Chapter 6

CHANGES IN SEA LEVEL DETERMINED FROM TIDE OBSERVATIONS

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Heights on land as well as depths in the sea are measured with reference to the surface of the sea or sea level. But the level of the sea is constantly changing under the influence of the rise and fall of the tide and of varying meteorological conditions. For that reason use is made of an average level called mean sea level, this datum being derived from tide observations.

The concept of mean sea level is very simple. The surface of the sea is at all times disturbed by one cause or another and mean sea level at any point is simply defined as the average or mean level of the sea at that point. This concept of mean sea level, by implication, makes its determination appear a simple matter. For all we need do to determine mean sea level at any place is, apparently, merely to measure the changing level of the sea at that place for some time and derive the average value. But when we are actually confronted by the necessity for a precise determination, the problem is found to be not quite so simple.

To begin with, it must be noted that in determining mean sea level at any point, we are determining not a scale reading on an instrument with a fixed zero, but the location of a horizontal plane on the earth. For measuring the changing level of the sea we make use of a tide staff, which is merely a rod or staff graduated in feet and decimals, fixed in a vertical position. How far below the surface of the sea the zero of this staff is placed is wholly arbitrary. This means that the tide staff reading has meaning only when related to some fixed point on land. Ordinarily the tide staff is fixed to the face of a pile or wharf, but to make sure the tide staff can always be maintained at a fixed elevation, it must be referenced to a number of adequate bench marks on shore. This is an extremely important matter which in the past has not been carefully observed.

The most effective method for measuring the changing level of the sea is through the use of an automatic tide gage which makes a continuous record of the rise and fall of the surface of the sea. From this record we can determine the height of the sea at each hour of the day and from these hourly heights we can derive the average height of sea level for a day, a month, a year, or for as long a period as may be desired.

The question that immediately arises is, for how long a period of time must we average the changing level of the sea to arrive at a determination of mean sea level? Since the tide is the predominating cause of the fluctuation of the surface of the sea, and since the primary period of the tide is a day, it is obvious that if we average the hourly heights of the tide over the period of a day we will eliminate the tide and derive a first approximation to sea level.

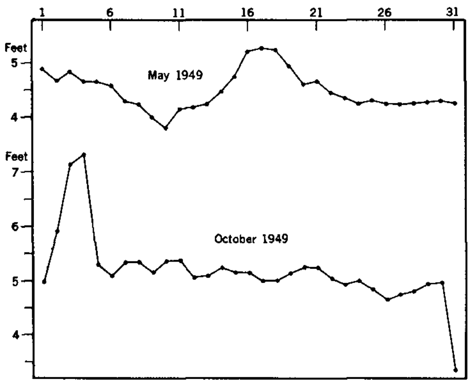

Fig. 1
Daily sea level, Galveston, Texas, May and October, 1949.

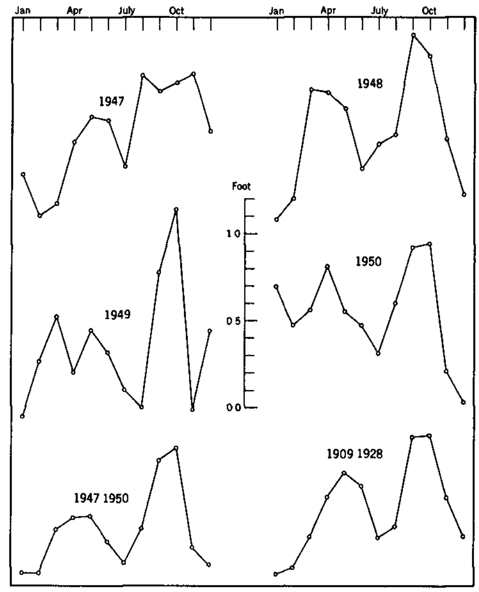

Fig. 2
Monthly sea level, Galveston, Texas.

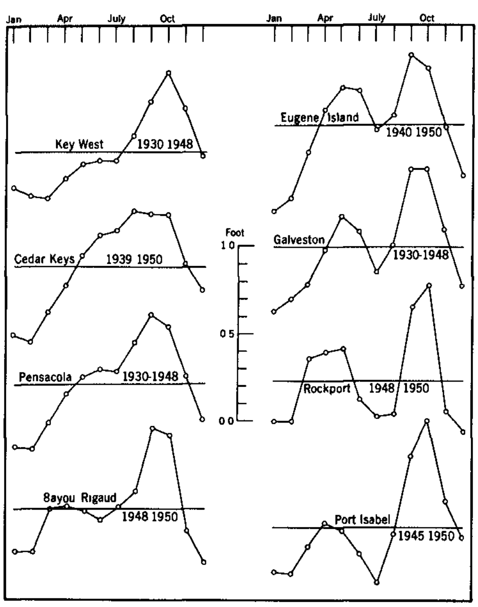

Fig. 3
Seasonal variation in sea level, Gulf coast.

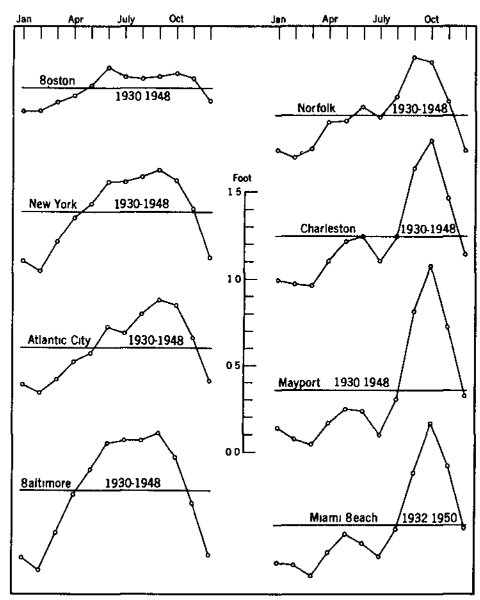

Fig. 4
Seasonal variation in sea level, Atlantic coast.

On investigation it is found that sea level at any place changes from day to day. In Figure 1 there are shown the daily sea levels at Galveston for the two months of May and October 1949. The heights are referred to the tide staff at the tide station. For May the change in sea level from day to day was generally less than a tenth of a foot, though at times it was several tenths of a foot. During this month sea level on the 17th was 1½ feet higher than on the 10th.

In October weather conditions were not as uniform as during May and greater variations in sea level from day to day occurred. For example, on the 5th, sea level was 2 feet lower than on the 4th. And during this month, sea level on the last day was nearly 4 feet lower than on the 4th.

Sea level thus varies considerably from day to day, and a determination of sea level from one day of observations, even in calm weather, can give only a very rough approximation to mean sea level. Clearly, therefore, to determine mean sea level with any pretense to precision, a longer series of observations is necessary, and a month suggests itself as a possibly desirable period.

In Figure 2 are shown the monthly heights of sea level at Galveston as measured on the tide staff for each of the four years 1947 to 1950. Each monthly height represents the average of some 700 hourly heights, and as might be expected, sea level from month to month differs less than from day to day. Generally the differences from one month to another are one or two-tenths of a foot, though occasionally they may be as much as a foot. Within a year the lowest and highest monthly values of sea level may differ by more than a foot.

A glance at these diagrams shows that sea level at Galveston for these four years was generally low in the winter months and high in the fall months, with a secondary maximum in spring and a secondary minimum in July. If we take the average of the sea level heights for corresponding months of the four years, we derive the curve shown in the lower left of Figure 2. This strongly suggests a seasonal variation in sea level. In the lower right of Figure 2 is shown the average monthly heights of sea level at Galveston for the 20 year period 1909-1928 and this is seen to approximate closely the curve derived from the four years 1947-1950.

Now a seasonal variation in sea level is a characteristic feature of the sea everywhere, but it has distinctive local, or perhaps more accurately, regional characteristics. In Figure 3 is shown the curves of seasonal variation of sea level at eight stations on our Gulf coast, based on various years of observations. The horizontal line on each diagram represents the height of mean sea level at each station for the period of observations indicated. Each place has its characteristic curve of variation, but places relatively near each other show much the same pattern. Thus, Key West, Cedar Keys and Pensacola resemble each other; likewise Eugene Island and Galveston, Rockport and Port Isabel.

It is of interest to note how the pattern from a single minimum and a single maximum, changes gradually from the eastern end of the Gulf to

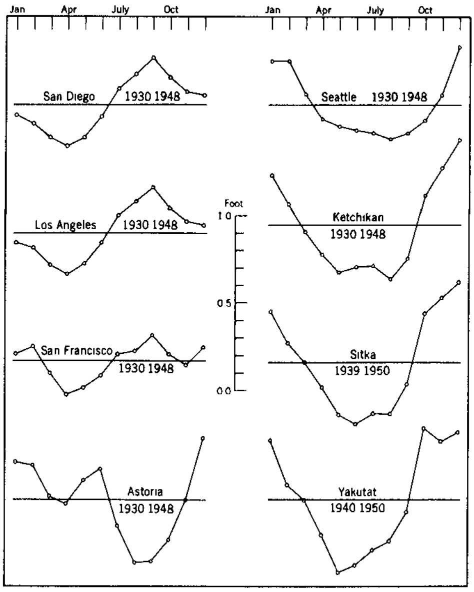

Fig. 5
Seasonal variation in sea level, Pacific coast.

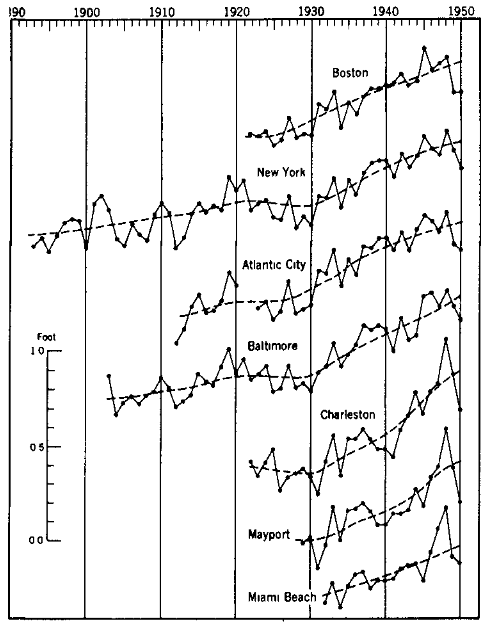

Fig. 6
Yearly sea level, Atlantic coast.

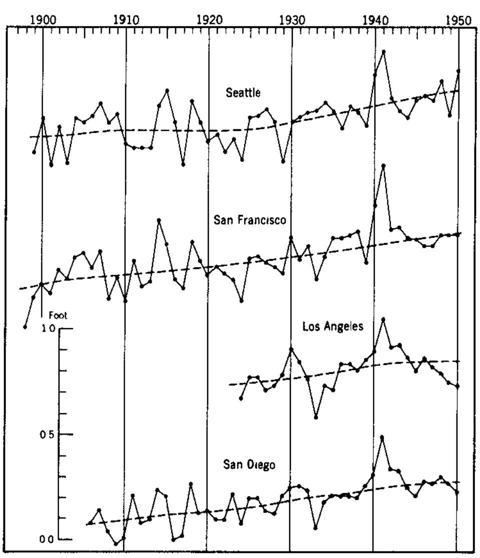

Fig. 7
Yearly sea level, Pacific coast.

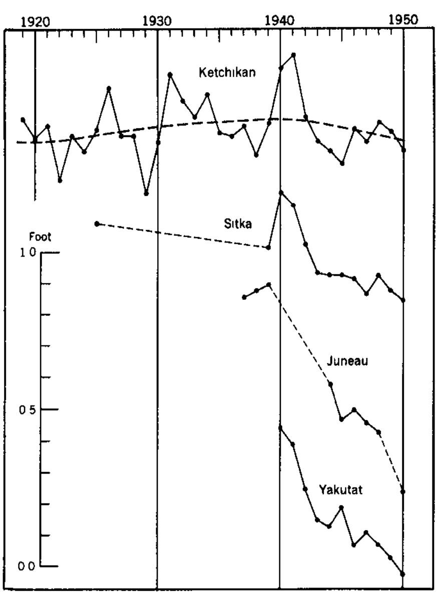

Fig. 8
Yearly sea level, Alaska

the double maxima and minima. At Key West there is barely an inkling of this; at Pensacola there is a beginning, but at Eugene Island, west of the Mississippi River it is well developed and continues to the western end.

If we examine the seasonal variation of sea level on the Atlantic coast of the United States, shown in Figure 4, we find again distinctive patterns which are characteristic for relatively large areas. Thus New York, Atlantic City and Baltimore show much the same pattern with a single maximum and minimum. Charleston, Mayport and Miami Beach, on the other hand have also a secondary maximum and a secondary mimimum.

In Figure 5 are shown the seasonal variations in sea level on our Pacific coast. Again, distinctive regional patterns, differing in the different regions. The seasonal variation in sea level is thus a characteristic feature of sea level throughout the world.

In view of the seasonal variation in sea level, it follows that a single month will not determine mean sea level accurately. A year immediately suggests itself as a desirable period, for within a year, the seasonal variation in sea level is eliminated and the effects of wind and weather likewise tend to balance out.

In Figure 6 are shown the yearly values of sea level at a number of our Atlantic coast stations. Each yearly height, represented by a small circle is the average of nearly 9,000 consecutive hourly heights.

Disregarding for the present the dashed-line curve associated with the diagram for each station, it is seen that sea level varies from year to year, generally by something like several hundredths of a foot but occasionally it may be as much as 0.2 foot. Furthermore, in the past 20 years there appears to have been a progressive rise in sea level. In the 20 year period from 1930 to 1950, the yearly sea level along the Atlantic coast for 1948 was about half a foot higher than the yearly sea level in 1930.

The fluctuations from year to year are in large part due to the disturbing effects of wind and weather; but if we smooth out these fluctuations - as is done by the dash-line curves - it is seen that there has been a steady progressive rise in sea level along the Atlantic coast which has averaged 0.02 foot per year.

The fluctuations in sea level from year to year are not confined to the Atlantic coast. In Figure 7 are shown the results from our Pacific coast tide stations. The fluctuations from year to year are of about the same character as on the Atlantic coast, but the progressive rise in sea level in the past two decades is only about 1/3 that on the Atlantic coast.

For the coast of Alaska our observations do not cover many years. But they are very interesting in their indications, for here sea level is falling. In Figure 8 the data for four stations are shown. At Ketchikan, which is the southernmost tidal station in Alaska, it appears that sea level was slowly rising till about 1940, and since that time sea level has been falling slowly. At Sitka, Juneau and Yakutat, the series are too short for definite quantitative evaluation, but the evidence decidedly indicates a fall in sea level.

In this connection tide observations made at Skagway, Alaska are of interest. From 1909 through 1911 we had a three year series of tide observations at that place, reference to bench marks. In 1944 the tide station was reestablished and we find that in the intervening period of about 35 years, sea level there fell about 2½ feet.

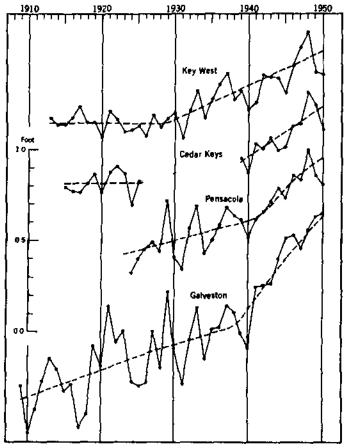

Fig. 9. Yearly sea level, Gulf coast

In Figure 9 are shown the yearly sea levels at four stations on the Gulf coast. At Key West the features are much the same as on the Atlantic coast - little change until 1930 and a rise since that time of about 0.02 foot per year. At Cedar Keys there was an interruption in the observations between 1925 and 1939, but the 10 years from 1915-1925 indicate little change in sea level, while from 1939 the rise is at a rate somewhat greater than at Key West. At Pensacola the rise in sea level is at a more rapid rate in recent years, the change appearing to have occurred about 1940.

For Galveston the results are especially interesting since a continuous series of 40 years is available. During this time sea level has changed by almost exactly one foot, but the results clearly indicate a change in rate of rise between 1937 and 1938. From 1909 to 1937 the rise was at the rate of about 0.015 foot per year, while since that year the rise is at the rate of about 0.05 foot per year or more than 3 times the previous rate.

It is convenient to speak of the rise or fall of sea level because the observations are made on a tide staff fixed to the land. But obviously, to say that sea level has risen with respect to a fixed point on the shore, is only another way of saying that the fixed point has subsided with respect to sea level. To determine which is the active agent and which the passive is another problem. If the coast is the active agent, the subsidence is absolute; if sea level is the active agent, the subsidence is relative; but in either case there is a lowering of the coast relative to sea level. What we have been trying to show is that tide observations are furnishing data which permit quantitative determinations of changes in the relative elevation of land to sea.

One other matter should perhaps be mentioned. The tide rises and falls from sea level. If at any place sea level is changing it means also that the datums of high water and low water are changing by the same amount as sea level.