MEAN SEA LEVEL

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The Coast and Geodetic Survey is interested in sea level as the basic datum for its precise geodetic levels and for use in the determination of a datum for its charts. On land, elevations are referred directly to mean sea level, and in harbors depths are referred for safety purposes to some low water datum, dependent upon the precise determination of mean sea level.

The definition of mean sea level is simple : At any place mean sea level is the average or mean level of the sea at that place. This simple definition immediately opens up two questions : 1° Does mean sea level thus determined at various places along a coast constitute an equipotentional surface ? 2° For how long a period of time must the changing level of the sea be averaged to give a precise determination of mean sea level ?

The first question, with regard to mean sea level constituting an equipotiental surface as defined above, need not detain us long here. From general considerations, it is clear that, because of different exposures to wind, weather and currents, different parts of a coast will have sea levels deviating somewhat from an equipotential surface. Precise leveling has brought out such deviations, but these are relatively small and, for practical purposes of mean sea level determination, may be ignored.

The second question : for how long a period must the changing level of the sea be averaged to give a precise determination of mean sea level — is of basic importance in determining the datum of mean sea level and is the one with which this paper is concerned.

Since the tide is the predominant periodic cause of the fluctuation of sea level, and since the primary period of the tide is approximately a day, it is clear that if we measure the height of the sea at any point at frequent intervals — say every hour — and then average these heights over the period of a day, we derive a first approximation to sea level. The hourly heights of the sea are most effectively derived from the record of an automatic tide gage.

On this slide are shown the daily sea levels at Atlantic City on the coast of New Jersey for two months of the year 1951, the upper diagram for June and the

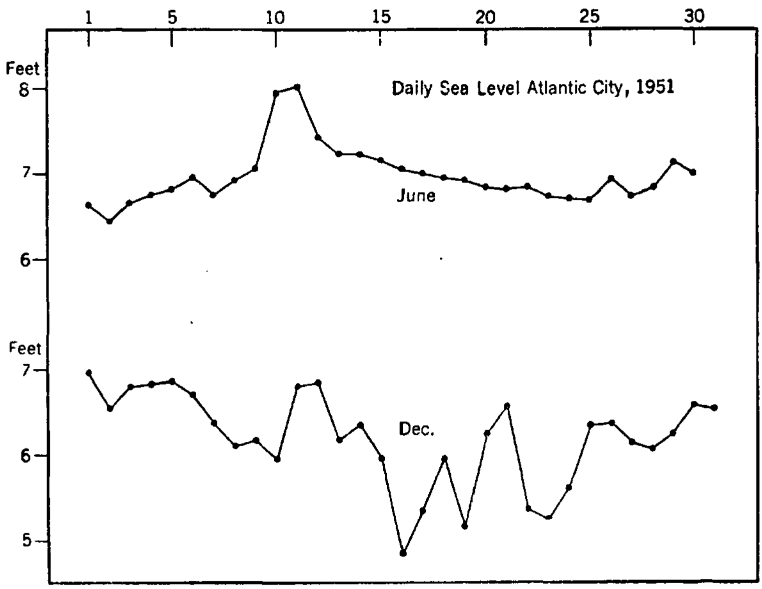

Fig. 1
Daily Sea Level Atlantic City, 1951

lower diagram for December. These daily sea levels were derived by averaging the 24 hourly heights of each day from the tide curve of the primary tide station at Atlantic City. The figures on the left give the heights as measured on a tide staff.

During June sea level is seen to have varied from day to day, generally by one - or two - tenths of a foot. Occasionally, however, the change was greater, reaching nearly a foot between the 9th and 10th. The difference between the lowest and highest daily sea levels during this month — on the 2nd and 11th respectively — was 1.5 feet.

During December the variation in sea level from day to day was considerably greater than during June ; instead of one - or two - tenths of a foot as in June, it is frequently half a foot or more in December. The difference between the highest and lowest sea levels for this month was 2.1 feet. In passing it may be noted that the sea level for June averaged 7.0 feet, while for December it averaged 6.2 feet, making the average sea level for June 0.8 foot higher than in December.

The relatively large differences in sea level from day to day are obviously ascribed to the effects of wind and weather. On the Atlantic coast of the United States, June is generally a month of light winds, while December is a month of stronger winds, and thus the changes from day to day in December are generally greater than in June.

Let us therefore investigate monthly sea level. A monthly sea level is the average of some 700 hourly heights. The larger fluctuations, due to changes in wind and weather from day to day, are averaged out in a month, and we may expect smaller changes in sea level from month to month than from day to day.

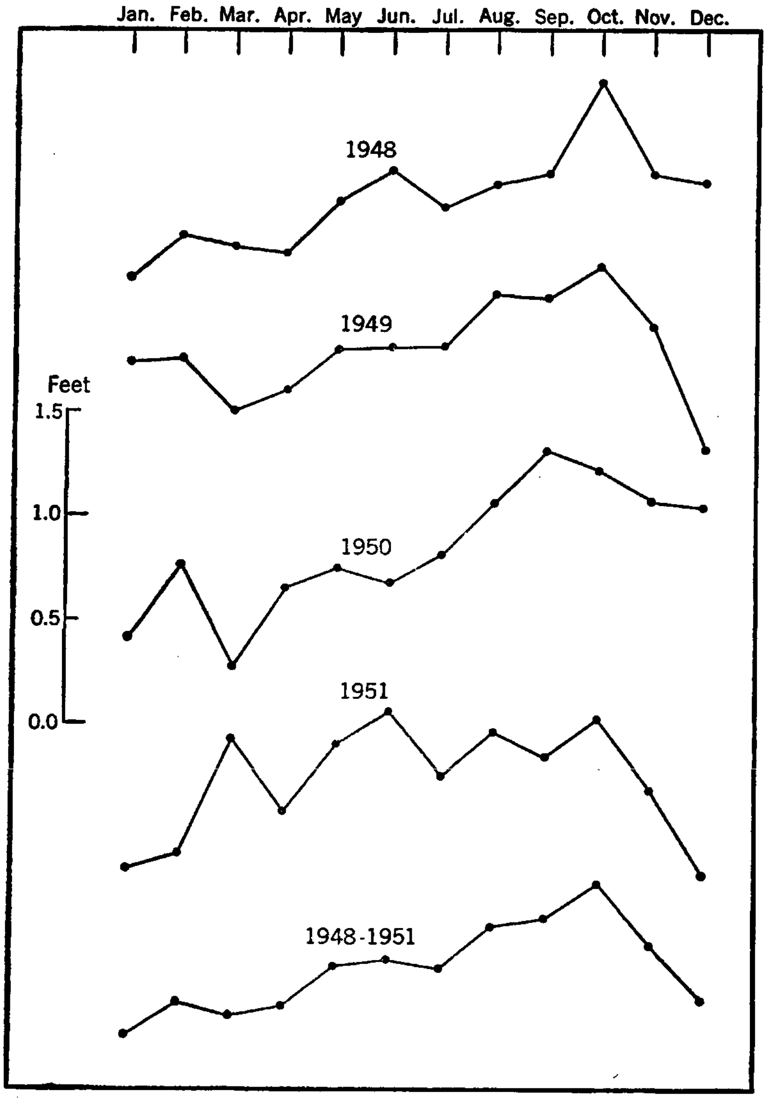

Fig. 2
Monthly Sea Level, Atlantic City

In this slide are shown the monthly values of sea level at Atlantic City for each month of the four-year period, 1948 through 1951. From one month to the next, sea level generally changes only a few tenths of a foot, though occasionally it may be as much as half a foot, as, for example, between November and December in 1949. Within a year, two monthly sea levels may differ by as much as a foot, as illustrated by the sea levels for March and September 1950.

An examination of the four diagrams shows that, in general, sea level at Atlantic City is high in the autumn months and low in the winter and spring. If we average the sea level heights for corresponding months during the four years, 1948-1951, we derive the lower curve shown in this slide, which suggests strongly a seasonal variation in sea level.

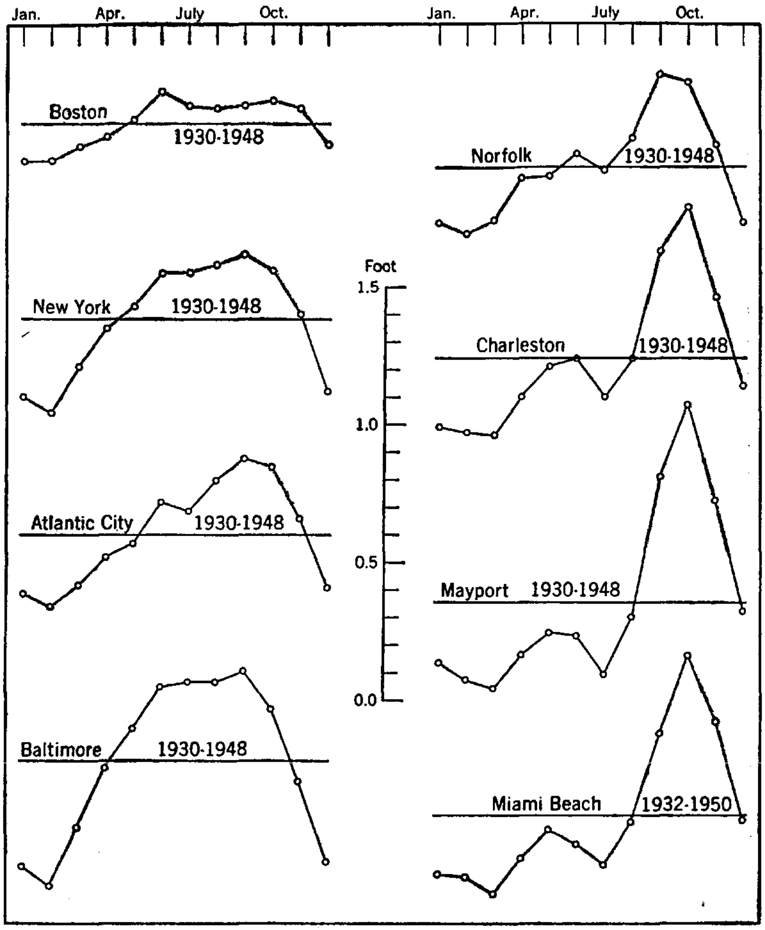

Fig. 3

Sea Level. Annual Variation, Atlantic Coast

If we investigate the matter, we find that the change in sea level from month to month at any place has a large element of periodicity, that is, it exhibits a seasonal variation. On this slide are shown the curves of seasonal variation in sea level at eight stations along the Atlantic coast of the United States. The horizontal line of each diagram represents the mean level of the sea at each station for the period of observations indicated. Each place has its own characteristic curve of seasonal variation, but places near each other show much the same pattern. Thus New-York and Baltimore, although nearly 200 miles apart and situated in different bays, have much the same pattern of change. Likewise, Charleston and Miami Beach, which are nearly 500 miles apart, have seasonal variations resembling each other closely.

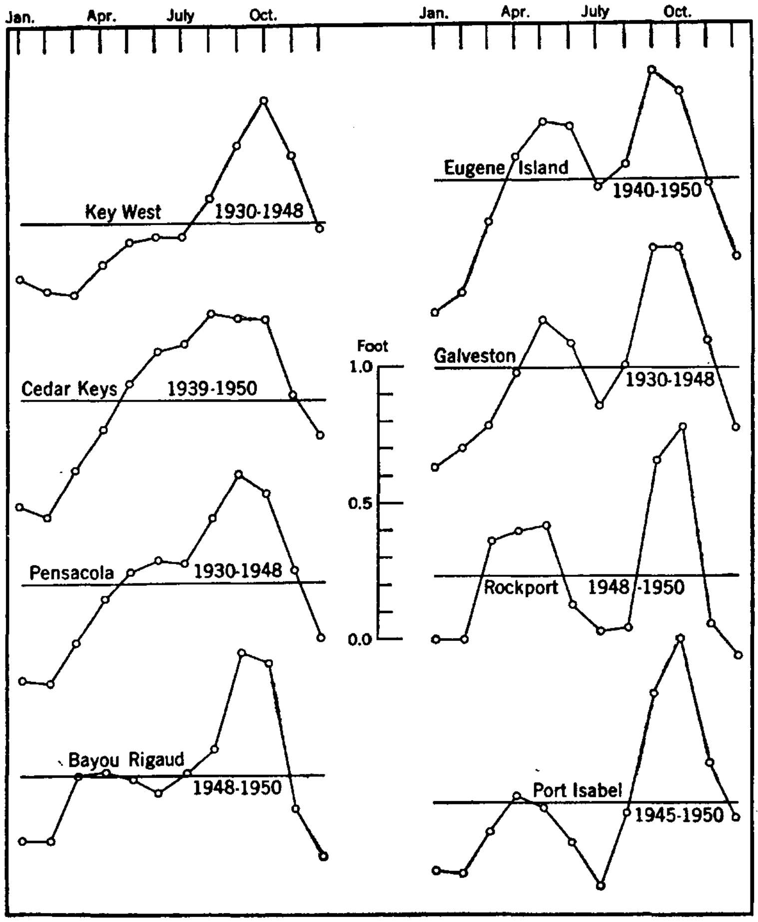

Fig. 4

Sea Level. Annual Variation, Gulf Coast

The seasonal variation in sea level is not confined to the Atlantic coast of the United States. Here are shown the curves of seasonal variation in sea level at eight stations on the Gulf of Mexico coast of the United States. Again it is seen that these stations have distinctive local features, but that they have much the same general pattern for places near each other. It is of interest, too, to note how the pattern changes gradually from a single maximum and minimum for more westerly points. At Key West there is a bare inkling of this ; at Pensacola there is a beginning ; while at Eugene Island, west of the Mississippi River, it is well developed and continues to the western end of the Gulf at Port Isabel.

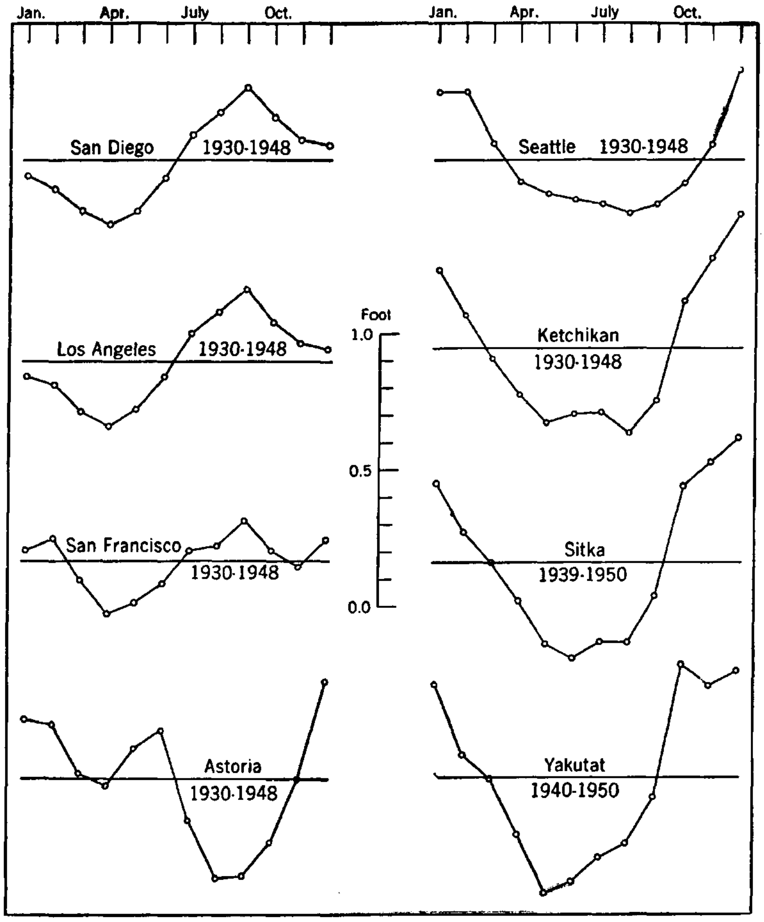

Fig. 5

Sea Level. Annual Variation, Pacific Coast

Here are shown the curves of seasonal variation in sea level at a number of stations on the Pacific coast of the United States and Alaska. Once more local features are seen in different regions, but much the same pattern covers considerable stretches of the coast.

A seasonal variation in sea level thus appears to be a characteristic feature of the sea throughout the world, the pattern of this variation, both in amplitude and in phase, being different in different regions. It follows therefore that, in general, a single month of observations will not accurately determine mean sea level.

In view of the seasonal variation in sea level, a year suggests itself as a more desirable period for the determination of mean sea level because in a year the seasonal variation is eliminated.

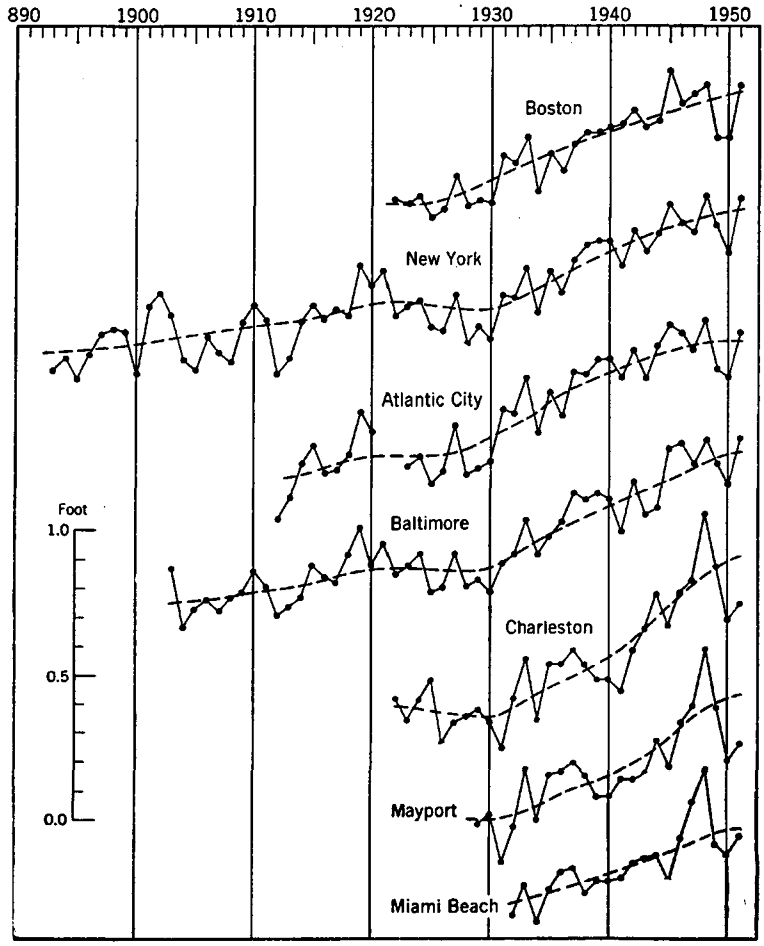

Fig. 6
Yearly Sea Level, Atlantic Coast to 1951

In this slide are shown the yearly heights of sea level at a number of tide stations along the Atlantic coast of the United States. Each yearly height, represented by a small circle, is the average of the nearly 9.00 consecutive hourly heights of the sea for the year.

An examination of the diagram for any on the these stations shows that sea level varies from year to year, generally only by several hundredths of a foot, though occasionally the difference may be as much as two-tenths of a foot. Moreover, since 1930 there appears to have been a progressive rise of sea level which now amounts to more than one-third of a foot.

The change in sea level from one year to another must be ascribed in large part to the disturbing effects of wind and weather. The dashed-line curve associated with each of the diagrams was obtained by averaging the sea level values. In these curves can be seen the steady rise in sea level since 1930.

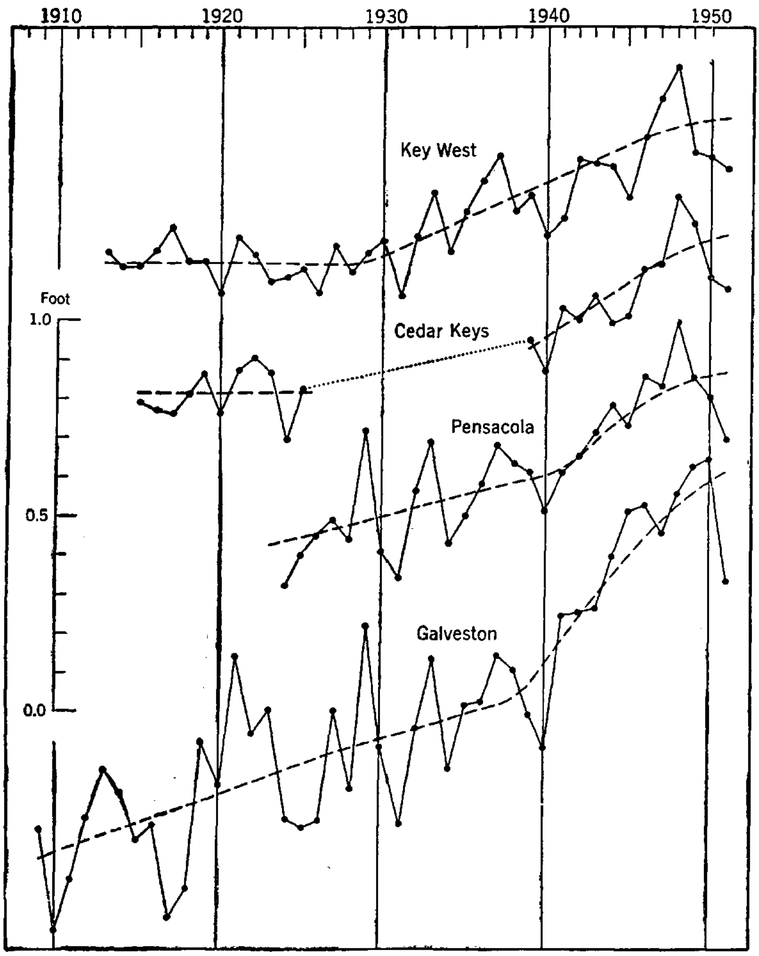

Fig. 7

Yearly Sea Sevel, Gulf Coast to 1951

Here are the yearly sea levels from our tide stations along the coast of the Gulf of Mexico. For Key West the features are much the same as for the Atlantic coast stations — little change until 1930 and a progressive rise since then amounting to about a third of a foot. For Cedar Keys there is an interruption in the observations between 1925 and 1939, but the two parts of the series indicate little change in sea level between 1915 and 1925 and a decided rise since 1939. At Pensacola there has been a steady rise since the beginning of the series in 1924, with a more accelerated rise since 1940.

For Galveston the observations extend for more than 40 years. From 1909 to 1937 the rise was at a rate averaging fifteen-thousandths of a foot per year, but since then the rise has been about three times as great — nearly five-hundredths of a foot per year.

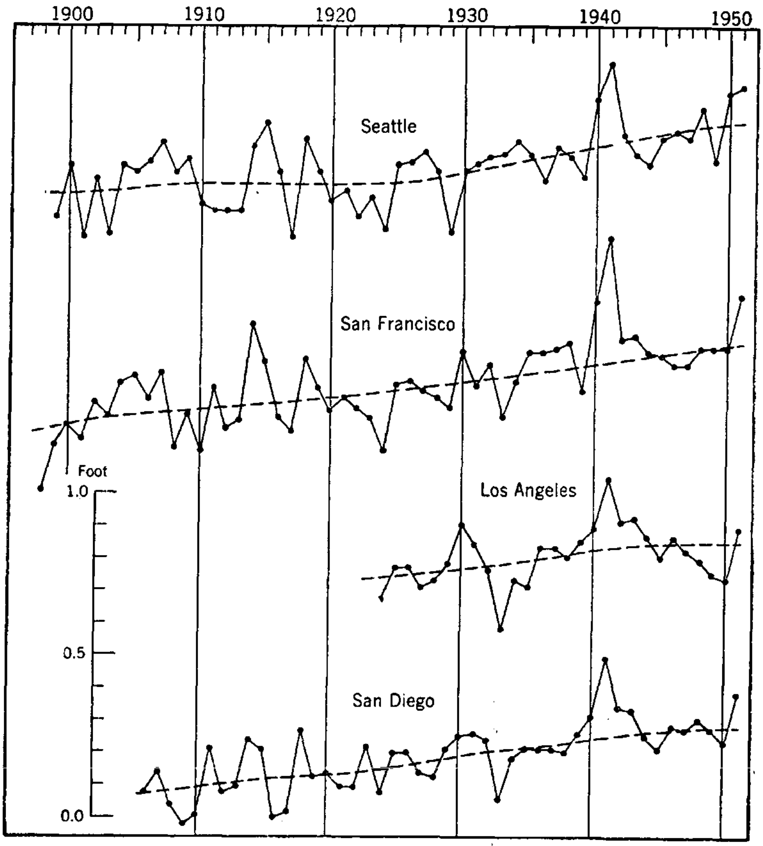

Fig. 8

Yearly Sea Level, Pacific Coast to 1951

Here are the yearly values of sea level from our Pacific coast tide stations. The fluctuations from year to year are of the same character as on the Atlantic and Gulf coasts, but the progressive rise in sea level in recent years is at a much smaller rate — only about a third that of the Atlantic coast.

For the Alaska coast, our tide observations do not cover many years, but their indications are very interesting. Here are the yearly sea levels at four Alaska stations. At Ketchikan, which is the southernmost tidal station in Alaska, sea level appears to have risen somewhat until 1940, since which time it appears to be falling slowly. At Sitka, Juneau and Yakutat the observations are not of sufficient length for precise quantitative evaluation, but the evidence is unquestionable for a fall of sea level.

In this connection, tide observations made at different times at Skagway, Alaska, are of interest. In conjunction with hydrographic work at Skagway, three years of tide observations, from 1909 through 1911, were obtained. About 35 years later, in 1944, the tide station there was re-established and connected with the bench marks established in the 1909-1911 series. These observations show that in the 38 years from 1910 to 1948, sea level at Skagway has fallen 2,5 feet.

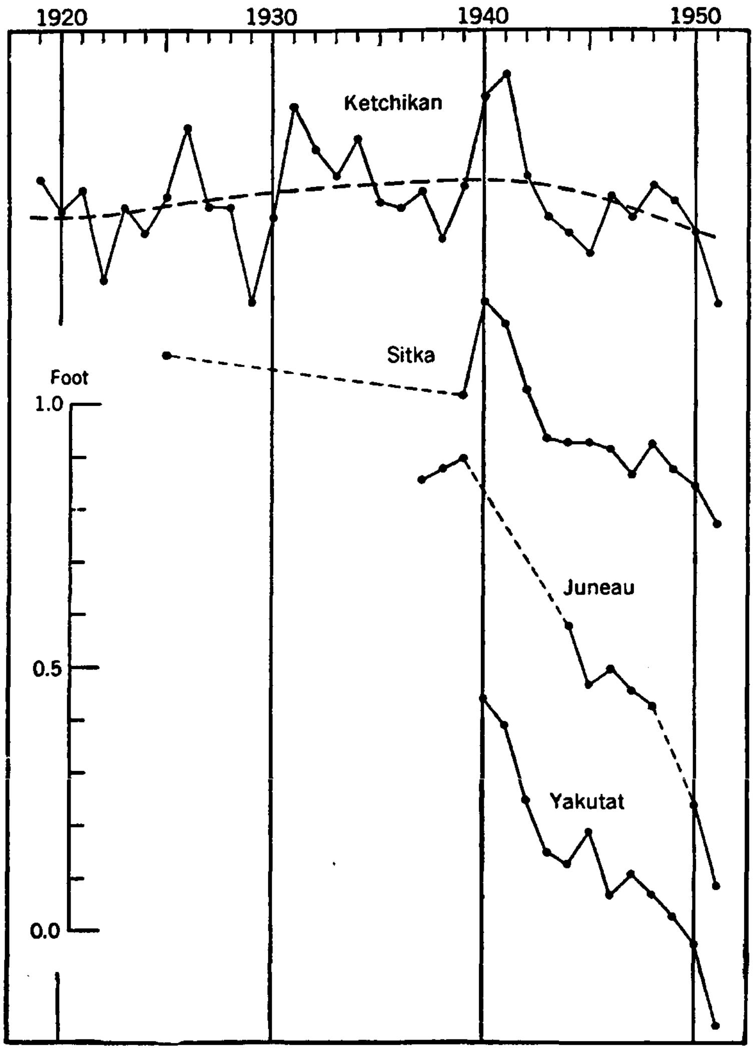

Fig. 9
Yearly Sea Level, Alaskan Coast to 1951

In view of the variations to which sea level is subject, it is obvious that the concept of mean sea level as a fixed and unchanging elevation, good for all time, is not a valid concept. Instead we must adopt a mean sea level datum based on a definite number of years of observations and refer it to a given epoch.

With regard to the number of years of observations to be used, there is a theoretical variation in sea level depending on the longitude of the moon's node, which has a period of 18,6 years or, in round numbers, 19 years. Moreover, high water and low water likewise are affected by the periodic changes in the longitude of the moon's node, but to a much larger extent than sea level, so that mean high water and mean low water are based on 19 years of observations. Hence, we may take 19 years as constituting a primary determination of mean sea level.

As regards epoch, any specified epoch will do. At the present time the Coast and Geodetic Survey is using the period 1924-1942.

With the adoption of a definite number of years as constituting a primary determination of mean sea level, and basing it on a given epoch, we not only make of mean sea level a precise datum, but we also are enabled to correlate this datum for large regions without the need of making 19 years of observations at all places where this datum is desired. An example will make this clear.

Suppose that in 1931 sea level at Mayport had been determined from a year of observations and referenced to adequate bench marks. Seventeen years later, in 1948, another year of observations was made there, and from that series sea level was found to be 0.73 foot higher. From these two sets of observations alone, we would not know whether or not the bench marks had changed in elevation during the intervening 17 years. And even if we did have other evidence to substantiate the stability of the bench marks, we would still be at a loss to know on which year of observations to base our datum of mean sea level.

However, we know that sea level fluctuates from year to year, and we should like our mean sea level datum to approximate a 19-year mean. We have a 19-year series at Charleston, wich is about 200 miles north of Mayport, and we know that the fluctuations in sea level along that stretch of coast are much the same. For the year 1931, sea level at Charleston was 0.19 foot below its 19-year (1924-1942) value, while for 1948 it was 0.62 foot above the mean value. Hence, to correct the 1931 and 1948 observations at Mayport to a 19-year mean, epoch 1924-1942, we must add 0.19 foot to the 1931 value and subtract 0.62 foot from the 1948 value. As a result, the two series of observations which differed by 0.73 foot give mean sea level values which differ by only 0.02 foot.

We can check our results further in this particular case, since we have tide observations at Mayport for the 19-year period, 1924-1942. From these 19 years, mean sea level comes out as 3.69 feet on the staff, which is 0.03 foot above the mean sea level value derived from the 1931 observations and 0.01 foot above the mean sea level value from the 1948 observations.

Hence, with the adoption of a definite number of years for determining mean sea level, and basing it on a given epoch, mean sea level becomes a precise datum.