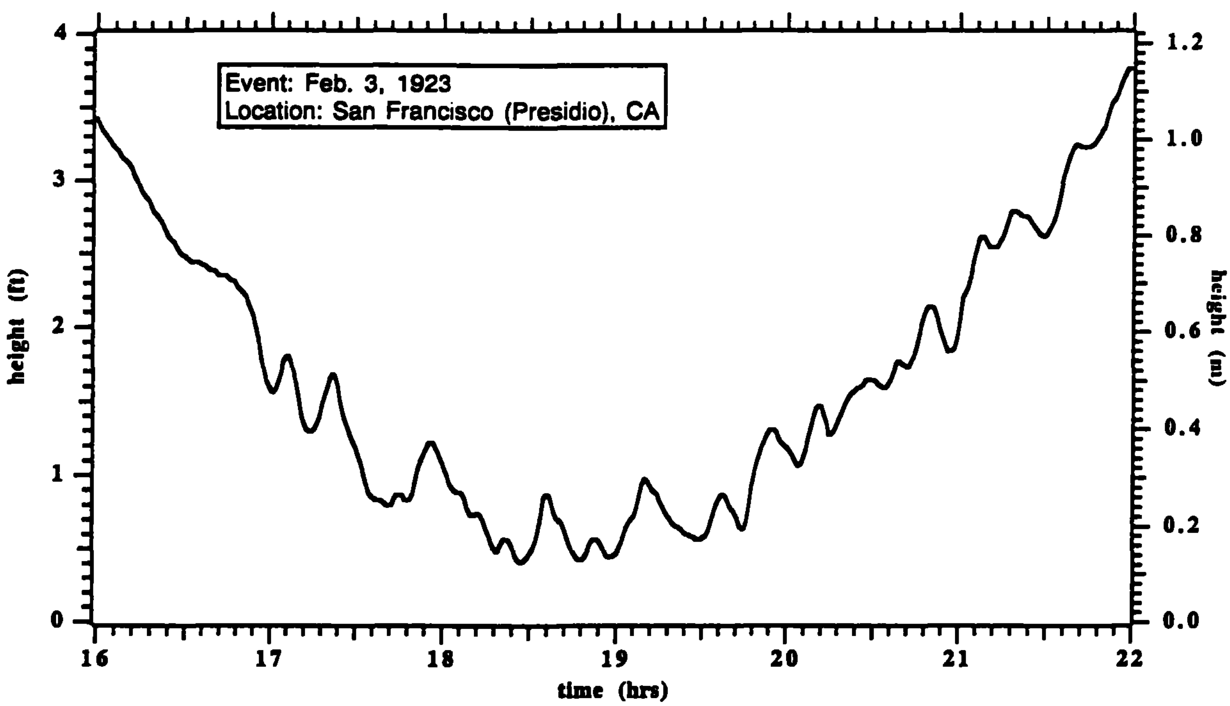


Figure 58.

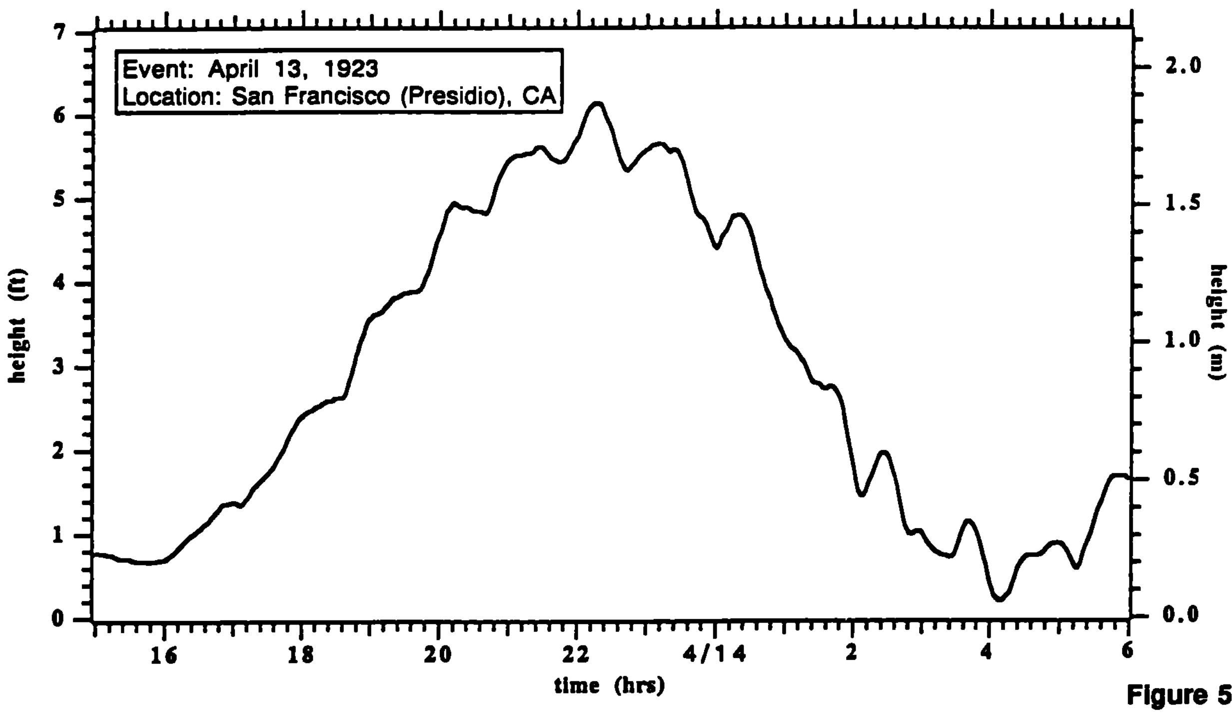


Figure 59.

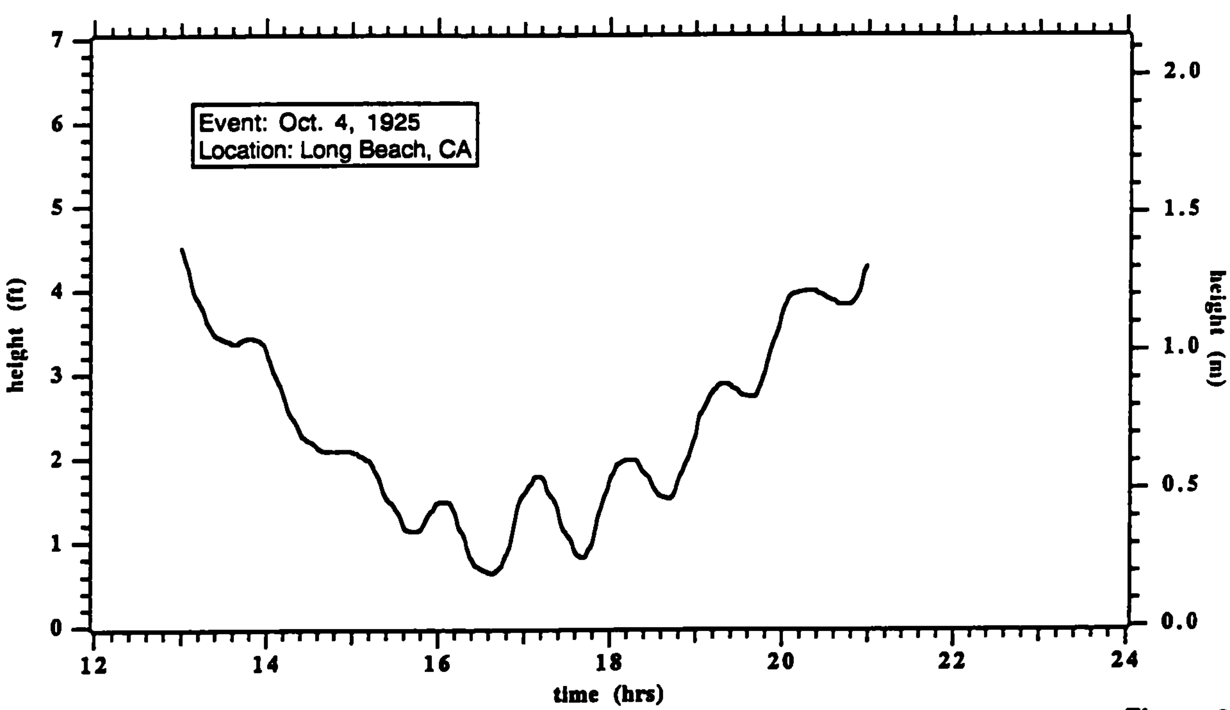


Figure 60.

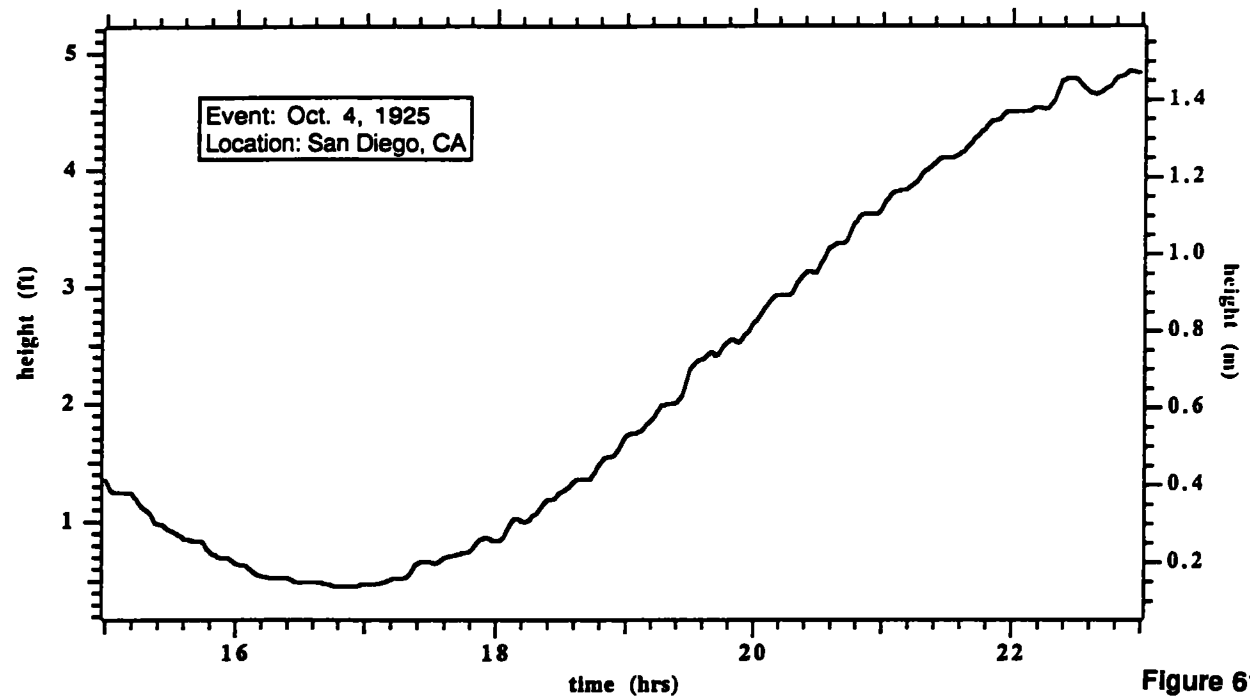


Figure 61.

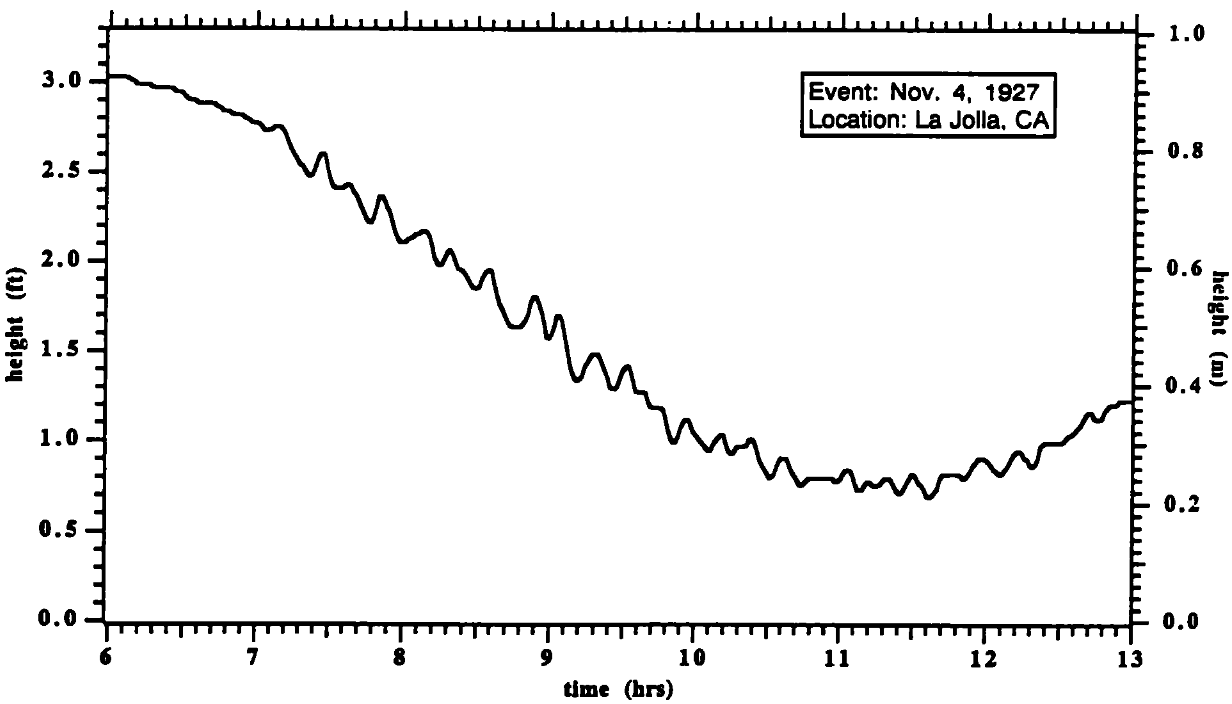


Figure 62.

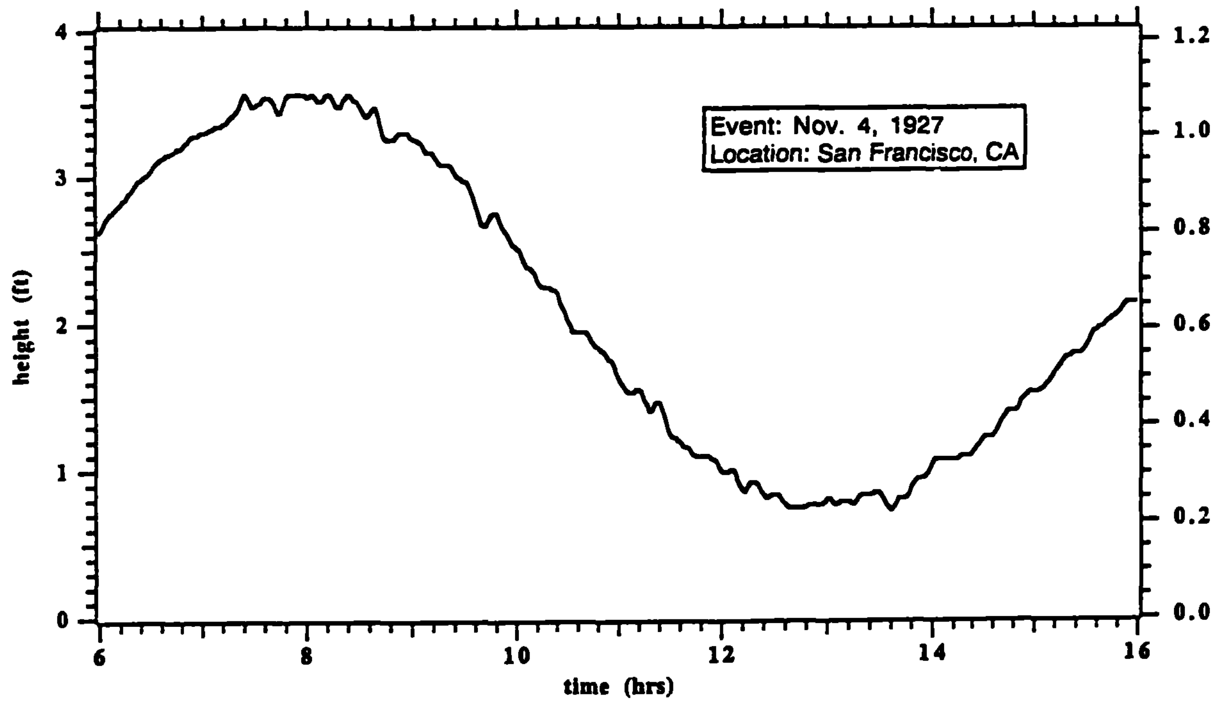


Figure 63.

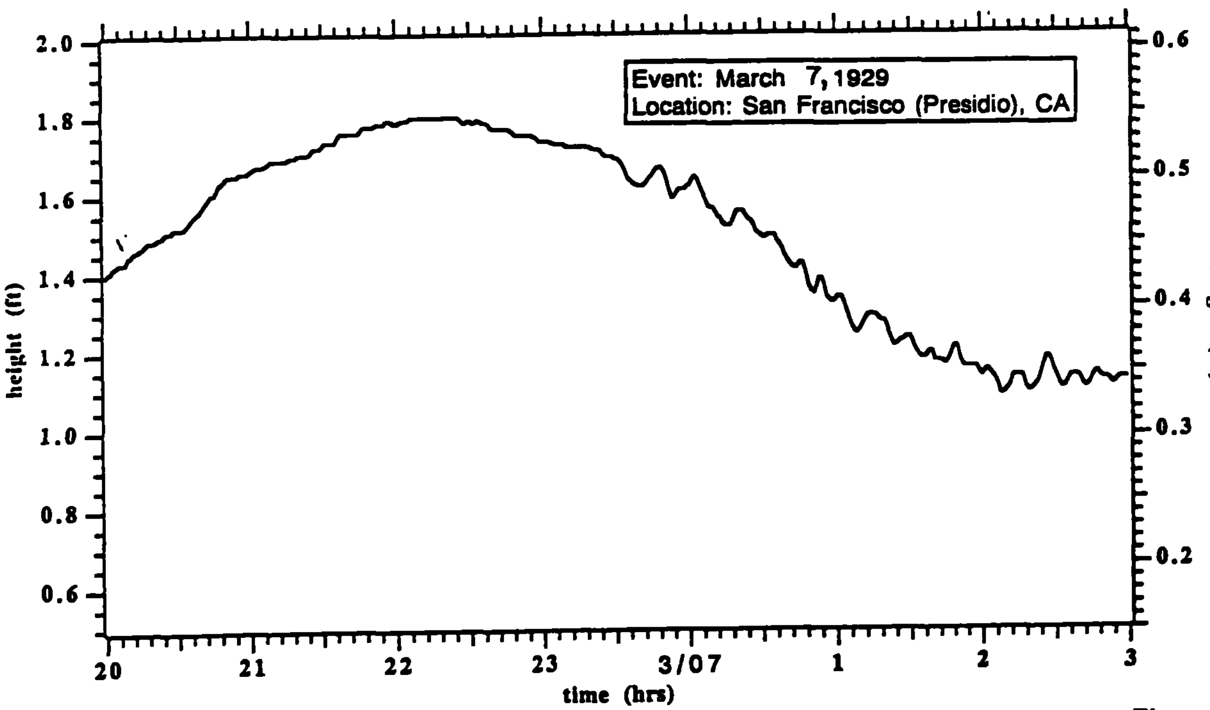


Figure 64.

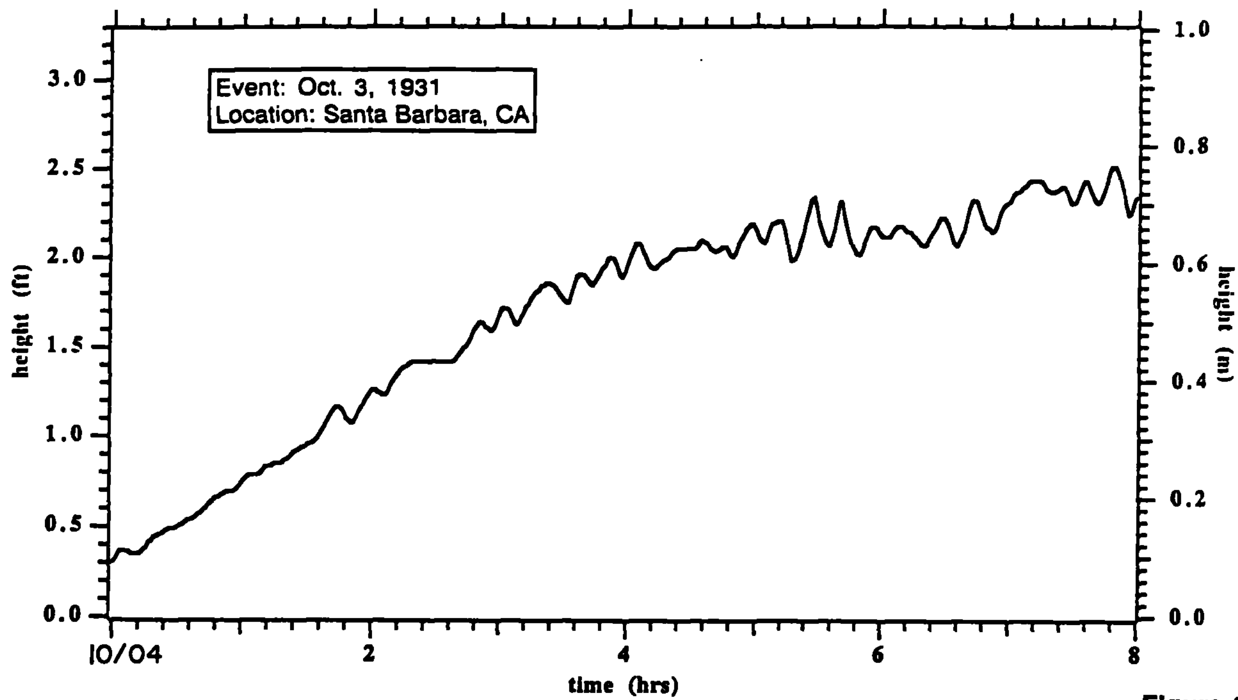


Figure 65.

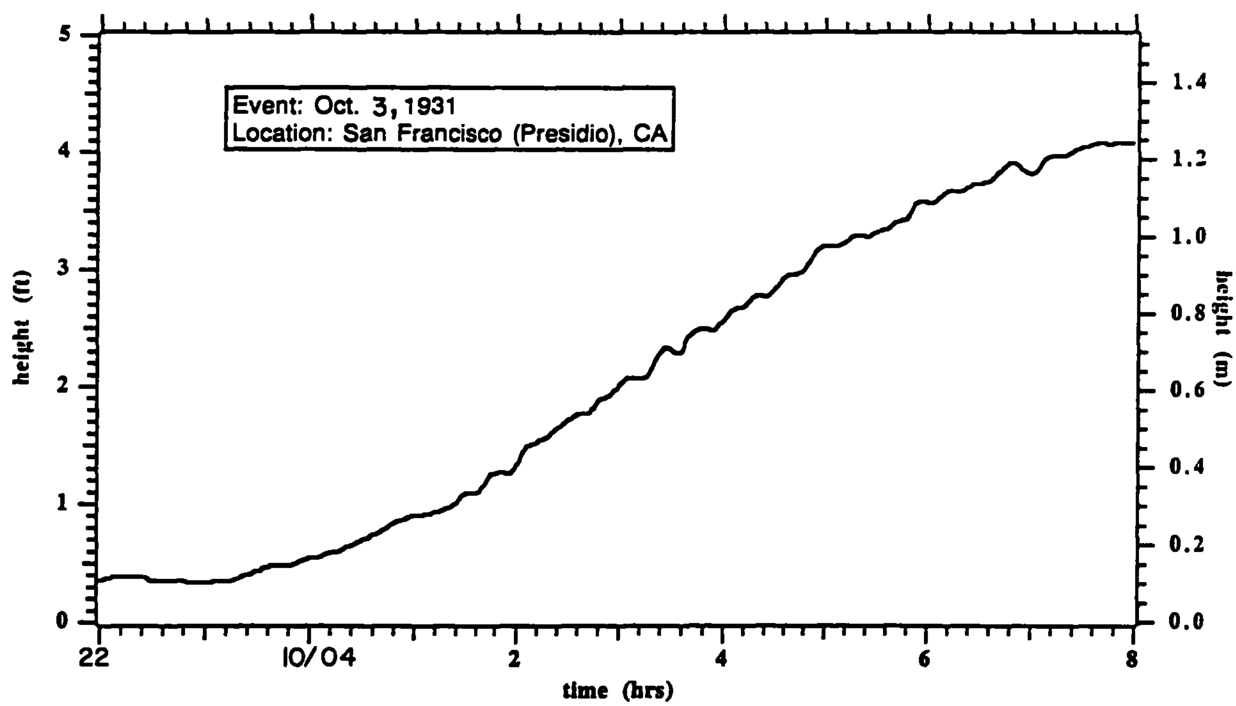


Figure 66.

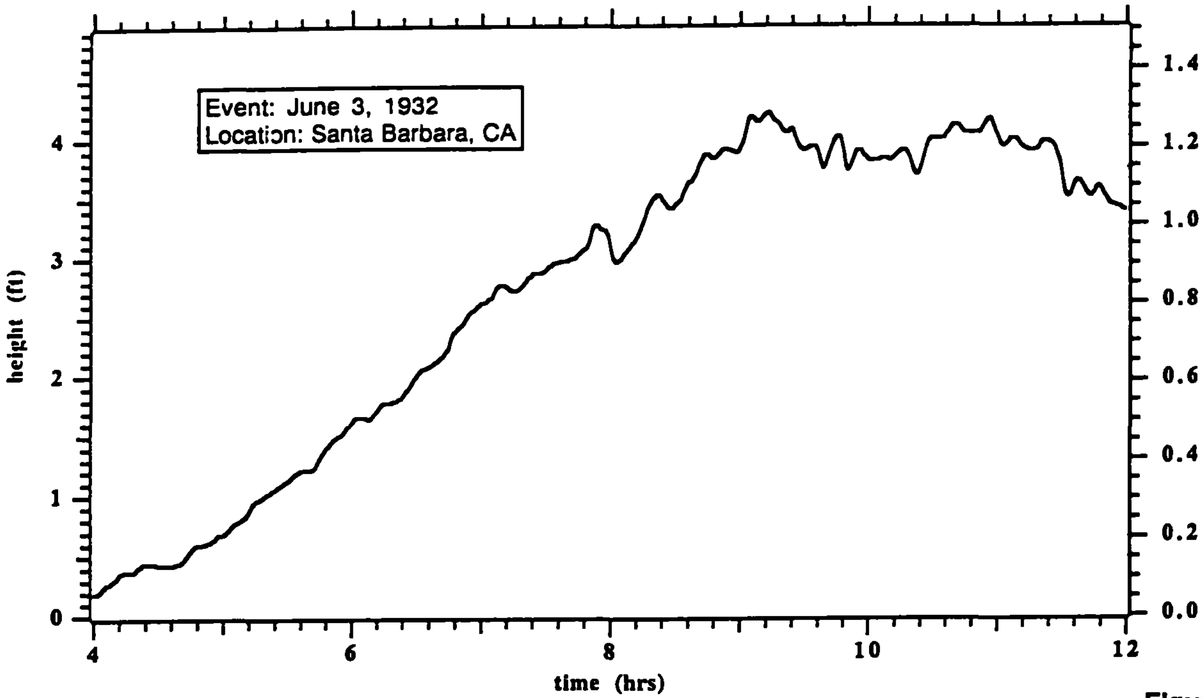


Figure 67.

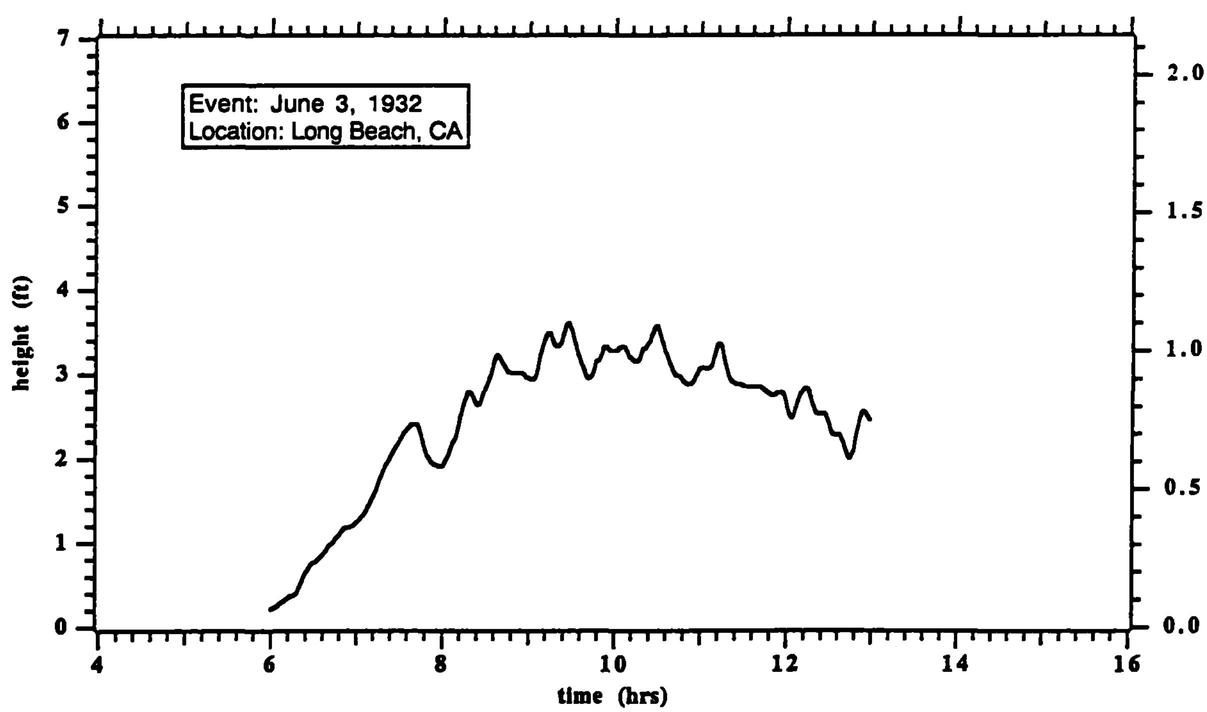


Figure 68.

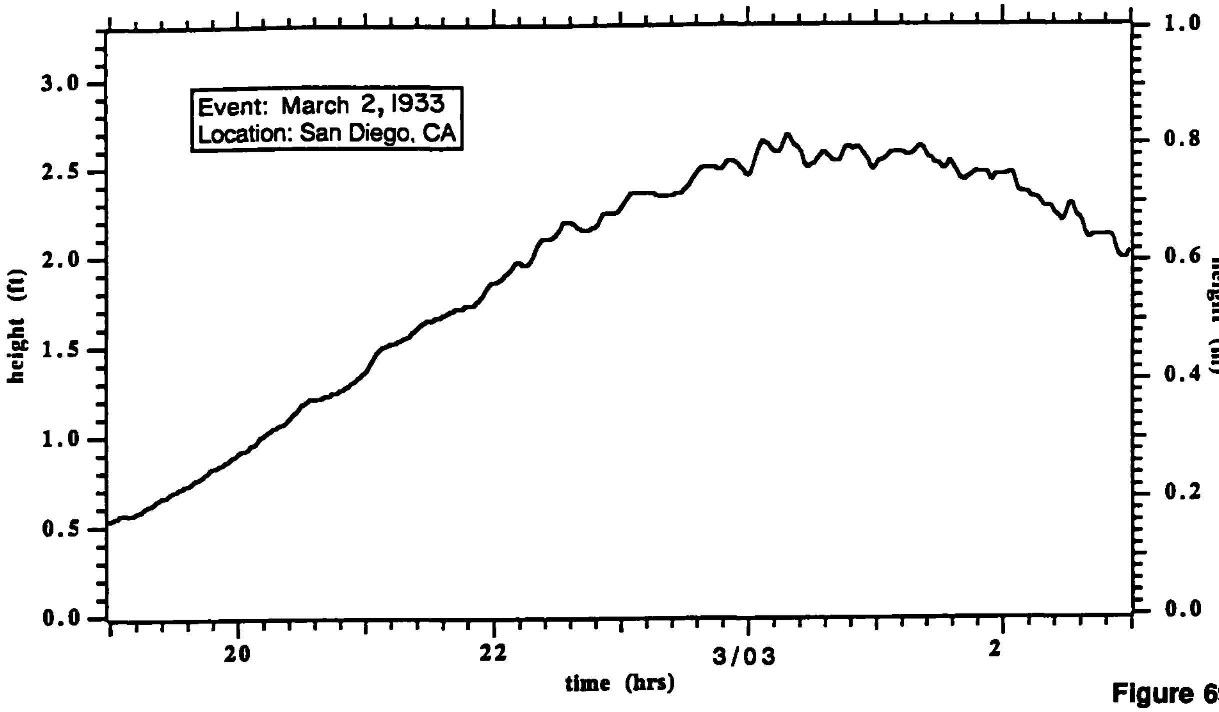


Figure 69.

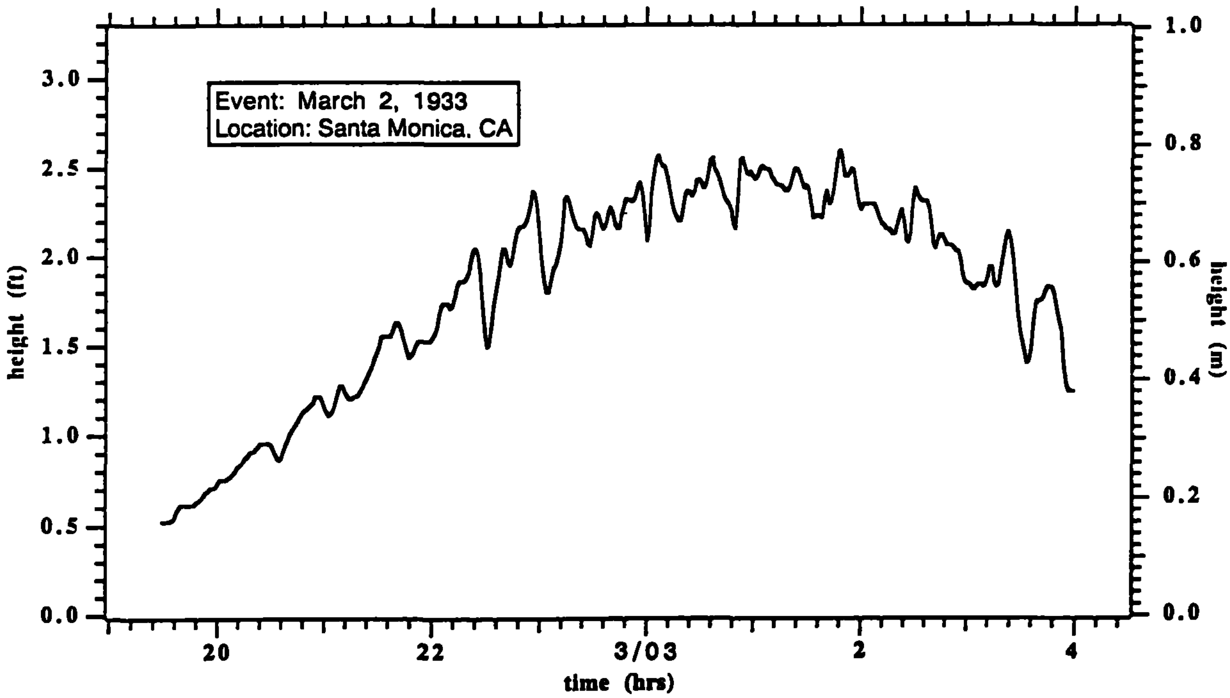


Figure 70.

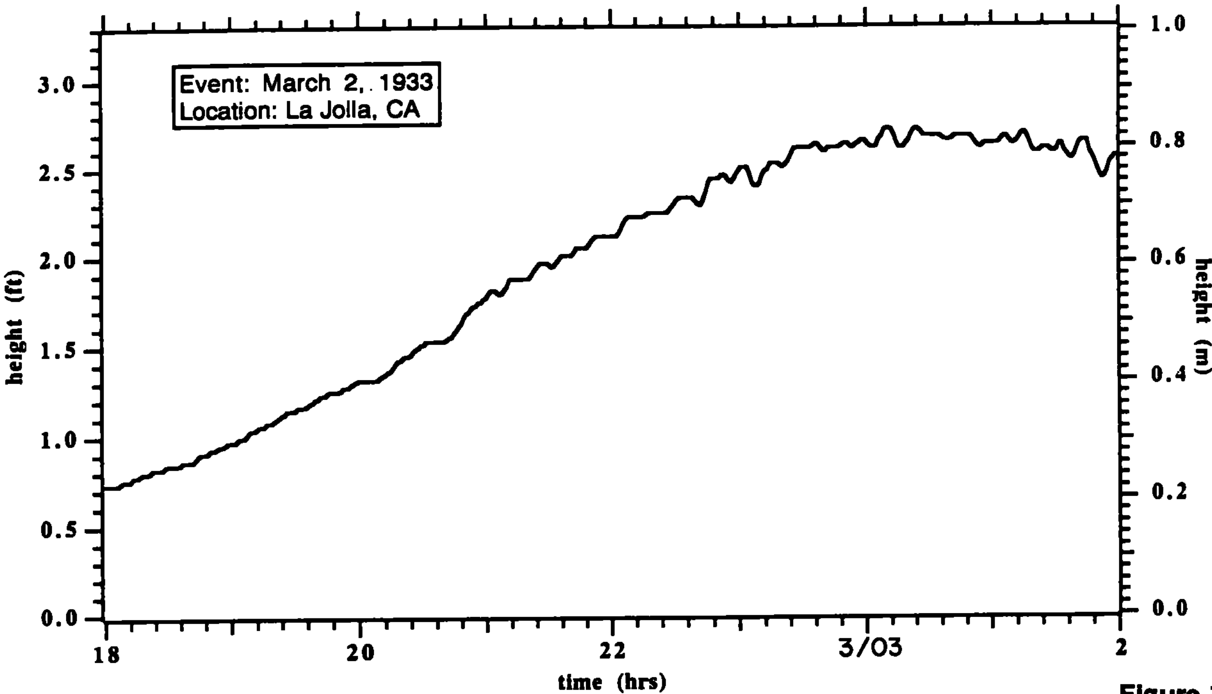


Figure 71.

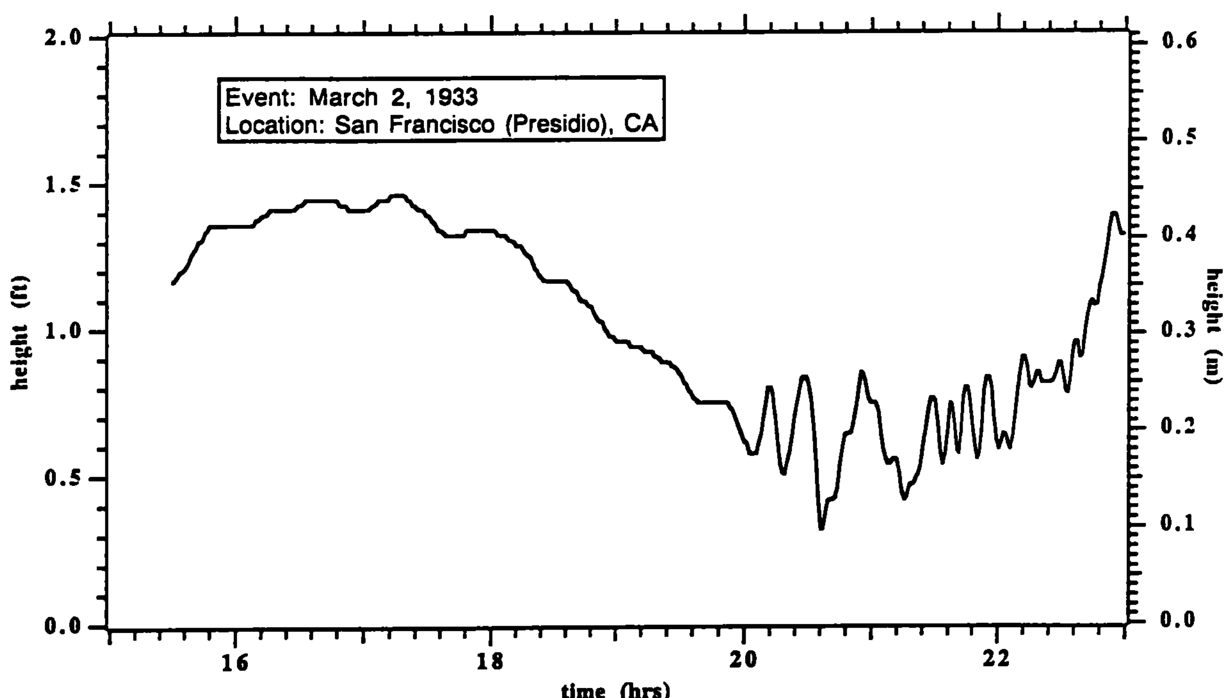


Figure 72.

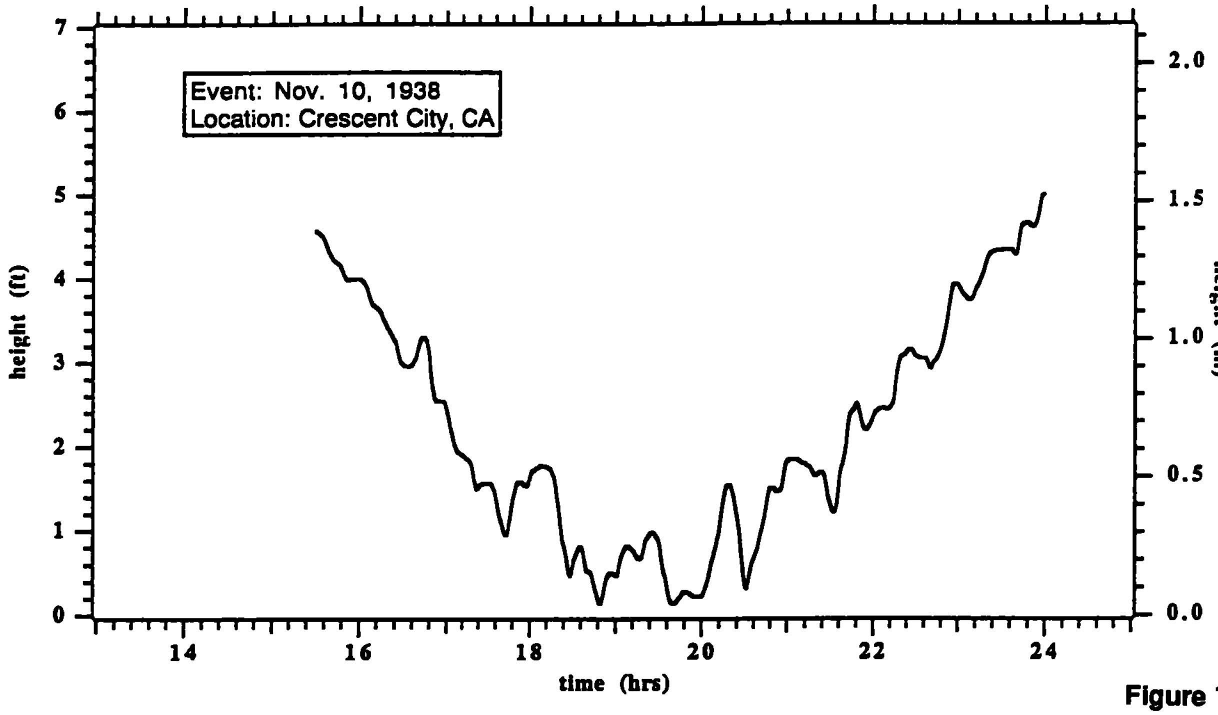


Figure 73.

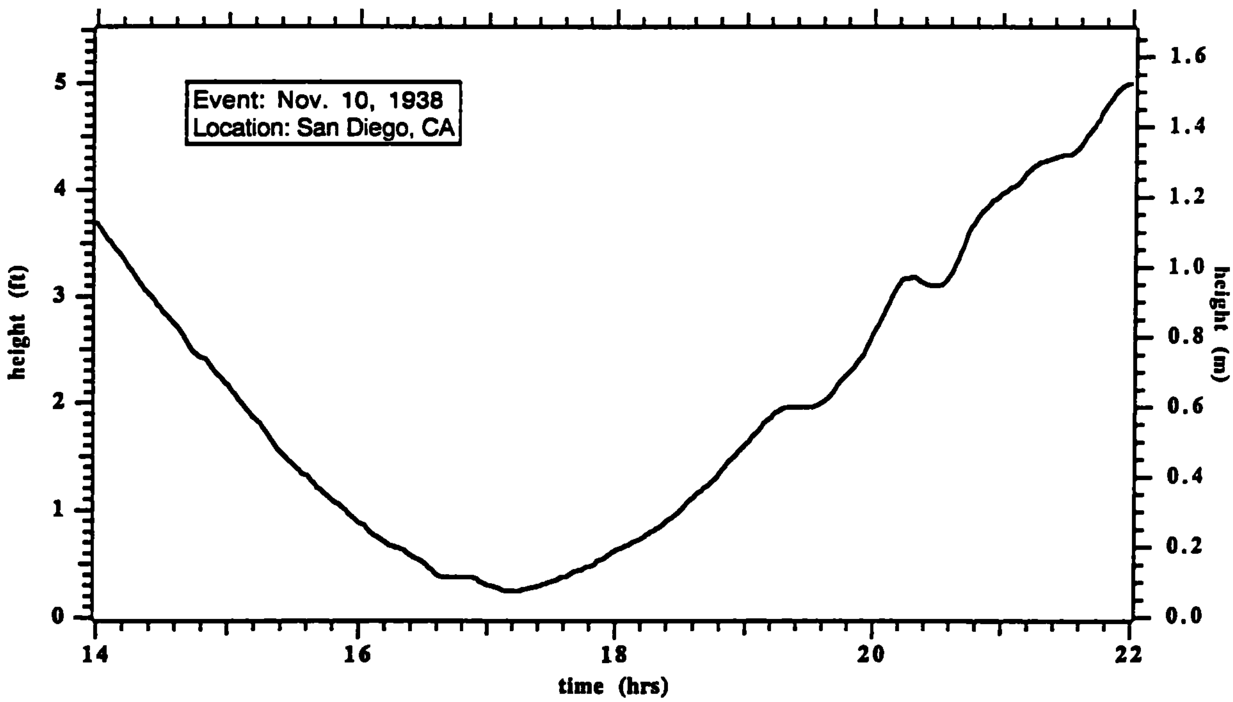
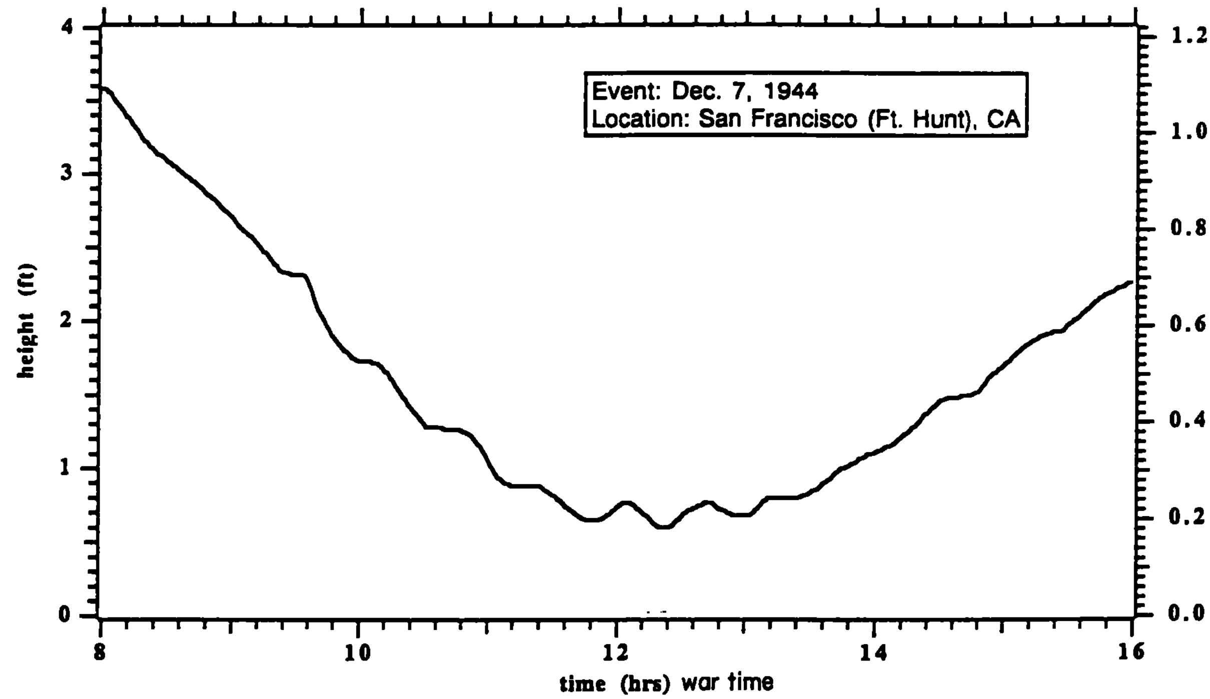


Figure 74.



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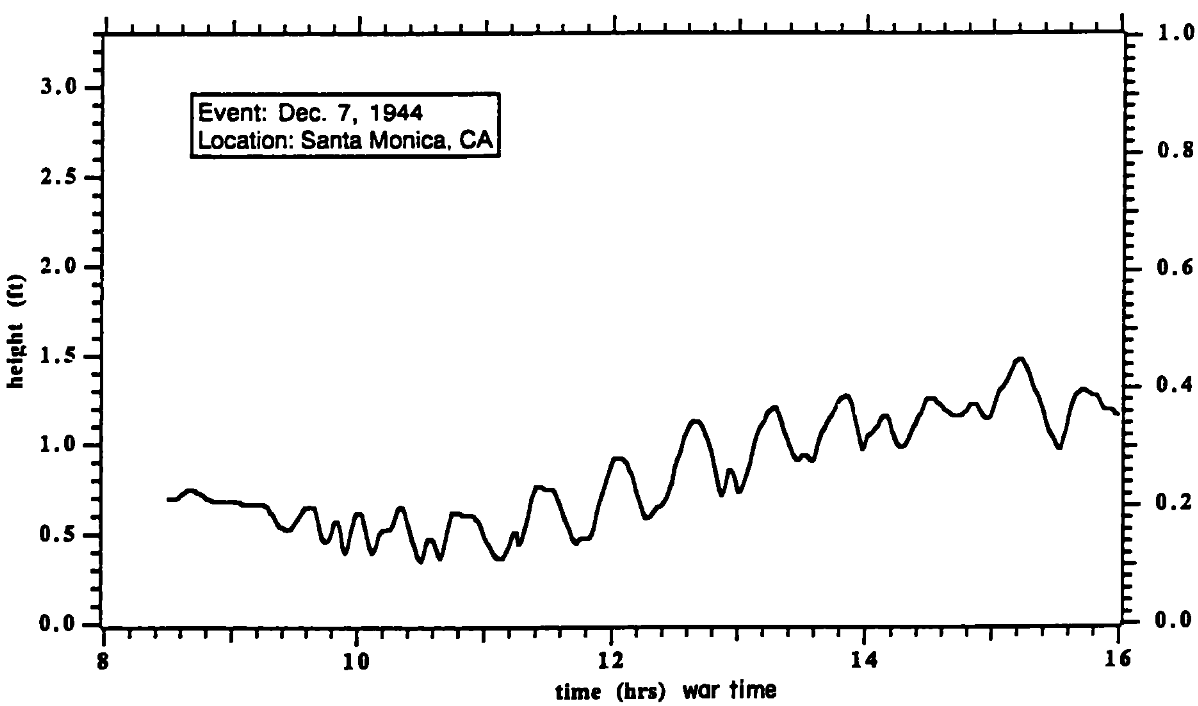


Figure 76.

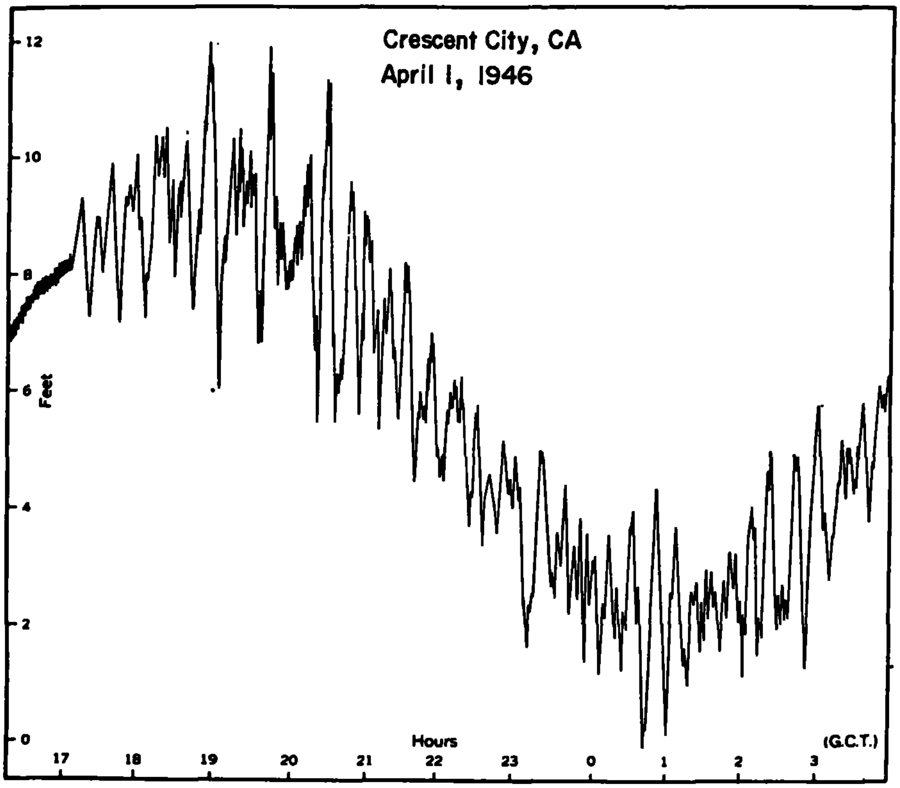
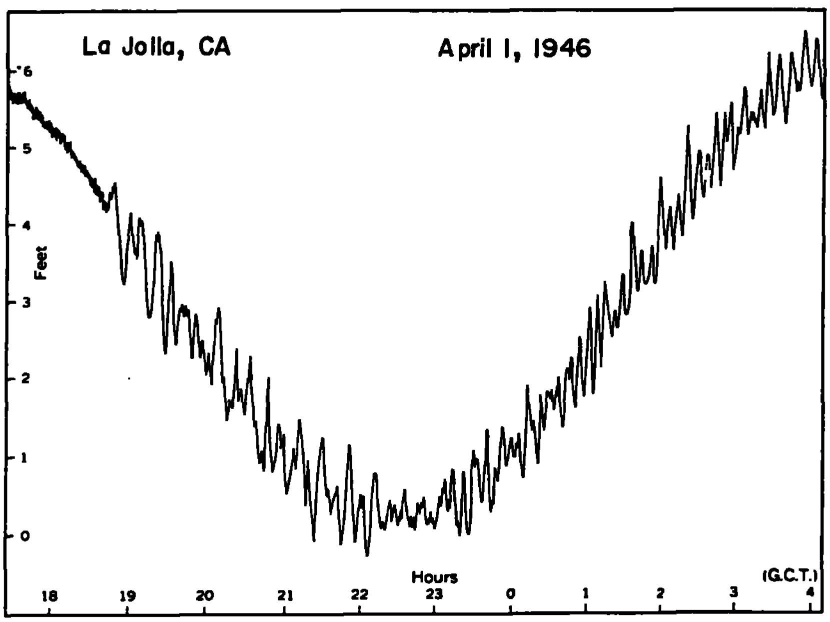


Figure 77.



From Green (1946)

Figure 78.

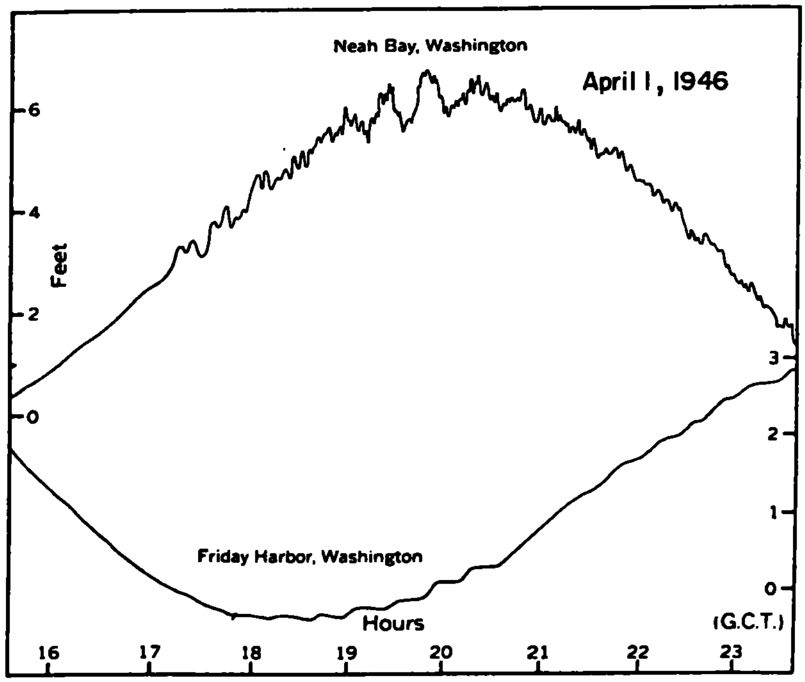
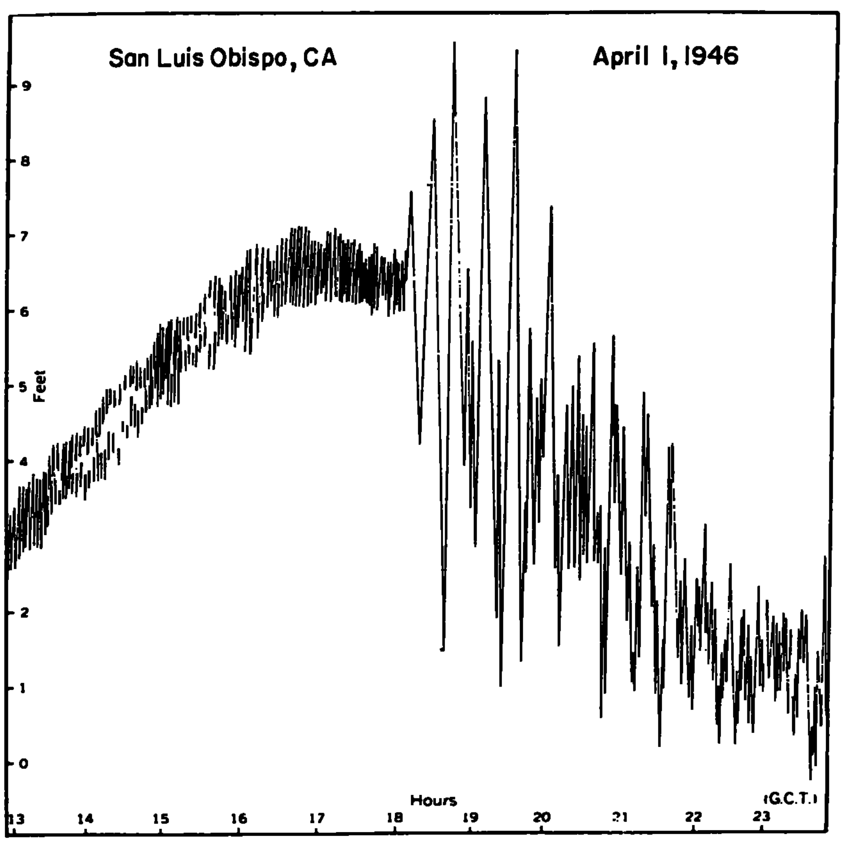


Figure 79.



Green (1946)

Figure 80.

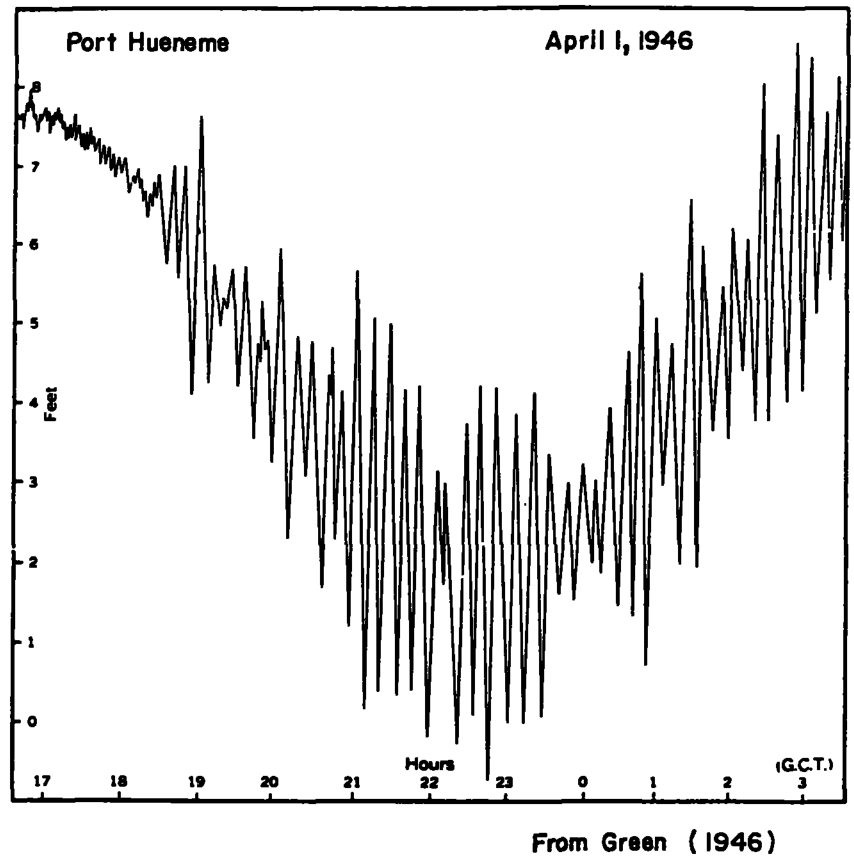


Figure 81.

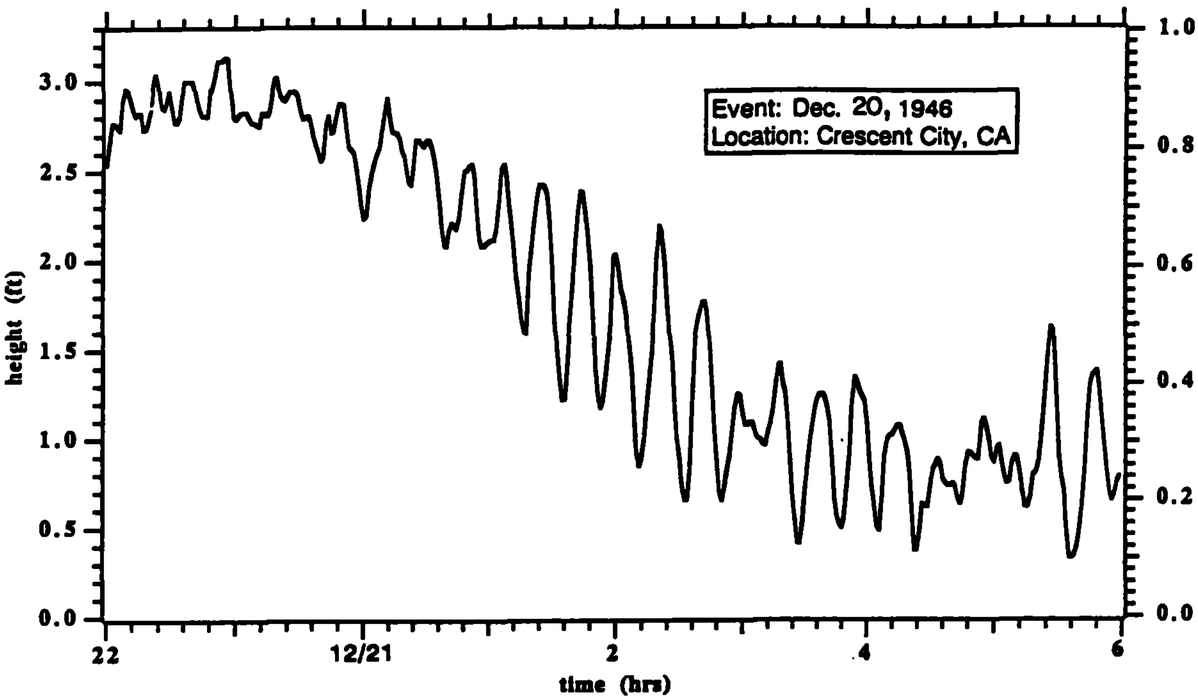


Figure 82.

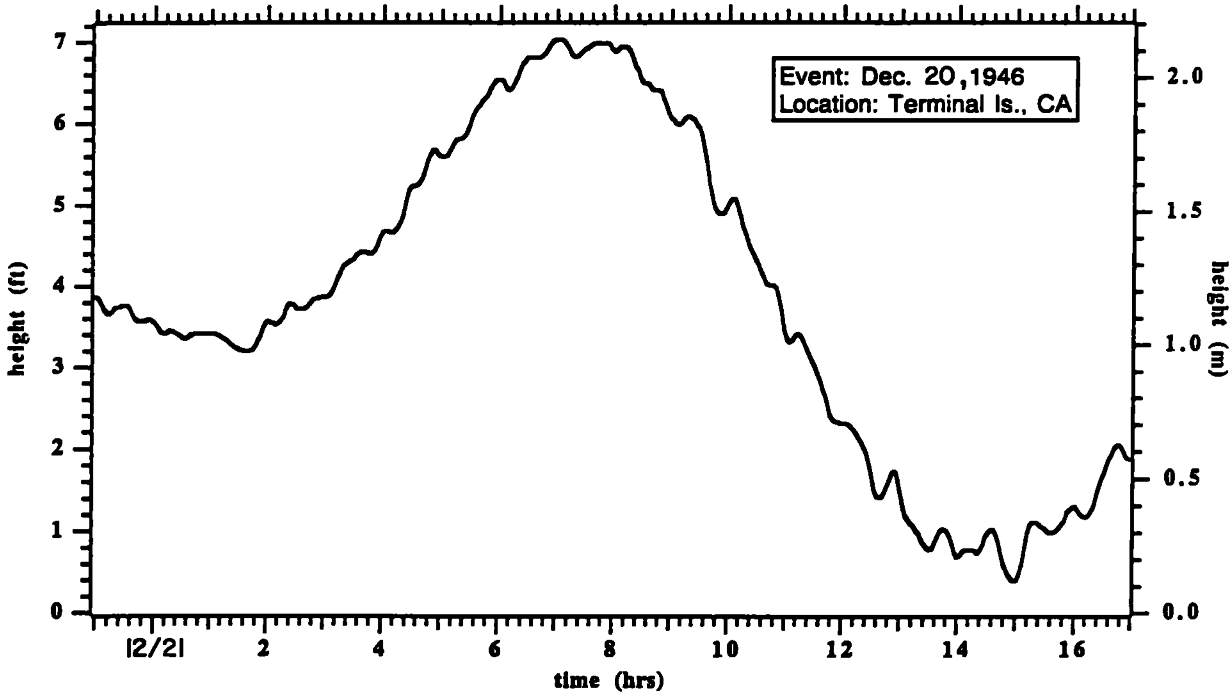


Figure 83.

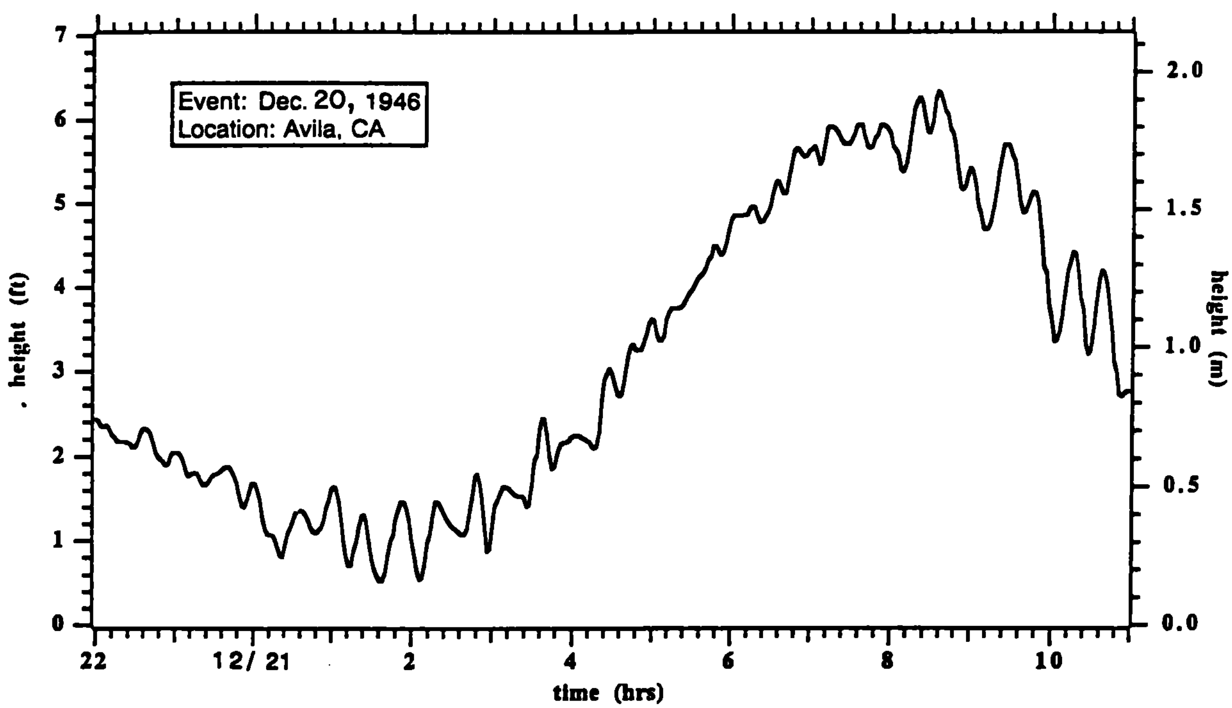


Figure 84.

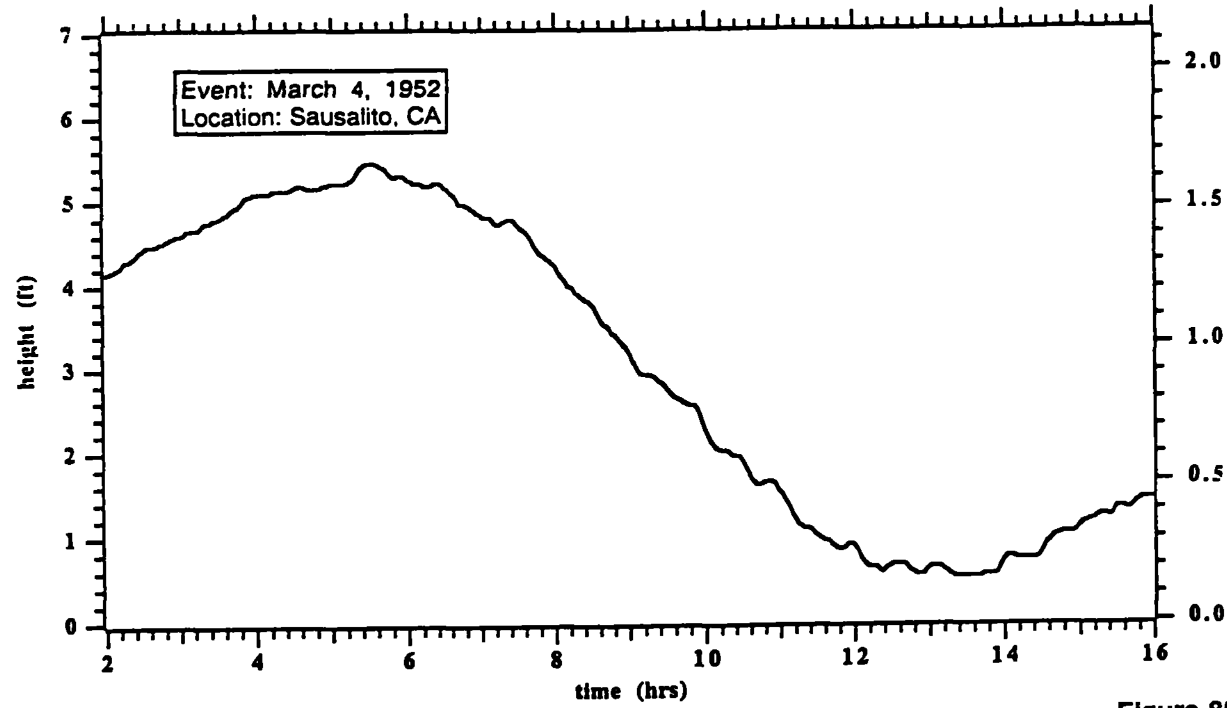


Figure 85.

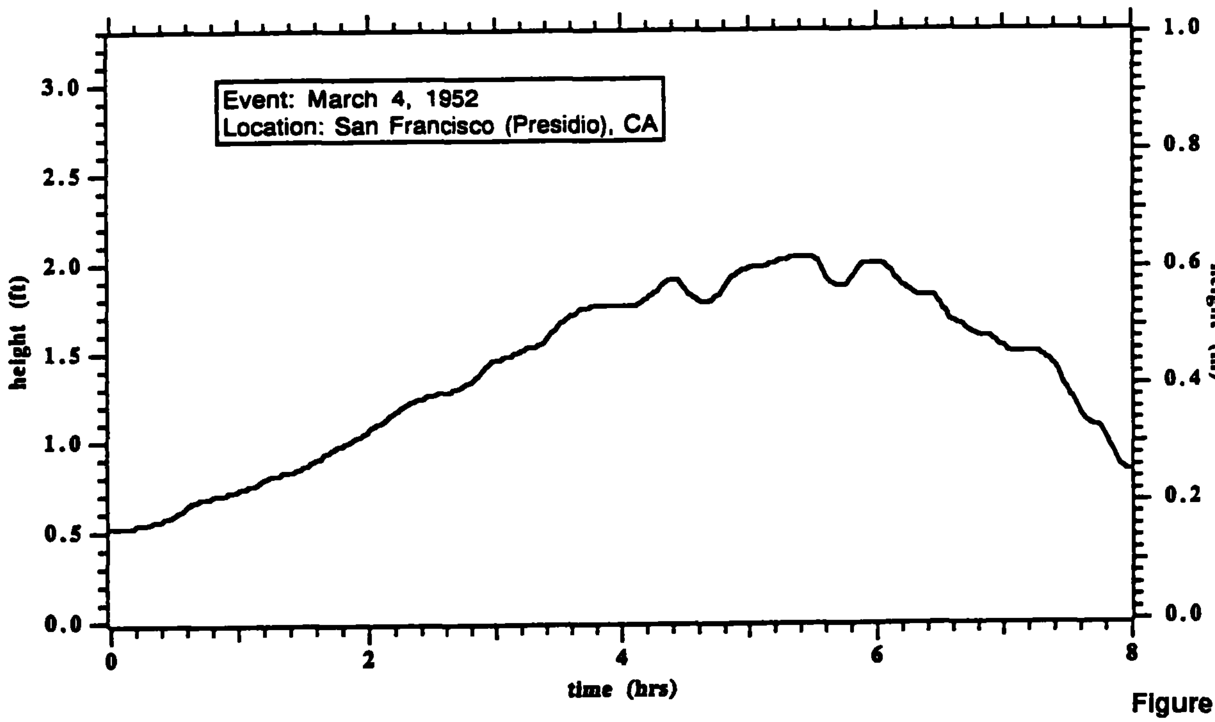


Figure 86.

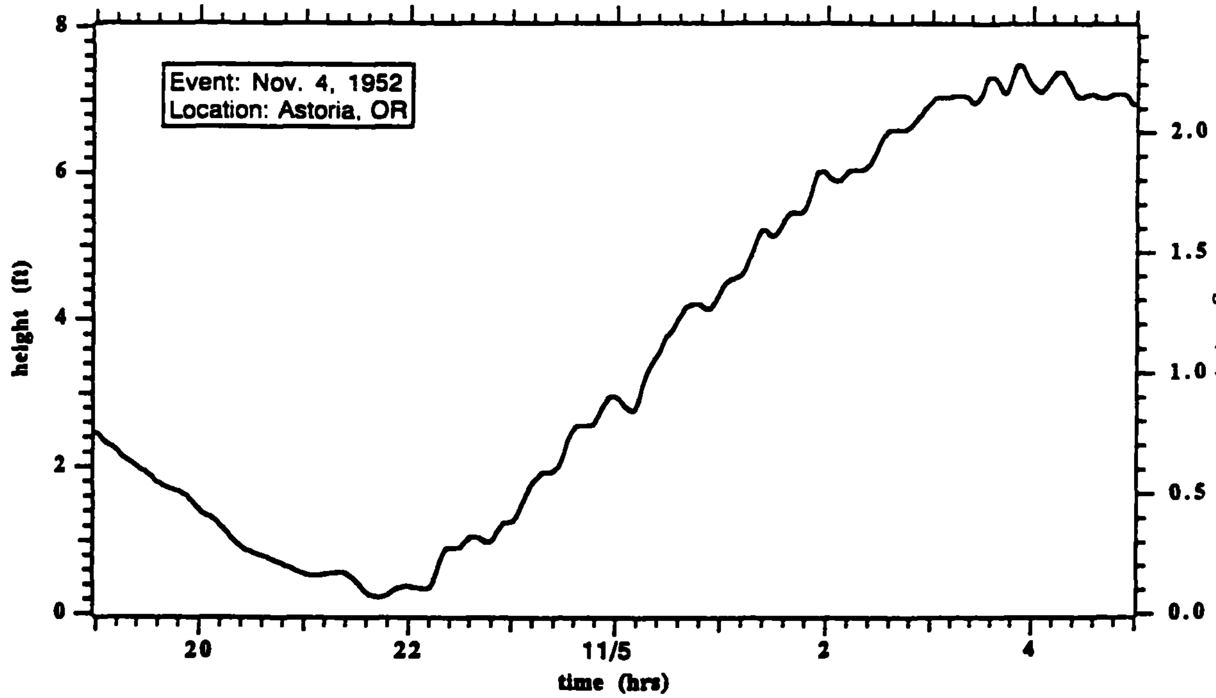


Figure 87.

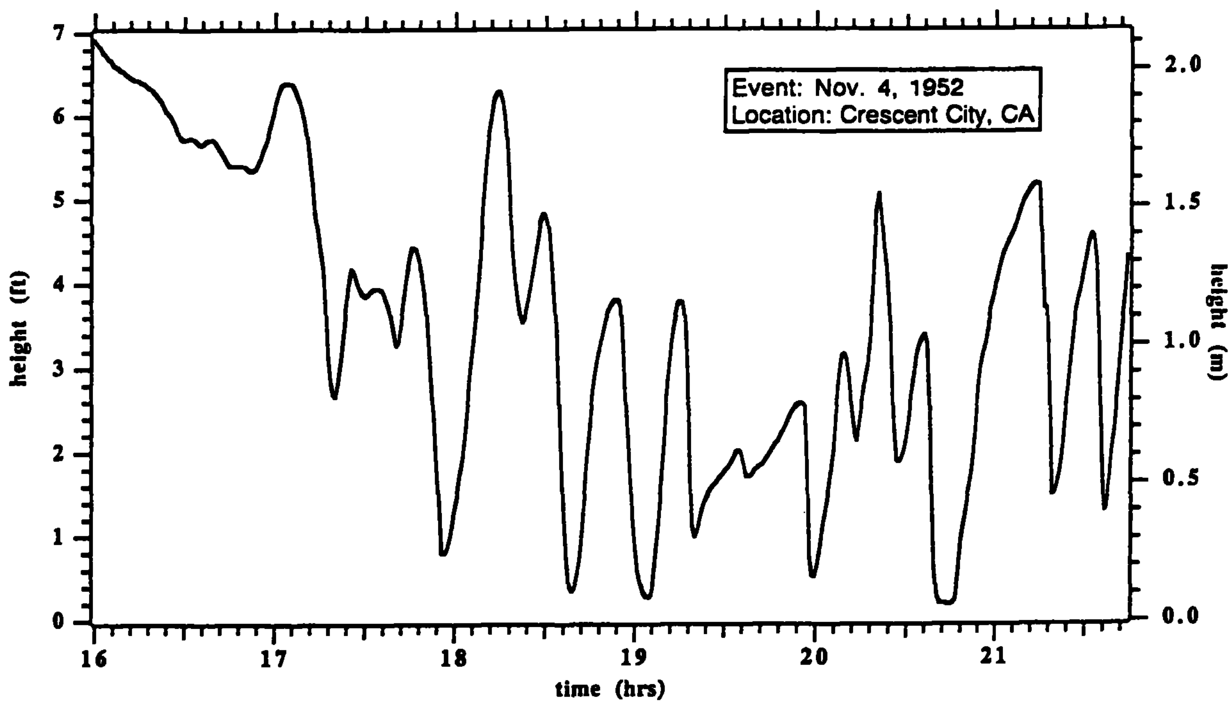


Figure 88.

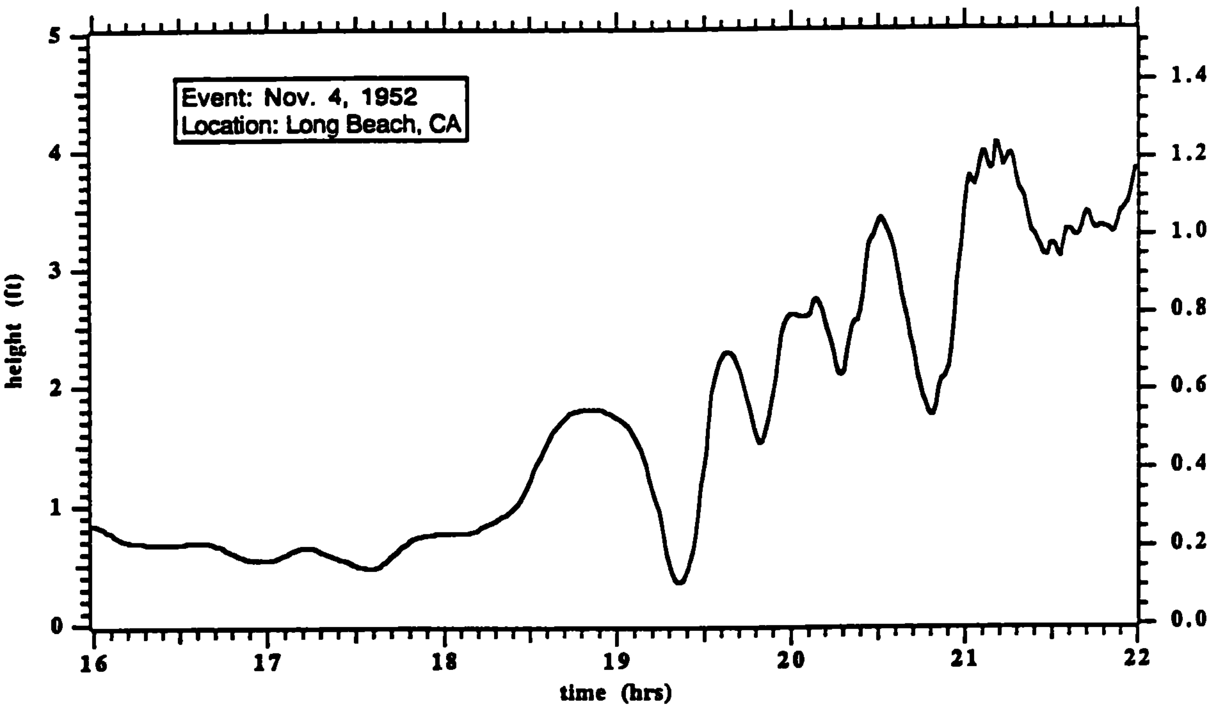


Figure 89.

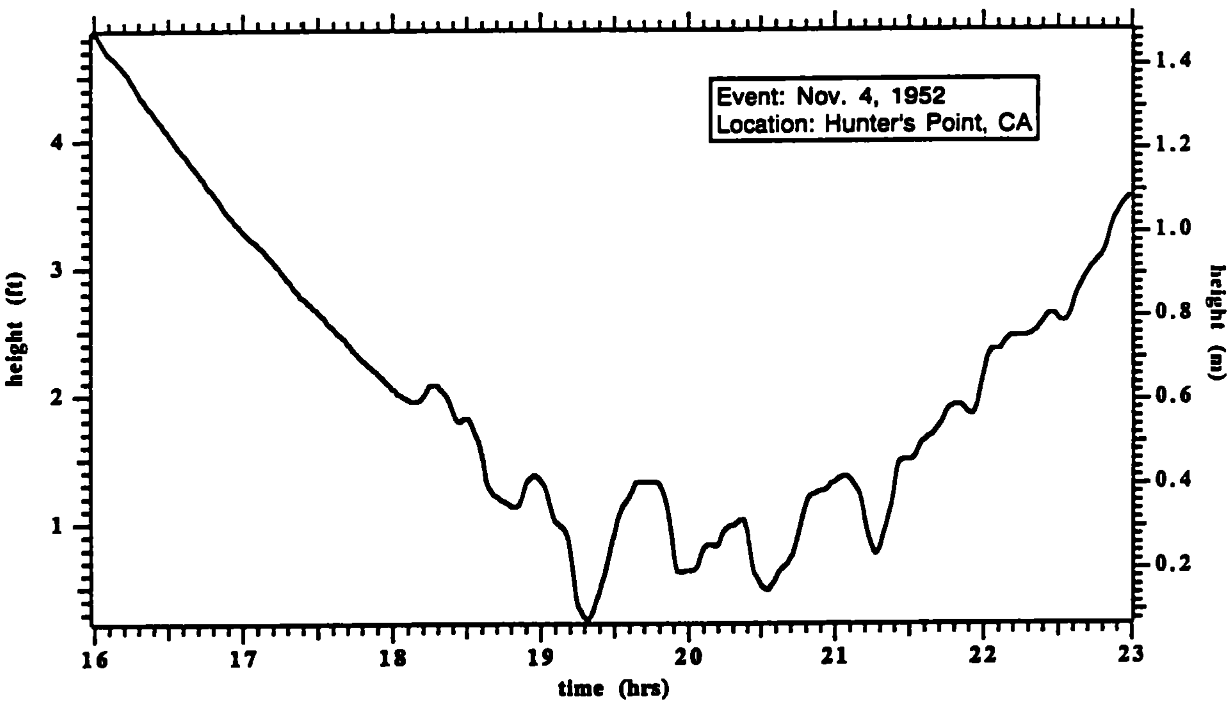


Figure 90.

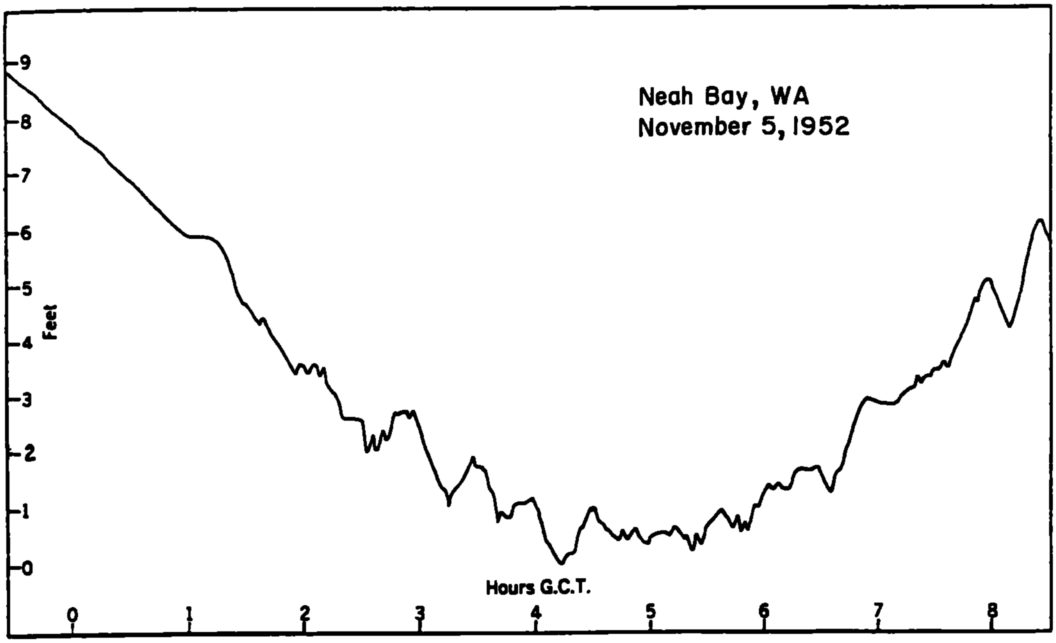
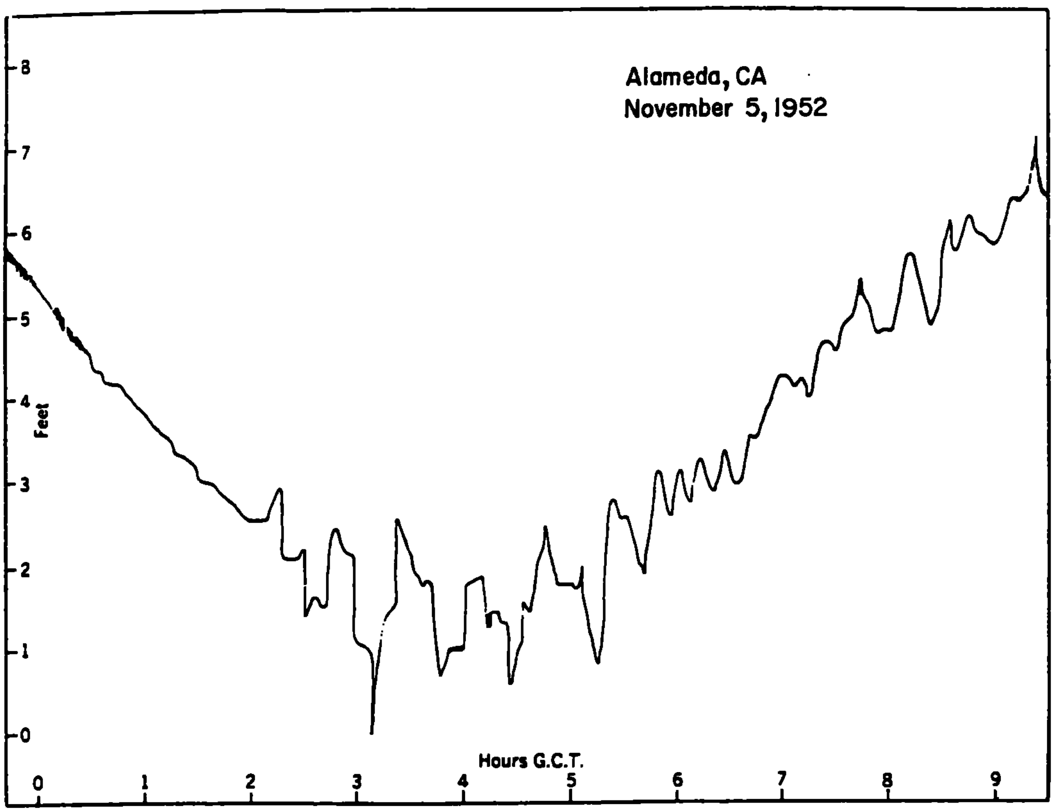


Figure 91.



Zerbe (1953)

Figure 92.

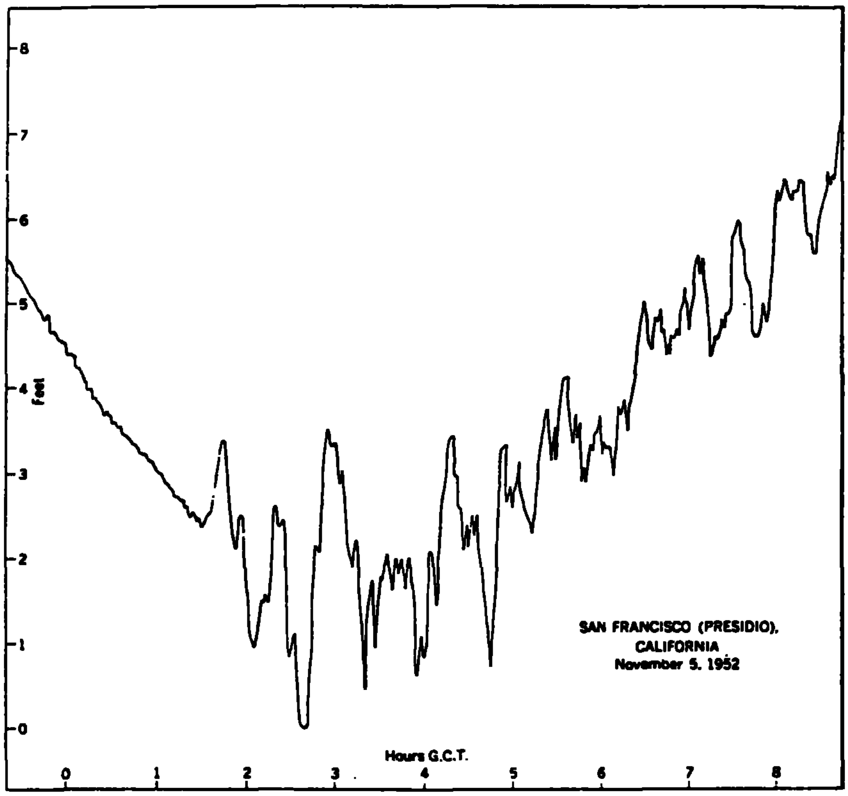
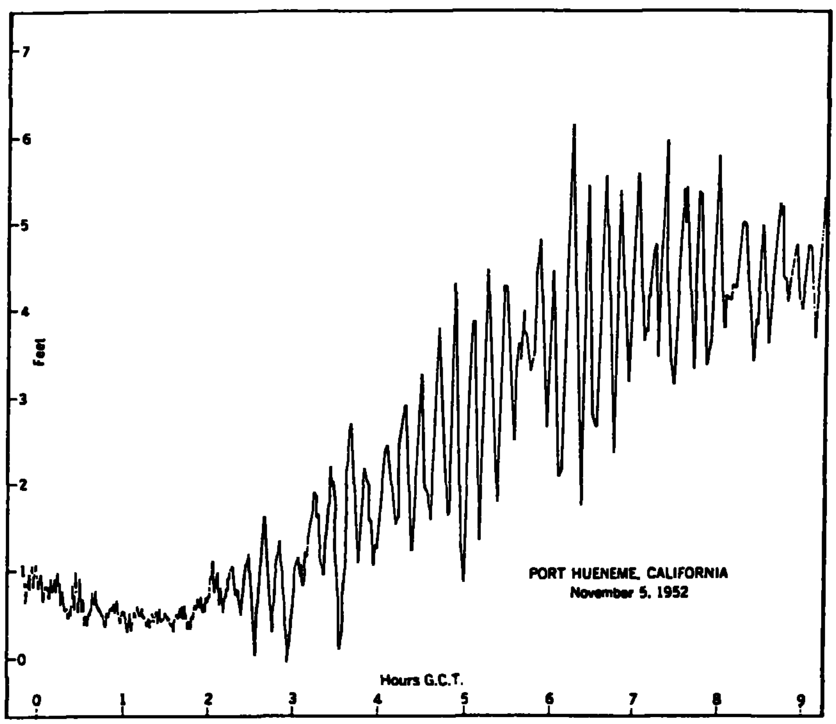


Figure 93.



Zerbe (1953)

Figure 94.

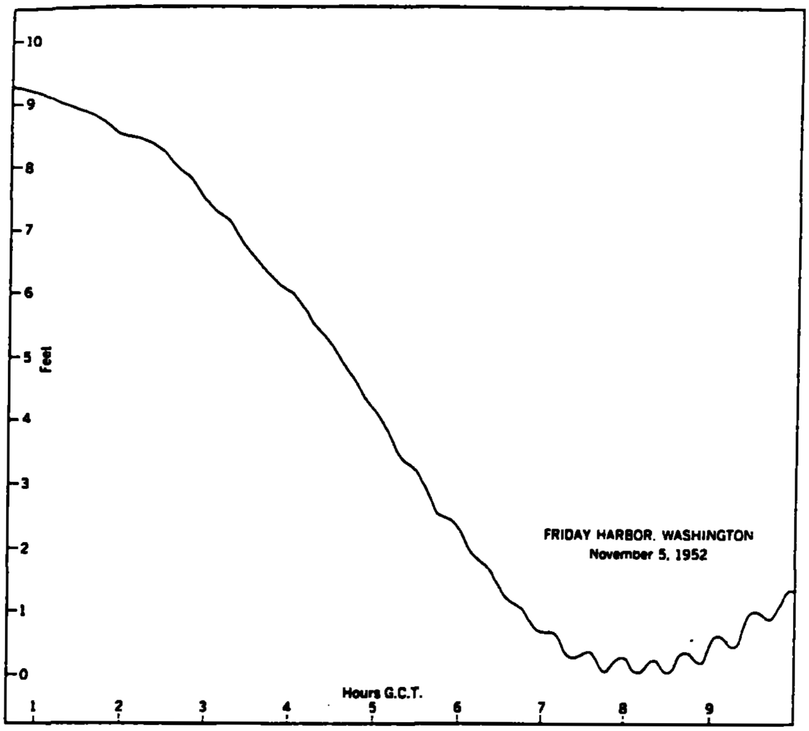
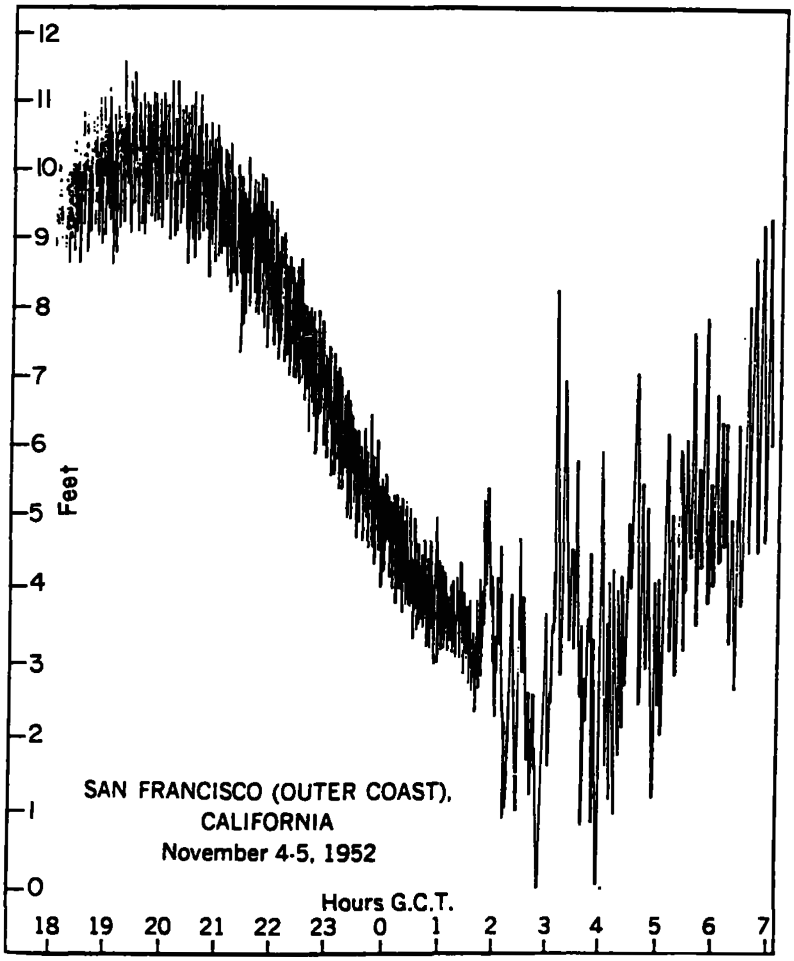


Figure 95.



Zerbe (1953)

Figure 96.

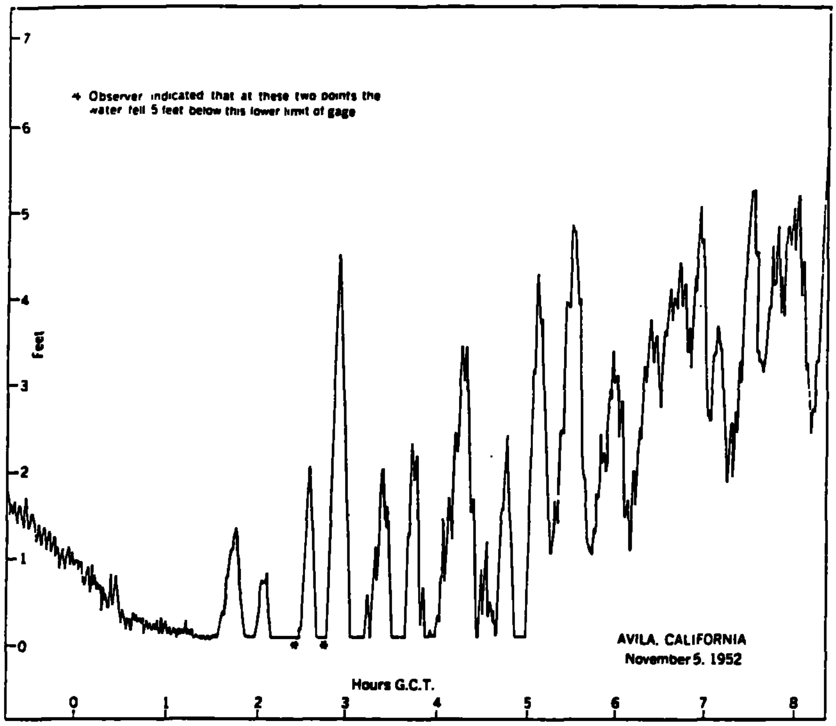
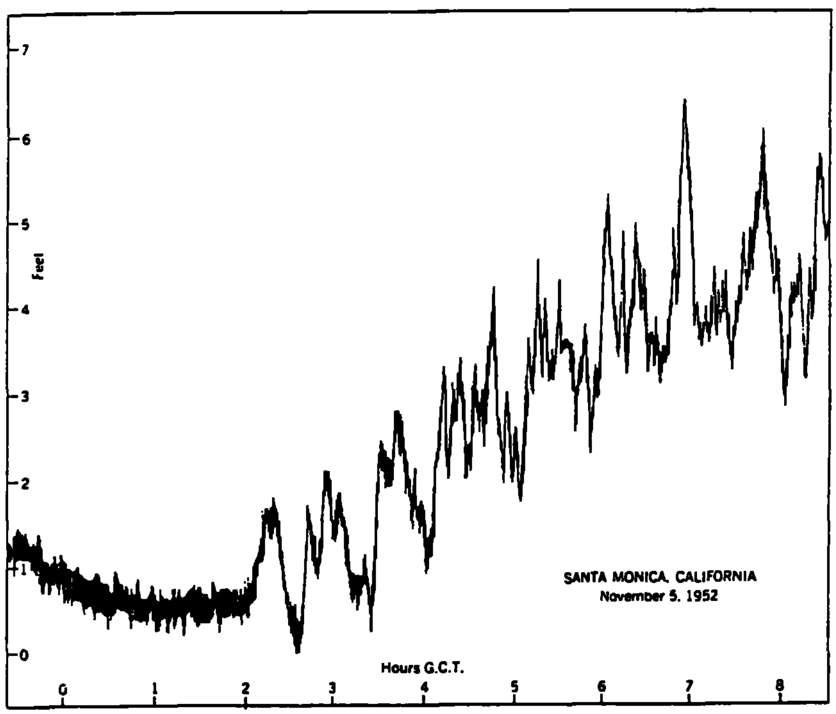


Figure 97.



Zerbe (1953)

Figure 98.

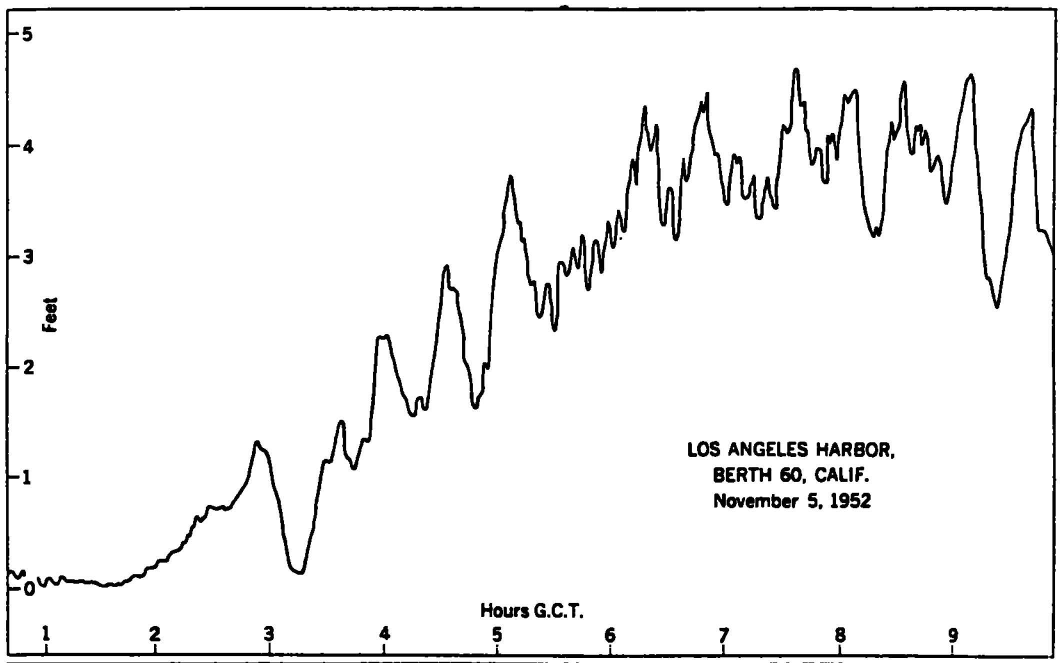
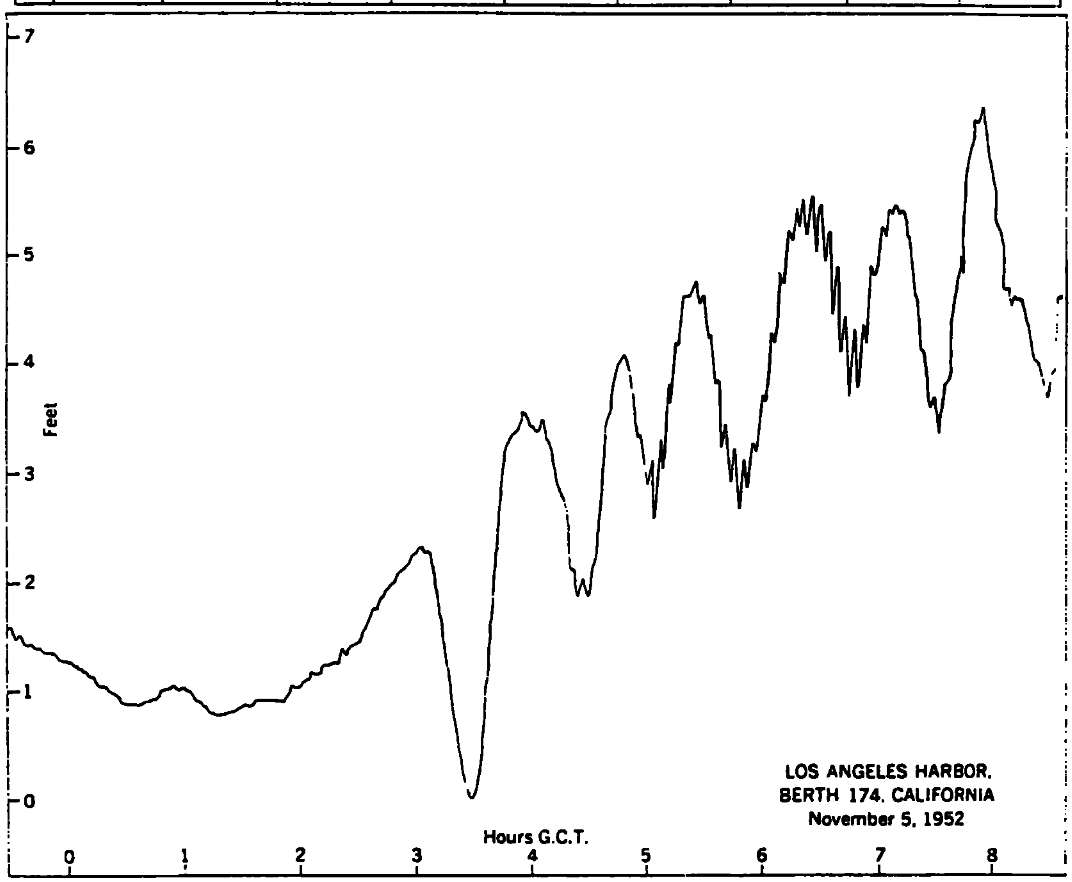


Figure 99.



Zerbe (1953)

Figure 100.

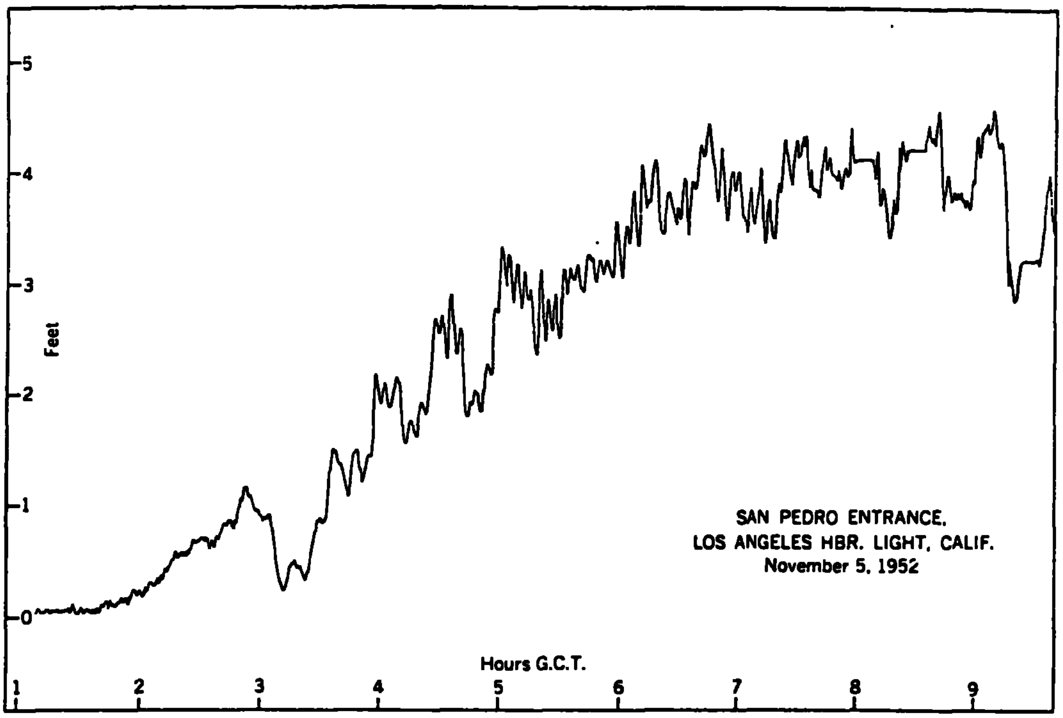
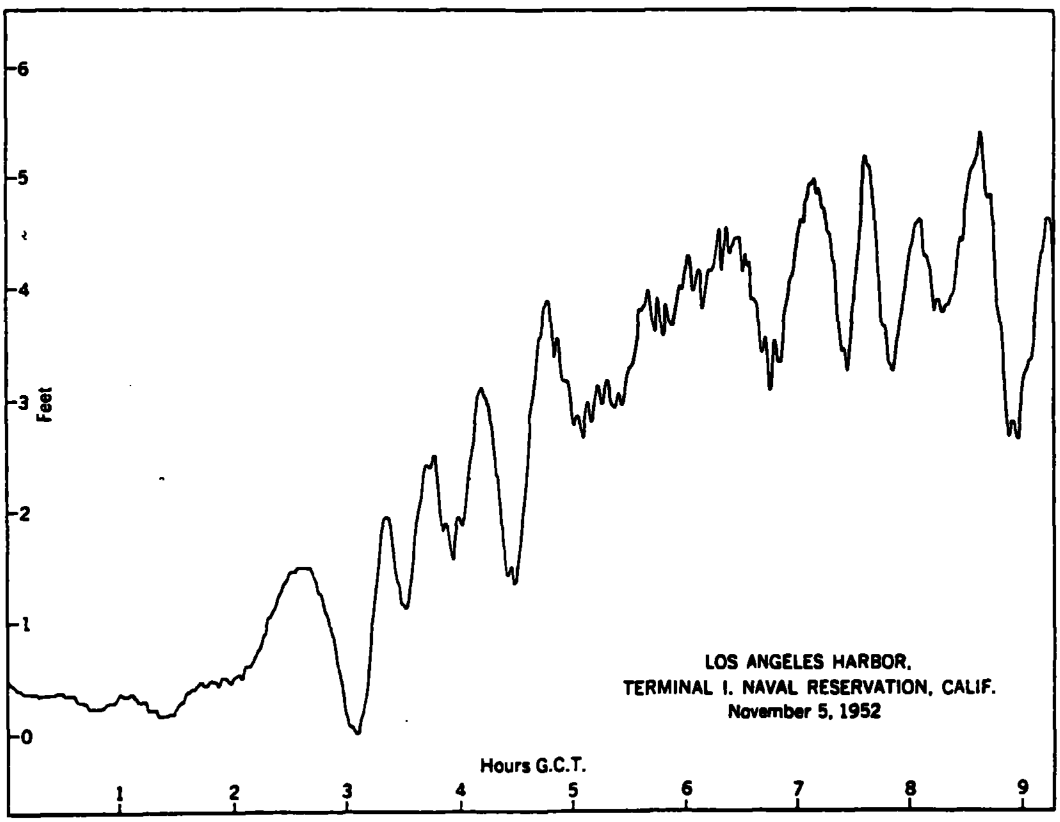


Figure 101.



Zerbe (1953)

Figure 102.

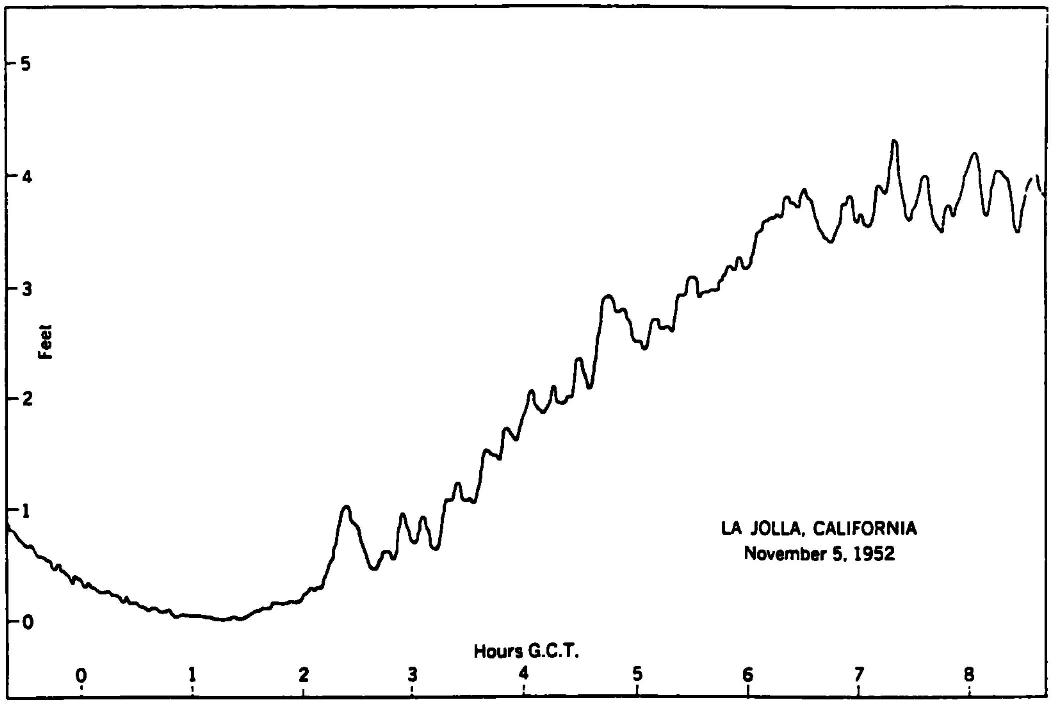
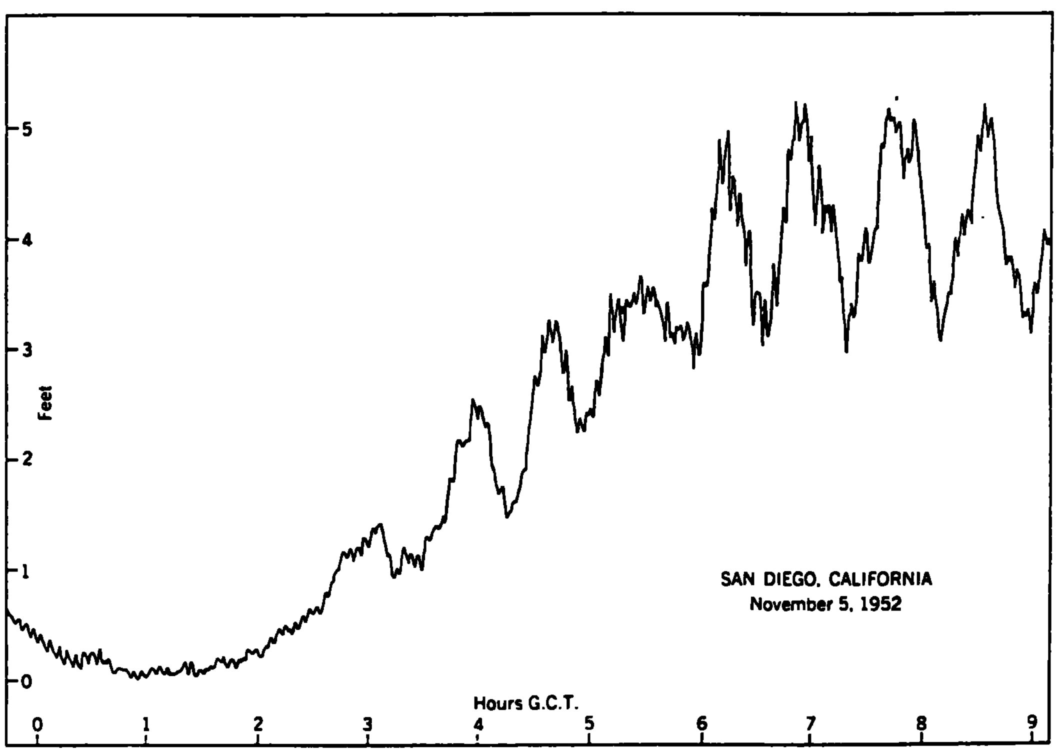


Figure 103.



Zerbe (1953)

Figure 104.

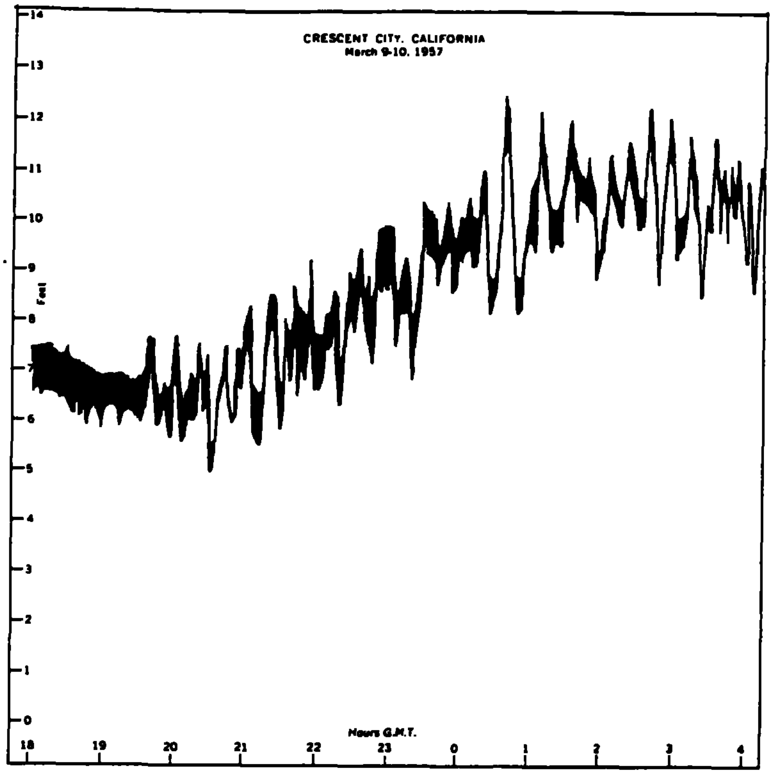
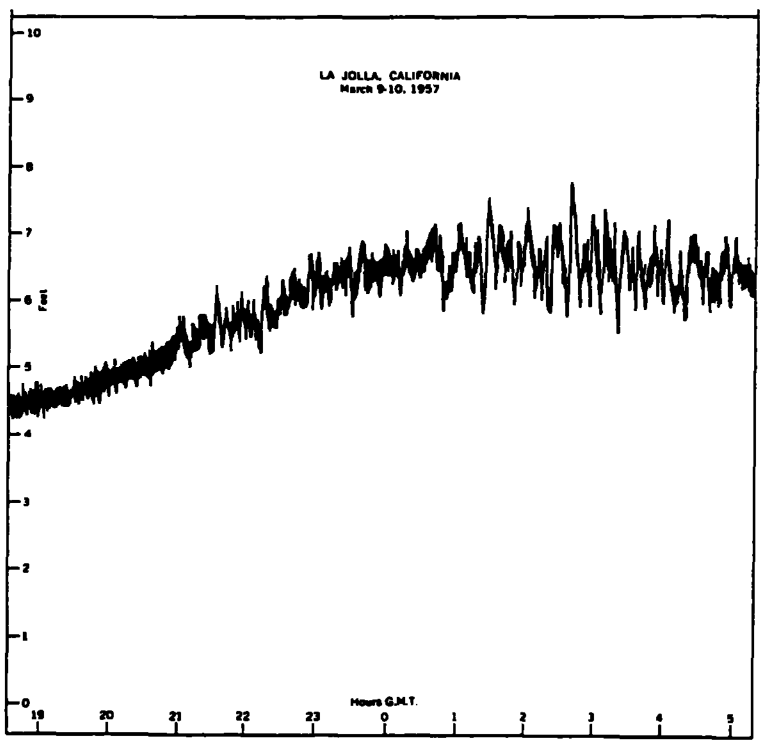
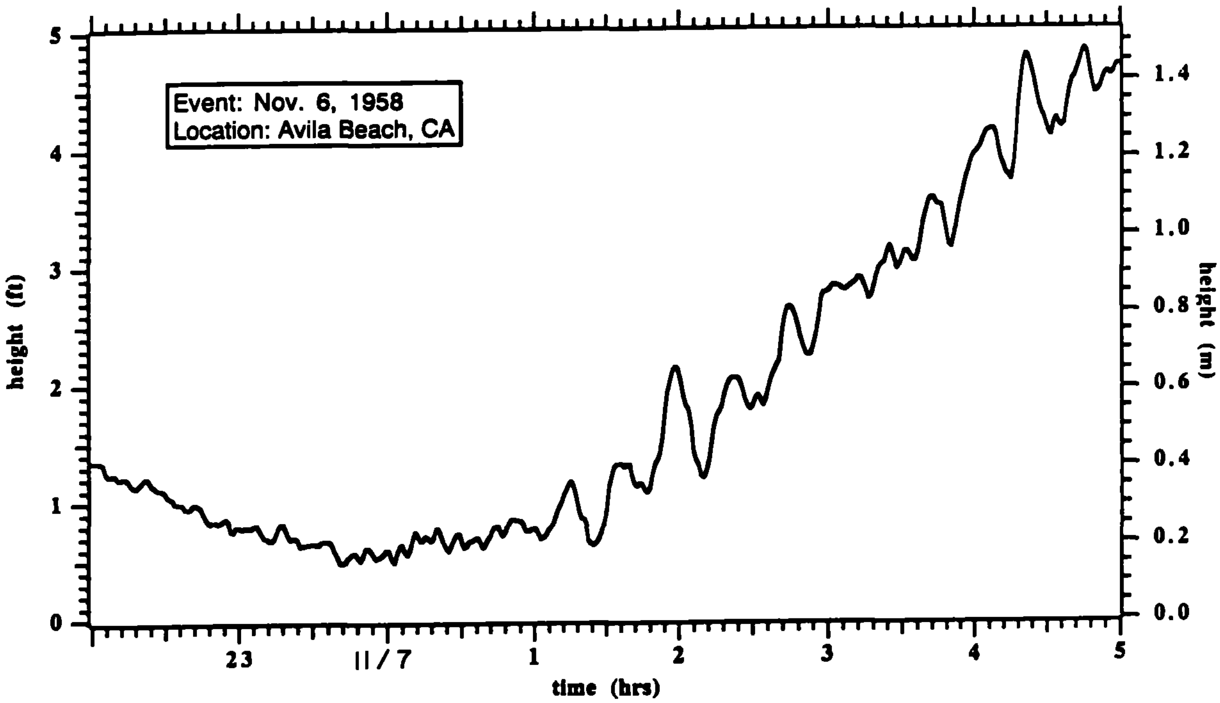


Figure 105.



From Salsman (1959)

Figure 106.



Event: Nov. 6, 1958
Location: Avila Beach, CA
height (ft)
height (m)
time (hrs)
5
4
3
2
1
0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
23
11/7
1
2
3
4
5

Figure 107.

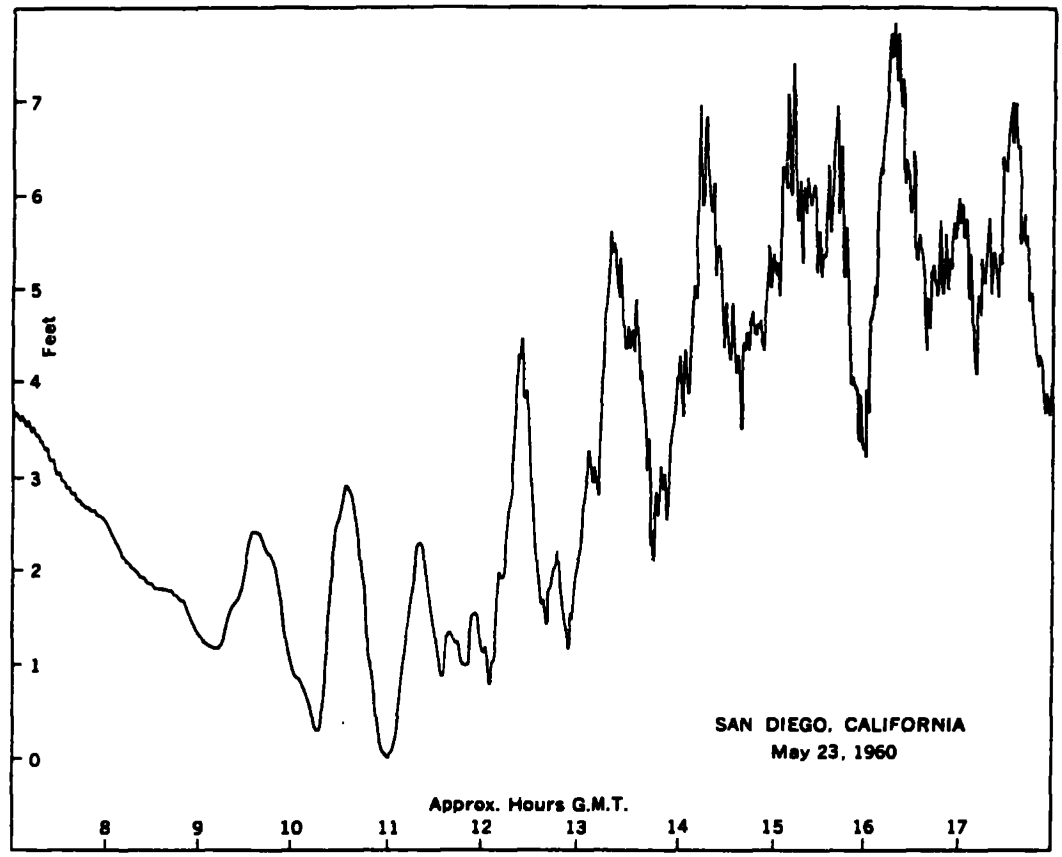
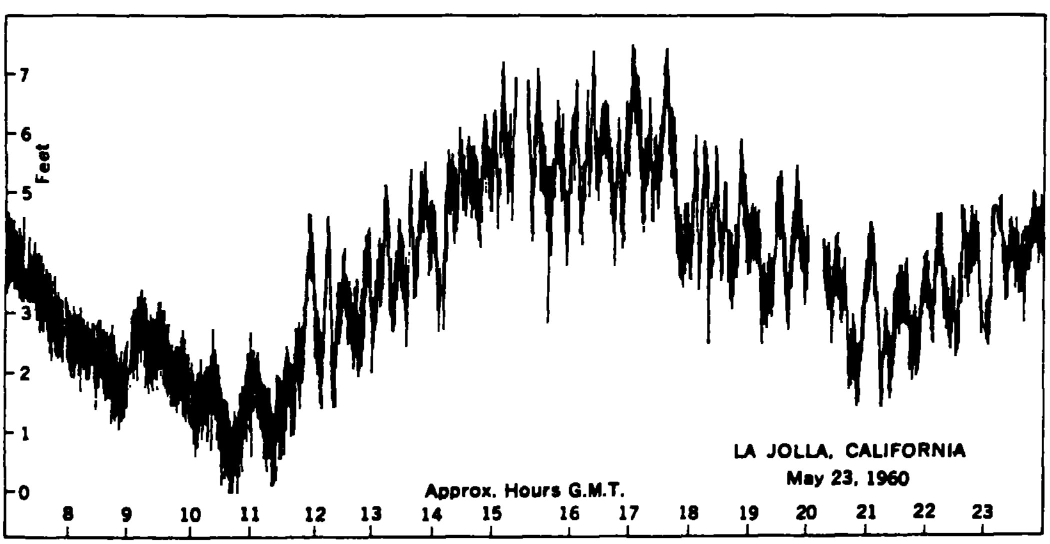


Figure 108.



Berkman and Symons (1964)

Figure 109.

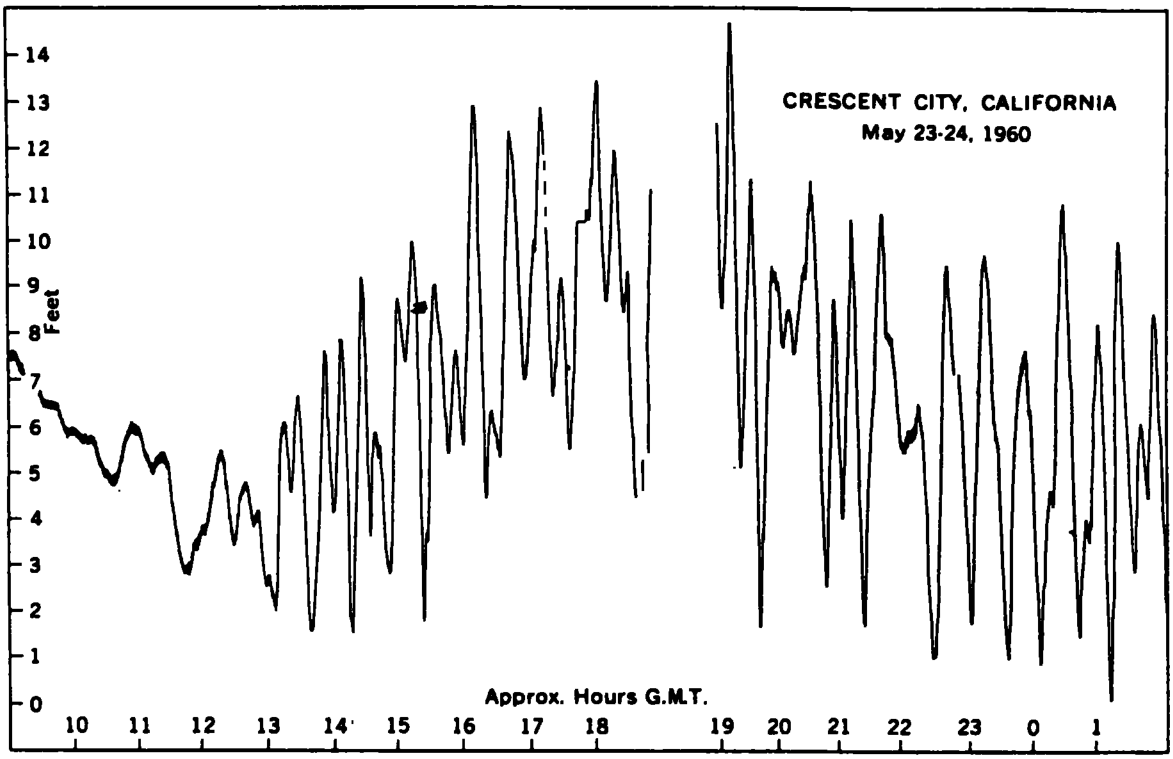

CRESCENT CITY, CALIFORNIA
May 23-24, 1960
Feet
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Approx. Hours G.M.T.
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
1

Figure 110.

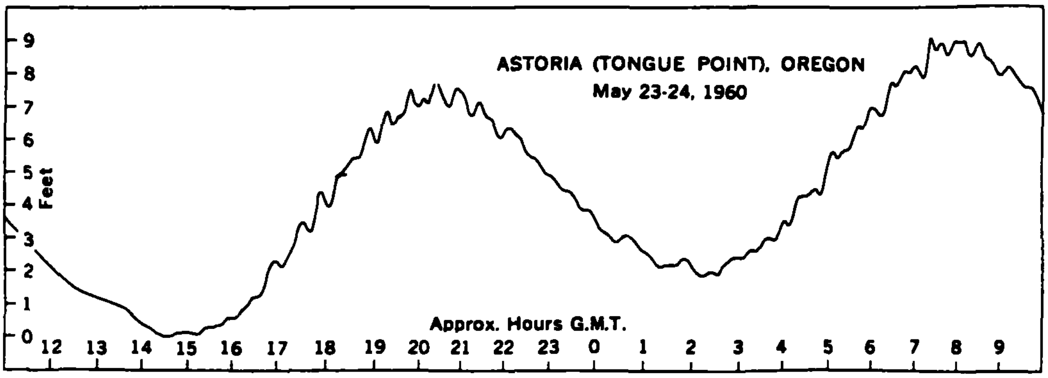


Figure 111.

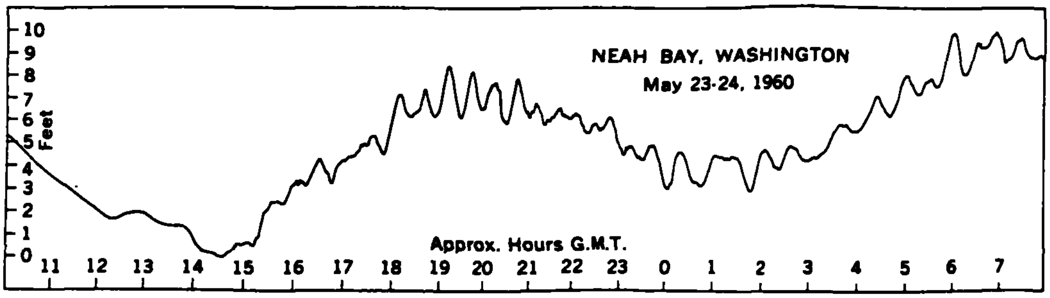
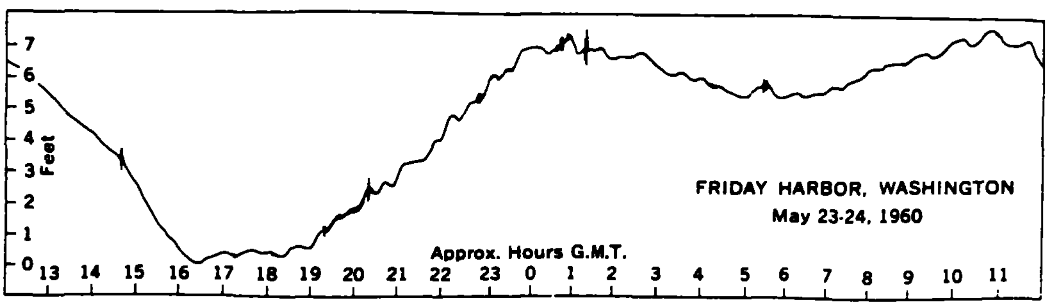


Figure 112.



Berkman and Symons (1964)

Figure 113.

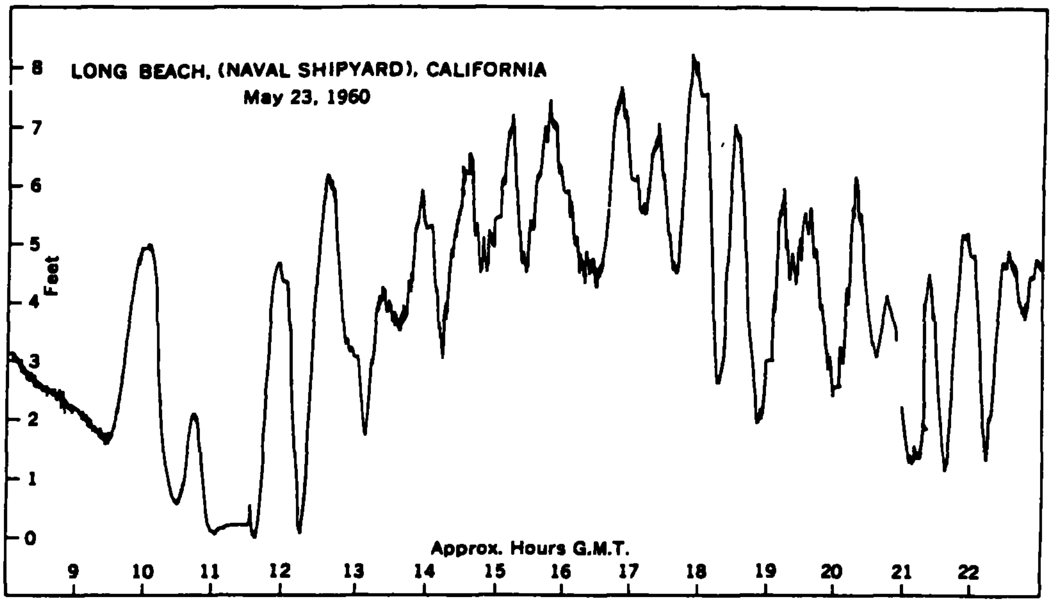
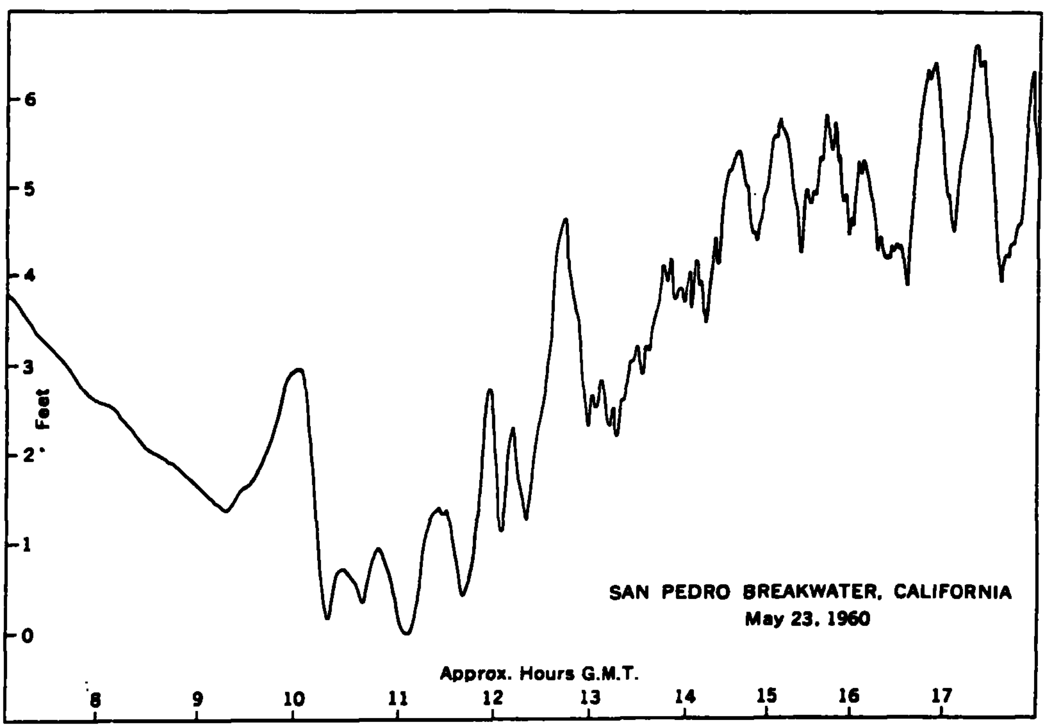


Figure 114.



Berkman and Symons (1964)

Figure 115.

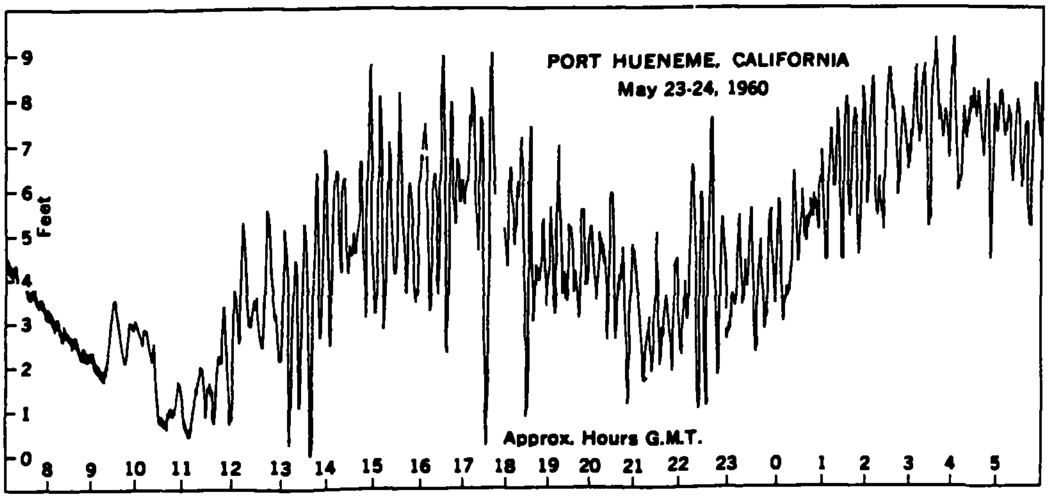


Figure 116.

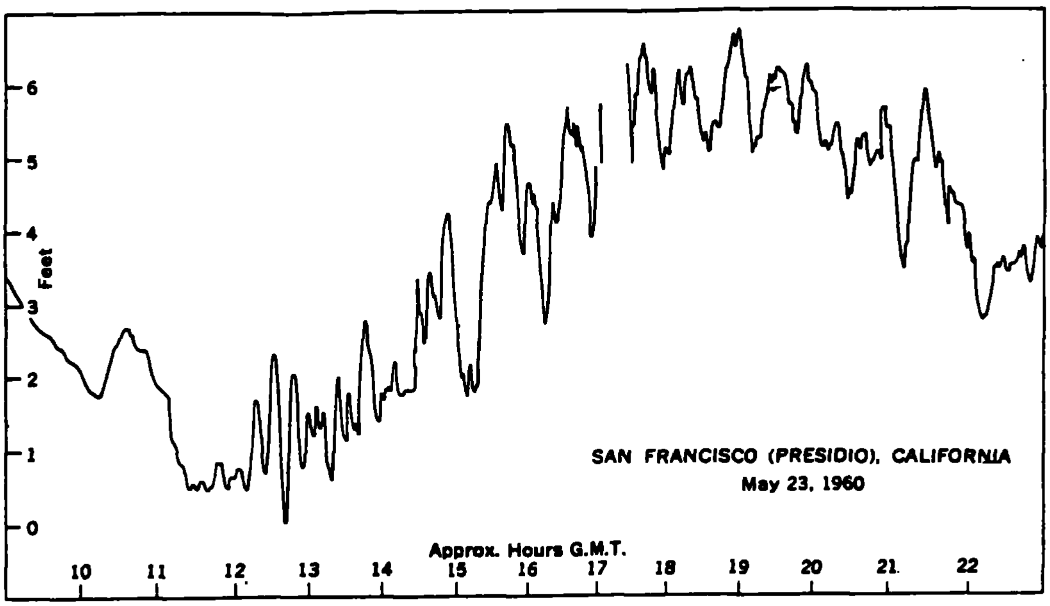
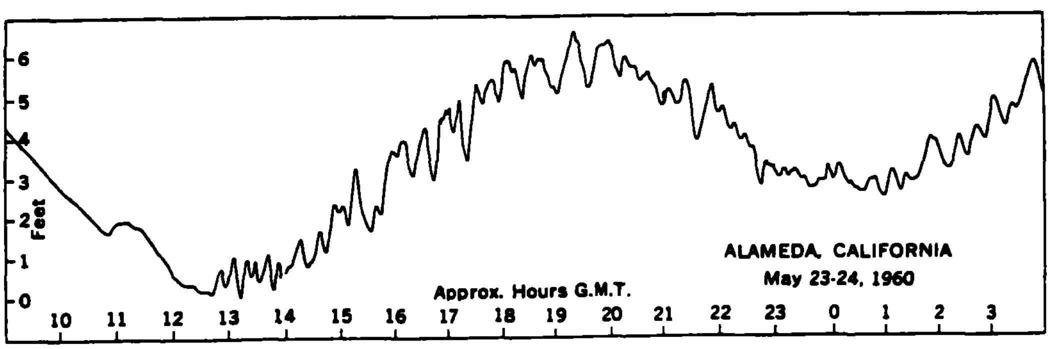


Figure 117.



Berkman and Symons (1964)

Figure 118.

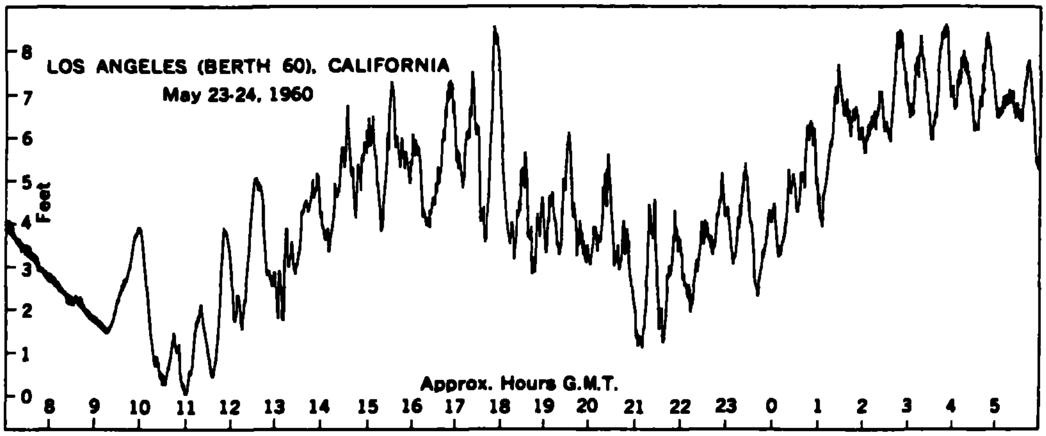
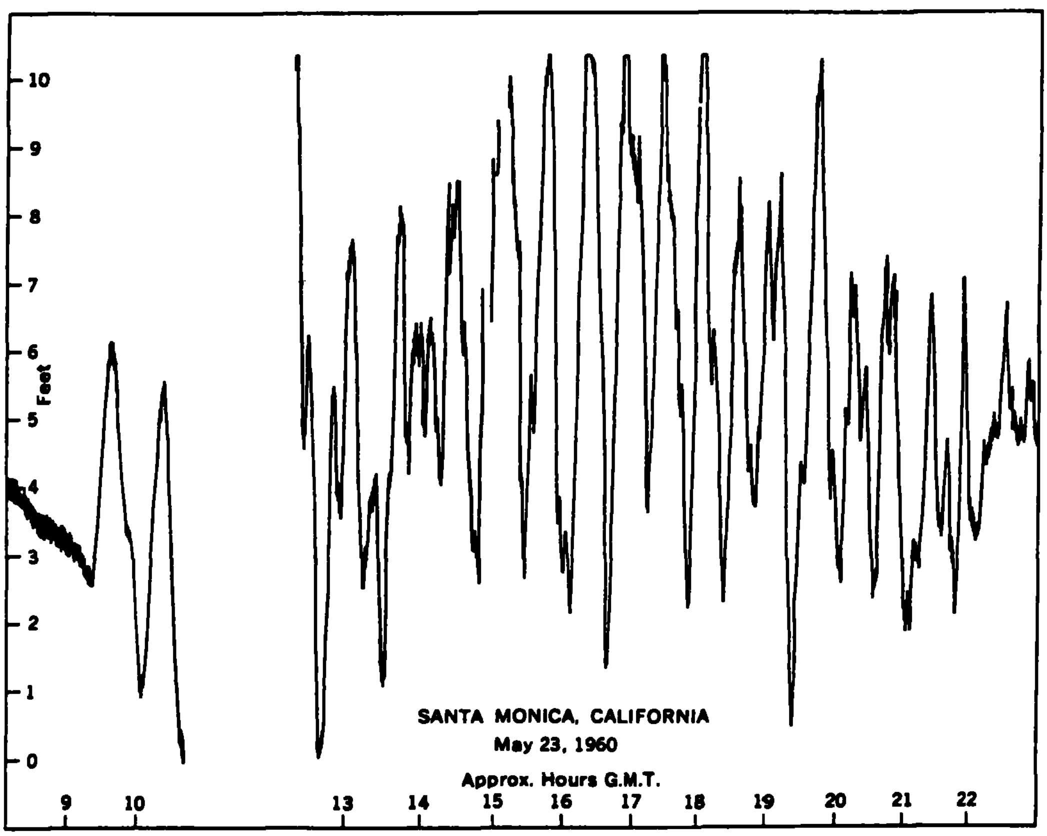


Figure 119.



Berkman and Symons (1964)

Figure 120.

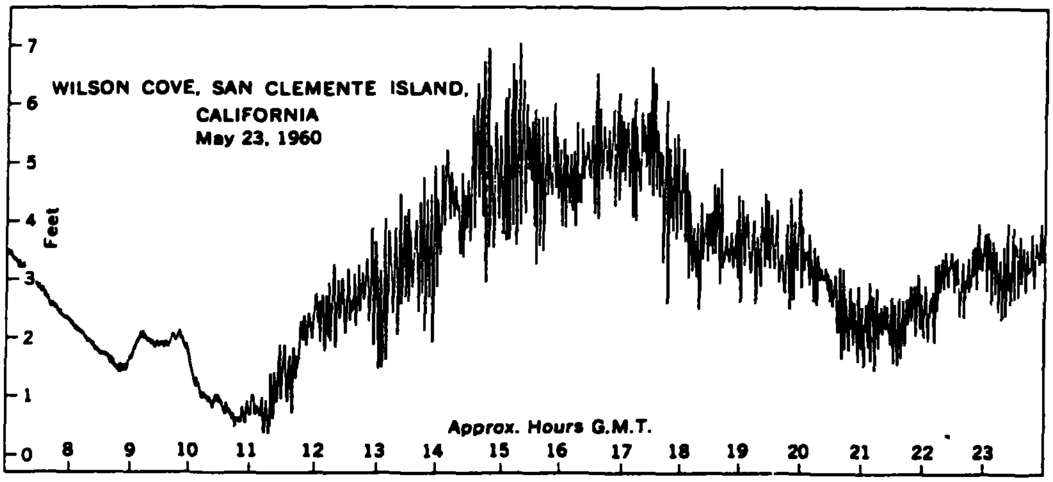


Figure 121.

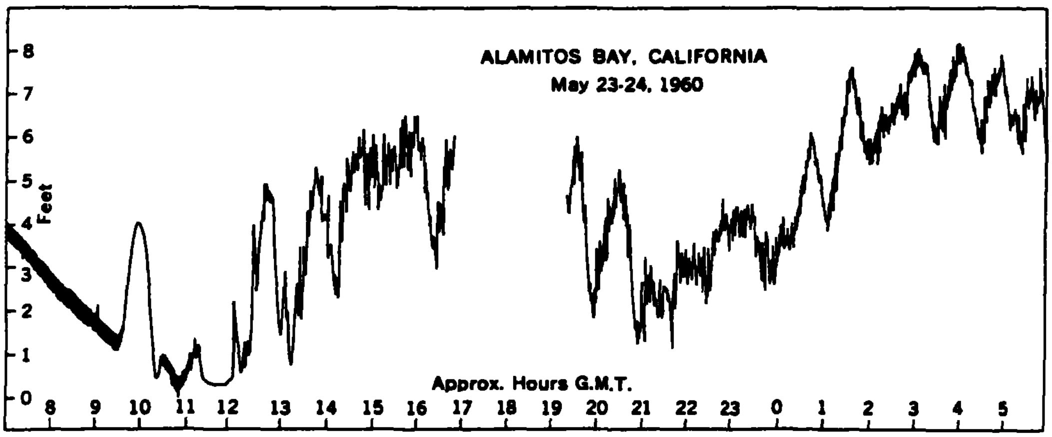
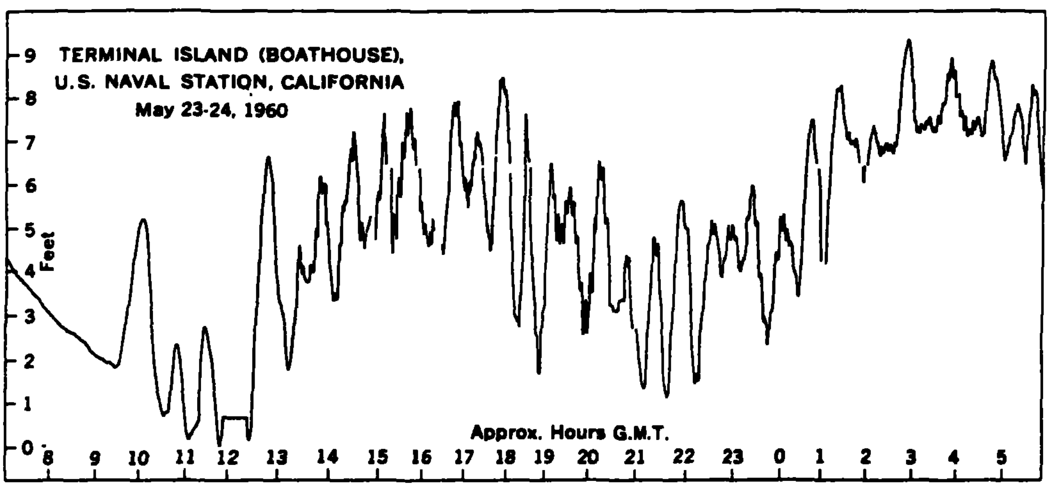


Figure 122.



Berkman and Symons (1964)

Figure 123.

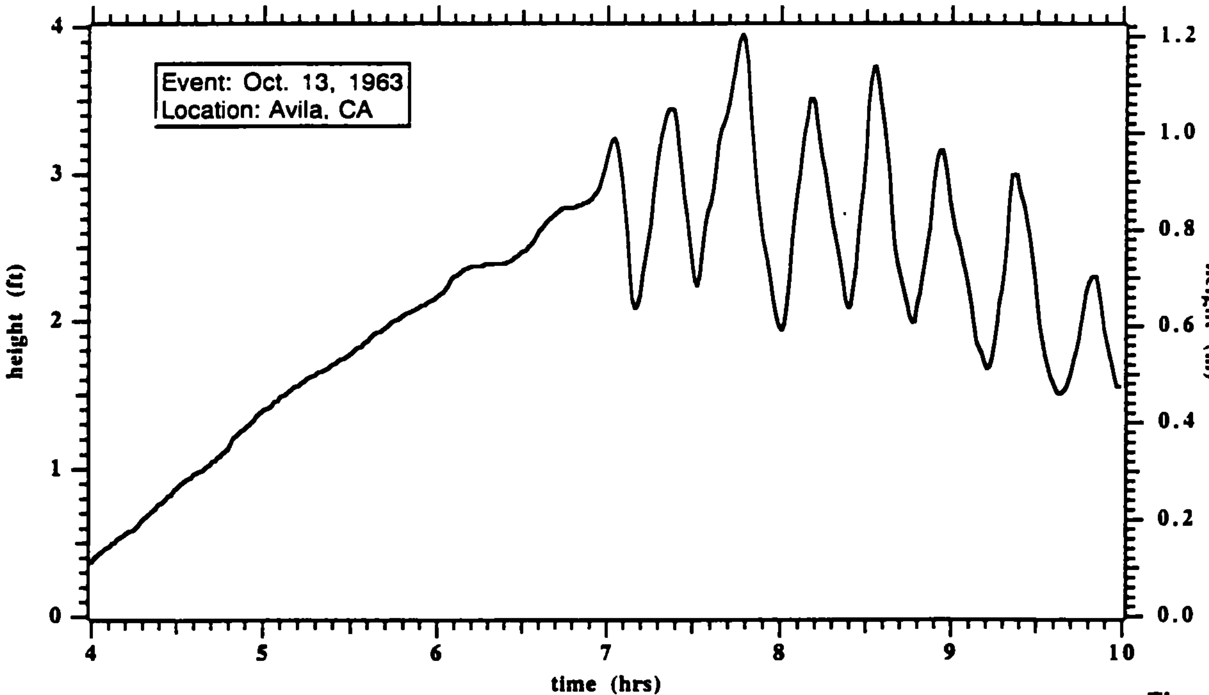
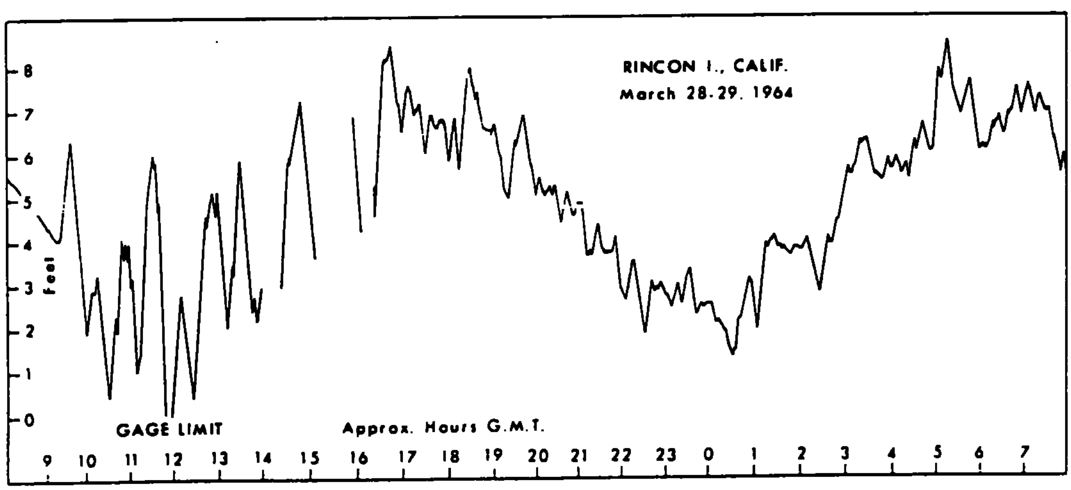


Figure 124.



Spaeth and Berkman (1972)

Figure 125.

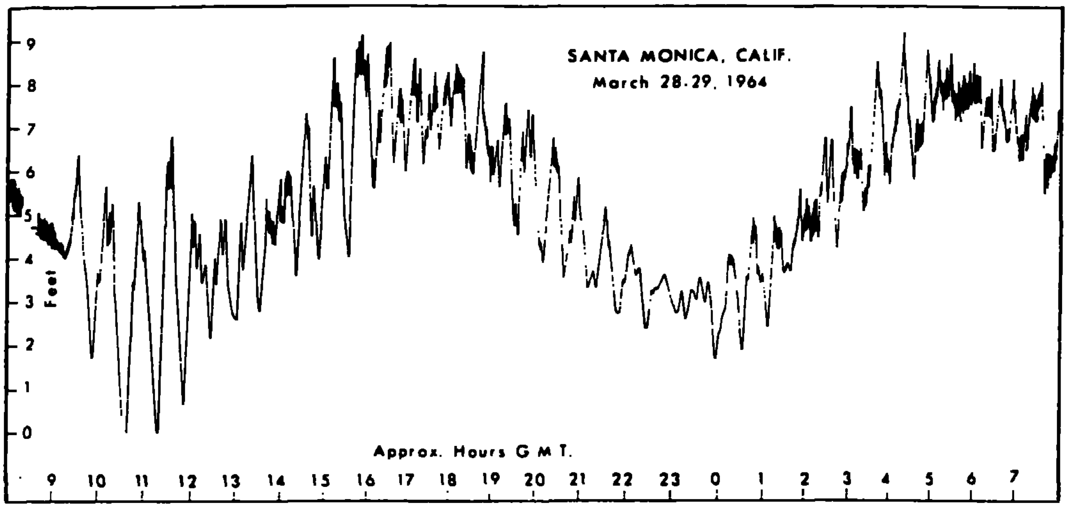


Figure 126.

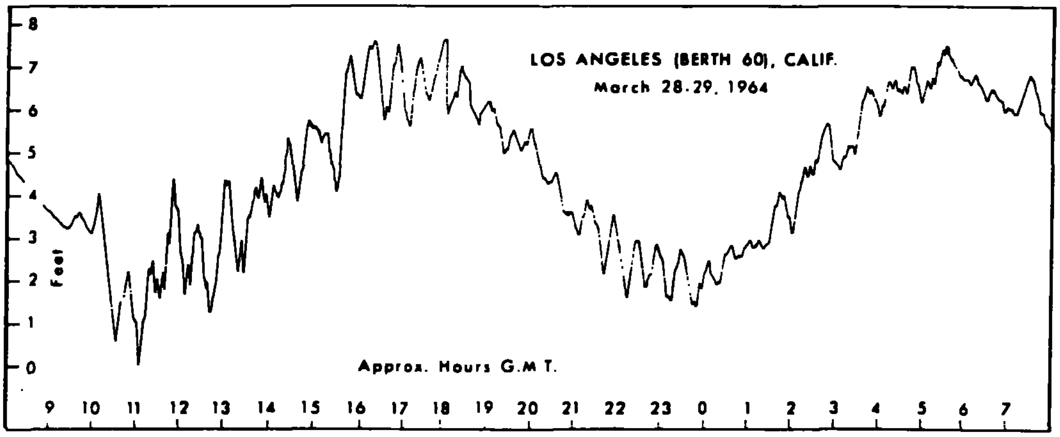
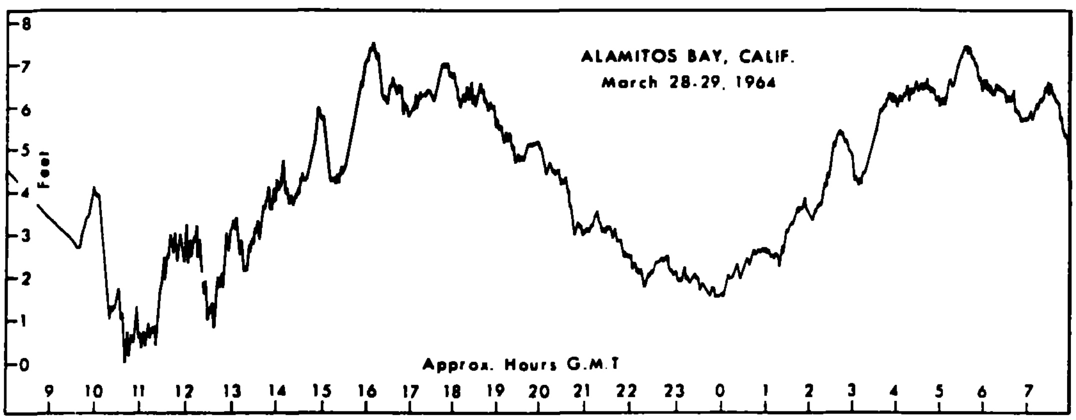


Figure 127.



Spaeth and Berkman (1972)

Figure 128.

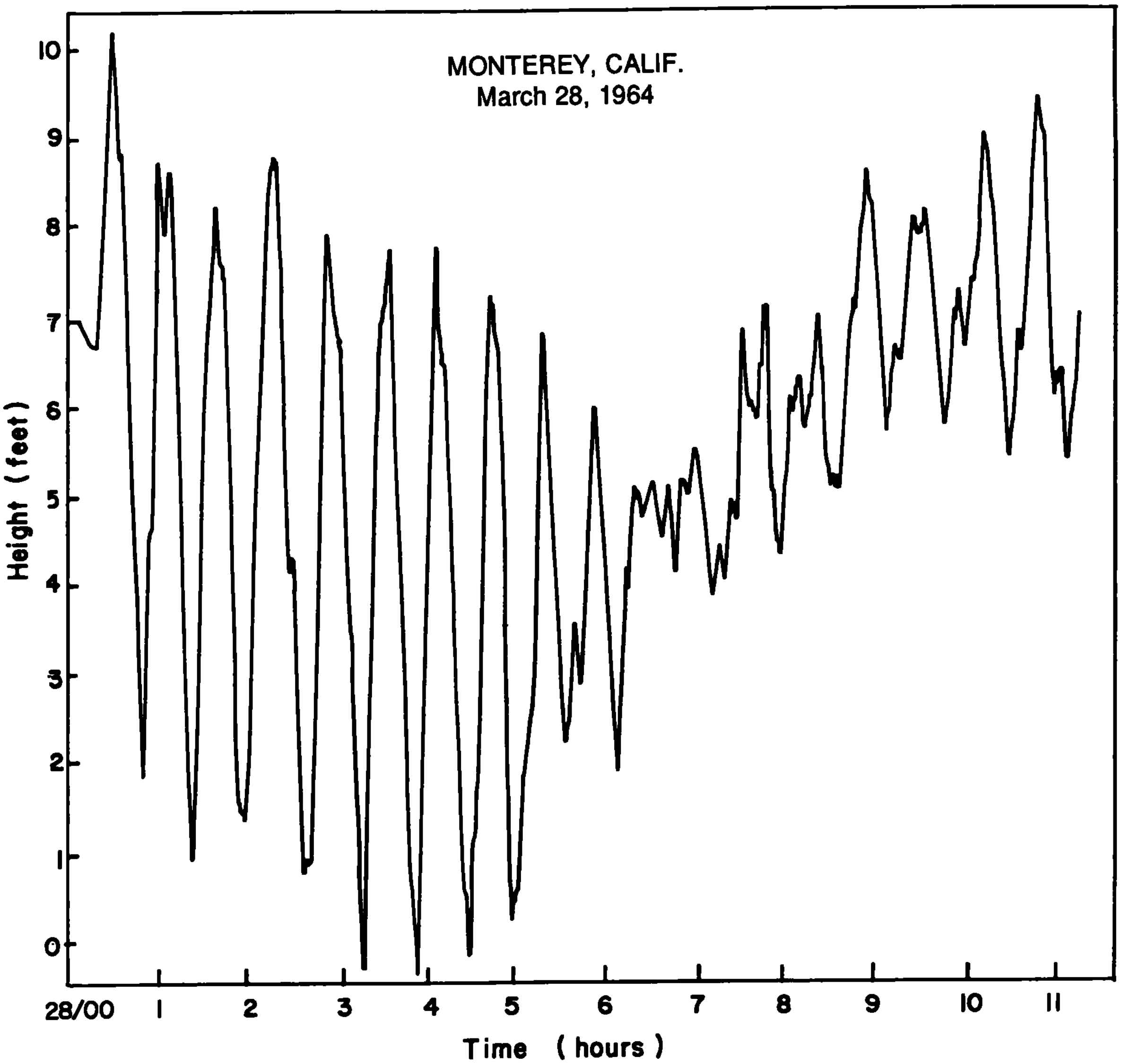

MONTEREY, CALIF.
March 28, 1964
Height (feet)
0
1
2
3
4
5
6
7
8
9
10
28/00
1
2
3
4
5
6
7
8
9
10
11
Time (hours)

Figure 129.

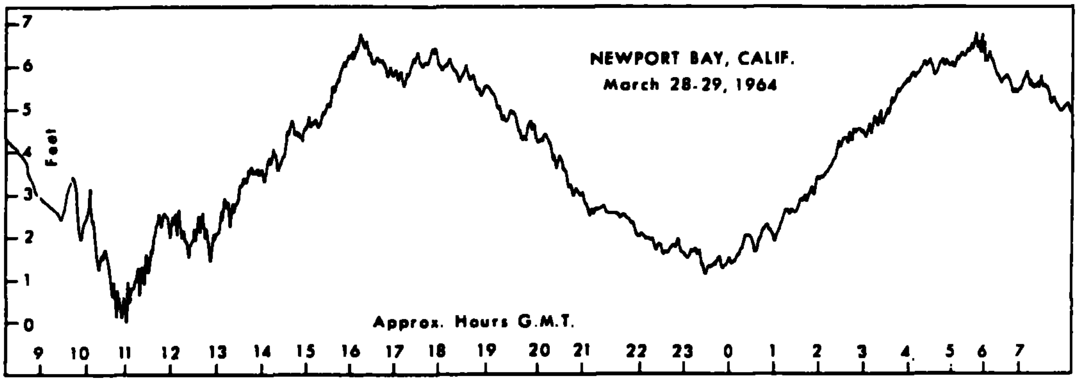


Figure 130.

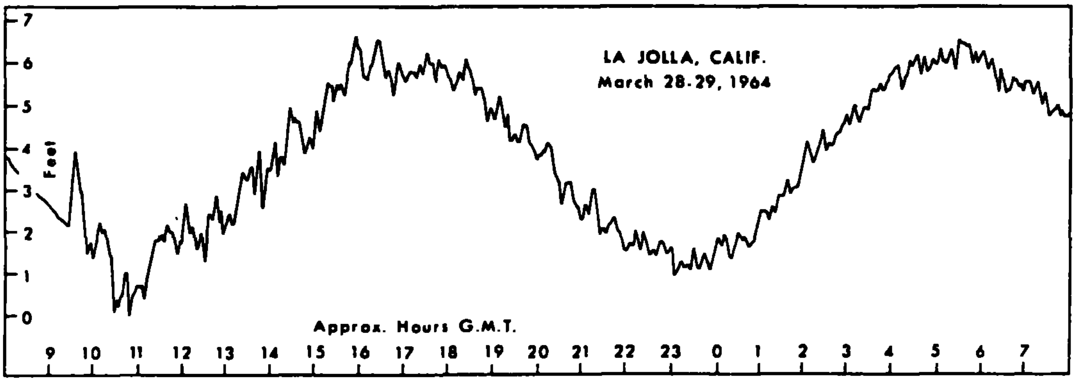
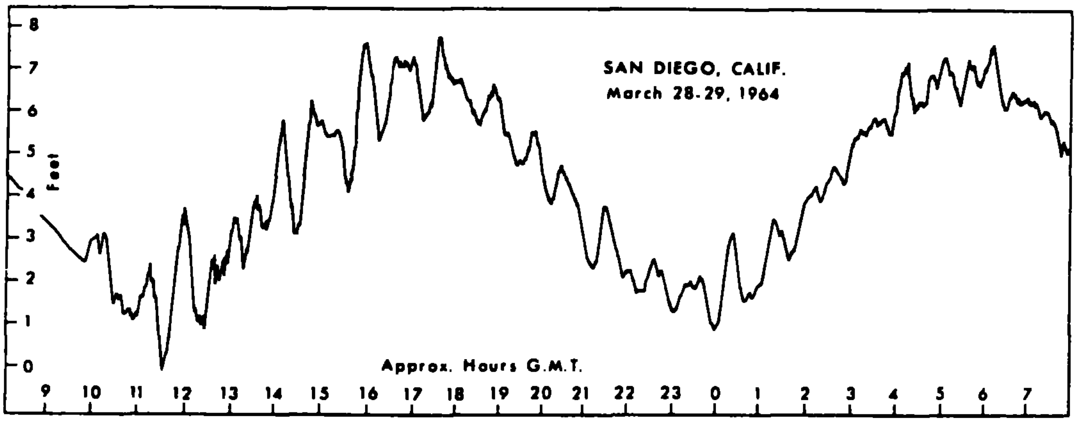


Figure 131.



Spaeth and Berkman (1972)

Figure 132.

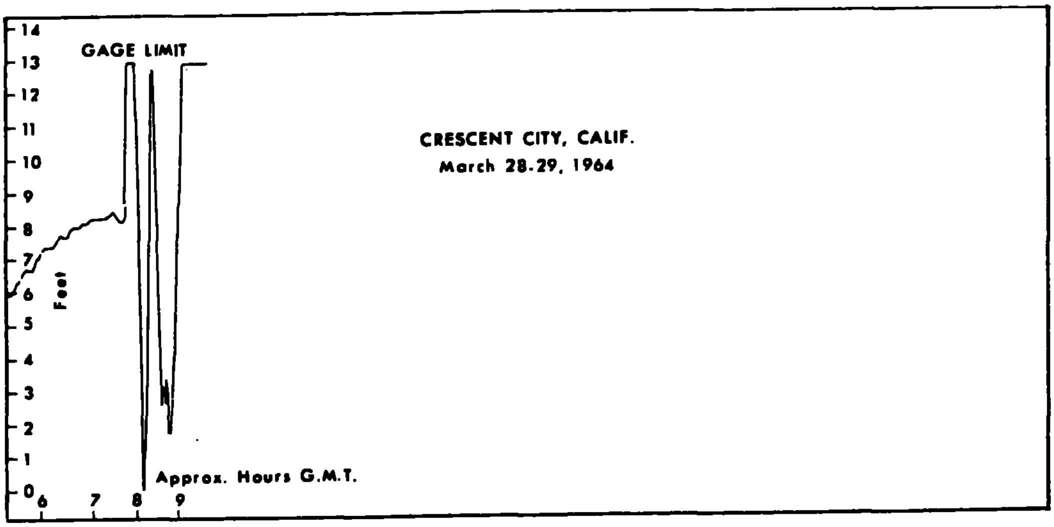


Figure 133.

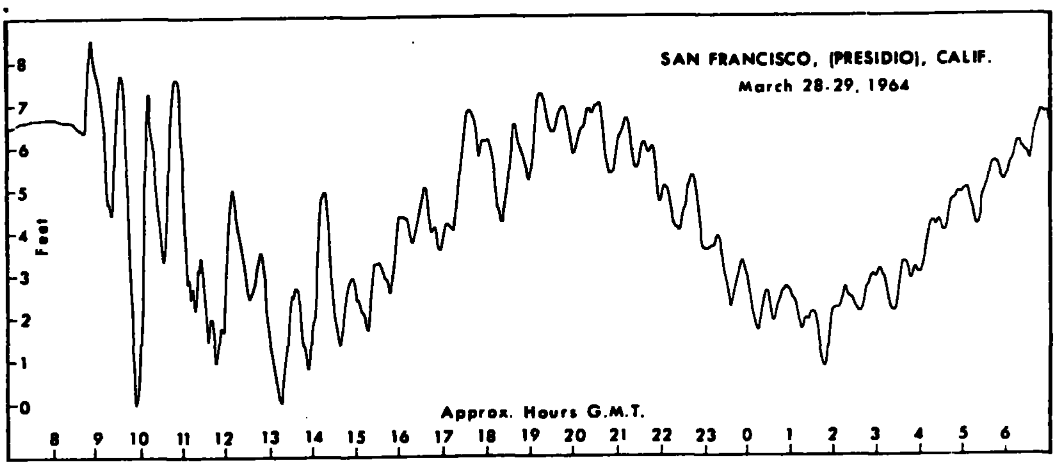
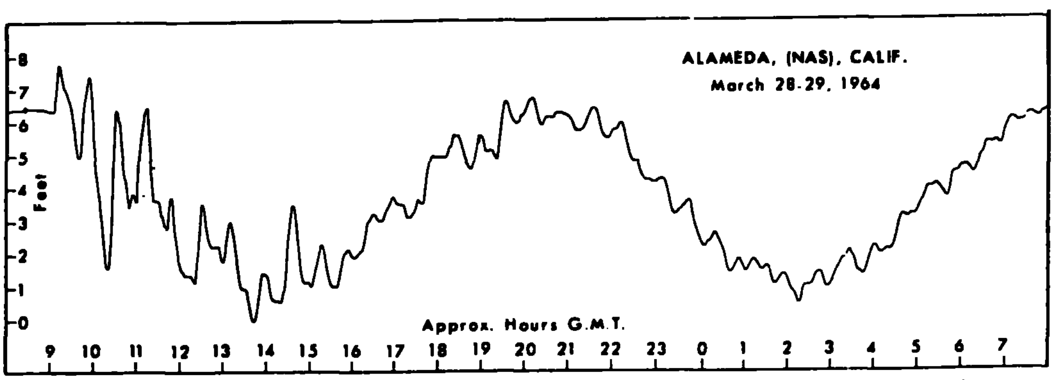


Figure 134.



Spaeth and Berkman (1972)

Figure 135.

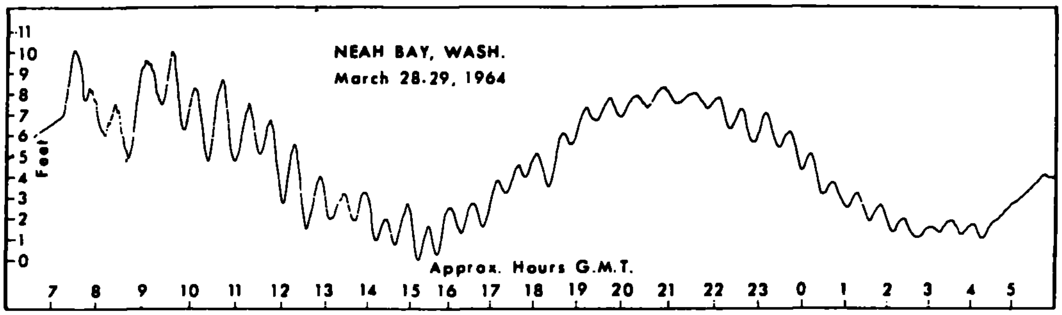


Figure 136.

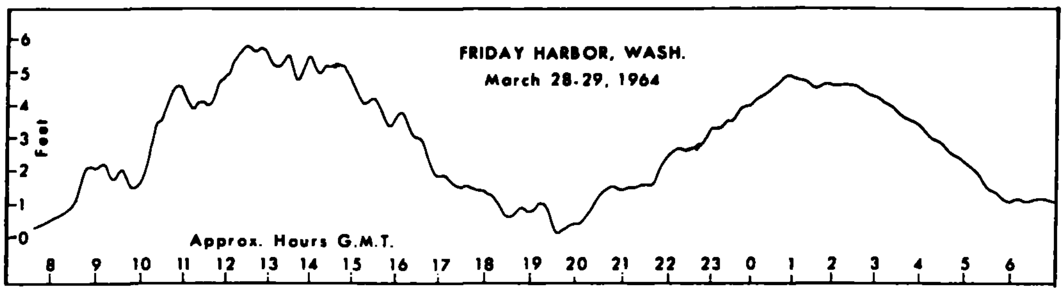


Figure 137.

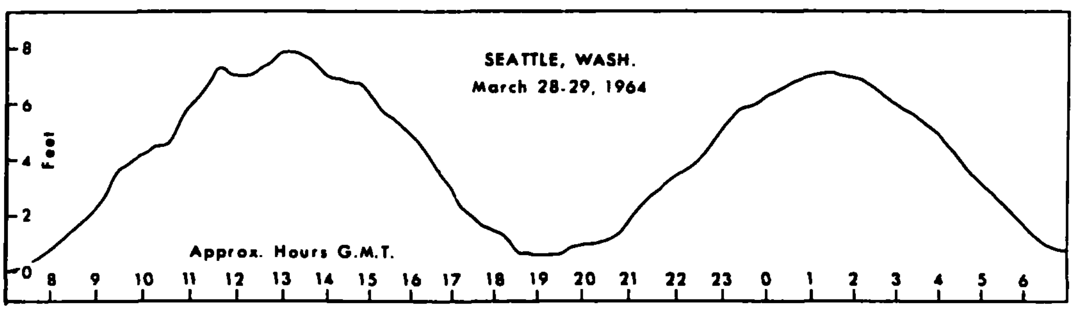
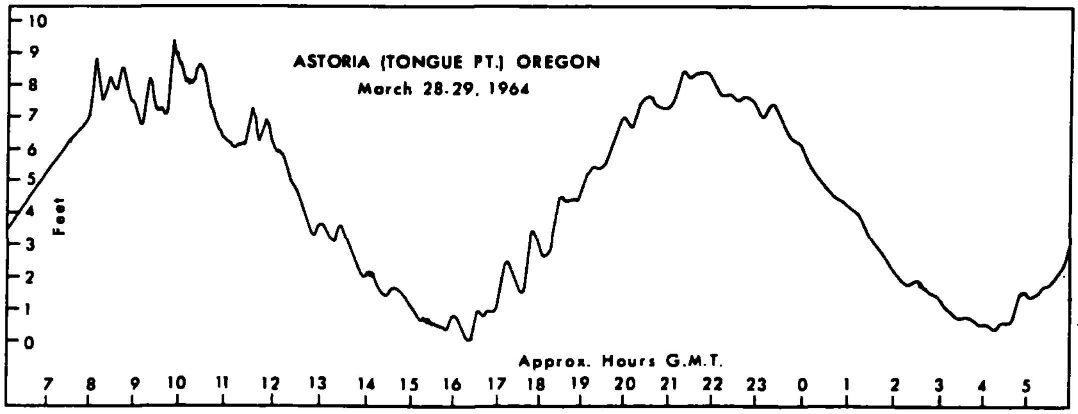
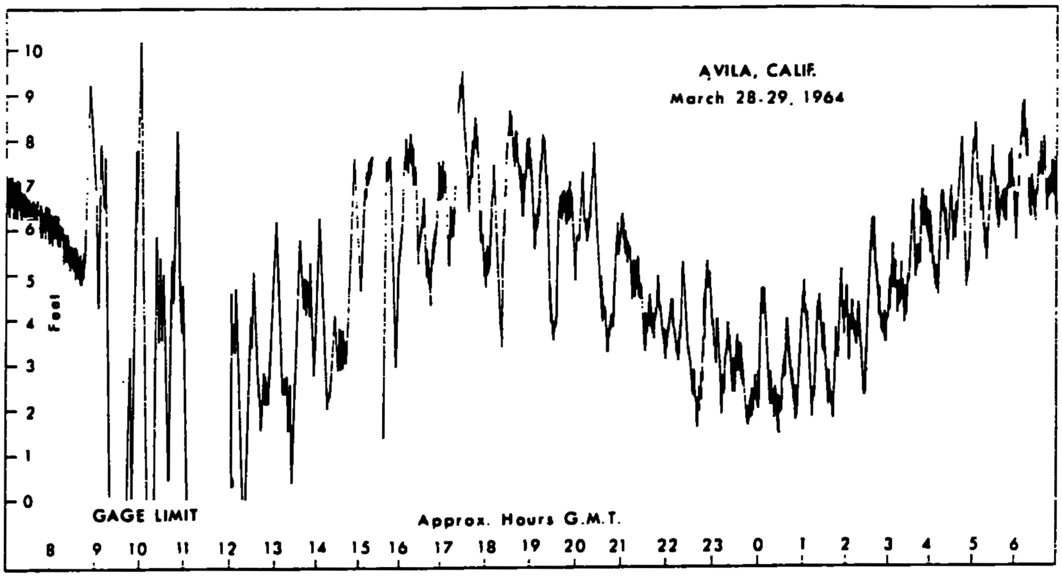


Figure 138.



Spaeth and Berkman (1972)

Figure 139.



Spaeth and Bergman (1972)

Figure 140.

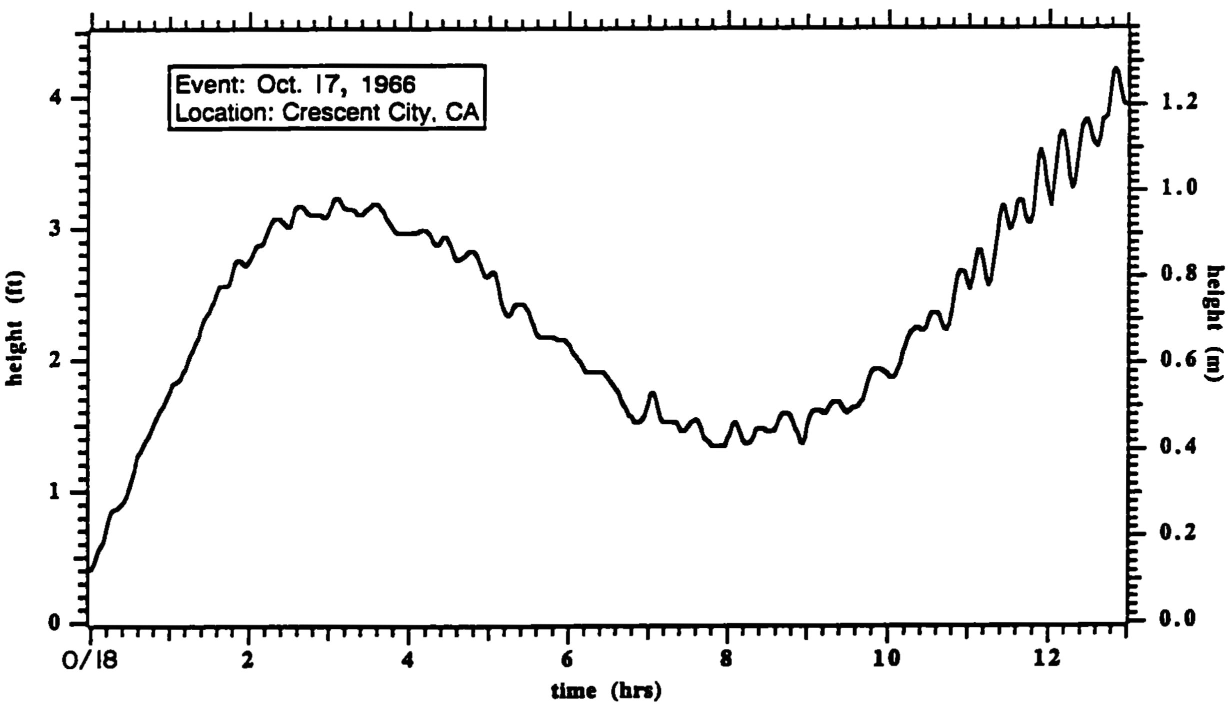


Figure 141.

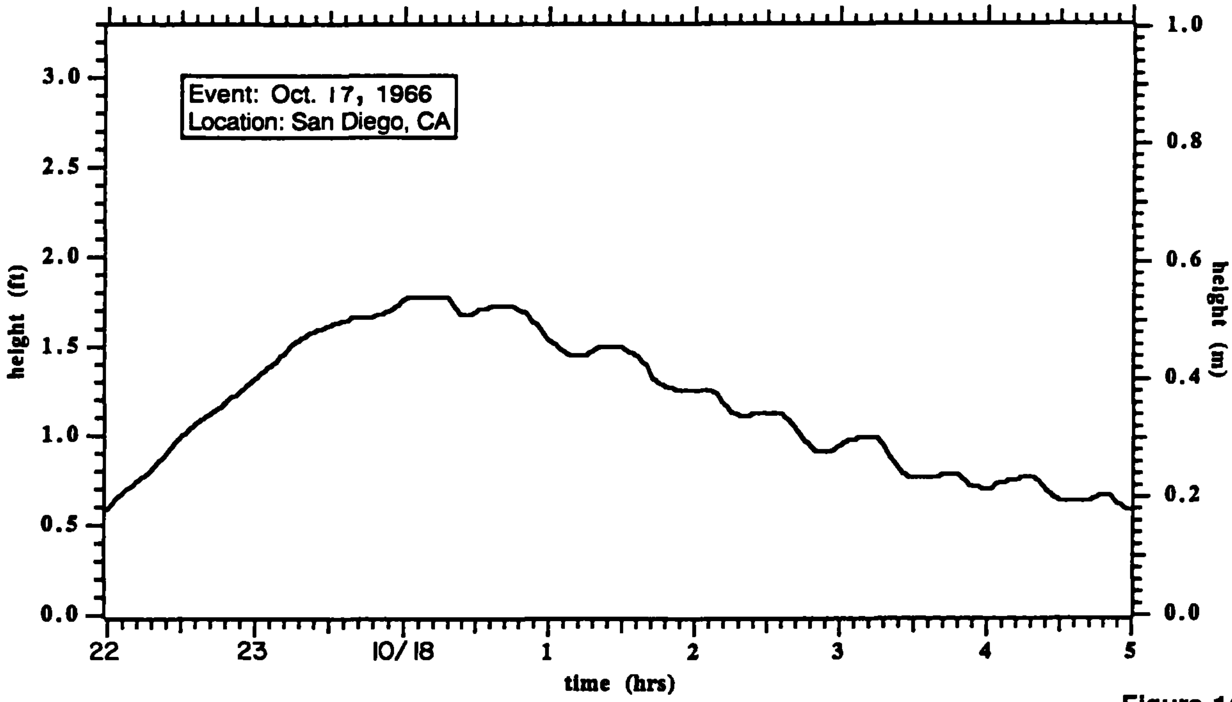


Figure 142.

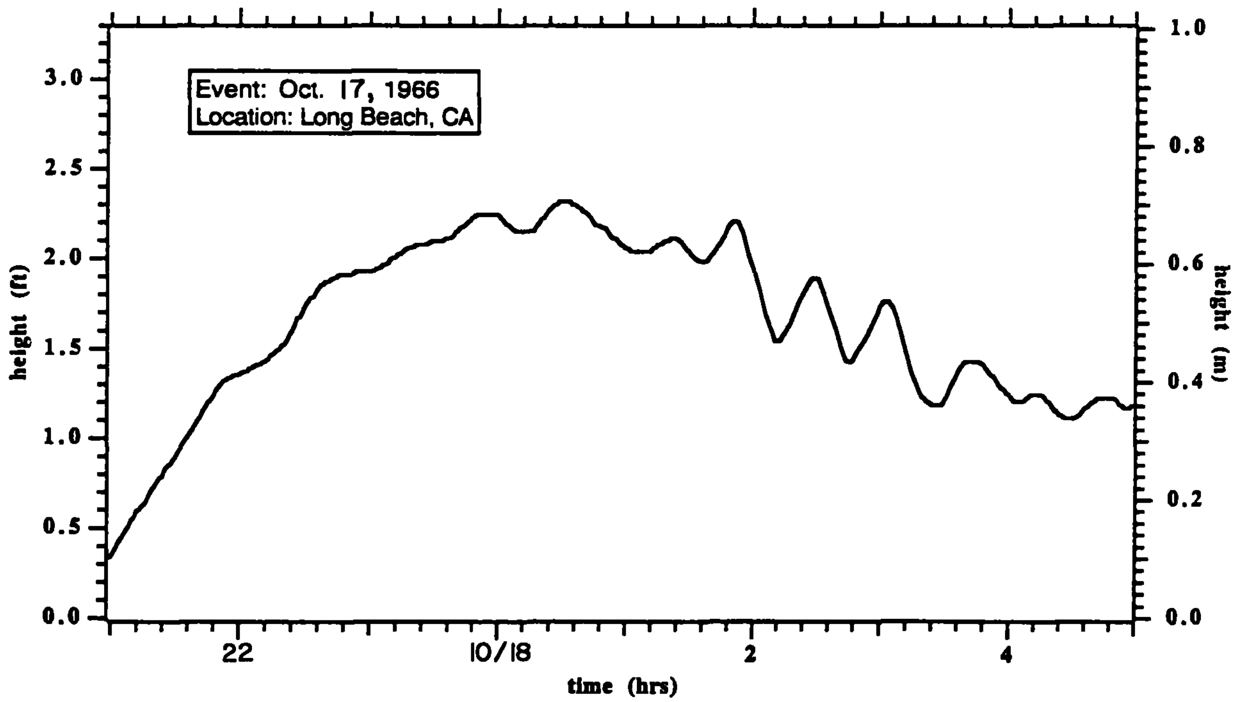


Figure 143.

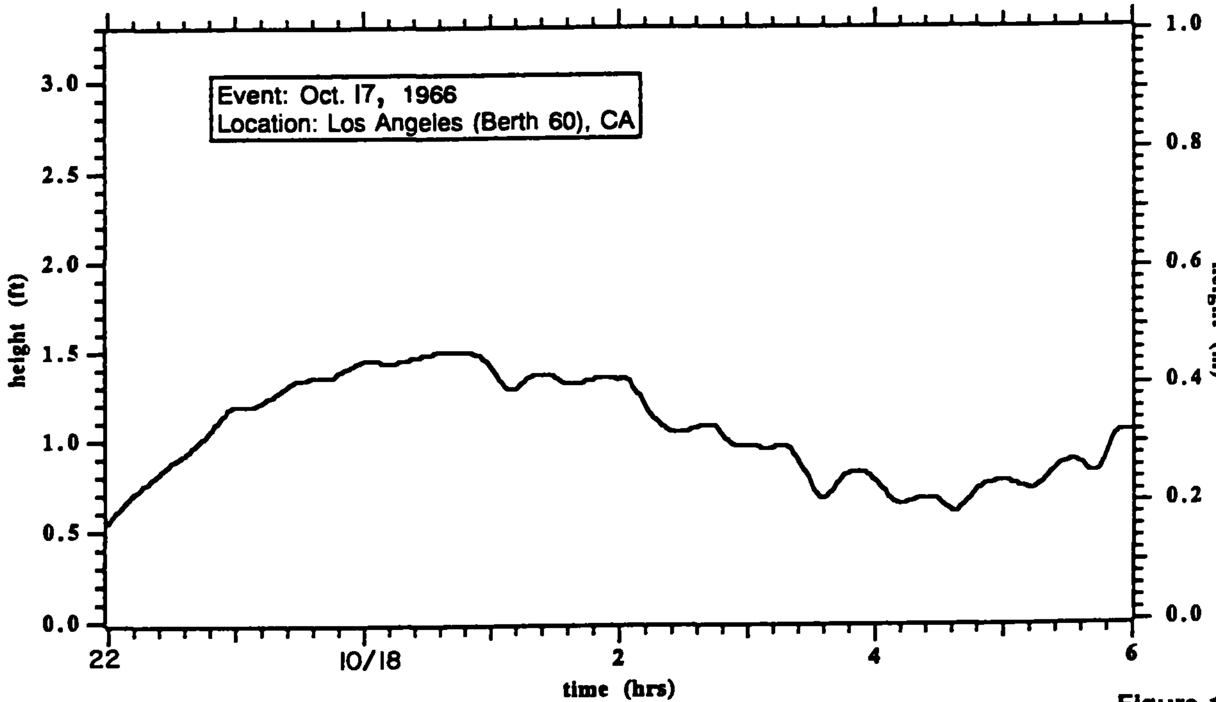


Figure 144.

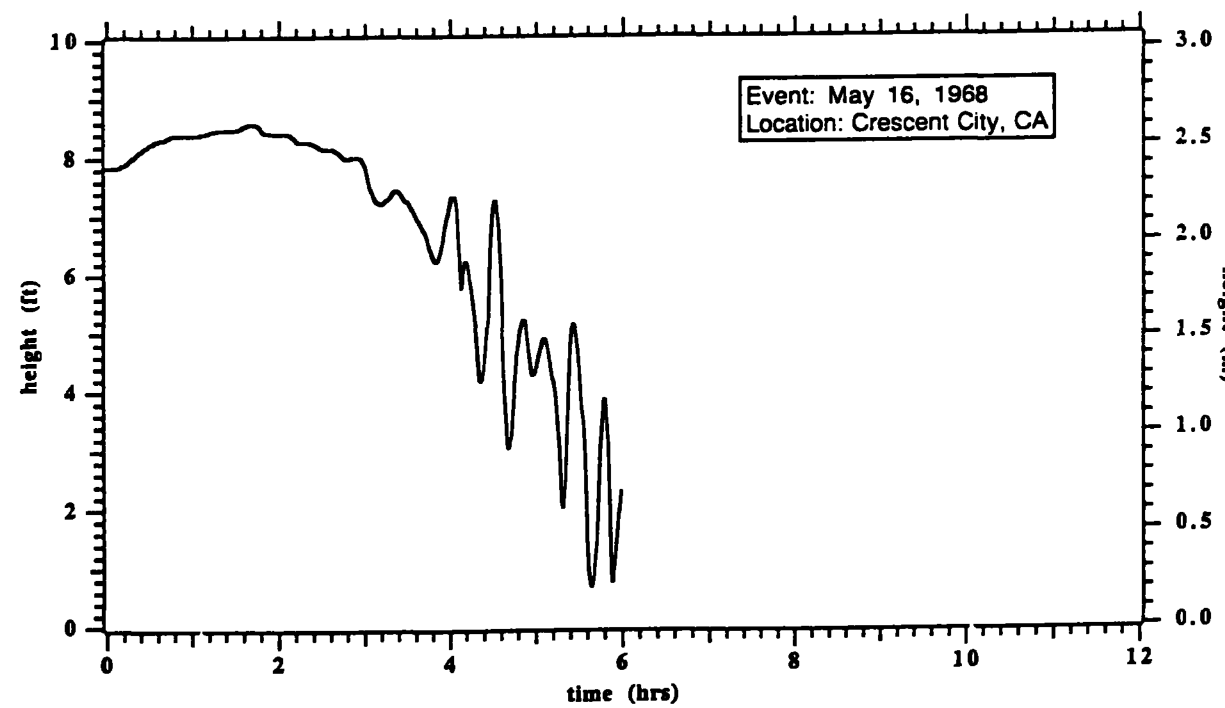


Figure 145.

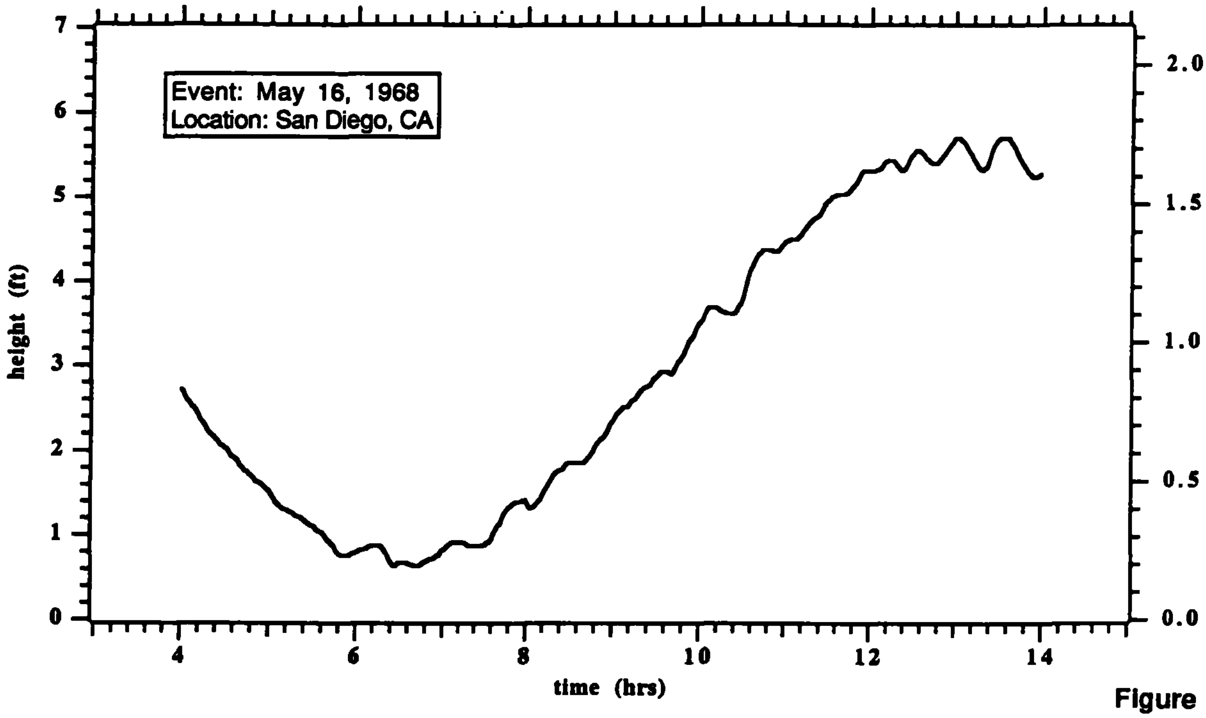


Figure 146.

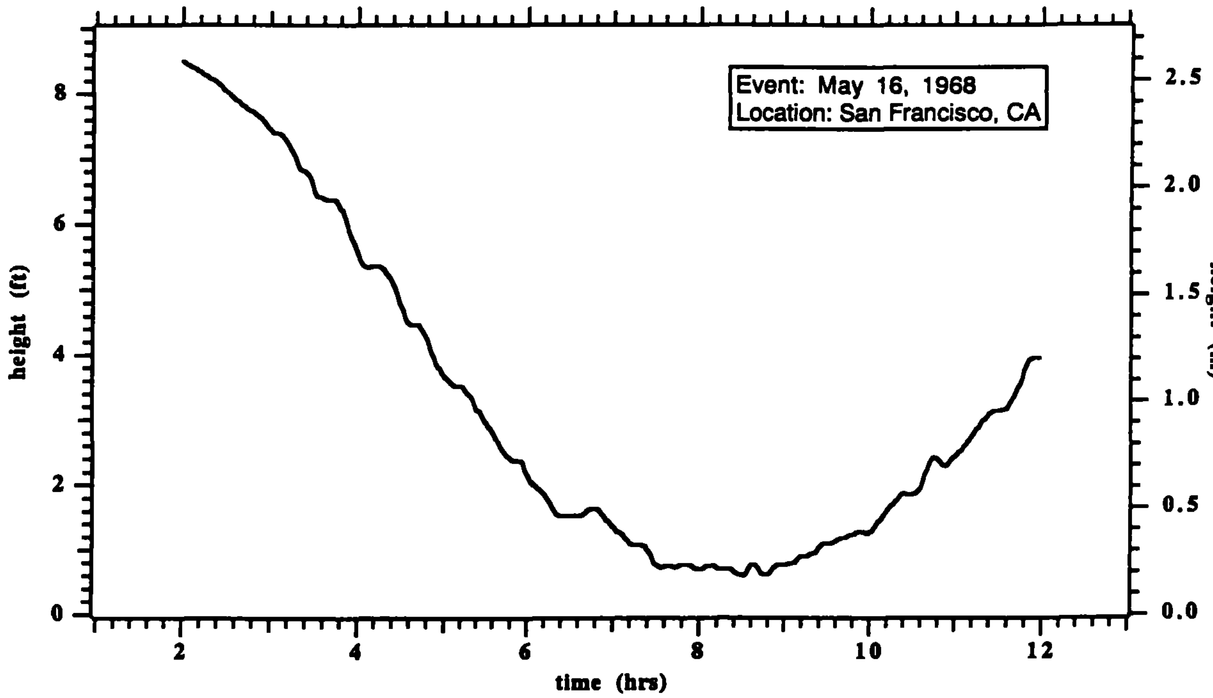


Figure 147.

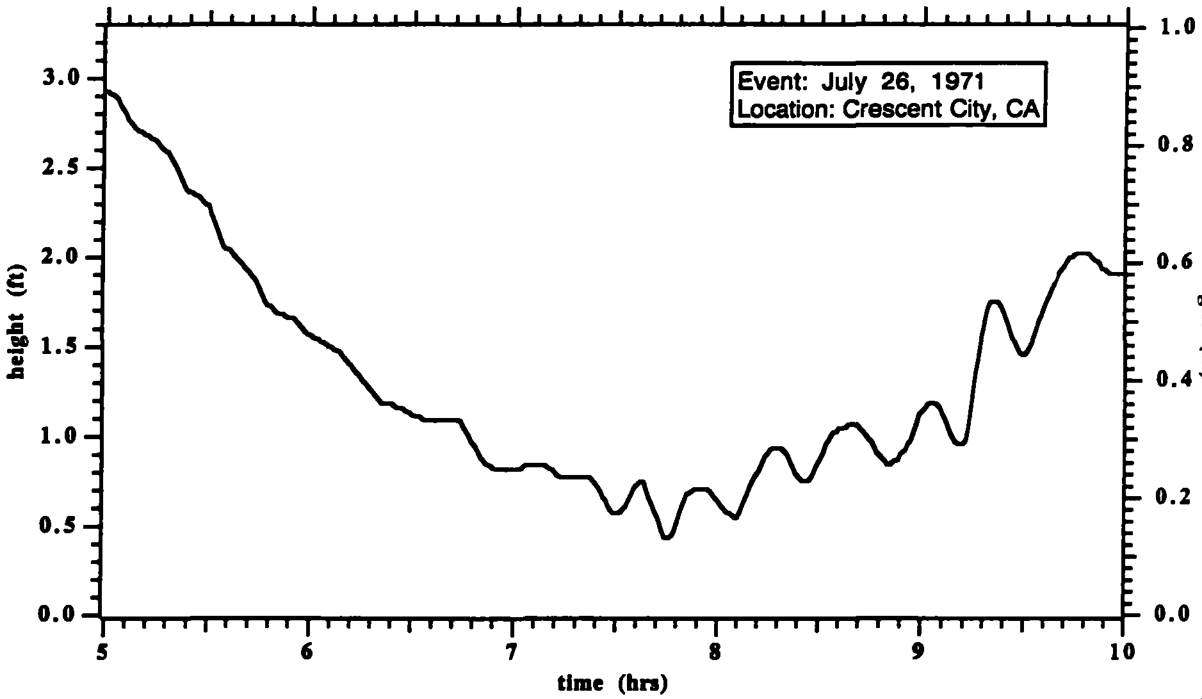


Figure 148.

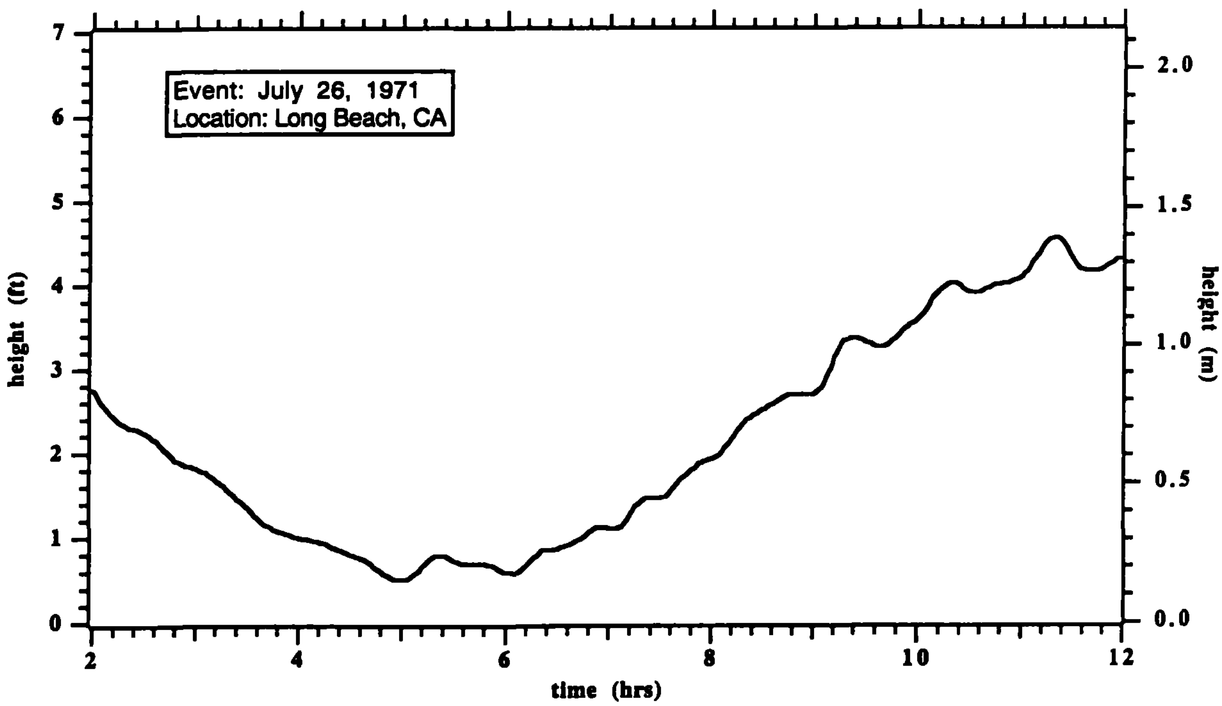


Figure 149.

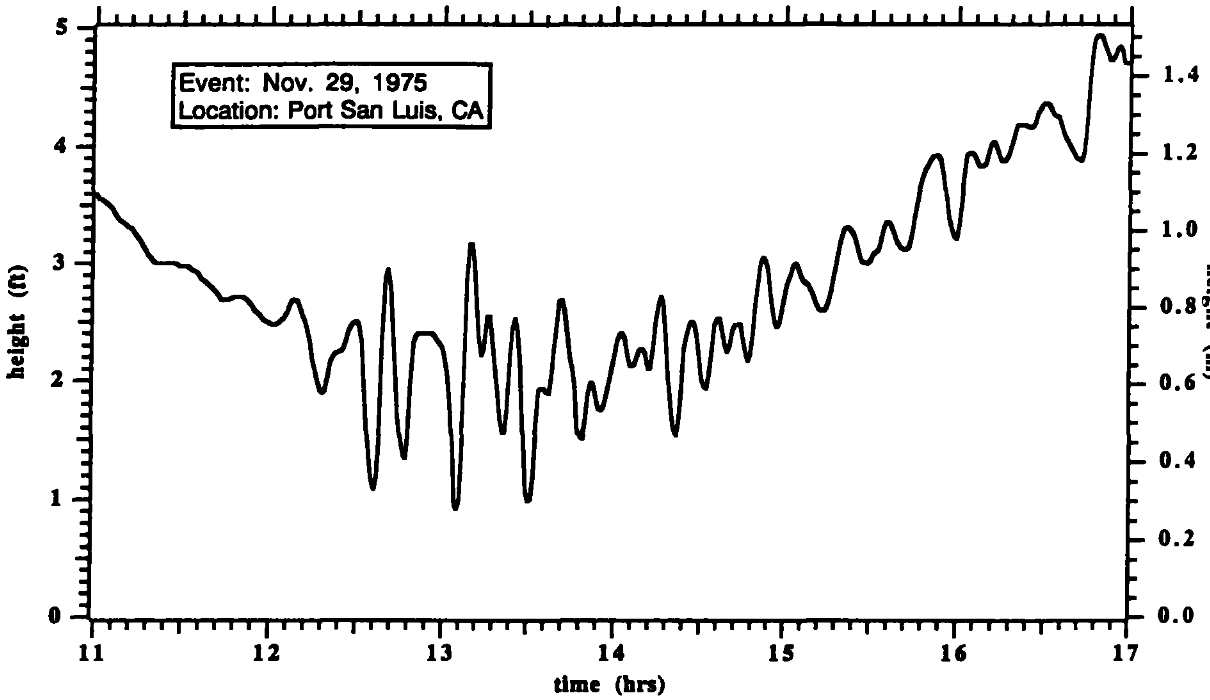


Figure 150.

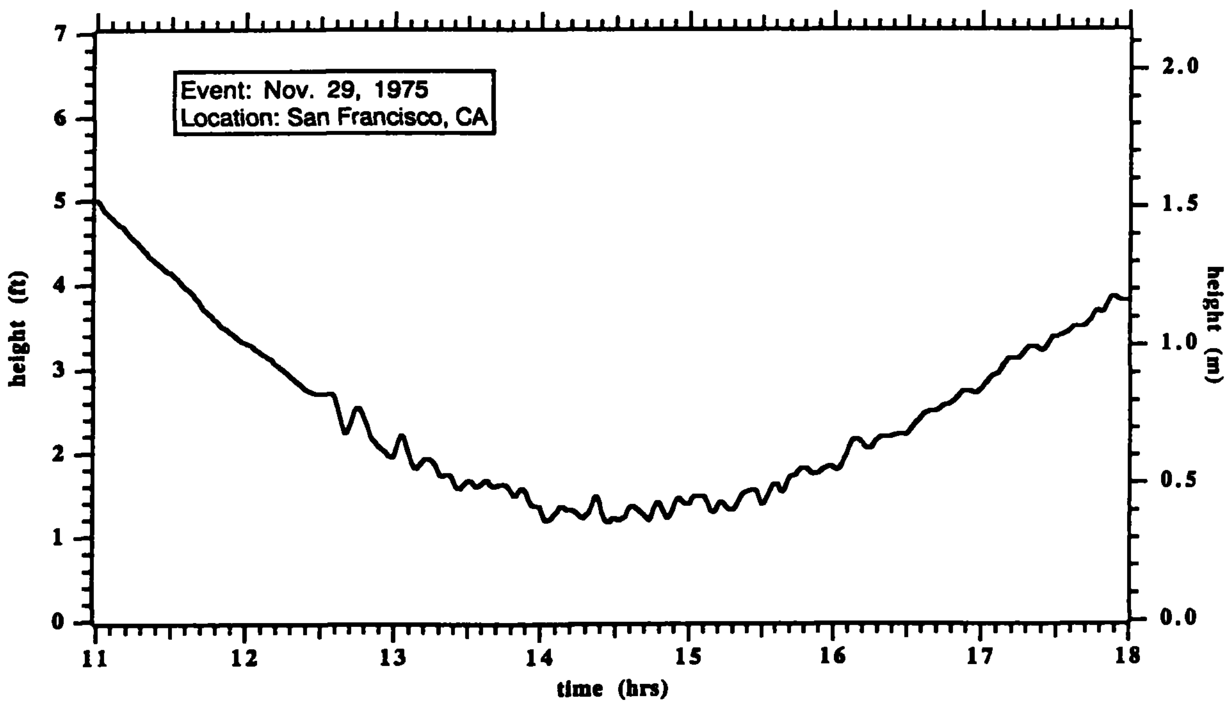


Figure 151.

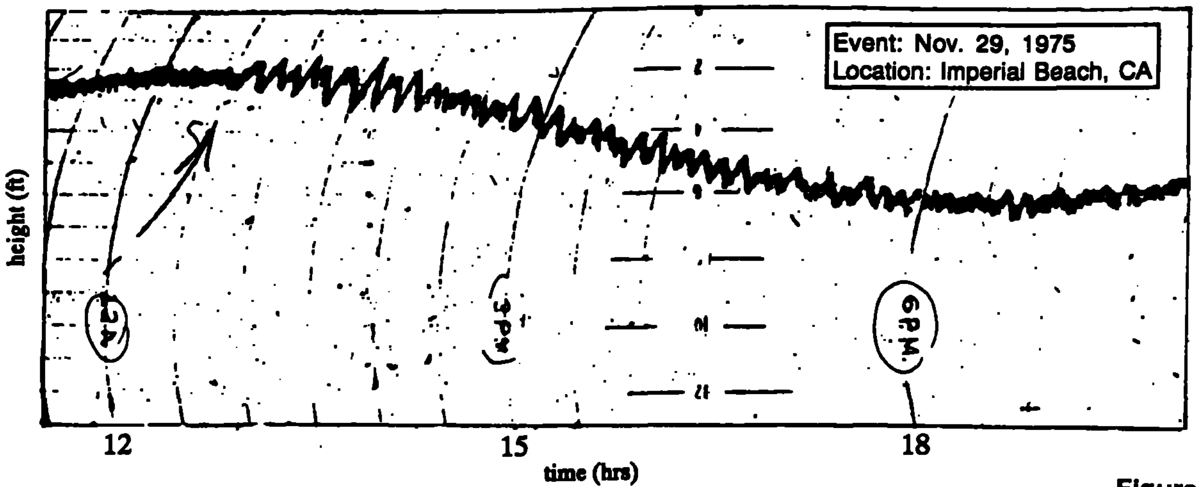


Figure 152.

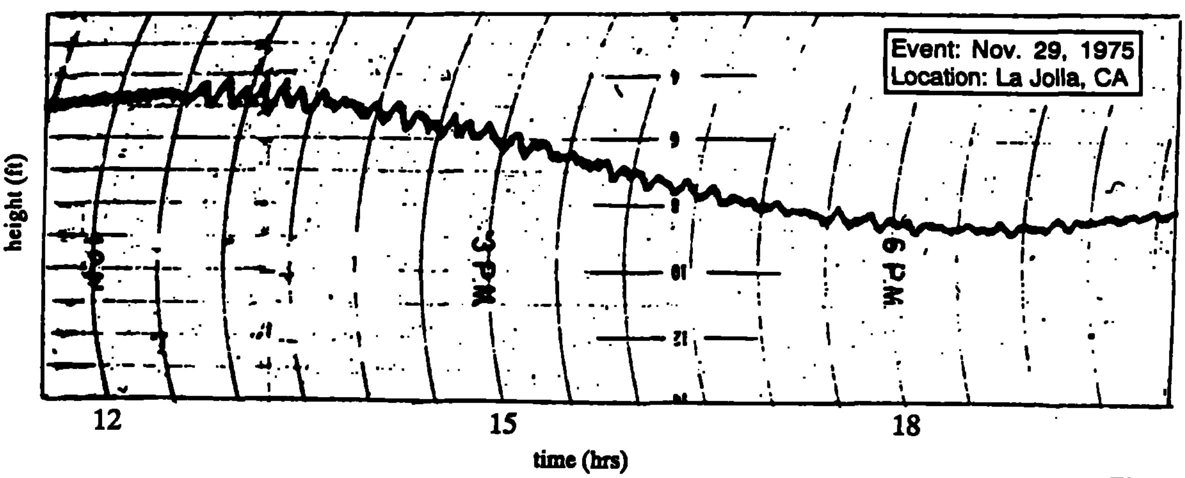


Figure 153.

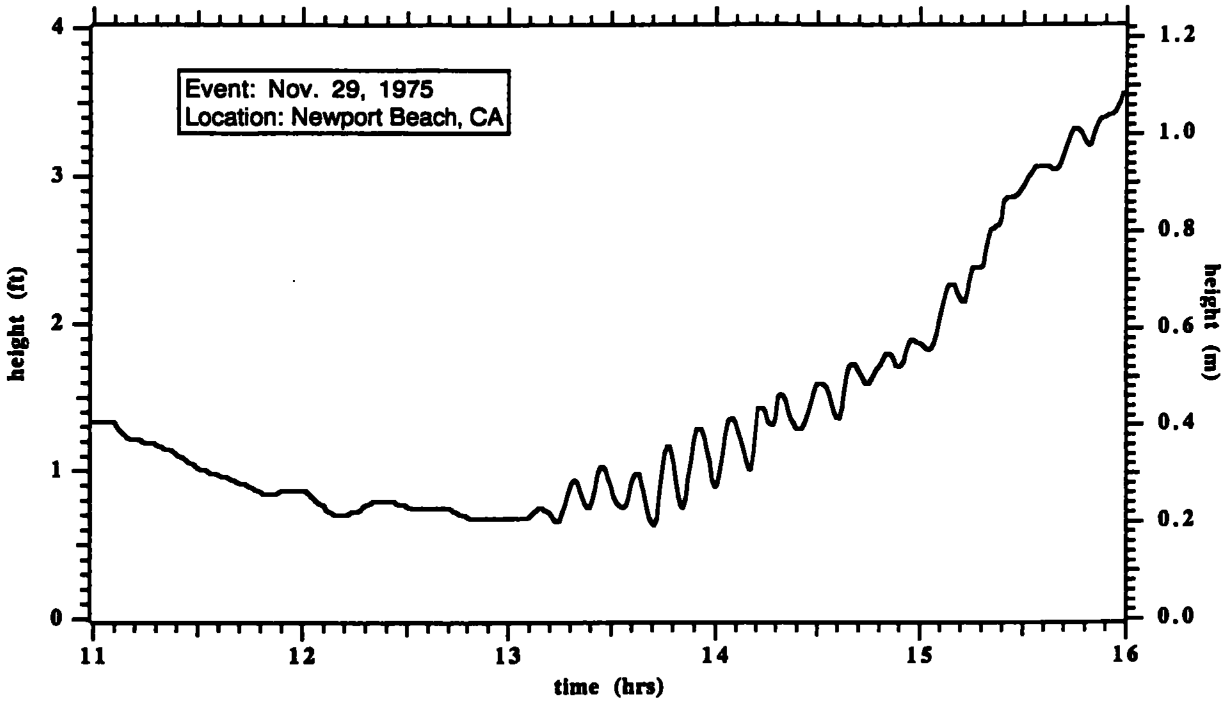


Figure 154.

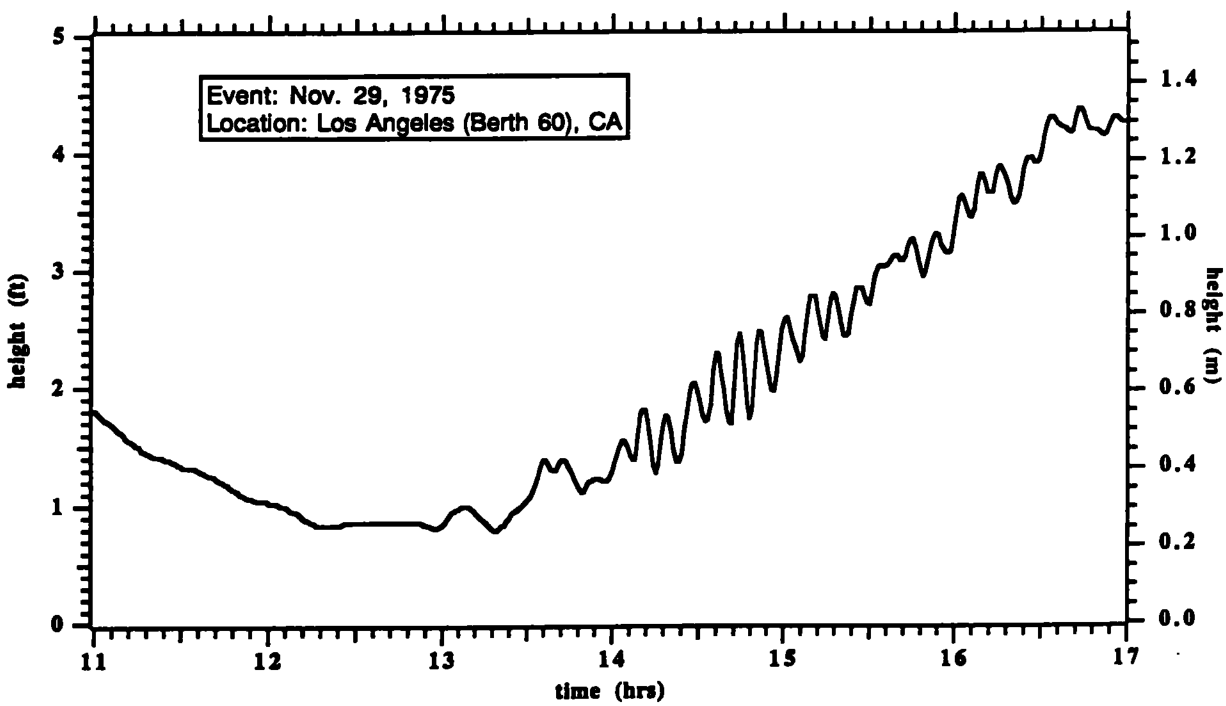


Figure 155.

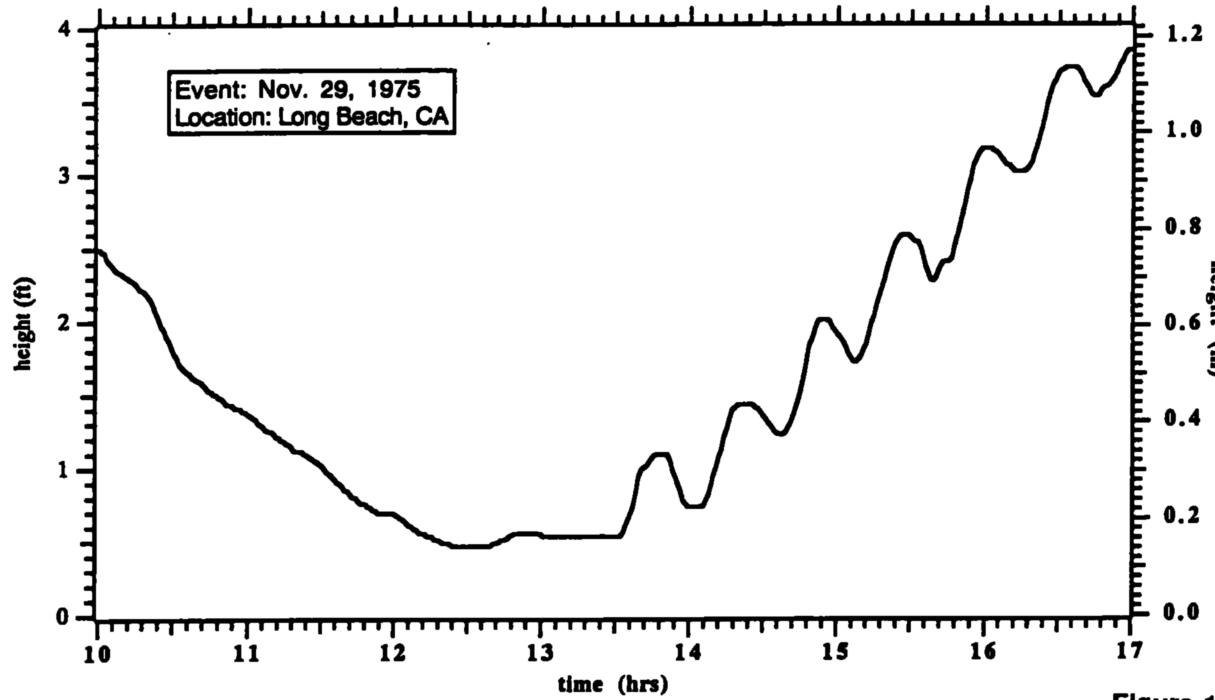


Figure 156.

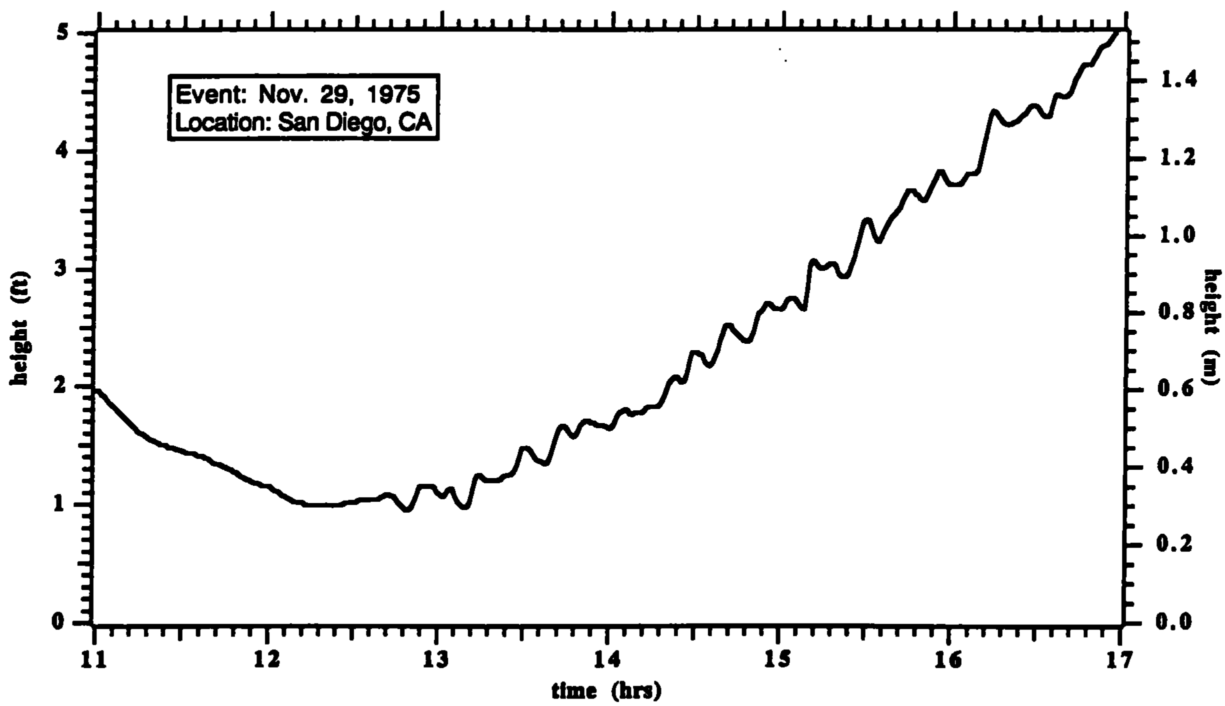
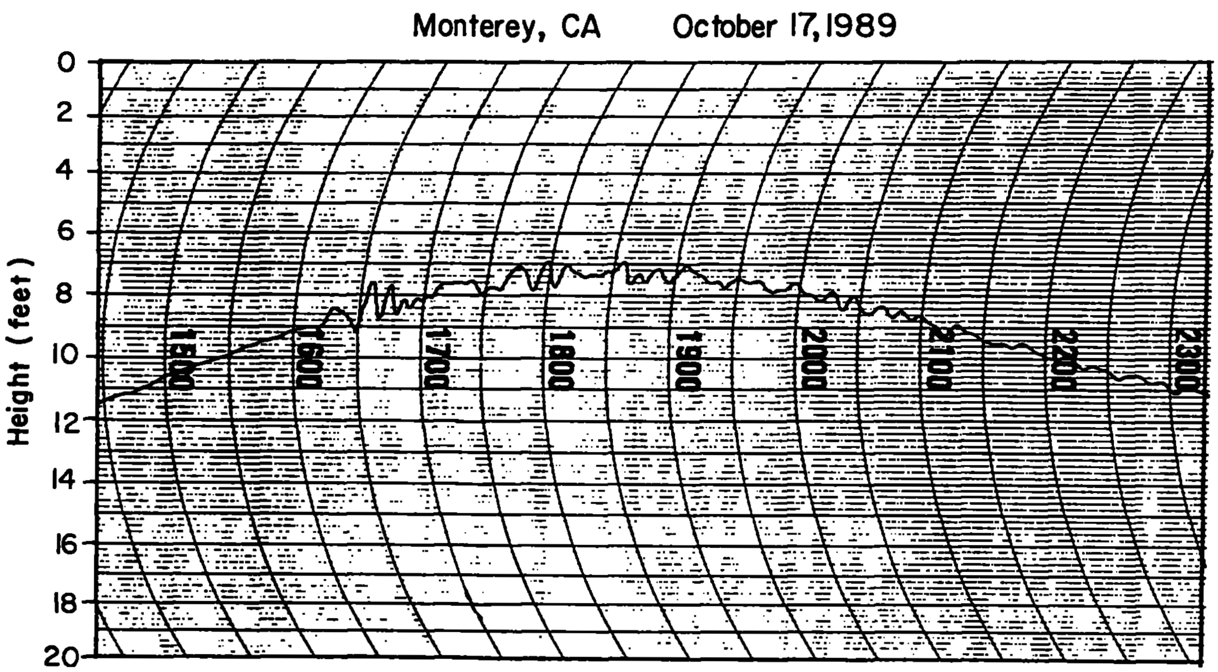


Figure 157.



Monterey, CA October 17, 1989
Height (feet)
0
2
4
6
8
10
12
14
16
18
20
1500
1600
1700
1800
1900
2000
2100
2200
2300

Figure 158.

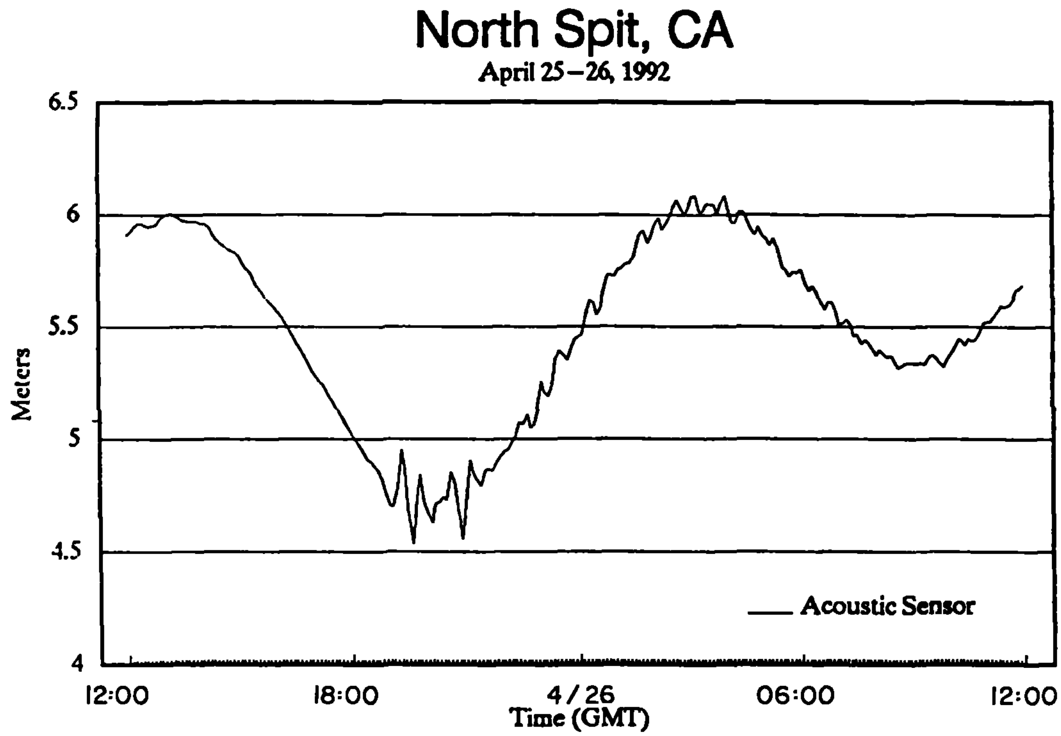


Figure 159.

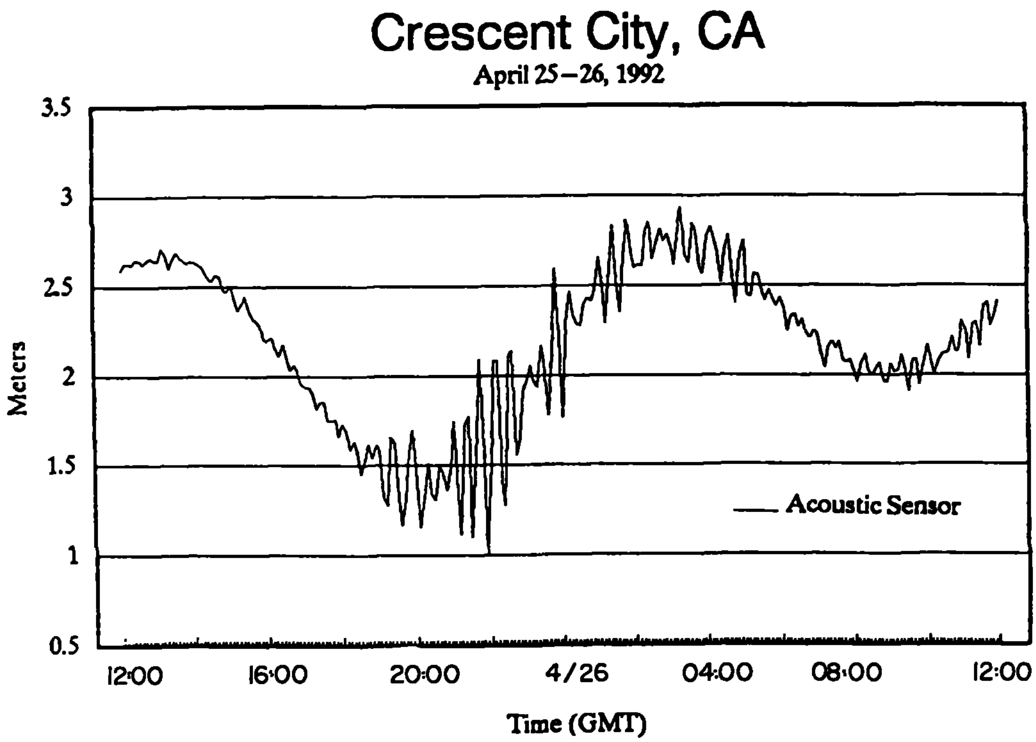


Figure 160.

ARENA COVE, CA TSUNAMI

25 APRIL 1992

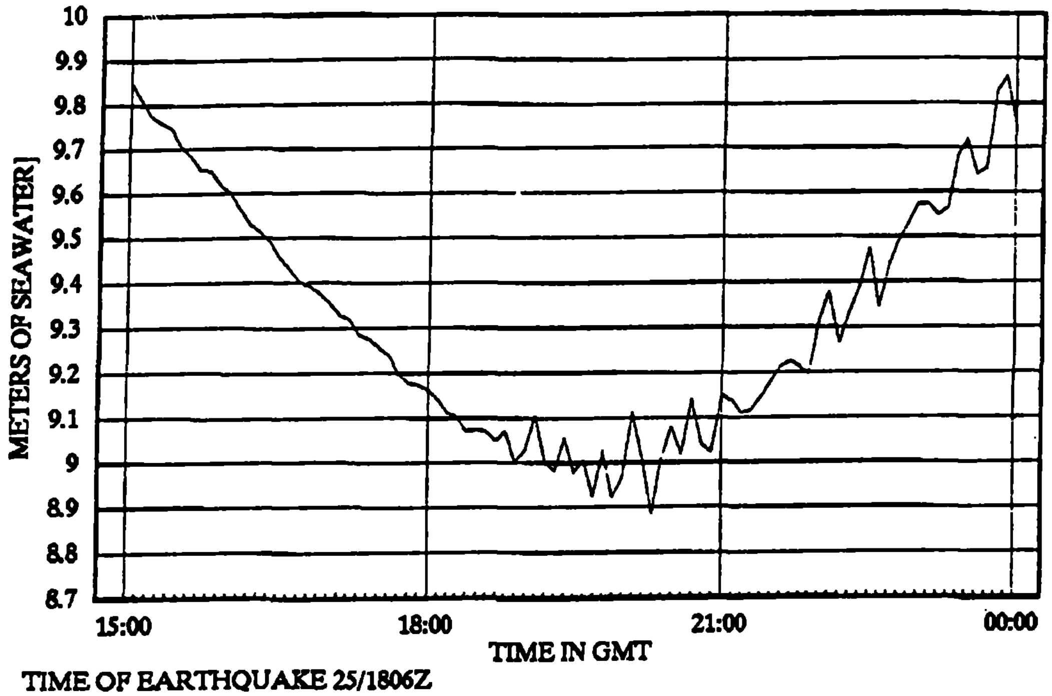


Figure 161.

PORT ORFORD, OREGON TSUNAMI

25–26 APRIL 1992

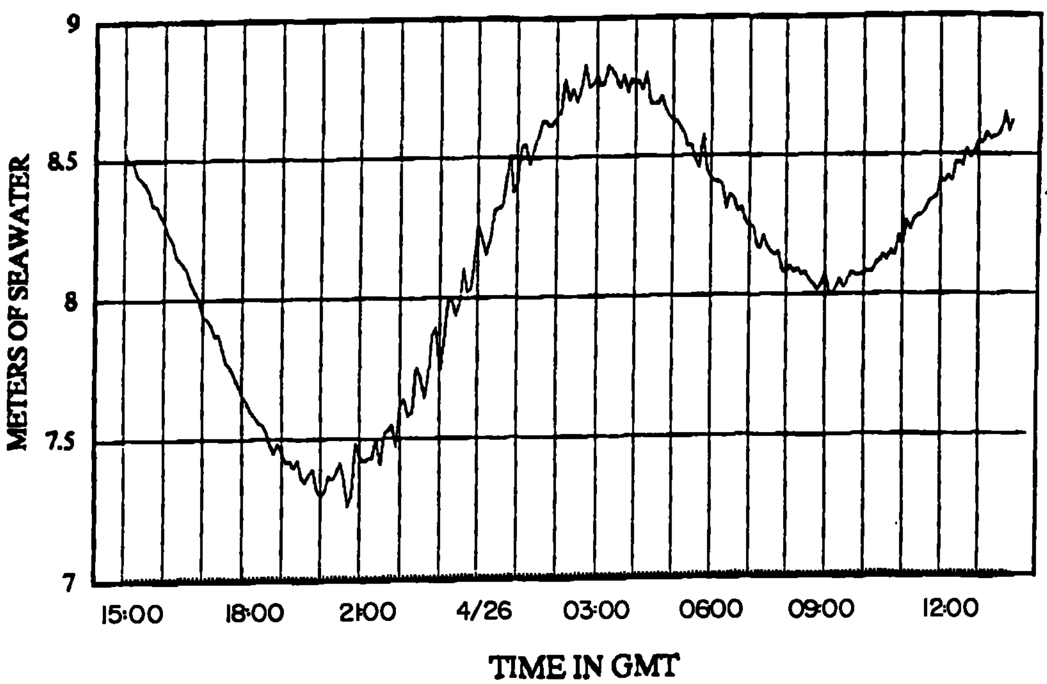


Figure 162.

7.0 Tsunami Travel Time Charts

This section includes five tsunami travel time charts prepared for U.S. west coast locations:

Figure 163. Neah Bay, Washington
Figure 164. Cresecent City, California
Figure 165. La Jolla, California
Figure 166. San Francisco, California
Figure 167. San Pedro, California

The charts originally appeared in *Tsunami Travel-Time Charts for Use in the Tsunami Warning System* (NOAA, 1971).

Given an epicenter or tsunami source, the number of hours it would take a tsunami to reach the location can be determined. Knowing the origin time of the earthquake or disturbance, the time of the first arrival of the tsunami can be approximated. For example, the southern Chile tsunami of May 22, 1960 occurred at 39.5°S, 74.5°W at 19:11 GMT. From the chart the travel time would be about 15½ hours and the first wave would be expected at 10:41 GMT on May 23 or 2:41 A.M. PST.

For localities other than the five given here the time can be approximated by interpolation between the values of nearby localities with charts.

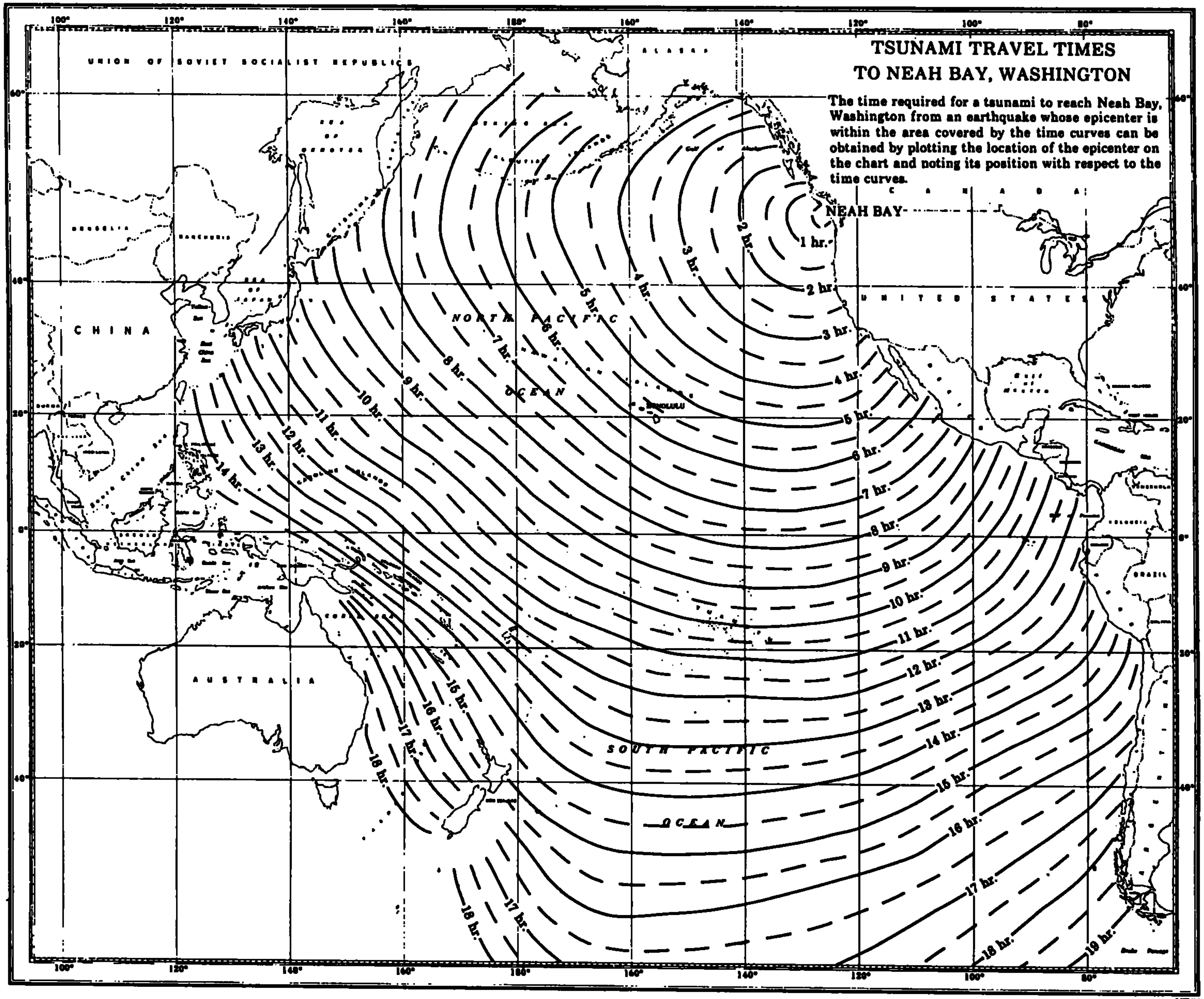

TSUNAMI TRAVEL TIMES
TO NEAH BAY, WASHINGTON
The time required for a tsunami to reach Neah Bay, Washington from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
NEAH BAY
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
HONOLULU
BRAZIL
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°

Figure 163.

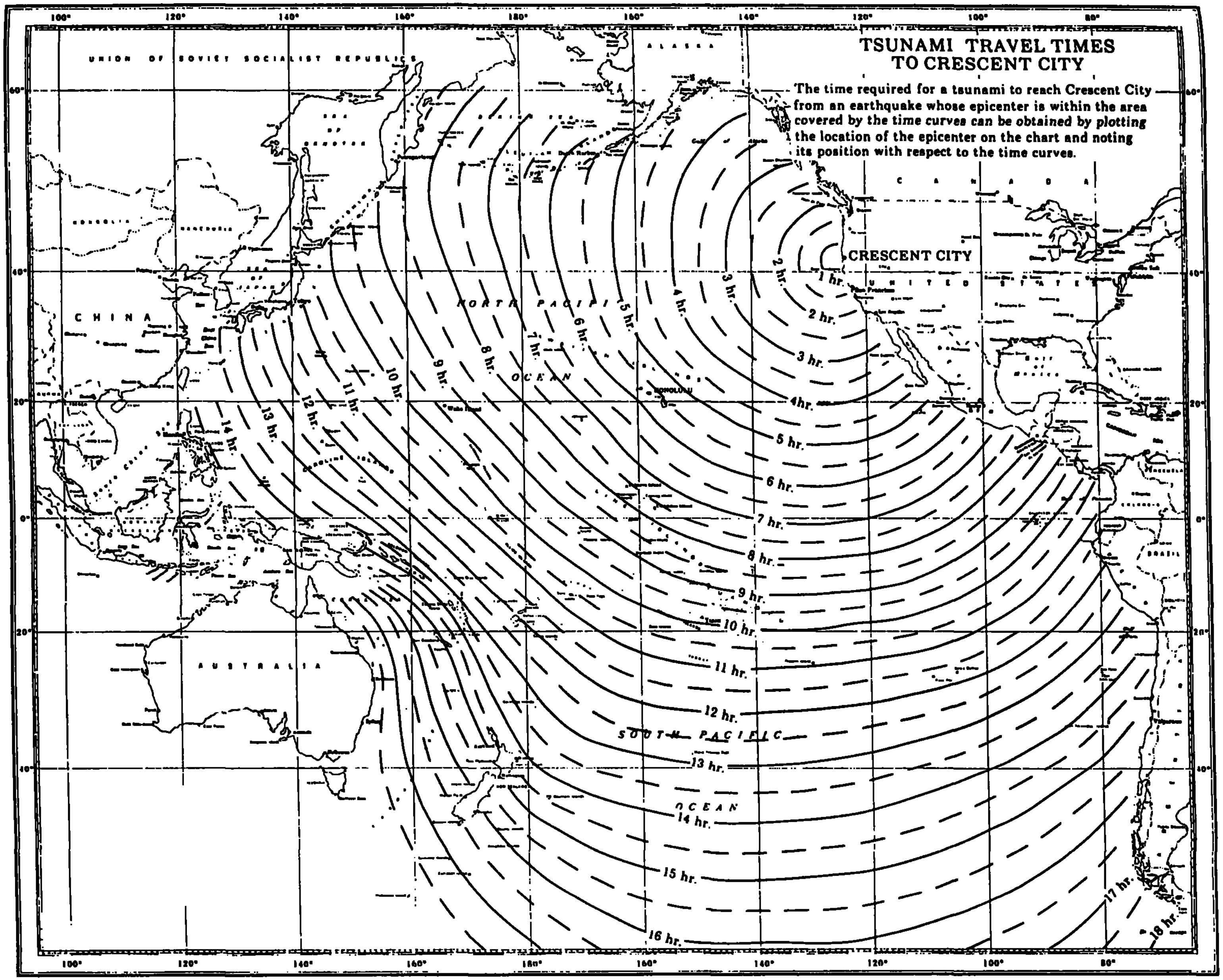

TSUNAMI TRAVEL TIMES
TO CRESCENT CITY
The time required for a tsunami to reach Crescent City from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
CRESCENT CITY
UNION OF SOVIET SOCIALIST REPUBLICS
CHINA
AUSTRALIA
ALASKA
CANADA
UNITED STATES
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°

Figure 164.

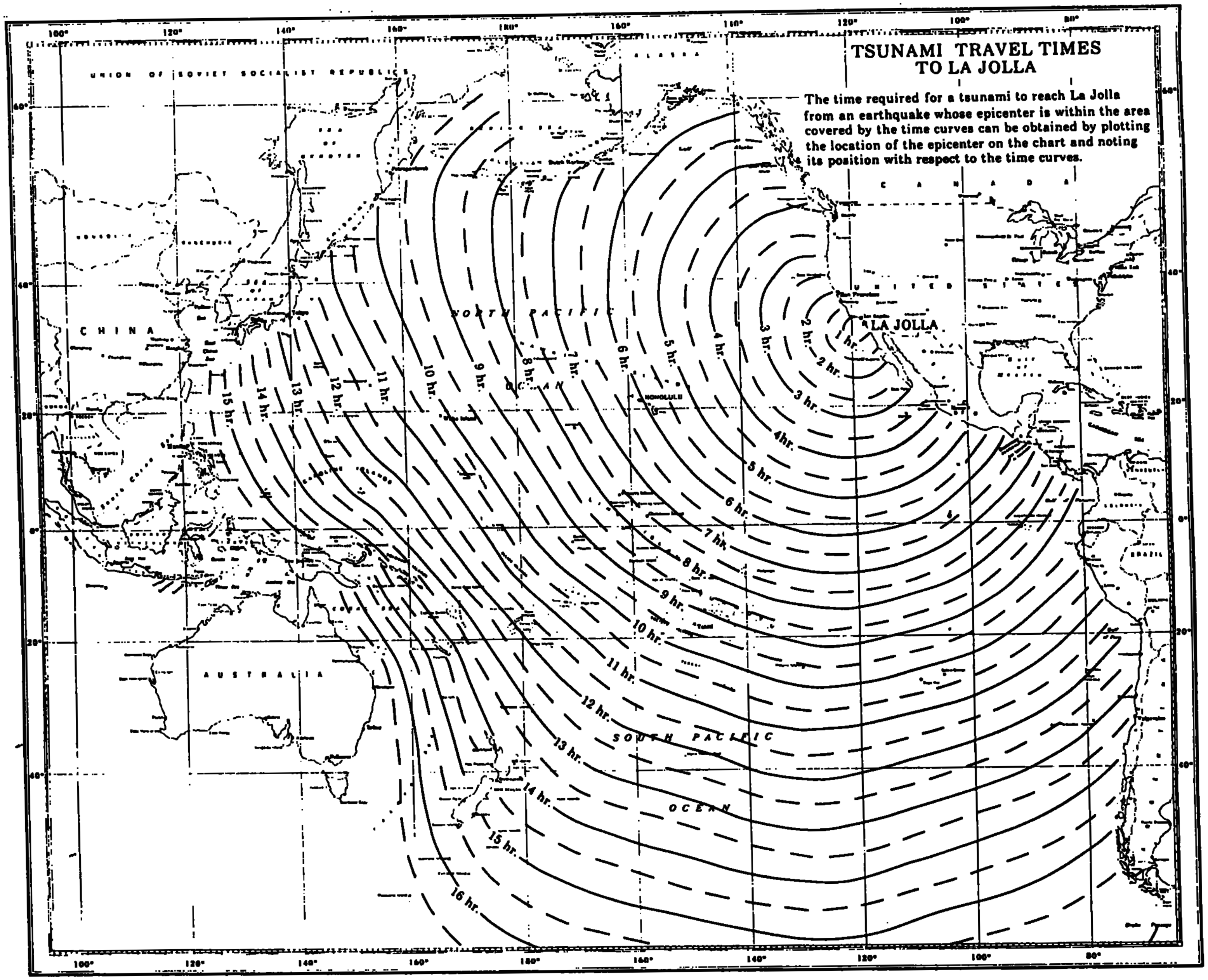

TSUNAMI TRAVEL TIMES
TO LA JOLLA
The time required for a tsunami to reach La Jolla from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
UNION OF SOVIET SOCIALIST REPUBLICS
CHINA
AUSTRALIA
CANADA
UNITED STATES
LA JOLLA
HONOLULU
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.

Figure 165.

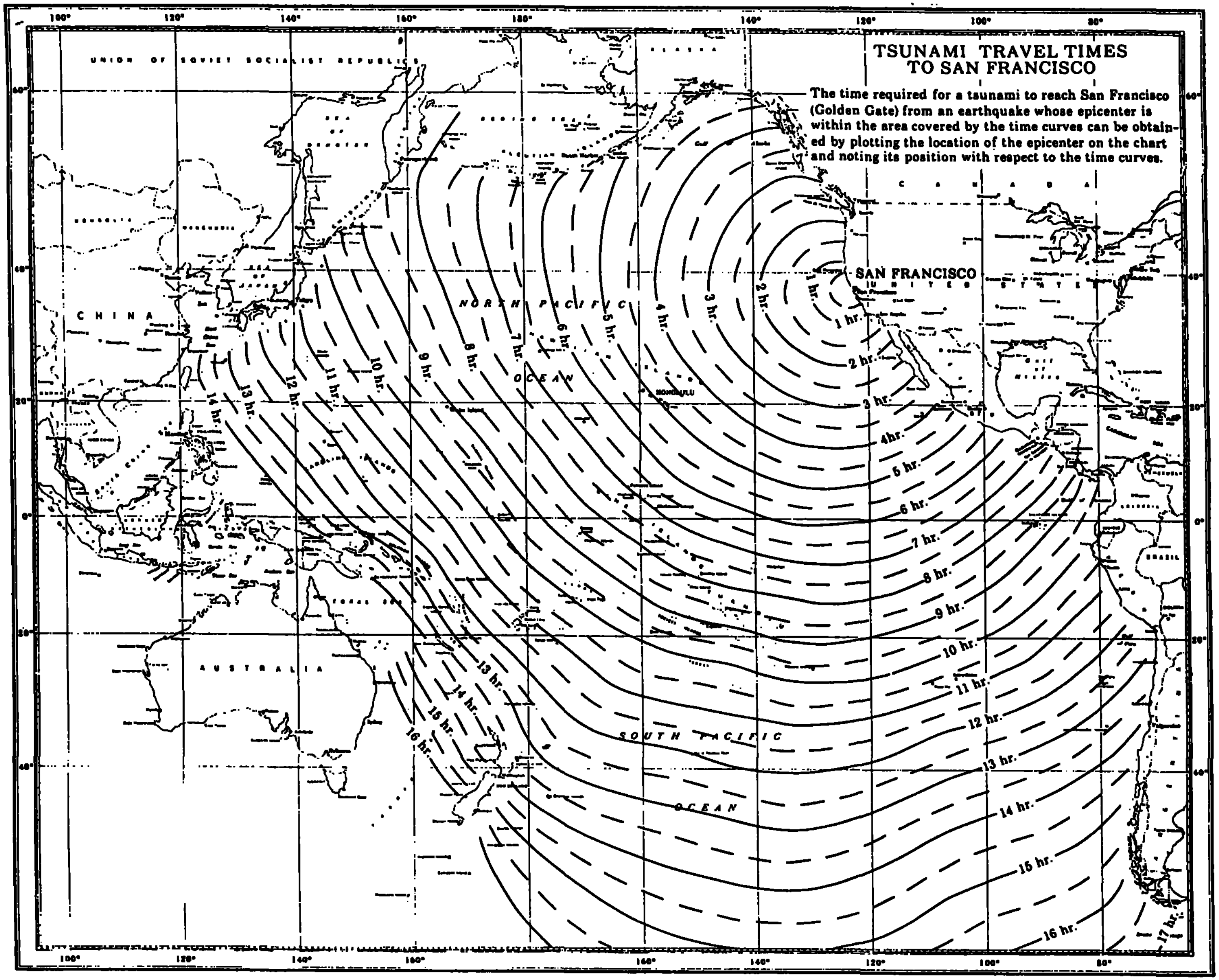

TSUNAMI TRAVEL TIMES
TO SAN FRANCISCO
The time required for a tsunami to reach San Francisco (Golden Gate) from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
SAN FRANCISCO
UNION OF SOVIET SOCIALIST REPUBLICS
CHINA
AUSTRALIA
CANADA
UNITED STATES
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
HONOLULU
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.

Figure 166.

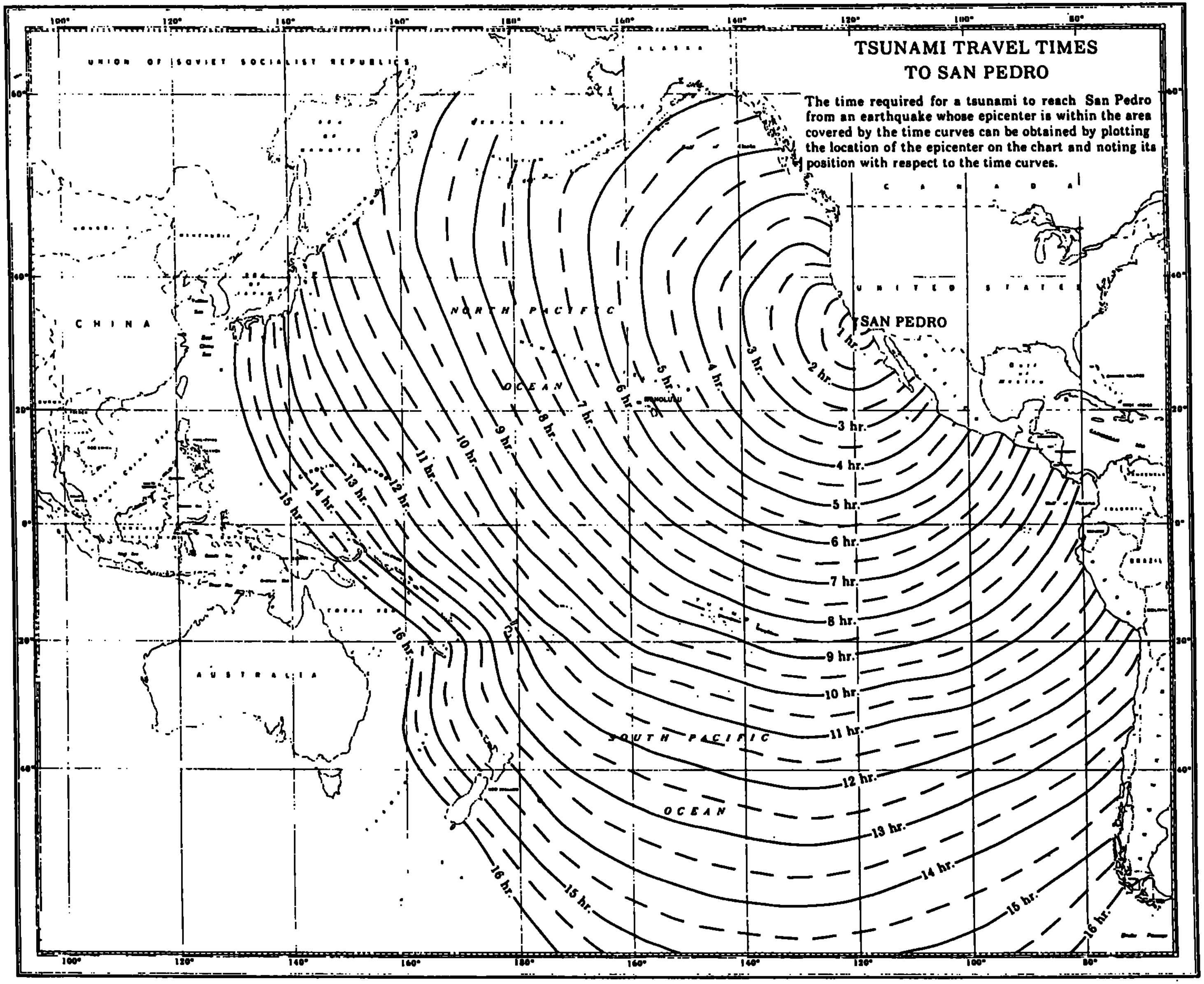

TSUNAMI TRAVEL TIMES
TO SAN PEDRO
The time required for a tsunami to reach San Pedro from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC
OCEAN
SOUTH PACIFIC
OCEAN
SAN PEDRO
HONOLULU
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°

Figure 167.

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(Note: References are organized by first author and date.)

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