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TRENDS AND VARIABILITY OF YEARLY MEAN SEA LEVEL 1893-1972

Steacy D. Hicks and James E. Crosby

Rockville, Md.
March 1974

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NOS 12	Trends and Variability of Yearly Mean Sea Level 1893-1971. Steacy D. Hicks, March 1973. (COM-73-10670)

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UNITED STATES DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary
/ NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator
/ NATIONAL OCEAN SURVEY
Allen L. Powell, Director

TRENDS AND VARIABILITY OF YEARLY MEAN SEA LEVEL, 1893-1972

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ABSTRACT. Sea-level trends, their standard errors, and variability are presented in tabular form for 50 locations along the coasts of the United States. The values are given for the entire series length at each station, the oldest dating from 1893 at New York. For intrastation comparisons, values also are given for the longest length of series common to 46 of the stations, 1940-72. Graphs of yearly mean sea level, upon which the calculations were performed, are plotted for 44 stations.

1. INTRODUCTION

This Technical Memorandum is directed toward the management fields of wetlands preservation, pollution abatement and control, conservation, coastal zone management, and global energy; the engineering fields of beach erosion, harbor and waterway construction, shore and sea boundaries, and coastal inundation; and the scientific fields of glaciology, physical and geological oceanography, meteorology and climatology, tectonics, and geodesy. Since the uses of the calculations may vary greatly, no interpretive text is included. This publication will be issued annually; each issue will incorporate the new yearly mean sea level values in each tabulated calculation and graph.

2. EXPLANATION OF TRENDS AND VARIABILITY

Yearly mean sea level is the arithmetic mean of hourly sea level heights obtained from an analog tide gage over a period of one calendar year. The tide gage, often located on a pier, continuously measures sea-level heights relative to the land adjacent to the station location. The gage is connected to bench marks on the adjacent land by precise first-order leveling. If possible, the bench marks are located in bedrock.

One table and nine illustrations show the trends and variability of yearly mean sea level at permanent tide stations operated by the National Ocean Survey (NOS). Column 1 of the table lists all of the NOS-operated stations that were in operation by 1939 and that had very few and short breaks in measurement. In addition, all permanent stations in the greater New York Bight area are included. The inclusive dates of each station series are given in column 2. Where the length of a break in the series is sufficient to invalidate a yearly mean, the missing year is shown in column 3.

If a series of yearly mean sea level values is plotted on a graph of height against date, an apparent secular trend and yearly variability become evident. "Secular" means nonperiodic; "apparent" means it is not known whether the trend is nonperiodic or is merely a segment of a very long oscillation. Apparent secular trends in sea level result from glacial-eustatic, tectonic, and climatological and oceanographic apparent secular trend effects. Columns 4 and 7 show the apparent secular trend as the slope of a straight line mathematically fitted through the yearly mean sea level values (see note *a* on table). About two-thirds of repeated calculations of the apparent secular trend will differ from the true apparent secular trend by less than the standard error of slope listed in columns 5 and 8 (see note *b* on table). About 95% of repeated calculations of the apparent secular trend will differ by less than two times the standard error of slope, and practically all repeated calculations will differ by less than three times the standard error of slope.

Yearly variability is caused by variations in the meteorological and oceanographic parameters of wind, direct atmospheric pressure, river discharge, currents, salinity, and water temperature. About two-thirds of the yearly mean sea level values will differ from the straight line slope by less than the variability given in columns 6 and 9 (see note *c* on table). About 95% of the yearly mean sea level values will differ from the line by less than two times the variability, and practically all the values will differ by less than three times the variability.

Trends and variability of yearly mean sea level through 1972

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Entire Series			1940-1972		
Location	Date series began	Dates of missing data	Trend[a]	Standard error of trend[b]	Variability[c]	Trend	Standard error of trend	Variability
			$mm\ yr^{-1}$	$\pm\ mm\ yr^{-1}$	$\pm$ mm	$mm\ yr^{-1}$	$\pm\ mm\ yr^{-1}$	$\pm$ mm
Atlantic Coast								
1. Eastport, Me.	1930	1957,58	3.60	0.29	23.75	4.05	0.46	25.22
2. Portland, Me.	1912		2.30	.21	29.09	2.45	.54	29.66
3. Portsmouth, N.H.	1927	1935-39	2.42	.26	21.77	1.85	.38	20.93
4. Boston, Mass.	1922		2.89	.24	25.19	1.40	.42	22.86
5. Woods Hole, Mass.	1933	1965,67-69	3.46	.32	21.12	3.10	.42	20.83
6. Buzzards Bay, Mass.	1956	1959	1.17	1.28	24.92			
7. Newport, R.I.	1931		3.04	.27	21.57	2.50	.39	21.32
8. Providence, R.I.	1939	1947-56,67	2.37	.44	23.71	2.36	.48	24.29
9. Montauk, N.Y.	1948	1959,72	2.31	.74	25.07			
10. New London, Conn.	1939		2.63	.38	21.51	2.57	.40	21.77
11. Port Jefferson, N.Y.	1958		3.62	1.71	28.66			
12. New Rochelle, N.Y.	1958		3.10	2.04	34.06			
13. Willets Pt., N.Y.	1932		3.24	.35	26.43	2.81	.50	27.25
14. New York, N.Y.[d]	1893		2.87	.13	27.29	3.10	.40	21.98
15. Sandy Hook, N.J.	1933		4.92	.33	24.05	5.00	.45	24.76
16. Atlantic City, N.J.	1912	1921,22,70,71	3.90	.22	28.06	3.30	.54	27.38
17. Lewes, Del.	1921	1923-36,40-47, 50-52	3.54	.45	31.40	2.89	1.06	33.87
18. Philadelphia, Pa.	1901	1921,22,59,60	2.67	.22	38.69	2.38	.74	40.29
19. Baltimore, Md.	1903		3.39	.15	25.90	2.94	.46	25.38
20. Annapolis, Md.	1929	1969	4.23	.30	24.62	3.49	.45	23.86
21. Washington, D.C.	1932		3.28	.44	33.35	3.26	.63	34.57
22. Solomons, Md.	1938	1970	3.87	.43	24.87	3.83	.49	25.64
23. Hampton Roads, Va.	1928		4.63	.35	30.30	3.84	.55	29.83
24. Portsmouth, Va.	1936		3.81	.41	26.44	3.87	.50	27.56
25. Charleston, S.C.	1922		3.61	.33	35.05	2.22	.66	36.01
26. Fort Pulaski, Ga.	1936		2.65	.50	32.43	2.37	.61	33.21
27. Fernandina, Fla.	1939		1.84	.60	34.19	1.66	.62	34.18
28. Mayport, Fla.	1929		2.69	.39	32.83	1.85	.61	33.18
29. Miami Beach, Fla.	1932		2.50	.29	22.20	1.97	.41	22.44
Gulf Coast								
30. Key West, Fla.	1913		2.10	0.19	25.69	0.99	0.47	25.78
31. Cedar Key, Fla.	1915	1926-38	2.04	.25	29.23	0.96	.55	30.22
32. Pensacola, Fla.	1924		2.36	.36	35.94	0.80	.61	33.52
33. Eugene I., La.	1940	1971,72	9.21	.73	36.41	9.21	.73	36.41
34. Galveston (Pier 21), Tex.	1909		5.95	.32	46.82	4.92	.81	44.57

Trends and variability of yearly mean sea level through 1972 (continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Entire Series			1940-1972		
Location	Date series began	Dates of missing data	Trend [a]	Standard error of trend [b]	Variability [c]	Trend	Standard error of trend	Variability
			$mm\ yr^{-1}$	$\pm\ mm\ yr^{-1}$	$\pm$ mm	$mm\ yr^{-1}$	$\pm\ mm\ yr^{-1}$	$\pm$ mm
West Coast								
35. San Diego, Calif.	1906		1.99	0.16	25.16	1.56	0.51	28.15
36. La Jolla, Calif.	1925	1954,55	1.91	.28	26.81	1.89	.54	29.47
37. Los Angeles, Calif.	1924		0.66	.27	26.86	-0.30	.49	26.65
38. Alameda, Calif.	1940		0.45	.66	36.08	0.45	.66	36.08
39. San Francisco, Calif.	1898		1.97	.17	31.33	1.80	.63	34.49
40. Crescent City, Calif.	1933		-0.49	.42	30.77	-1.37	.55	30.24
41. Astoria, Oreg.	1925		0.05	.43	40.79	-0.43	.72	39.60
42. Seattle, Wash.	1899		1.93	.17	30.83	2.64	.53	28.91
43. Neah Bay, Wash.	1935	1959	-0.86	.45	30.25	-1.36	.56	30.70
44. Friday Harbor, Wash.	1934		1.15	.43	30.39	0.79	.57	31.15
45. Ketchikan, Alaska	1919		0.003	.31	35.95	-0.16	.76	41.42
46. Sitka, Alaska	1938		-2.31	.49	29.26	-2.31	.55	30.15
47. Juneau, Alaska	1936		-13.46	.56	36.28	-13.52	.70	38.15
48. Yakutat, Alaska	1940		-5.33	.63	34.43	-5.33	.63	34.43
49. Honolulu, Hawaii	1905		1.56	.22	35.89	0.004	.55	29.92
50. Cristobal, C.Z.	1909		1.24	.15	22.79	0.74	.39	21.59

[a] Slope of a least-squares line of regression:

$$b = \frac{\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}$$

Where x = date,
y = height of yearly mean sea level, and
n = number of yearly mean sea-level values.

[b] Standard Error of Slope:

$$s_b = \frac{s_{y.x}}{\sqrt{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}}$$

Where $s_{y.x}$ = Standard Error of Estimate.

[c] Standard Error of Estimate (standard deviation from line of regression):

$$s_{y.x} = \sqrt{\frac{\Sigma y^2 - \frac{(\Sigma y)^2}{n} - b\left(\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}\right)}{n - 2}}$$

[d] 1893-1920, Ft. Hamilton; 1921-72, The Battery.

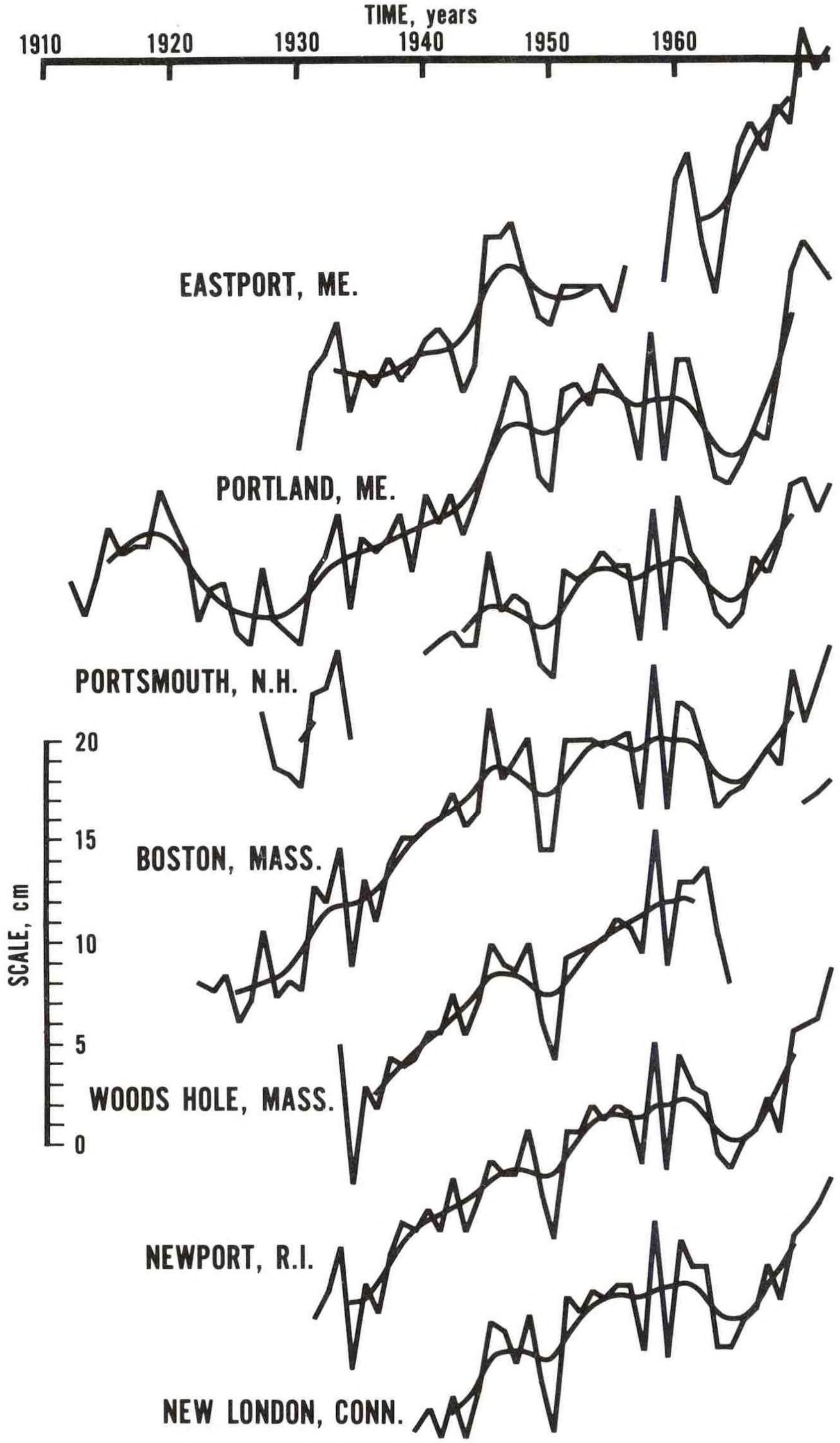

Figure 1.--Change in sea level with respect to adjacent land for stations from Maine to Connecticut. Straight-line segments connect yearly mean sea level values. Curved lines connect yearly values smoothed by weighting array.

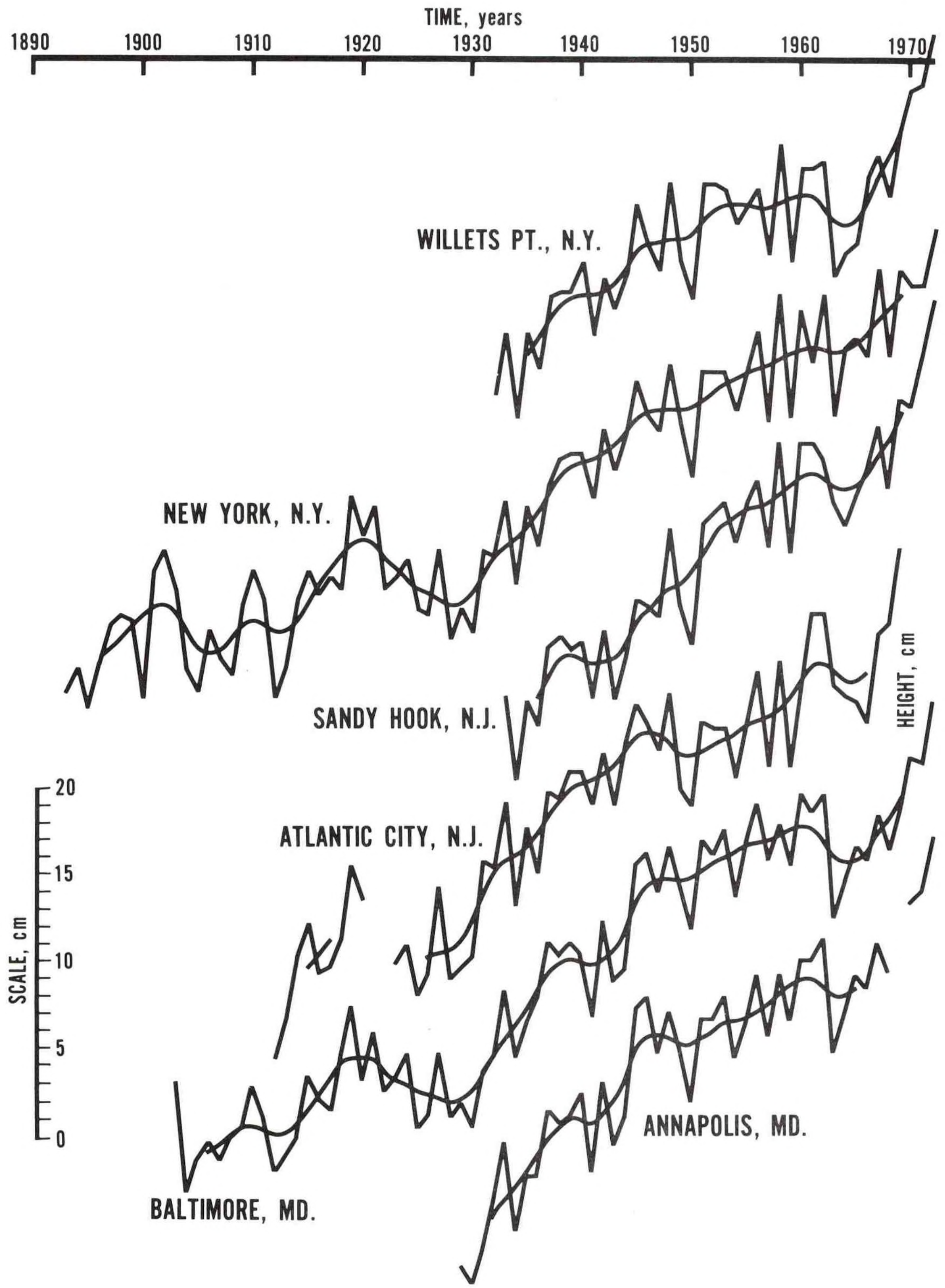

Figure 2.--Change in sea level with respect to adjacent land for stations from New York to Maryland.

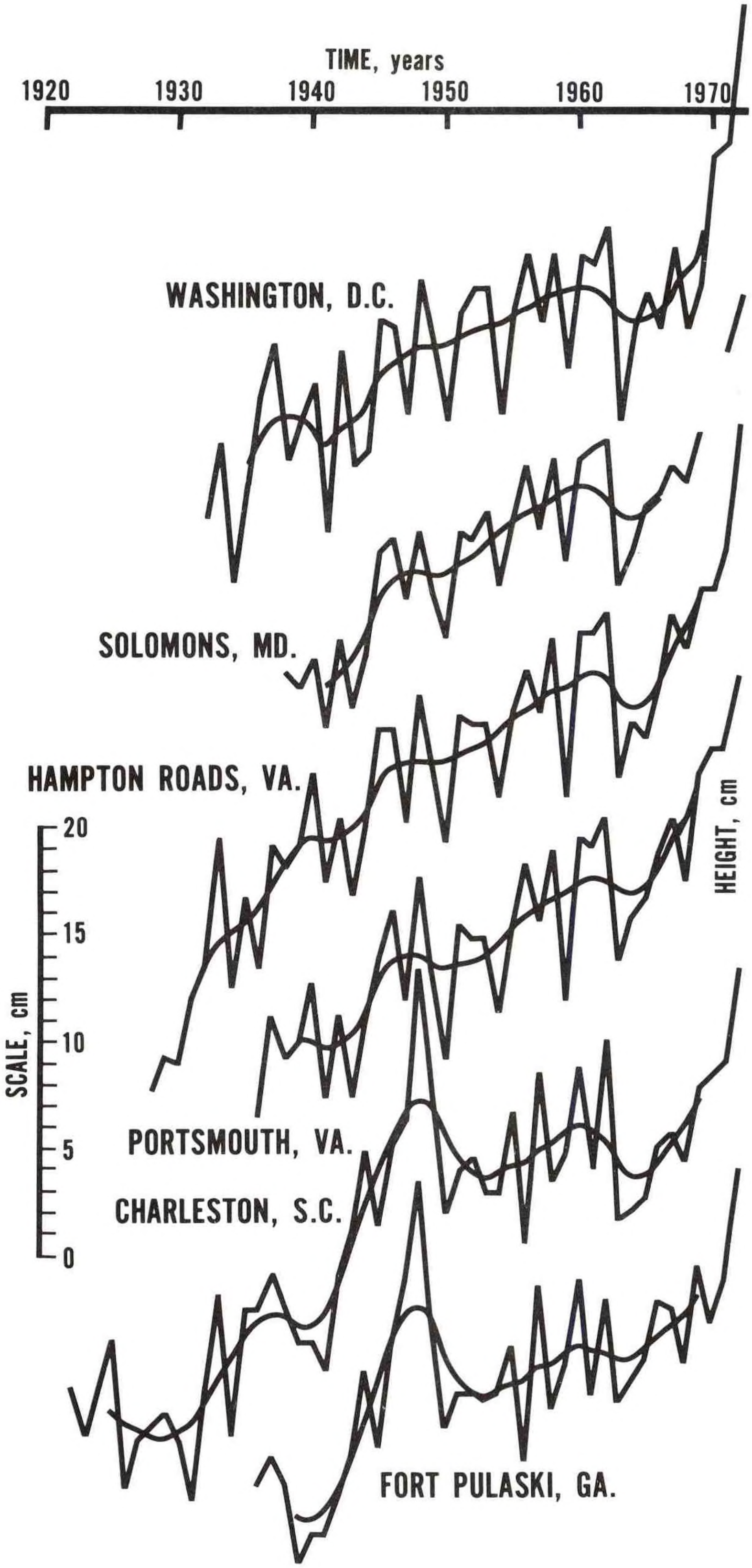

Figure 3.--Change in sea level with respect to adjacent land for stations from the District of Columbia to Georgia.

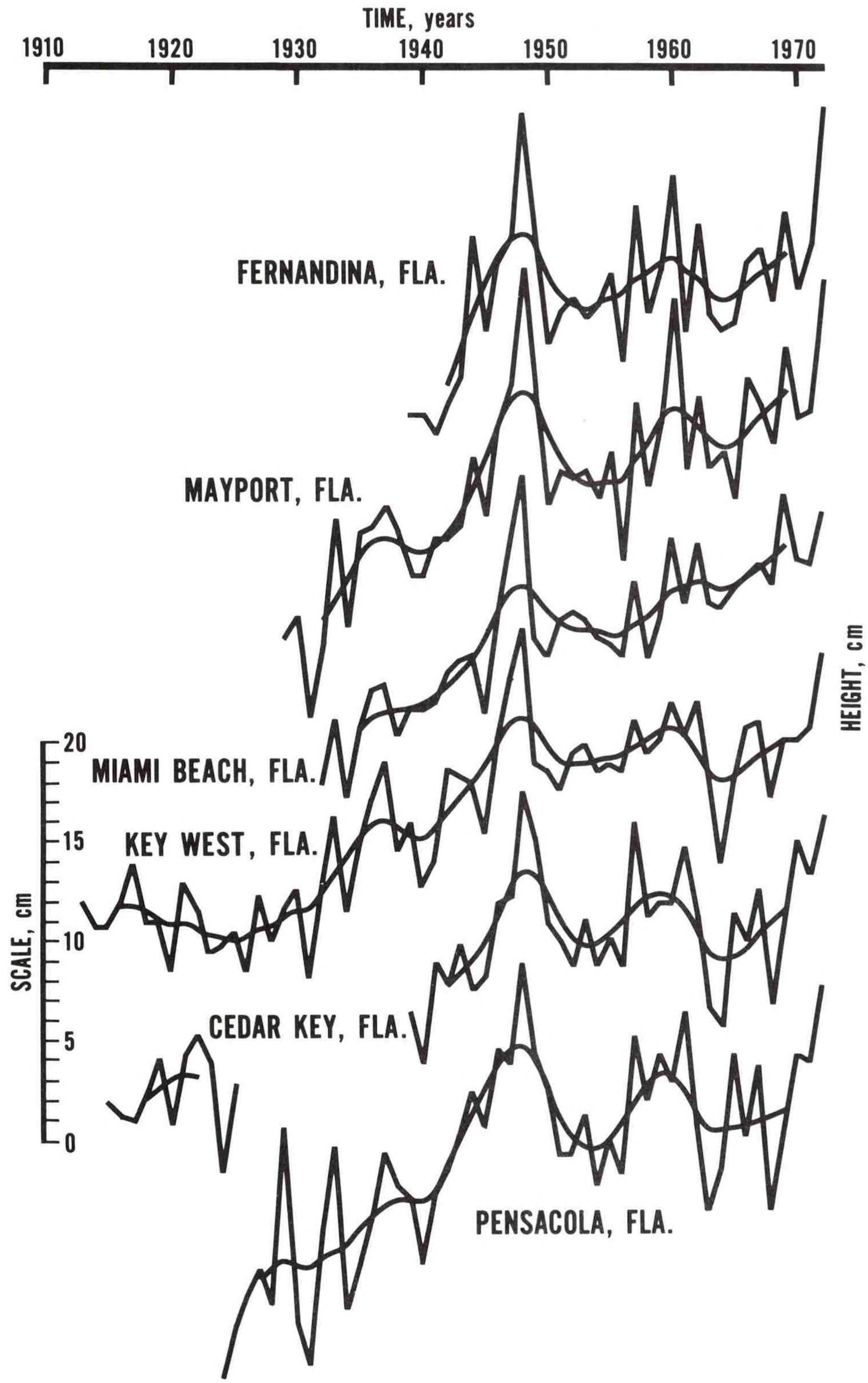

Figure 4.--Change in sea level with respect to adjacent land for stations in Florida.

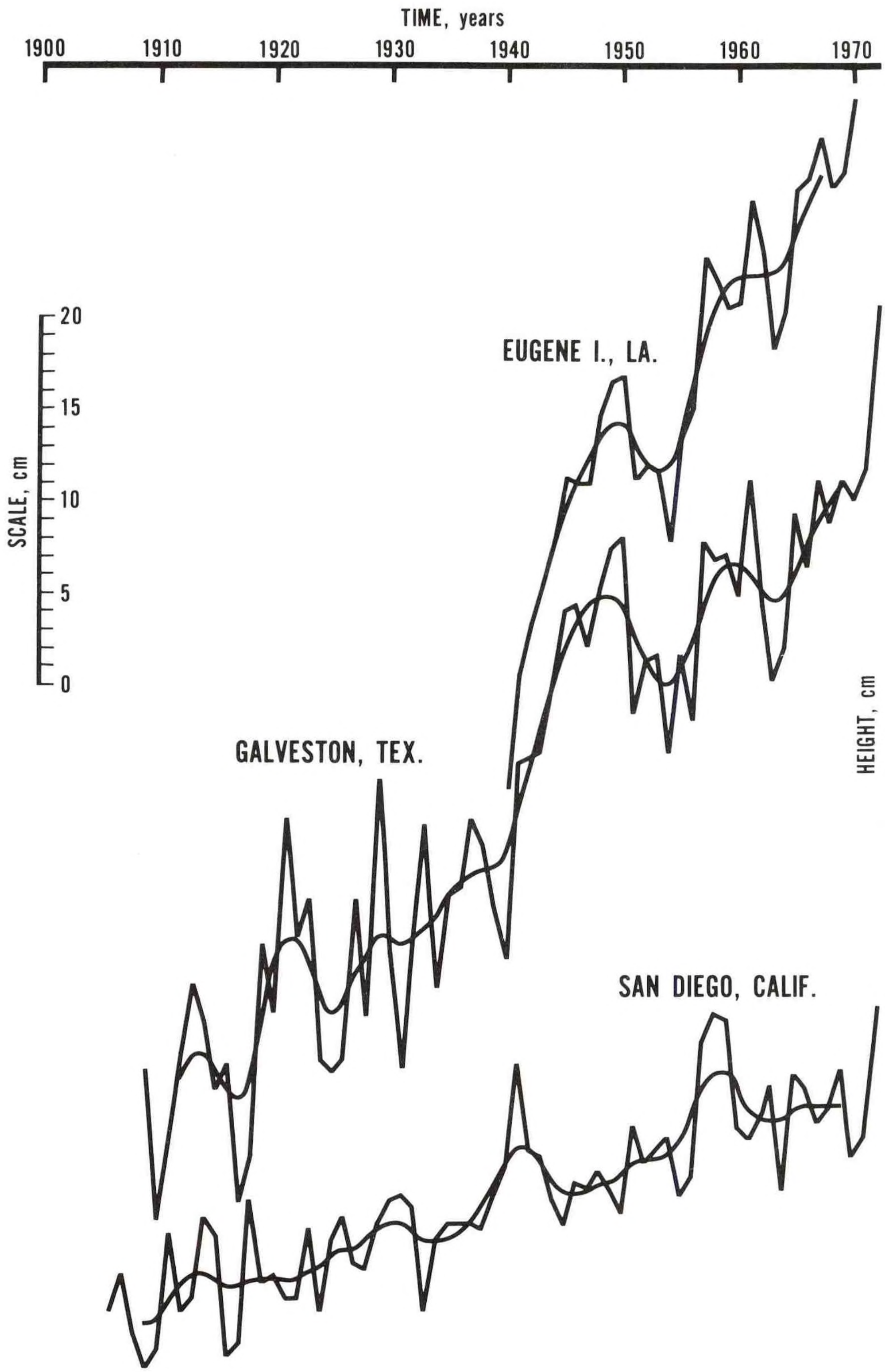

Figure 5.--Change in sea level with respect to adjacent land for stations from Louisiana to California.

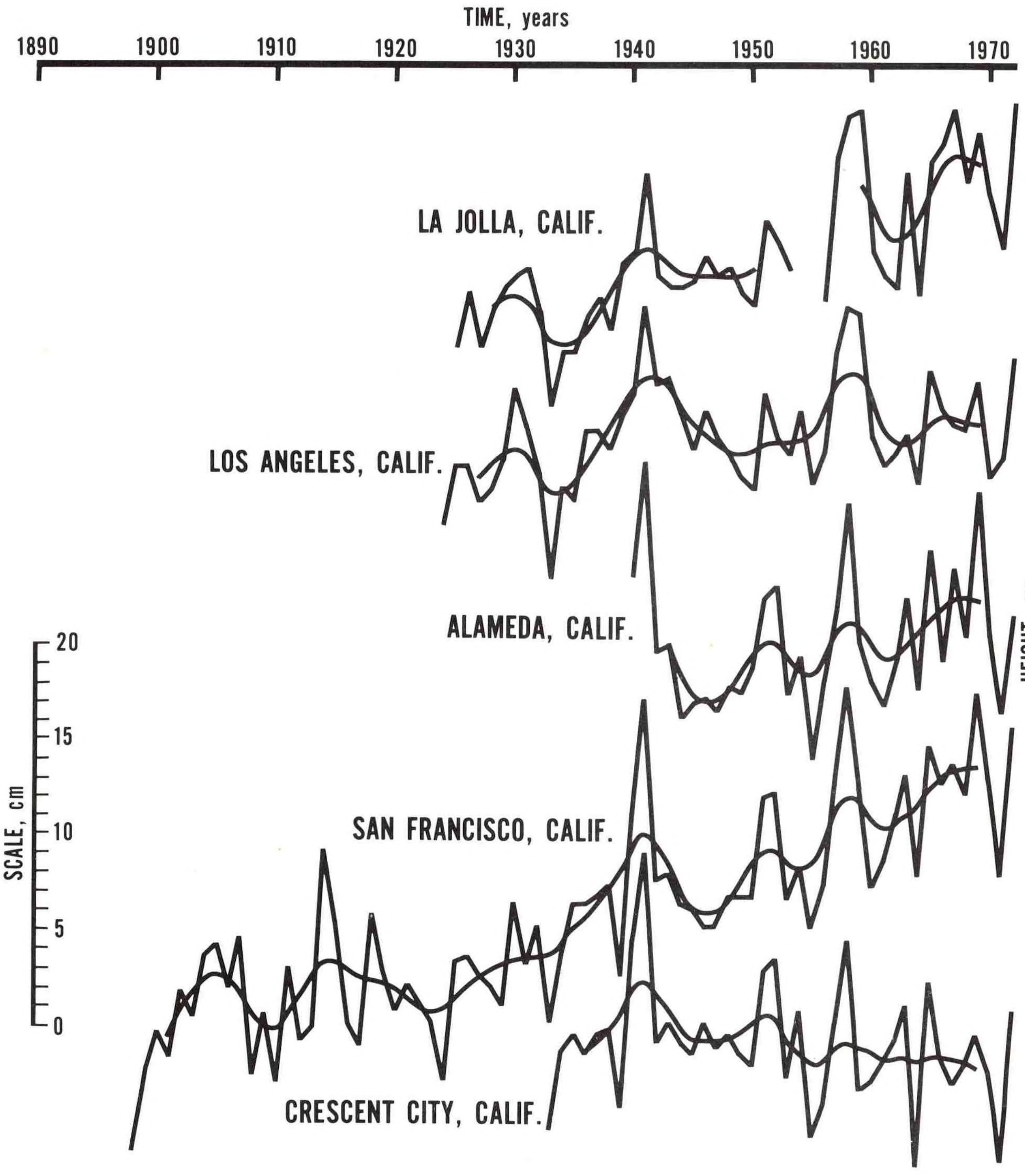

Figure 6.--Change in sea level with respect to adjacent land for stations in California.

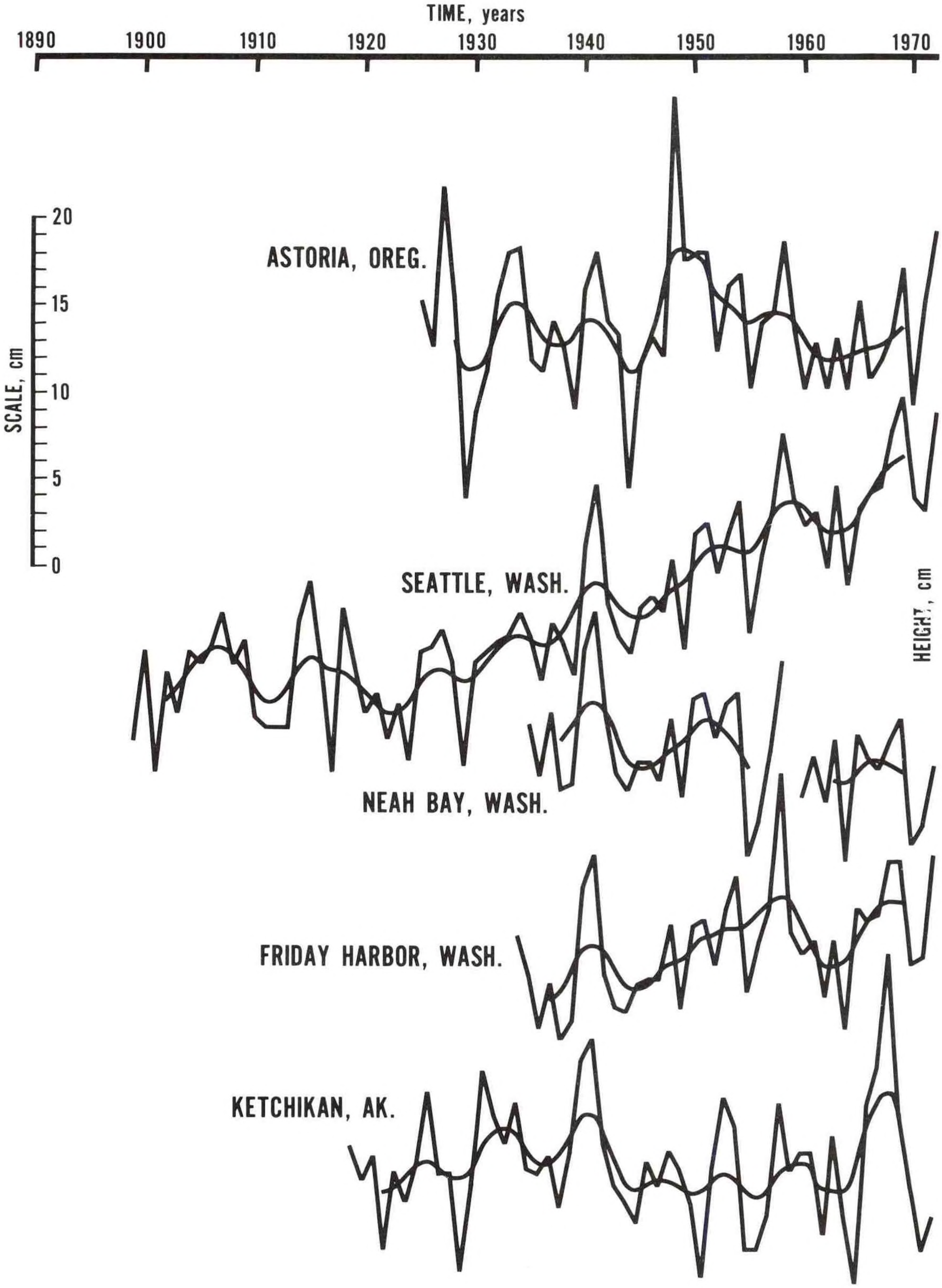

Figure 7.--Change in sea level with respect to adjacent land for stations from Oregon to Alaska.

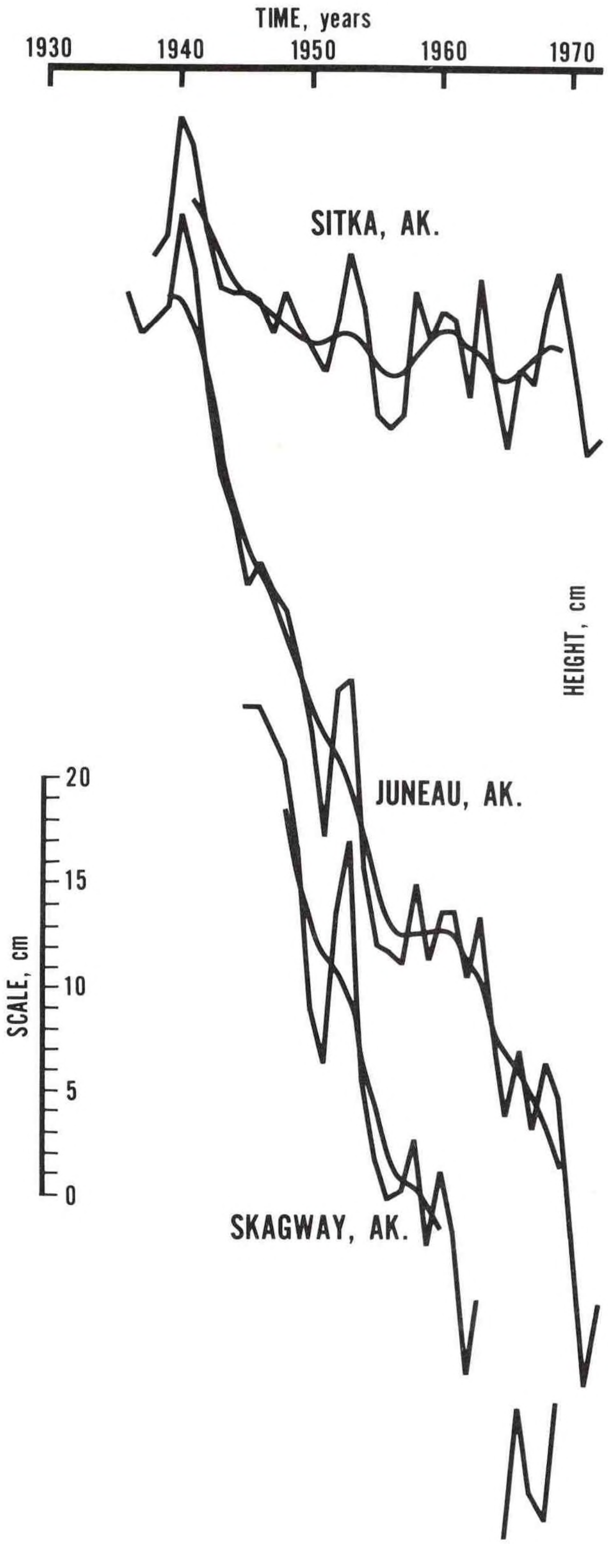

Figure 8.--Change in sea level with respect to adjacent land for stations in Alaska.

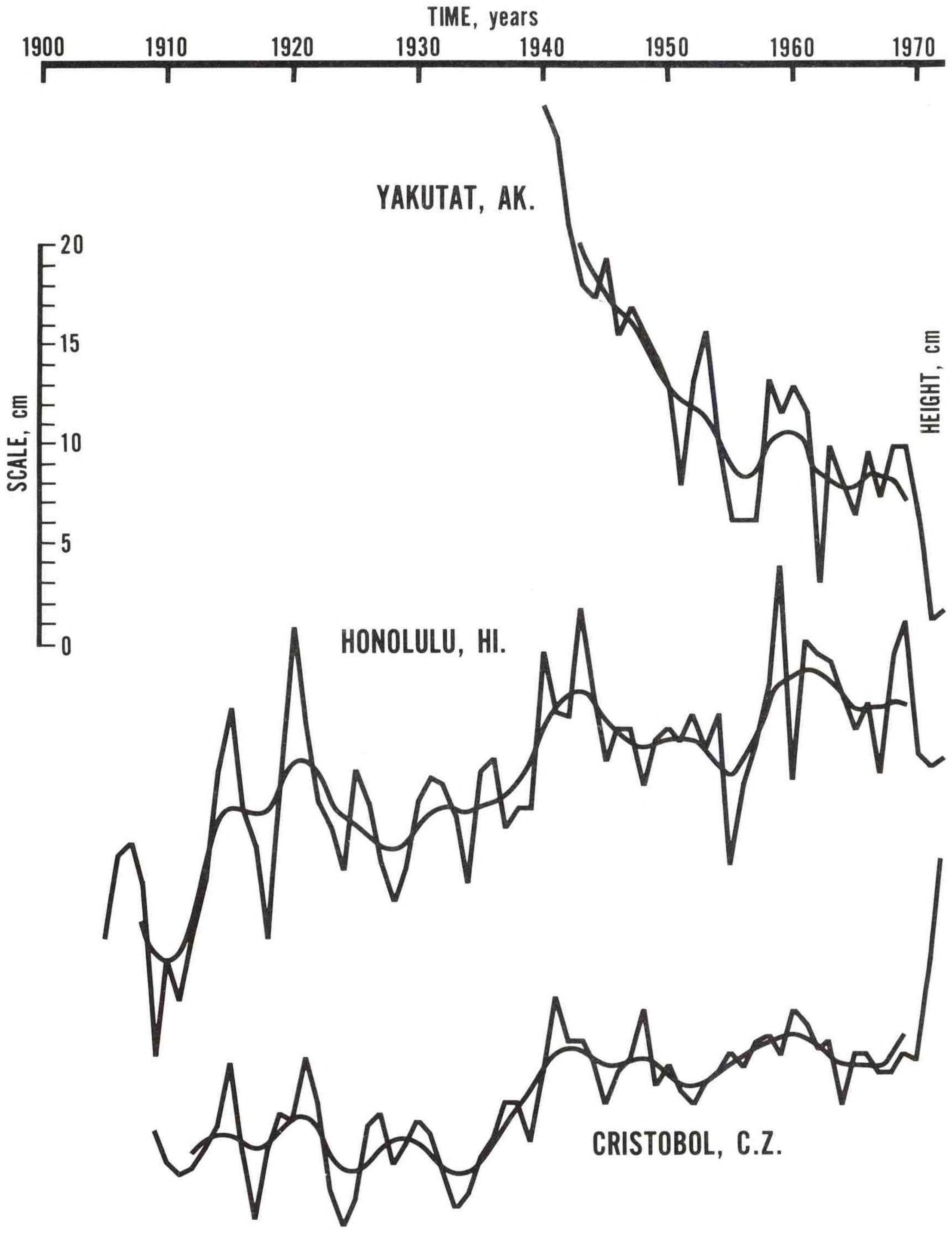

Figure 9.--Change in sea level with respect to adjacent land for Yakutat, Alaska, Honolulu, Hawaii, and Cristobal, C.Z.