A Technical Memorandum NOS 15

DEPARTMENT OF COMMERCE · UNITED STATES OF AMERICA

AN AVERAGE, LONG-PERIOD, SEA-LEVEL SERIES FOR THE UNITED STATES

Steacy D. Hicks
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ABSTRACT. An average, long-period, sea-level series for the United States (except Alaska and Hawaii), from which a representative curve and a single-value rate were derived, is presented for the first time. The series was obtained by averaging common-length, uninterrupted, sea-level series obtained from tide gage measurements. The averaging was by coastal area. The curve, with amplitudes of its meteorological and oceanographic oscillations of periods less than 5 1/3 years attenuated more than 90%, shows the relative, apparent secular trend and its changes for the United States as a whole. During the 34-year period, 1940 through 1973, sea level rose along the coasts of the United States at the average rate of 1.5 mm (0.005 ft) per year.

INTRODUCTION

Many investigators have published glacial-eustatic, sea-level rates. Munk and Revelle (1952) created an indirect method based on variations in the speed of the earth's rotation and the tilting of its axis of rotation. Most methods, however, have dealt with time series from sea-level measurements relative to the adjacent land. By averaging linear approximations of the apparent secular trend (with or without removal of meteorological and oceanographic effects) at, hopefully, representative stations, glacial-eustatic rates are stated. These rates are summarized and evaluated by Lisitzin (1974). The numerous problems inherent in the direct measurement methods have also been discussed by Hicks (1972). A far more realistic approach of these latter types has been made by Fairbridge and Krebs (1962). They constructed a glacial-eustatic curve by averaging the yearly mean sea-level series from selected, representative, station series over the period 1860 through about 1958.

In this study, we make no attempt to provide yet another glacial-eustatic rate or even an eustatic curve. What is attempted is merely to provide a Fairbridge-type curve of the average, representative, relative, apparent secular trend and its variations for the shores of the United States as a whole (except Alaska and Hawaii) during the period 1940 through 1973.

DATA AND SERIES

Sea-level series are obtained from water elevation measurements conducted at tide stations. The National Ocean Survey operates 29 tide stations that have continuous measurements from 1939 or earlier on the coasts of the United States (except Alaska and Hawaii). Series composed of yearly mean sea level values from 27 of these stations were used in this study. Each value is the arithmetic mean of a calendar year of hourly heights. The hourly heights were either scaled directly from the marigram or obtained from a digital output of the analog tide gage at each tide station. Statistical values and graphs for station series (through 1972 only) are given by Hicks and Crosby (1974).

COMPUTATIONS

The coastline of the United States was divided into five areas. The division was based on a subjective balance between series coherence (Hicks and Shofnos, 1965), equal coastal lengths, and Gutenburg's (1941) regions. The areas, together with their inclusive stations, are listed in table I.

Although both Sandy Hook, N.J., and Galveston, Tex., have continuous series dating long before 1940, they were not used in this study. Both stations are undergoing anomalous, localized subsidence as determined independently by terrestrial leveling. This is not to say that the other stations are not undergoing subsidence; only that the two anomalous ones differ greatly from their area patterns. See Holdahl and Morrison (1974), Cole (1928), and Dawson (1962) for discussion.

For each year, the yearly mean sea-level values at all stations in an area were averaged for that year. An average series was thus obtained for every one of the five areas. Likewise, for each year, the average area values for all five areas were averaged for that year. The resulting graph, with straight lines connecting the averaged yearly points, is shown in figure 1. The curve is the result of a seven-point (five and three-point near ends), triangular, weighting array applied to the averaged yearly points on the graph. The array attenuates by more than 90% the amplitudes of all meteorological and oceanographic oscillations with periods less than 5 1/3 years (Hicks and Shofnos, 1965).

Apparent secular trends are not linear or regular and can easily be separated visually into segments of their time series. Thus, when results from different stations are to be compared, it is always necessary to use a common series length in the analyses and computations. The common series length, 1940 through 1973, was an arbitrary subjective choice. The choice was a trade-off between the desire to have as long a time span as possible common to all stations selected, and the need to include a sufficient number of stations for a representative coverage of the coast.

Uninterrupted (without missing data) series, as well as a series length common to all stations, is also necessary in the averaging computations. Terrestrial leveling has been conducted between most tide stations. However, the connections are usually composed of a network of lines leveled in different years (often in different decades) and adjusted by least squares. Although perfectly valid for geodetic purposes, this procedure is not applicable in connecting a specific time period, or even a relatively short time period, between time series at different stations. As a result, the averaging must be done each time with the same number of values. Otherwise, the curve would be "pulled" toward the average of the values that <u>are</u> present for that year.

The slope (trend) of a least-squares line of regression was computed for the averaged yearly points in figure 1. The trend is 1.5 mm (0.005 ft) per year with a standard error of trend of ± 0.3 mm (0.001 ft) per year. The standard error of estimate (standard deviation from the line of regression), which quantifies variability, is ± 16.7 mm (0.055 ft).

Using the average single-value rate, relative sea level rose 5.1 cm (0.17 ft) along the coasts of the United States as a whole during the period 1940 through 1973. The largest excursion of the averaged yearly points is 9.0 cm (0.30 ft) from 1940 to 1972. The largest rise for a station used in this study, 13.2 cm (0.43 ft), using its average single-value rate, occurred at Portsmouth, Va. The rise at Galveston, one of the anomalous stations, is 16.7 cm (0.55 ft) over this same 1940 through 1973 time span.

REFERENCES

L. A. Cole, "Tidal bench marks," Sp. Pub. No. 148, U.S. Coast and Geodetic Survey, 1928, 48 pp.

R. F. Dawson, "A review of the land subsidence problems in the Texas gulf coast area," Read before Surveying and Mapping Division, American Society of Civil Engineers, Houston, 1962.

R. W. Fairbridge and O. A. Krebs, Jr., "Sea level and the southern oscillation," Geophysical Journal, vol. 6, 1962, pp. 532-545.

B. Gutenberg, "Changes in sea level, postglacial uplift, and mobility of the earth's interior," Bulletin of the Geological Society of America, vol. 52, 1941, pp. 721-772.

S. D. Hicks, "Vertical crustal movements from sea level measurements along the east coast of the United States," Journal of Geophysical Research, vol. 77 (30), 1972, pp. 5930-5934.

S. D. Hicks and W. Shofnos, "Yearly sea level variations for the United States," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, vol. 91 (HY5), 1965, pp. 23-32.

S. D. Hicks and J. E. Crosby, "Trends and variability of yearly mean sea level, 1893-1972," NOAA Technical Memorandum NOS 13, 1974, 14 pp.

S. R. Holdahl and N. L. Morrison, "Regional investigations of vertical crustal movements in the U.S., using precise relevelings and mareograph data," Tectonophysics, vol. 23, 1974, pp. 373-390.

E. Lisitzin, "Sea-level changes," Elsevier Oceanography Series, 8. Amsterdam: Elsevier, 1974, 286 pp.

W. Munk and R. Revelle, "Sea level and the rotation of the Earth," American Journal of Science, vol. 250, 1952, pp. 829-833.

Table I. Coastal areas with inclusive tide station locations

Northern East Coast to Cape Hatteras

- Portland, Me.
- Seavey I. (Portsmouth), N.H.
- Boston, Mass.
- Newport, R.I.
- New London, Conn.
- Willets Pt., N.Y.
- New York, N.Y.
- Baltimore, Md.
- Washington, D.C.
- Hampton Rds. (Norfolk), Va.
- Portsmouth, Va.

Southern East Coast

- Charleston, S.C.
- Ft. Pulaski (Savannah), Ga.
- Fernandina, Fla.
- Mayport, Fla.
- Miami Beach, Fla.

Gulf Coast

- Key West, Fla.
- Cedar Key, Fla.
- Pensacola, Fla.

Southern West Coast to Pt. Arena

- San Diego, Calif.
- Los Angeles, Calif.
- Alameda, Calif.
- San Francisco, Calif.

Northern West Coast

- Crescent City, Calif.
- Astoria, Oreg.
- Seattle, Wash.
- Friday Harbor, Wash.

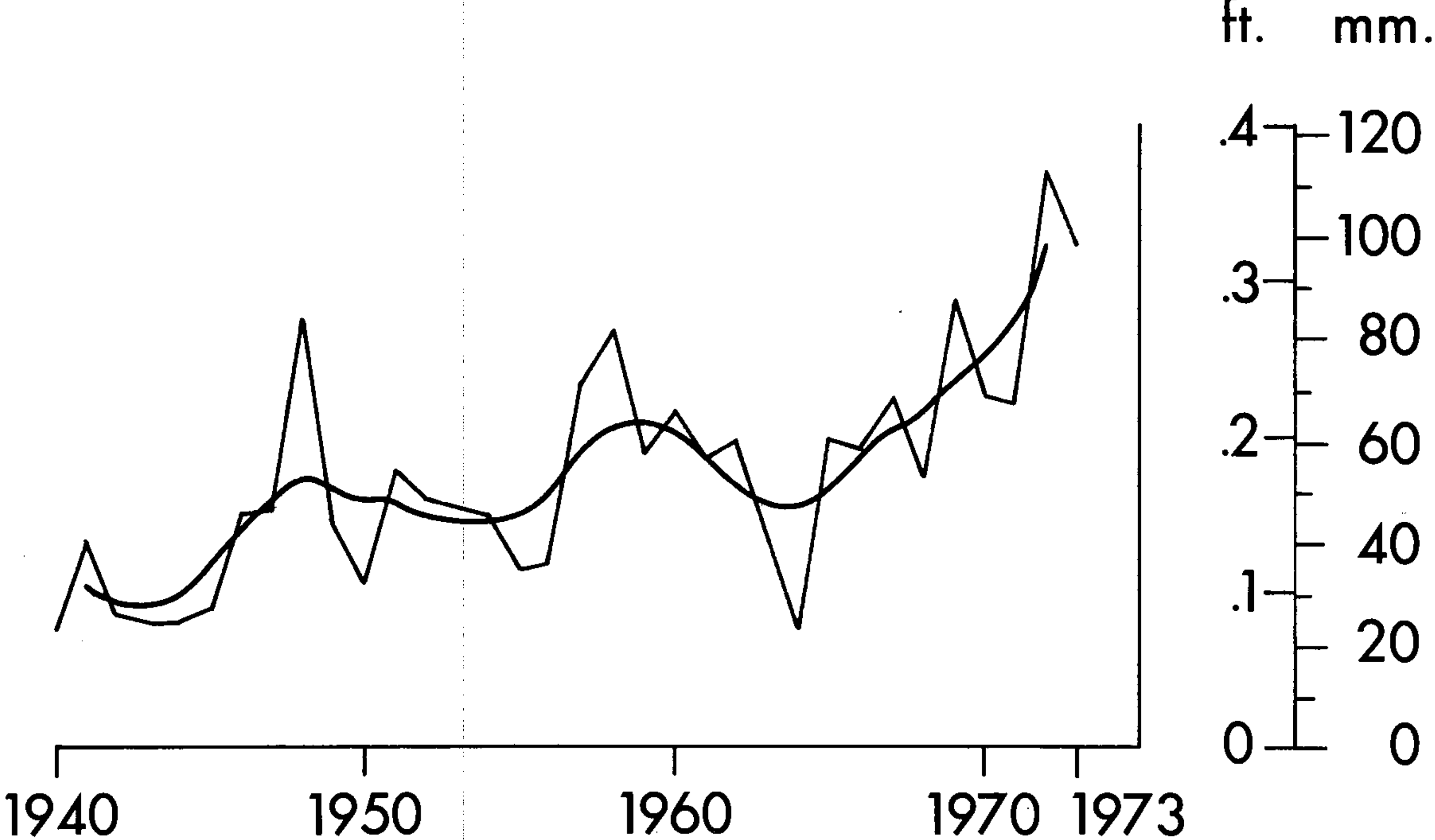

Figure 1. Averaged sea-level series and curve for the United States (except Alaska and Hawaii).