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PREPRINT

REGIONAL INVESTIGATIONS OF VERTICAL CRUSTAL MOVEMENTS IN THE U.S. USING PRECISE RELEVELINGS AND MAREOGRAPH DATA

By

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ABSTRACT

Regional Investigations of Vertical Crustal Movements in the U.S. Using Precise Relevelings and Mareograph Data.

In the past two years, the National Geodetic Survey has been creating a data base of vertical crustal movement information. The data elements are relative elevation changes along lines of releveling which are used to produce graphic displays on microfilm. In separate studies, the releveling data, together with information extracted from mareograph records, have been used to create two networks of velocity differences. The two networks, one in the vicinity of Chesapeake Bay and the other covering the Gulf Coast states, have been adjusted in order to prepare maps showing the velocities of elevation change. In the adjustments, the velocities derived from mareograph records were treated as observations. The results indicate annual subsidence ranging between -1.2 mm and -4.0 mm in the Chesapeake Bay area, with significant local variation. In the Gulf Coast region there is generally slight subsidence along the coast, ranging between 0.0 and -1.5 mm/yr. Stability and slight uplift is indicated to the north where bedrock reaches the terrain surface. Anomalous subsidence of -7.0 mm/yr occurs at New Orleans, La., and at Houston, Texas, where there has been several decimeters change in the last ten years.

Introduction

During the last two years, the Vertical Network Branch of the National Geodetic Survey (NGS) has been establishing a data base of vertical crustal movement information. Also within this period, vertical movement velocity maps have been prepared for two areas; the Gulf Coast of the U.S., and the vicinity of Chesapeake Bay. These efforts contribute to the work being done by the North American Working Group of the IUGG Commission on Recent Crustal Movements.

The NGS Data Base of Vertical Crustal Movements

The elements of the vertical crustal movement data base are digitized profiles of relative vertical movement along lines of releveling. Computer programs have been written which produce microfilm graphic displays of the information. The elevation changes are computed using either unadjusted first-order or second-order levelings.

To facilitate the dissemination of the data to other scientists, and to more easily maintain the data base, the data have been organized into the eight geographic zones shown in figure 1. A scientist desiring roll-microfilm copies of all profiles and tabulations in any of the zones can obtain them by a written request to the Director of the National Geodetic Survey, 6001 Executive Blvd., Rockville, Maryland 20852.

Most profiles which now reside in the data base show only the elevation changes, along lines of levelings, which occurred during the period between surveys. The computer program which produces the graphics has now been modified so that, in the future, a terrain profile will be superimposed upon the profiles of elevation change.

Regional Investigations of Elevation Change

The Gulf Coast

The production of a velocity map of elevation changes for the Gulf Coast of the U.S. was accomplished by considering both geodetic and oceanographic data. Figure 2 shows the locations of the nine tide gages which provided tidal records, and the locations of lines of releveling which were used to compute velocity differences.

The Leveling Data

The traditional computational approach has been used. The velocity difference, Δr, between two points connected by releveling is computed using equation 1.

$$\Delta r = \frac{\Delta h_2 - \Delta h_1}{\Delta t} \qquad (1)$$

where Δh_1 and Δh_2 are the old and new observed height differences respectively, and Δt is the time elapsed between levelings.

The variance of the velocity difference is computed using equation 2,

$$\sigma_{\Delta r}^2 = \frac{(m_1^2 + m_2^2)\ S}{(\Delta t)^2} \qquad (2)$$

where m_1 and m_2 are the estimated standard deviations of the old and new leveling over a unit distance, and S is the distance between points. In the Gulf Coast study, the values assigned to m_1 and m_2 were not determined by analysis of forward and backward levelings, but were estimated using experience from similar computations and a knowledge of when different types of instrumentation and procedures were used. Thus, all first-order leveling of the same epoch and performed with the same type of instrumentation was assigned the same standard deviation.

The oldest leveling used in the Gulf Coast study was performed in 1897, but most of the old leveling was accomplished between 1906 and 1934 by the former U.S. Coast and Geodetic Survey. The precision of the older work is approximately 1.75 mm/km for the first-order leveling, and 3.5 mm/km for the second-order leveling. Nearly all of the old levelings used in the study were first-order. Almost all of the newer levelings are first-order and were obtained between 1955 and 1973 by the NGS. The standard deviation for the recent leveling would be less than 1.0 mm/km. A few of the lines in north Texas, which were taken as new, were performed during the period 1933-38, and the corresponding old lines were performed during the period 1902-20.

The Tidal Data

The locations of the nine mareograph stations which were used in the Gulf Coast study are shown in Figure 2, and specific details concerning the stations are summarized in Table 1.

Estimates of absolute velocities have been extracted from tidal records by assuming that the secular change in sea level relative to the tidal bench mark has two basic components: (1) the eustatic or world-wide rise in sea level, and (2) the apparent change in sea level due to local and regional vertical movement of the land. The eustatic rise was taken as +1.0 mm/yr. The initial velocities of vertical movement at the mareograph stations were derived by fitting straight lines through plots of annual mean sea levels. The slopes of these lines were considered to represent the velocities at which the sea is rising with respect to the land at each mareograph station. By reducing the slope to account for the eustatic rise in sea level, and changing the sign, a value was obtained for the velocity at which the land moves vertically with respect to a stable reference. The standard deviations of the slopes of the fitted lines were taken as the standard deviations of the corresponding velocities of elevation change at the nine tidal bench marks. In Tables 1 and 3, the velocities derived from mareograph records are called initial velocities.

The annual mean sea level values that were used in the study were not corrected for meteorological or other conditions. The entire series at each station was used rather than a series common to all stations. It was assumed that accidental effects dominate the trend more than periodic effects, and therefore it was desirable to use the longest possible series. Use of a long common series would have been preferable, but was impractical in this study because of a broken series at the Cedar Key station and a very short series at Port Isabel. The inclusion of the Port Isabel data was deemed necessary because of the sparse leveling data in Southern Texas, and because of the strategic location of Port Isabel on the Gulf Coast. Of course, the mareograph stations which had a longer series exerted greater influence in the final adjustment because of the weighting scheme that was used.

Figures 3-4 show the plots of annual mean sea levels together with the fitted straight lines through the data.

The Adjustment

Two adjustments were performed. In Adjustment I, only the velocity of elevation change derived at the Pensacola mareograph station was used to initialize the velocity differences obtained from the leveling data. After the adjustment, the uncertainty of the initial value was propagated through the network. Initialization by a single mareograph velocity does not influence the adjustment of velocity differences; therefore, Adjustment I gave adjusted velocity differences which were dependent only on leveling data. To achieve an optimum fit of these results with all nine of the velocities determined from mareograph records, a constant of +1.21 mm/yr would need to be added to each velocity listed under Adjustment I of Table I. This was done before computing the comparison column in Table 2.

In Adjustment II, the velocities of vertical movement derived at all nine mareograph stations were used as weighted initial values. The initial values can be regarded as observations from the center of the earth where we assume the velocity of vertical movement to be zero and perfectly known. Eight additional constraints were placed on the leveling data by inclusion of the nine additional observations. Adjustment II should be regarded as the optimum merger of the two kinds of data; the results, shown in Figure 5 and Table 2, reflect the strengths of both types of measurements.

In both adjustments, constraints were liberally used which required junctions in the same locality to take on the same velocity. This procedure was motivated by two considerations: (1) it was not always possible to connect all velocity differences at a common junction, and (2) there was little or no bedrock in the study area. The use of more than one point in a locality ought to give a desirable average velocity value and may, in some cases, be superior to the selection of a single point that could be affected by a local condition.

Summary and Tentative Conclusions

The compatibility of the leveling and tidal data was tested by comparing the sums of weighted squares of residuals obtained in Adjustments I and II. The increase was not significant. However, considerable warping was done to the leveling between Fort Pulaski, Ga., and Fernandina, Fla. The misclosure of leveling and tidal data on this coastal circuit was 4.02 mm/yr over a distance of only 235 km. There was no obvious reason to suspect either type of data so it was decided to let the least squares solution ameliorate the conflict. More study of this local incompatibility will be required before the data are incorporated into a larger adjustment of the Eastern United States.

The velocity differences which extend far from Houston into south, central, and north Texas are not highly regarded because the latest leveling for a few of the segments was of 1933-1943 vintage. The precision of the data is adequate, but the velocity differences computed from these levelings are already 30-40 years outdated. The tidal data at Port Isabel is recent, 1945-1971, and provides little or no overlap with the time interval between levelings which connect there. The regional pattern of elevation change for eastern Texas, extending outward 150 kilometers from Houston, is now adequate.

In the Gulf Coast area, there are several localities where subsidence velocities are anomalously large. Houston, Texas, and New Orleans, Louisiana, are two such localities. Figures 6-9 are profiles of relative vertical movement along lines of releveling which pass through these areas. The extreme subsidence at Houston is primarily due to withdrawal of water for industrial purposes. The subsidence at New Orleans is assumed to be due to withdrawal of water from underground and natural processes associated with the growth of the Mississippi delta.

Chesapeake Bay

The study of subsidence in Chesapeake Bay was approached in the same manner as described above for the Gulf Coast of the U.S. Fortunately, there are eight mareograph stations in the vicinity of Chesapeake Bay which, with the exception of the station at Kiptopeke, Va., have been in operation for more than 30 years. The locations of these stations are shown in Figure 10, along with lines of releveling that were used to compute velocity differences. Details concerning the mareograph records are shown in Table 3, and the records themselves are shown in Figures 11-12.

The oldest leveling used in the Chesapeake Bay study was performed in 1897, but most of the old levelings were accomplished between 1920 and 1942. The precision of the older work is approximately 1.5 mm/km for the first-order leveling and 3.0 mm/km for the second-order leveling. Most of the old levelings used in the study were first-order. The majority of new leveling lines were accomplished during 1970 and 1971 by the NGS, and are first-order. The standard deviation for the 1970-71 leveling, and additional 1963 leveling used in the study, is less than 1.0 mm/km.

In preliminary adjustment studies of the data, a common series (1940-71) was used to derive the initial velocities for the six mareograph stations on the south and west sides of the Bay. The stations at Lewes, Del. and Kiptopeke, Va., were not included at that time. The Lewes station has a long series, but large gaps occur in the record. The Kiptopeke record goes back only to 1952, i.e. 19 years. Later it was decided to incorporate the data from these two stations because the releveling nets on each side of the Bay are very weakly connected. The time intervals between levelings over the modern bridges connecting the eastern side are not sufficient to provide adequate strength. In the final adjustment, the initial velocities at mareograph stations were based on a common series for the six stations on the west side of the Bay, and the entire series for the two stations on the eastern side.

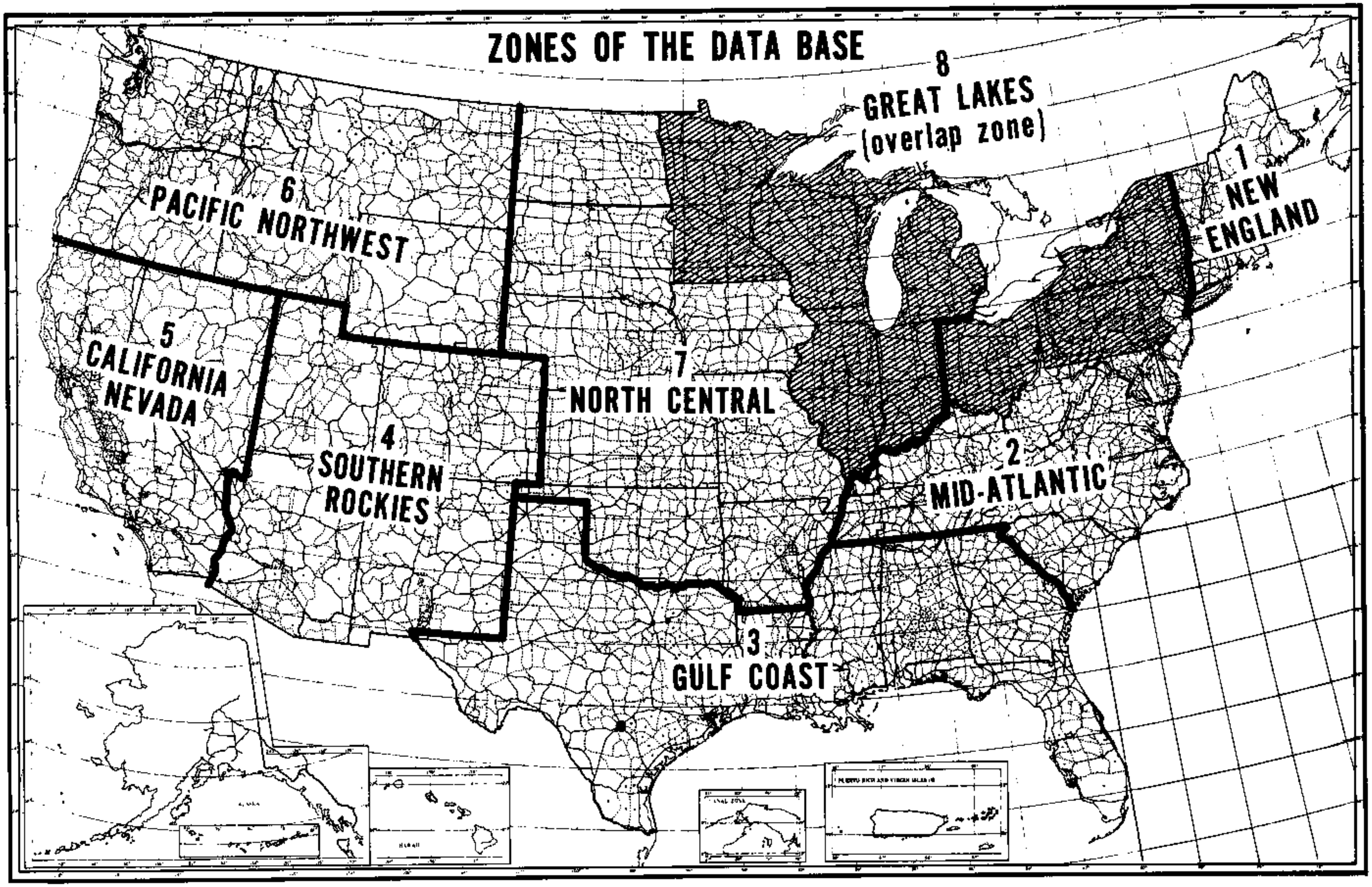
Summary

The differences between Adjustments II and I, shown in Table 4, are small and indicate that, for the Chesapeake Bay study, the combination of leveling and mareograph data is reasonable. The area mapped was considerably smaller than was the case for the Gulf Coast. In the vicinity of Chesapeake Bay, the density of lines of releveling was greater, and there were nearly as many mareograph stations (8) as there were for the states surrounding the Gulf Coast (9). Therefore, the smaller uncertainties for the adjusted velocities of Adjustment II, for Chesapeake Bay, were expected.

In the next few years, the areas which are now mapped with velocities of vertical movement will be enlarged, until eventually the entire United States is covered. Special emphasis is likely to focus on the Great Lakes area and the West Coast of the U.S.

The methods to be used in preparing a U.S. map may be different than those described above. It is doubtful that a model which requires vertical movement to be constant with time could be used for the whole of areas like California with its many active faults. It will be more feasible to attempt to divide these areas into blocks whose borders are natural lines of discontinuity of vertical movement.

The numerical methods may also be different. In particular, it may be desirable to use a surface fitting technique, similar to that which has been applied to releveling data by Vaníček and Christodulidis. Also, the preliminary refinement of mareograph data may prove to be worthwhile, and the manner in which this data is allowed to influence the releveling data will not necessarily be the same.



COMPARISONS OF REPEATED LEVELINGS

Figure 1.

LINES OF RELEVELING AND TIDAL CONTROL STATIONS

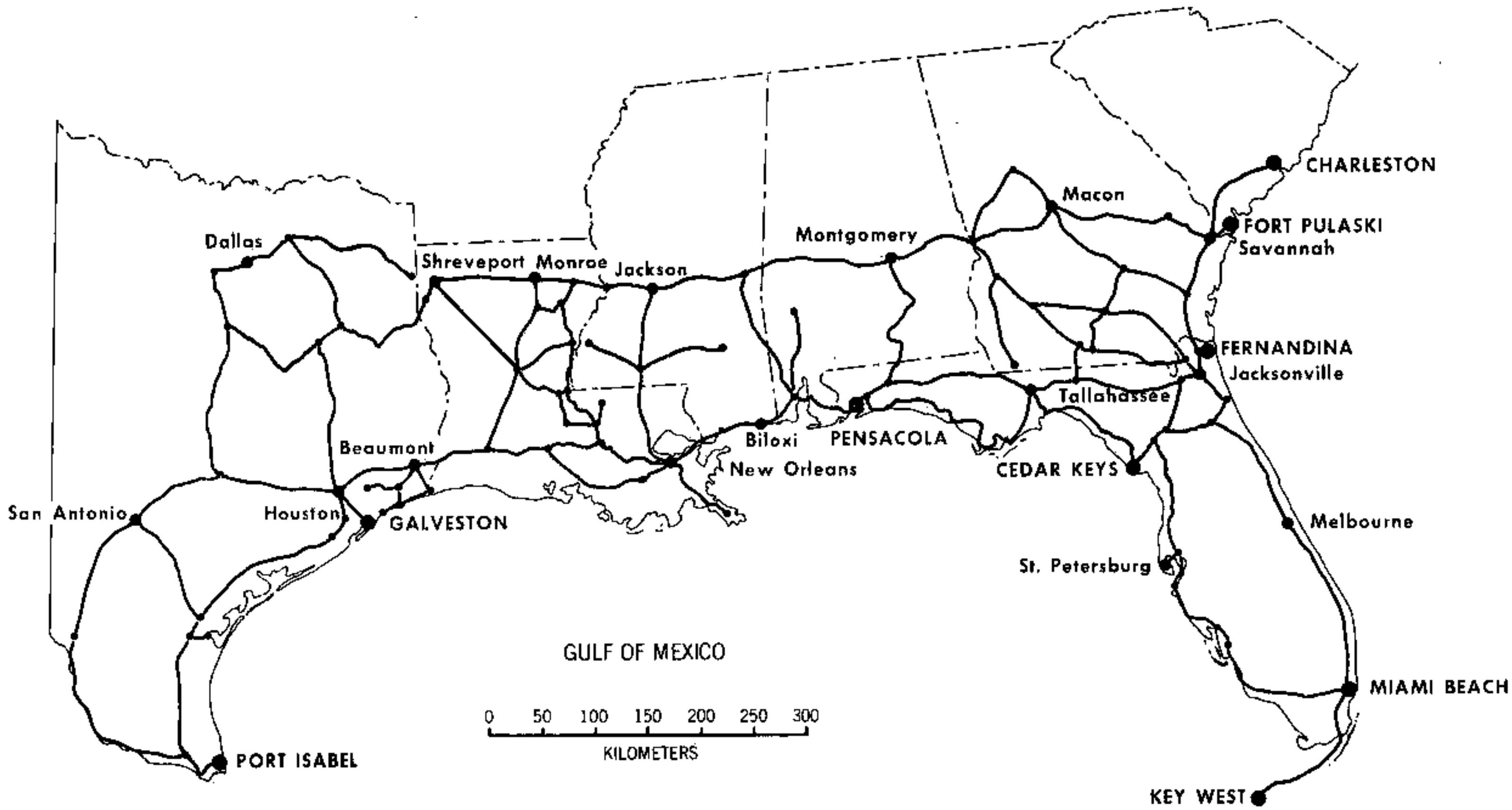


Figure 2

Table 1. Mareograph Stations - Gulf Coast
Velocities of Vertical Movement (mm/yr.)

Station Name	Series	Initial		Adjustment II		Adjustment I	
Port Isabel, Texas	1945-71	-0.27	±0.80	-0.14	±1.27	-1.07	±2.89
Galveston, Texas	1909-71	-4.83	±0.32	-4.95	±0.57	-6.27	±2.09
Pensacola, Fla.	1924-71	-1.28	±0.38	-1.10	±0.63	(-1.28)	±0.38
Cedar Key, Fla.	1915-71	-1.00	±0.26	-1.35	±0.45	-2.98	±1.54
Key West, Fla.	1913-71	-1.05	±0.20	-1.11	±0.37	-4.16	±2.79
Miami Beach, Fla.	1932-71	-1.47	±0.32	-1.43	±0.55	-3.36	±2.28
Fernandina, Fla.	1939-71	-0.51	±0.60	-0.49	±0.74	-0.51	±1.55
Fort Pulaski, Ga.	1935-72	-1.67	±0.47	-0.50	±0.74	+2.31	±1.88
Charleston, S.C.	1922-71	-2.53	±0.34	-2.47	±0.62	-0.04	±2.48

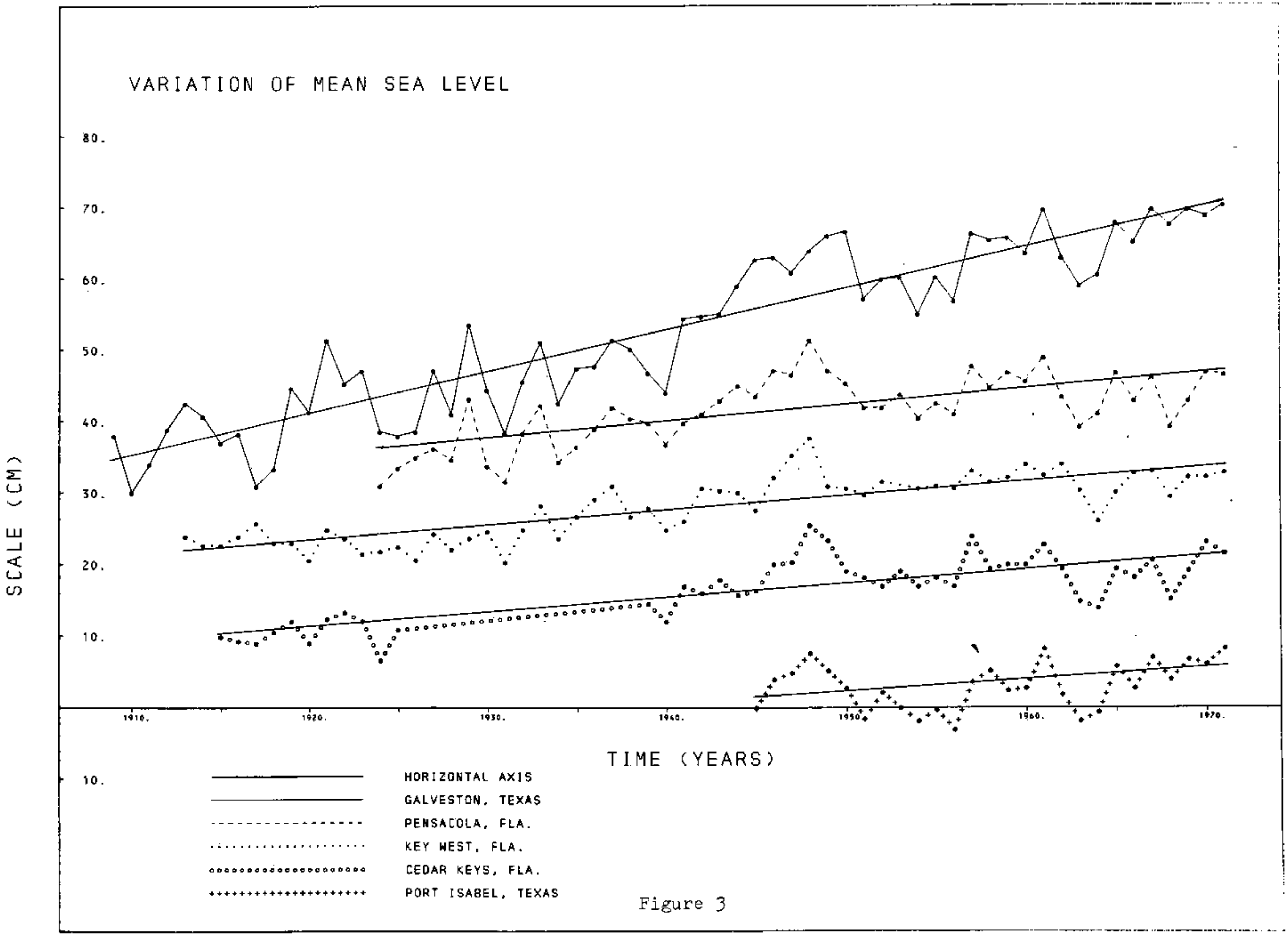

VARIATION OF MEAN SEA LEVEL
80.
70.
60.
50.
40.
30.
20.
10.
10.
SCALE (CM)
1910.
1920.
1930.
1940.
1950.
1960.
1970.
TIME (YEARS)
HORIZONTAL AXIS
GALVESTON, TEXAS
PENSACOLA, FLA.
KEY WEST, FLA.
CEDAR KEYS, FLA.
PORT ISABEL, TEXAS

Figure 3

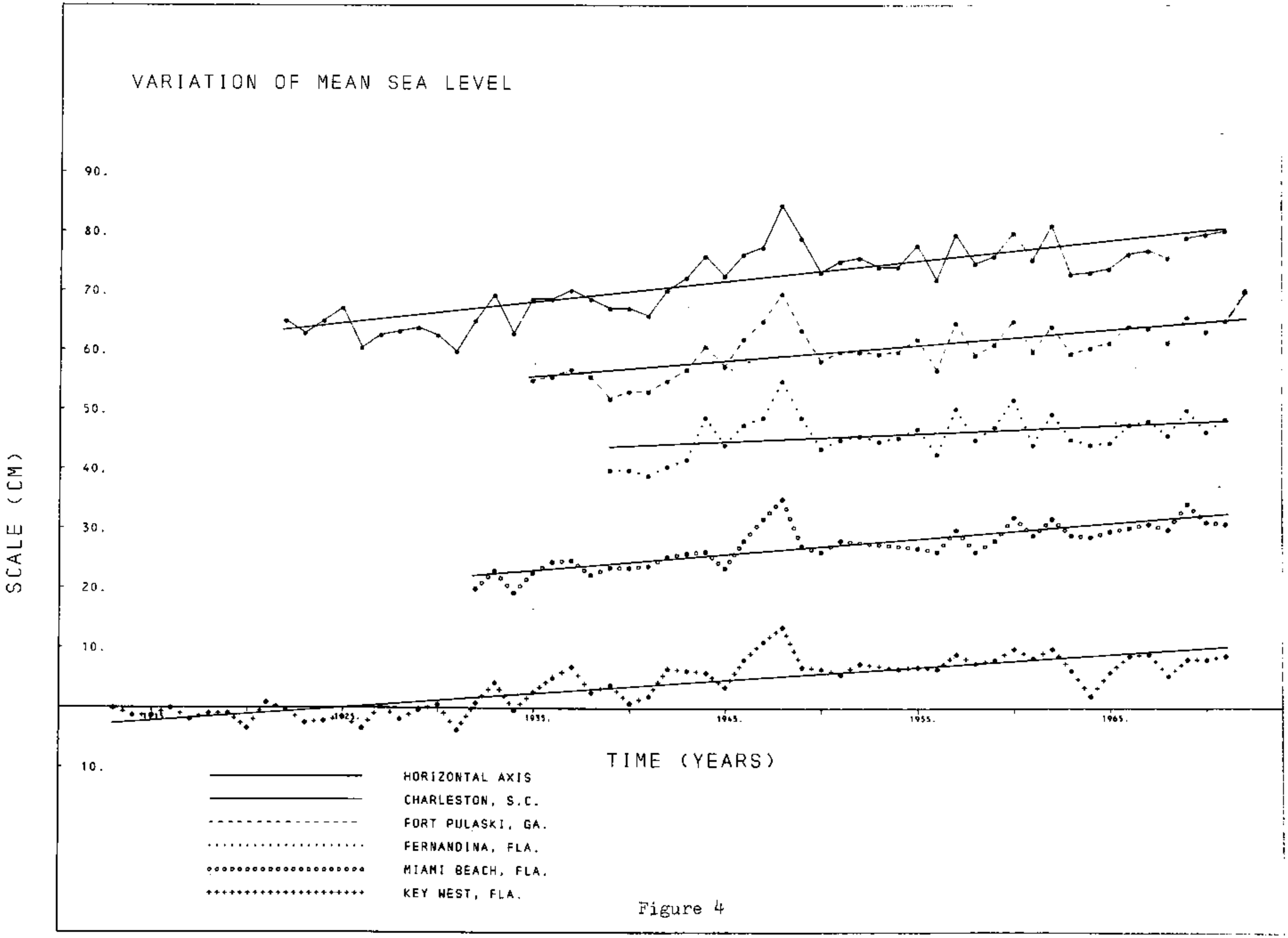

VARIATION OF MEAN SEA LEVEL
SCALE (CM)
90.
80.
70.
60.
50.
40.
30.
20.
10.
10.
1915
1925
1935
1945
1955
1965
TIME (YEARS)
HORIZONTAL AXIS
CHARLESTON, S.C.
FORT PULASKI, GA.
FERNANDINA, FLA.
MIAMI BEACH, FLA.
KEY WEST, FLA.

Figure 4

PRELIMINARY RATES OF ELEVATION CHANGE

Units for Contour Levels are mm/yr.

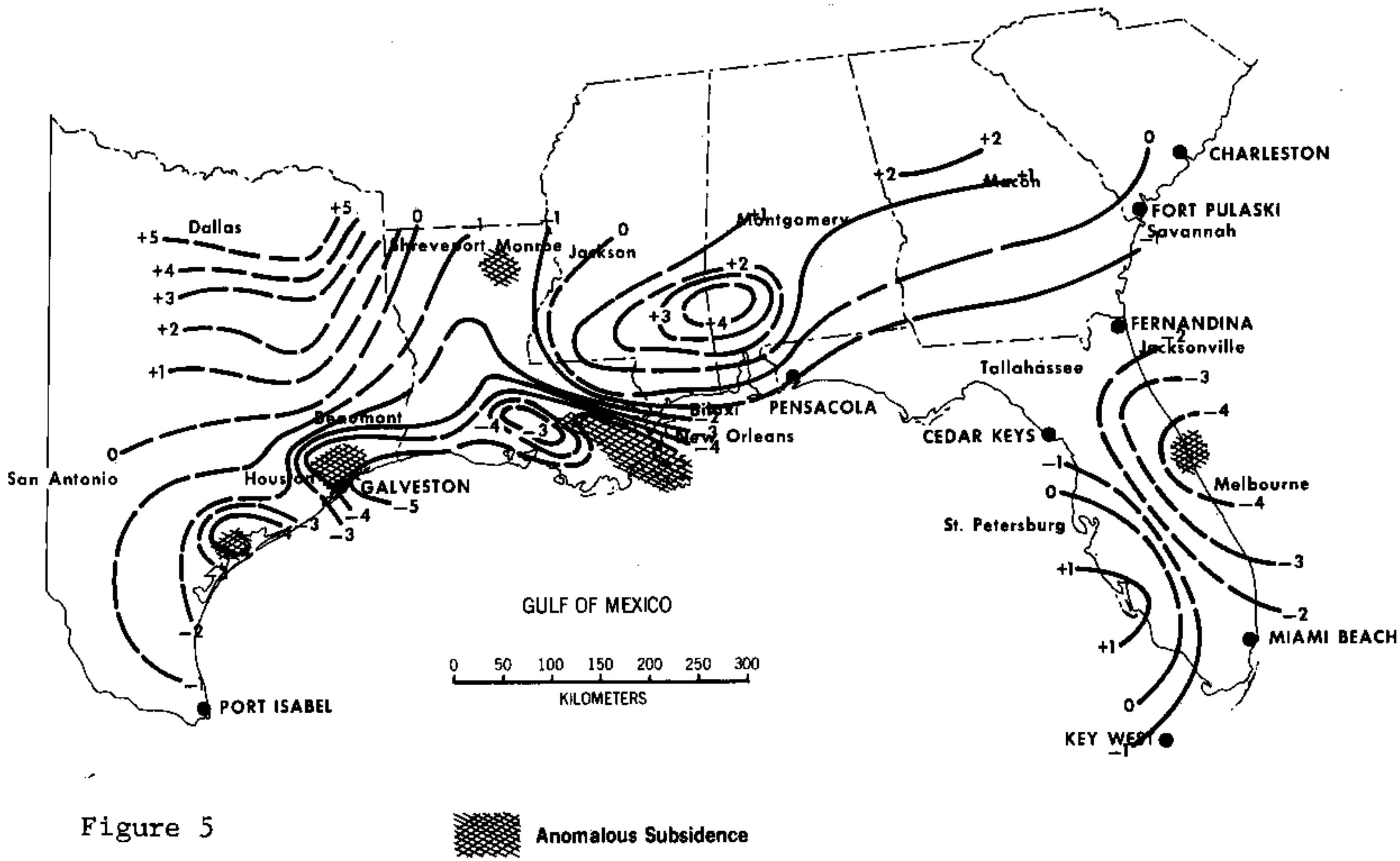


Figure 5

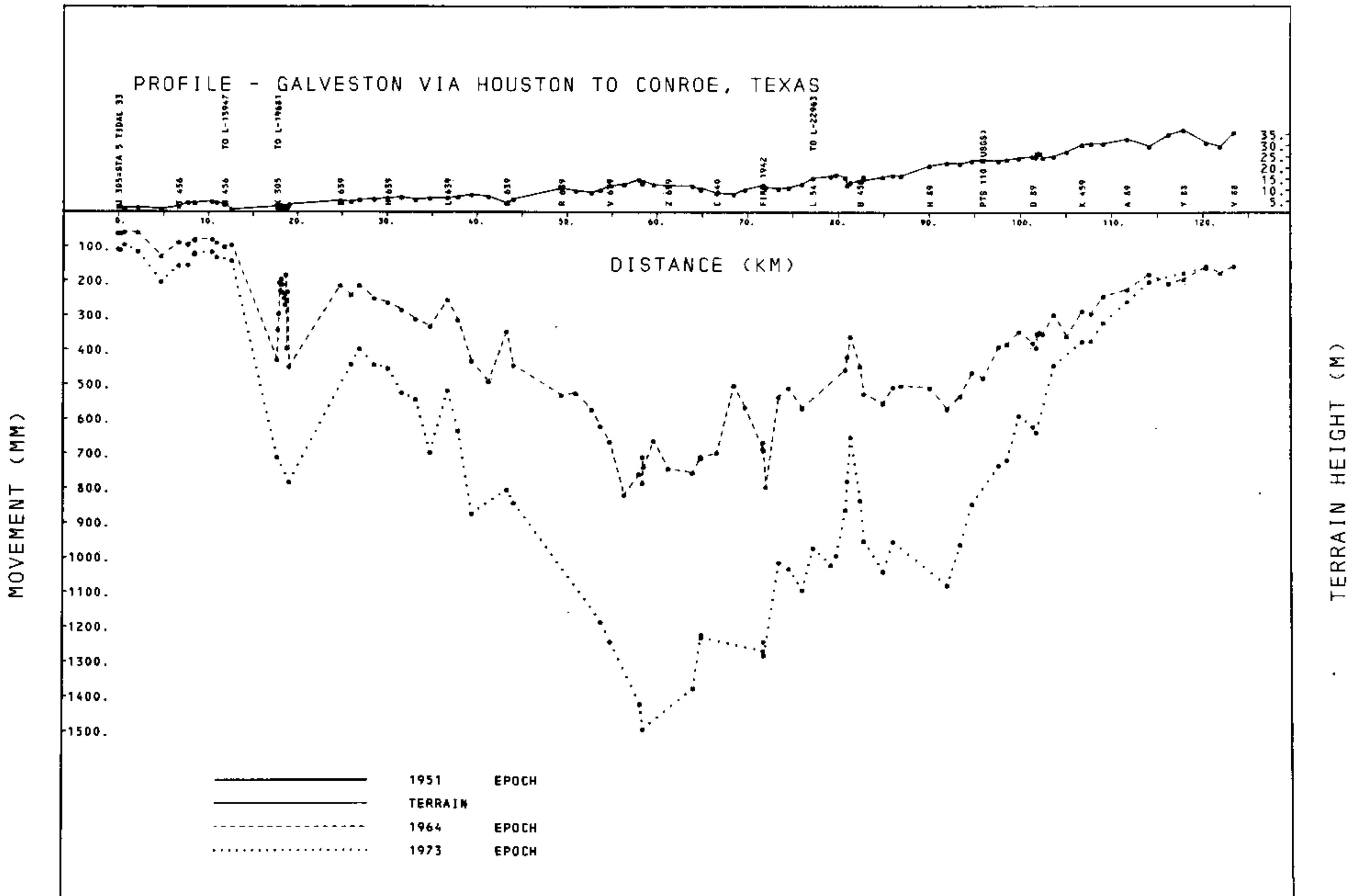
Table 2. Adjusted Velocities of Elevation Change - Gulf Coast

(All values in mm/yr.)

Location	Adjustment II Velocity	Adjustment II Std. Dev.	Adjustment II minus Adjustment I
Alexandria, La.	-3.43	1.22	-0.32
Baton Rouge, La. (PBM 2)	-4.89	1.28	-0.35
Beaumont, Texas (E 58)	-2.36	0.97	-0.13
Biloxi, Miss.	-0.51	1.20	-0.75
*Cedar Keys, Fla.	-1.35	0.45	+0.42
*Charleston, S.C.	-2.47	0.62	-3.64
Columbus, Ga.	+0.26	1.03	-1.36
Dallas, Texas	+6.14	1.98	-0.08
*Fernandina, Fla.	-0.49	0.74	-1.18
*Fort Pulaski, Ga.	-0.50	0.74	-4.02
*Galveston, Texas (19 (USE))	-4.95	0.57	+0.11
Houston, Texas (J 8)	-16.21	0.75	0.00
Jackson, Miss.	-1.37	1.32	-0.56
Jacksonville, Fla.	-1.53	0.71	-0.82
*Key West, Fla.	-1.11	0.37	+1.84
Macon, Ga.	+0.50	1.07	-1.66
Melbourne, Fla. (F 33)	-5.42	1.33	+0.17
Meridian, Miss.	0.95	1.34	-0.76
*Miami Beach, Fla.	-1.43	0.55	+0.72
Mobile, Ala.	+1.72	1.13	-0.21
Montgomery, Ala.	+0.82	1.14	-1.12
New Orleans, La. (77 LGS)	-7.57	1.27	-0.55
*Pensacola, Fla.	-1.10	0.63	-1.03
*Port Isabel, Texas	-0.14	1.27	-0.28
San Antonio, Texas	-0.62	1.59	-0.09
Shreveport, La.	-0.80	1.38	-0.31
St. Petersburg, Fla.	+0.80	1.46	+0.26
Tallahassee, Fla.	-2.13	0.91	-0.60
Venice, La.	-9.64	1.72	-0.55

* Mareograph station

Note: A constant value of +1.21 mm/yr has been added to each velocity from Adjustment I prior to comparison with Adjustment II.



PROFILE - GALVESTON VIA HOUSTON TO CONROE, TEXAS
MOVEMENT (MM)
TERRAIN HEIGHT (M)
DISTANCE (KM)
1951 EPOCH
TERRAIN
1964 EPOCH
1973 EPOCH

Figure 6

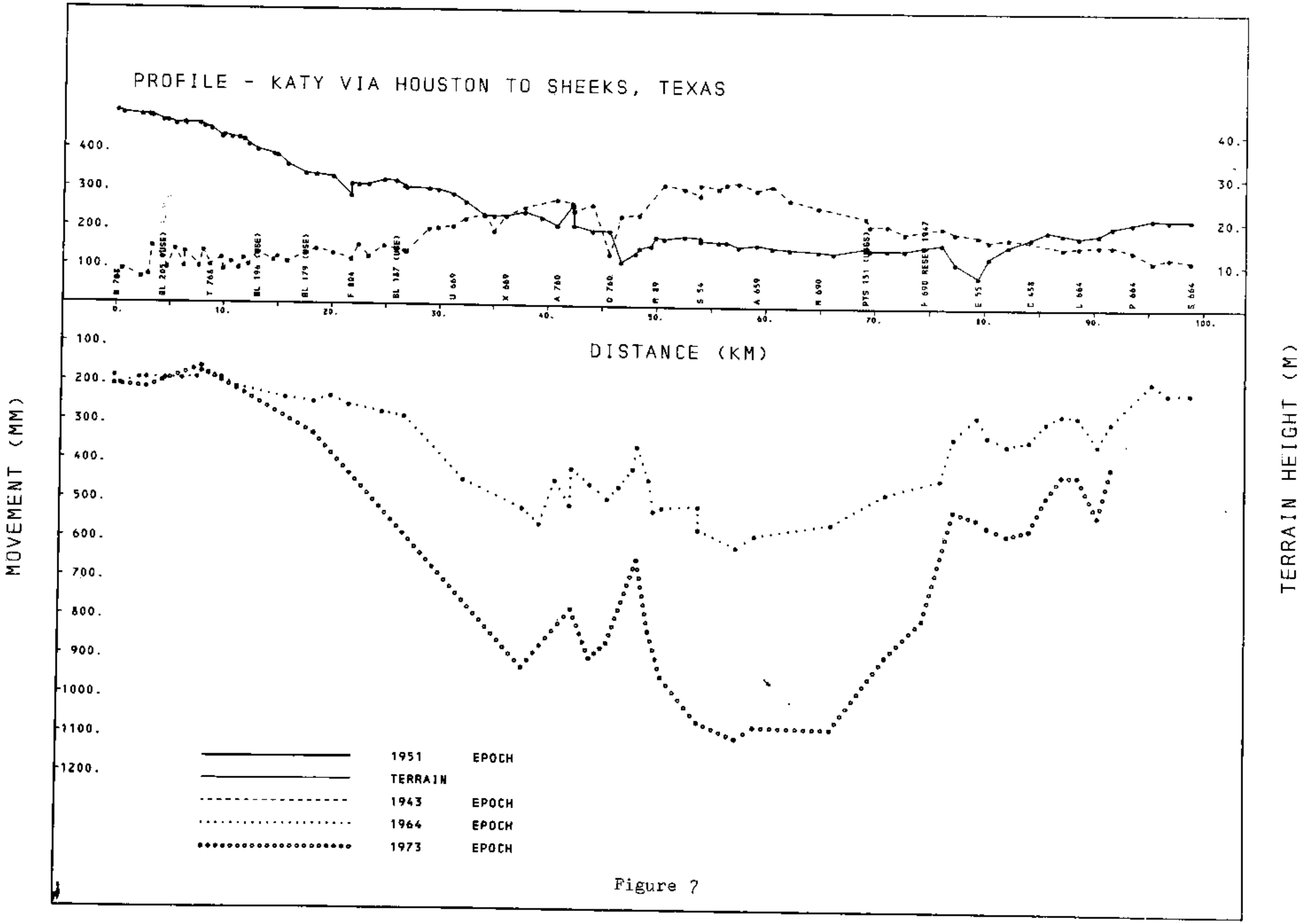

PROFILE - KATY VIA HOUSTON TO SHEEKS, TEXAS
MOVEMENT (MM)
TERRAIN HEIGHT (M)
DISTANCE (KM)
1951 EPOCH
TERRAIN
1943 EPOCH
1964 EPOCH
1973 EPOCH

Figure 7

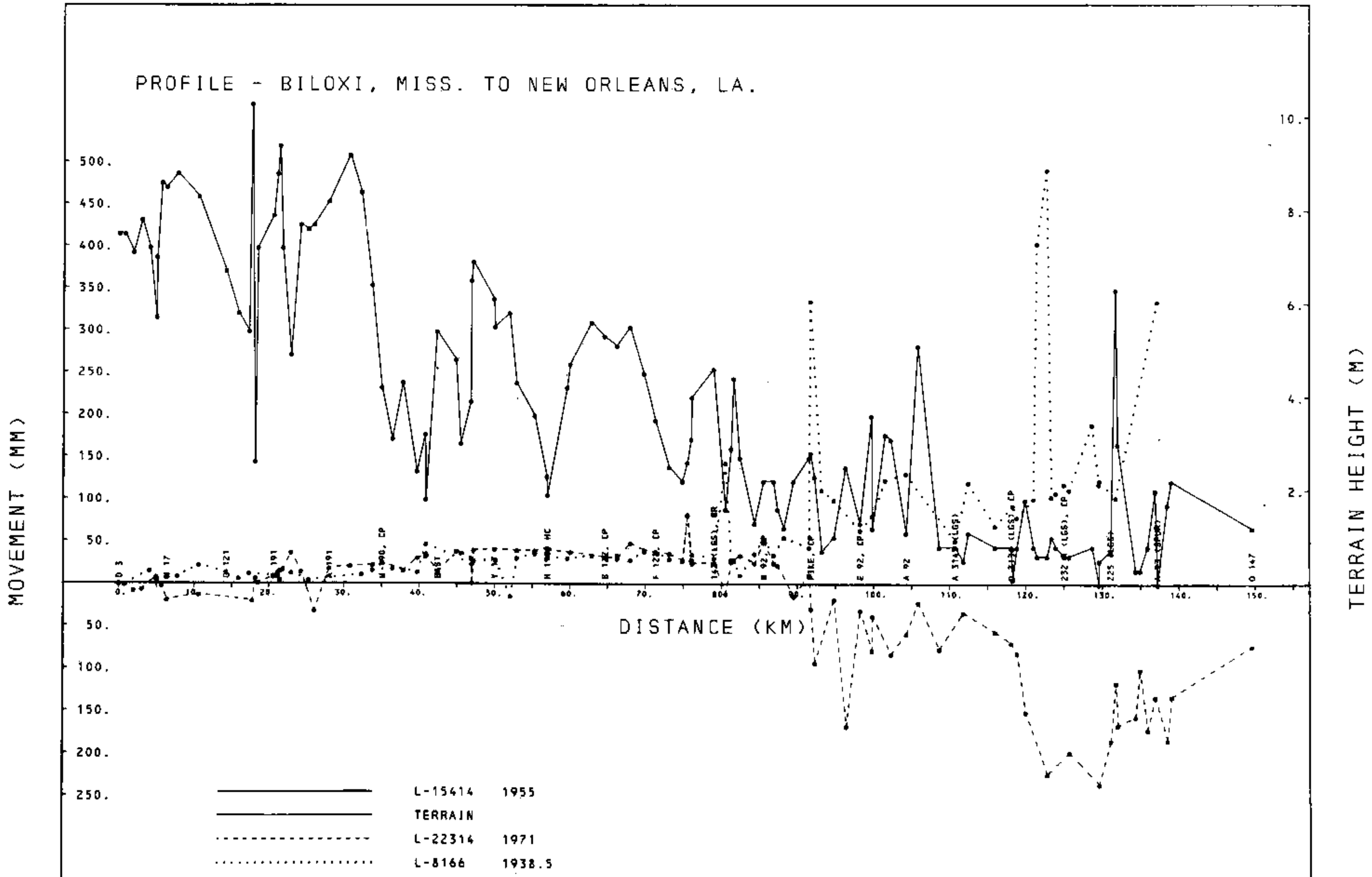

PROFILE - BILOXI, MISS. TO NEW ORLEANS, LA.
MOVEMENT (MM)
TERRAIN HEIGHT (M)
DISTANCE (KM)
L-15414 1955
TERRAIN
L-22314 1971
L-8166 1938.5

Figure 8

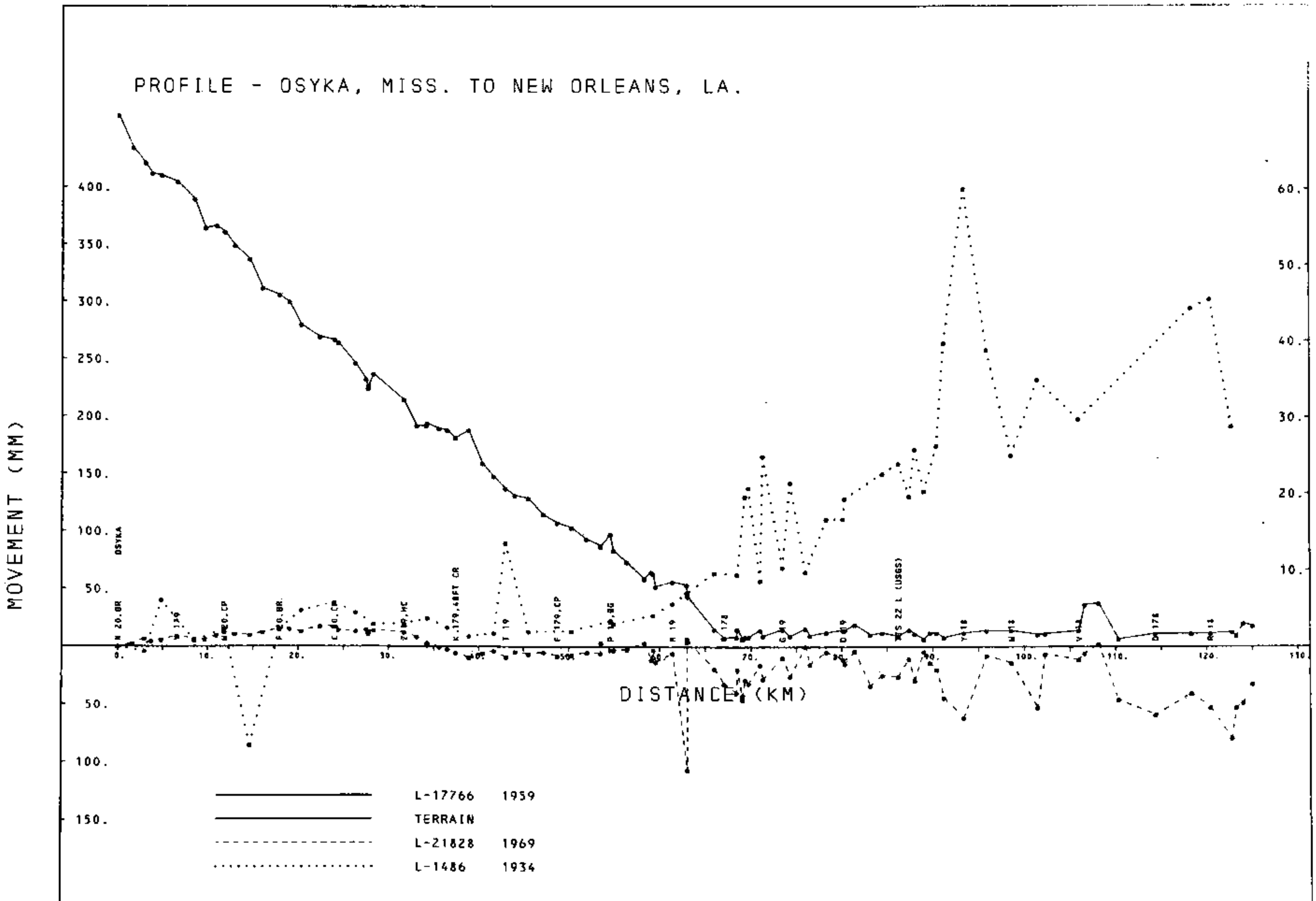
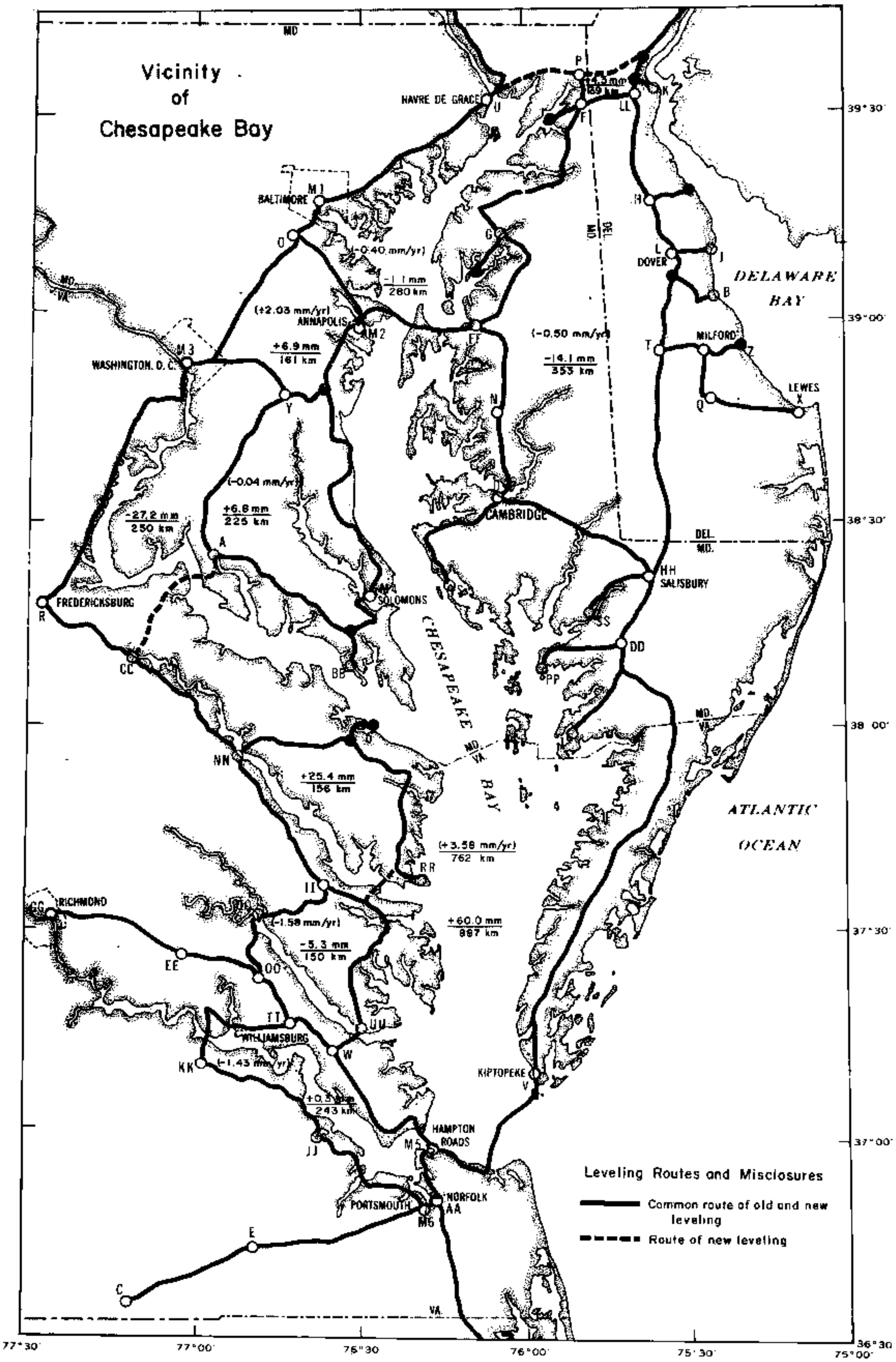

PROFILE - OSYKA, MISS. TO NEW ORLEANS, LA.
MOVEMENT (MM)
TERRAIN HEIGHT (M)
DISTANCE (KM)
L-17766 1959
TERRAIN
L-21828 1969
L-1486 1934
OSYKA

Figure 9



Vicinity of Chesapeake Bay
HAVRE DE GRACE
BALTIMORE
ANNAPOLIS
WASHINGTON, D. C.
CAMBRIDGE
SOLOMONS
FREDERICKSBURG
SALISBURY
DOVER
MILFORD
LEWES
DELAWARE BAY
CHESAPEAKE BAY
ATLANTIC OCEAN
RICHMOND
WILLIAMSBURG
KIPTOPEKE
HAMPTON ROADS
NORFOLK
PORTSMOUTH
(-0.40 mm/yr)
-1.1 mm
280 km
(+2.03 mm/yr)
+6.9 mm
161 km
(-0.50 mm/yr)
-14.1 mm
353 km
(-0.04 mm/yr)
+6.8 mm
225 km
-27.2 mm
250 km
+25.4 mm
156 km
(+3.58 mm/yr)
762 km
+60.0 mm
887 km
(-1.58 mm/yr)
-5.3 mm
150 km
(-1.43 mm/yr)
243 km
Leveling Routes and Misclosures
Common route of old and new leveling
Route of new leveling
77°30'
77°00'
76°30'
76°00'
75°30'
75°00'
39°30'
39°00'
38°30'
38°00'
37°30'
37°00'
36°30'

Figure 10

Table 3. Mareograph Stations - Vicinity of Chesapeake Bay
Velocities of Vertical Movement (mm/yr.)

Index Code	Station Name	Series	Initial		Adjustment II		Adjustment I	
M 1	Baltimore, Md.	1940-71	-1.68	±0.46	-1.79	±0.38	(-1.68)	±0.46
M 2	Annapolis, Md.	1940-71	-2.20	±0.46	-2.10	±0.38	-1.88	±0.66
M 3	Washington, D.C.	1940-71	-1.71	±0.58	-1.11	±0.40	-0.79	±0.72
M 4	Solomons, Md.	1940-71	-2.51	±0.49	-2.45	±0.48	-2.11	±0.99
M 5	Hampton Roads, Va.	1940-71	-2.41	±0.52	-2.42	±0.50	-2.78	±1.68
M 6	Portsmouth, Va.	1940-71	-2.57	±0.52	-2.77	±0.52	-3.24	±1.78
X	Lewes, Del.	1921-71	-2.42	±0.44	-2.84	±0.49	-3.64	±1.20
V	Kiptopeke, Va.	1952-71	-1.96	±0.94	-1.06	±0.71	-0.94	±1.34

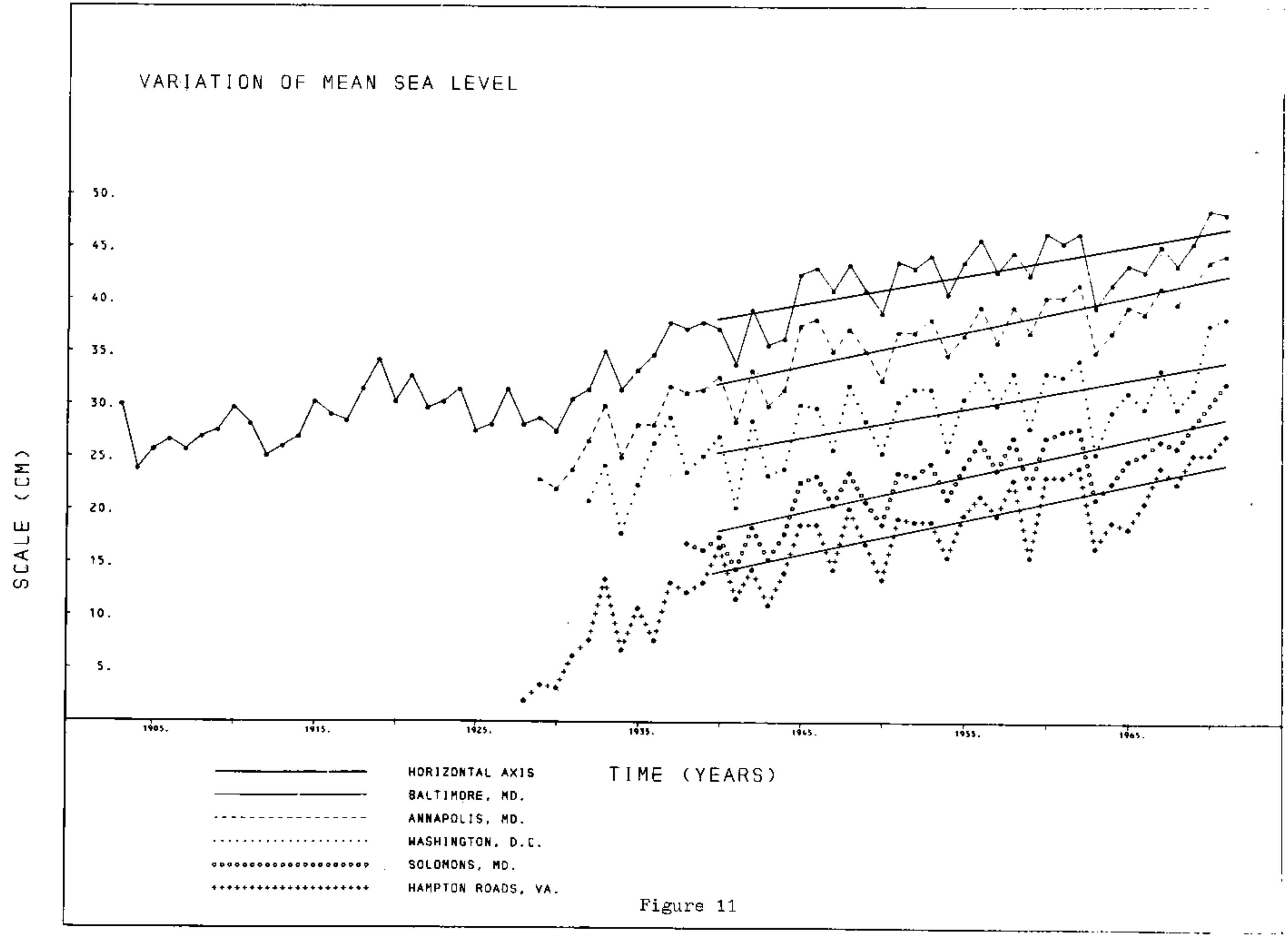
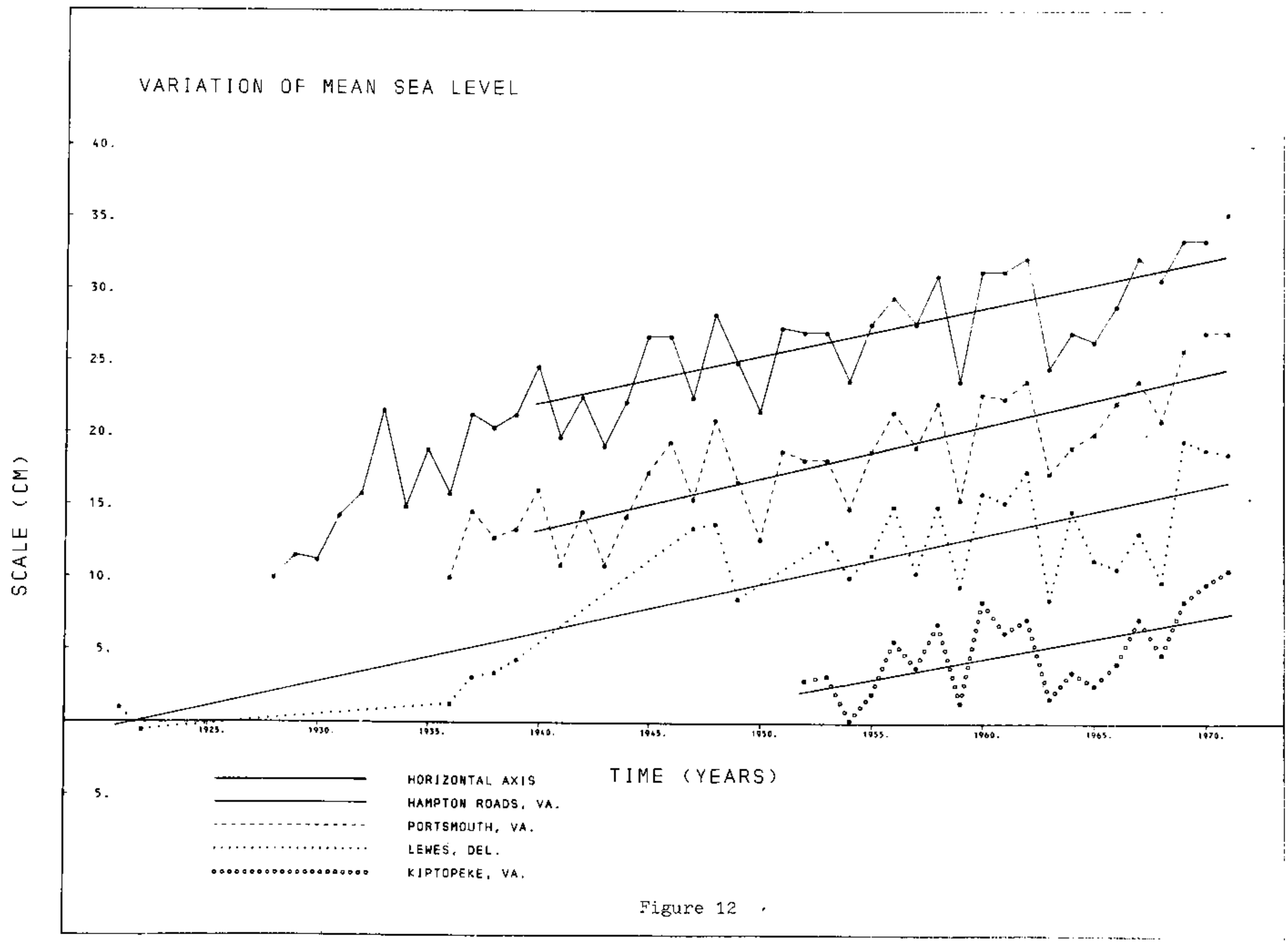
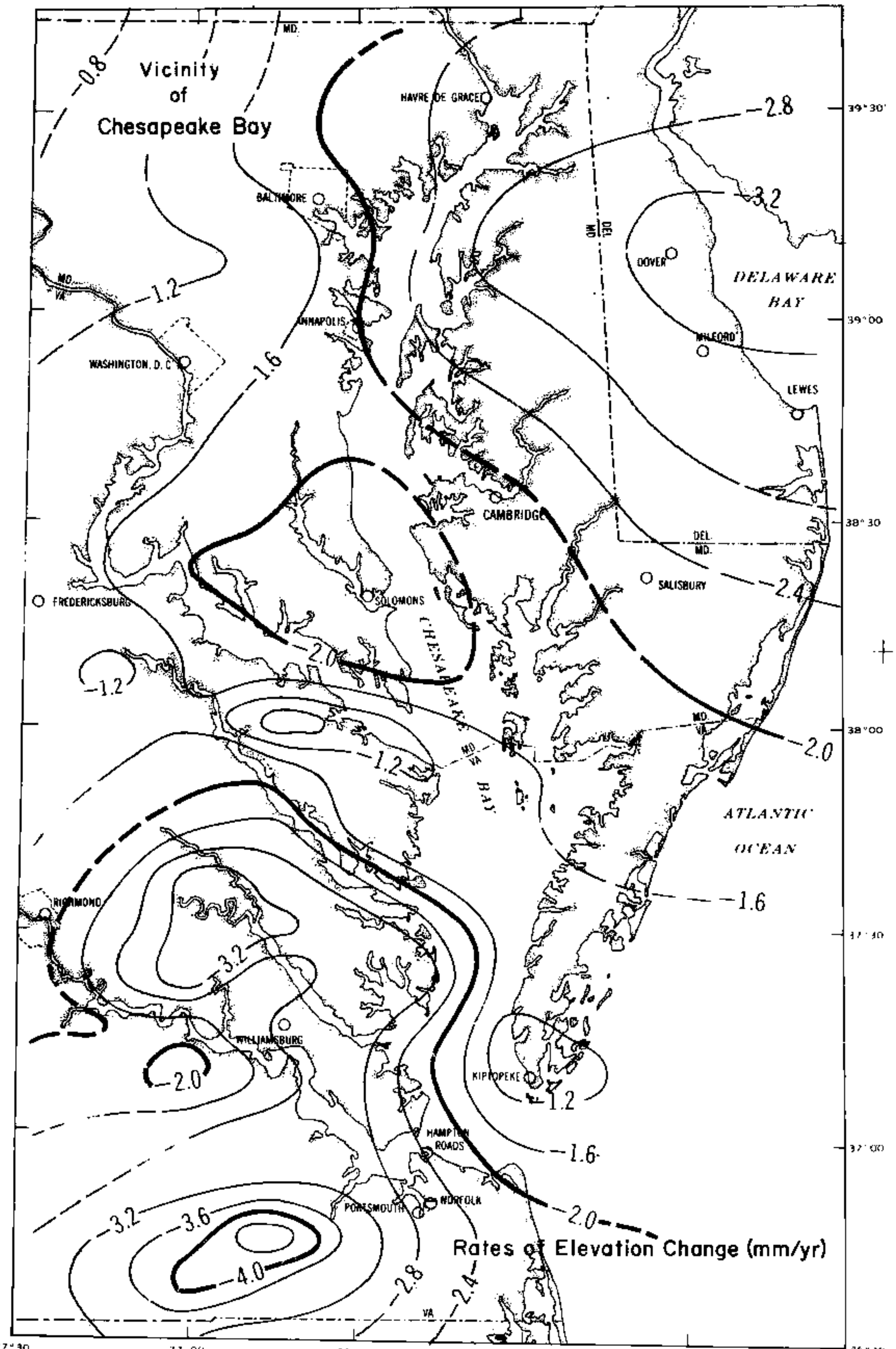

VARIATION OF MEAN SEA LEVEL
SCALE (CM)
50.
45.
40.
35.
30.
25.
20.
15.
10.
5.
1905.
1915.
1925.
1935.
1945.
1955.
1965.
TIME (YEARS)
HORIZONTAL AXIS
BALTIMORE, MD.
ANNAPOLIS, MD.
WASHINGTON, D.C.
SOLOMONS, MD.
HAMPTON ROADS, VA.

Figure 11



VARIATION OF MEAN SEA LEVEL
SCALE (CM)
40.
35.
30.
25.
20.
15.
10.
5.
5.
1925.
1930.
1935.
1940.
1945.
1950.
1955.
1960.
1965.
1970.
TIME (YEARS)
HORIZONTAL AXIS
HAMPTON ROADS, VA.
PORTSMOUTH, VA.
LEWES, DEL.
KIPTOPEKE, VA.

Figure 12



Vicinity
of
Chesapeake Bay
Rates of Elevation Change (mm/yr)
HAVRE DE GRACE
BALTIMORE
ANNAPOLIS
WASHINGTON, D.C.
CAMBRIDGE
SOLOMONS
FREDERICKSBURG
SALISBURY
DOVER
MILFORD
LEWES
DELAWARE
BAY
CHESAPEAKE
BAY
ATLANTIC
OCEAN
RICHMOND
WILLIAMSBURG
KIPTOPEKE
HAMPTON
ROADS
NORFOLK
PORTSMOUTH
MD.
VA.
DEL.
-0.8
-1.2
-1.6
-2.0
-2.4
-2.8
-3.2
-3.6
-4.0
39°30'
39°00'
38°30'
38°00'
37°30'
37°00'
36°30'
77°30'
77°00'
76°30'
76°00'
75°30'
75°00'

Figure 13

Table 4. Adjusted Velocities of Elevation Change - Chesapeake Bay
(All values in mm/yr.)

Index Code	Location	Adjustment II Velocity	Adjustment II Std. Dev.	Adjustment II minus Adjustment I
A	Allens Fresh, Md.	-1.97	0.60	-0.41
M2	Annapolis, Md.	-2.10	0.38	-0.32
M1	Baltimore, Md.	-1.79	0.38	-0.21
B	Bowers, Del.	-4.03	0.65	+0.17
C	Boykins, Va.	-3.16	0.91	+0.37
D	Cambridge, Md.	-1.93	0.65	-0.06
E	Carrsville, Va.	-4.79	0.76	+0.37
F	Chesapeake City, Md.	-2.32	0.49	-0.09
G	Chestertown, Md.	-3.03	0.61	-0.12
H	Clayton, Del.	-3.07	0.56	+0.08
I	Crisfield, Md.	-1.93	0.82	-0.05
J	Deep Water Pt., Md.	-2.95	0.63	+0.14
K	Delaware City, Del.	-2.51	0.63	-0.04
L	Dover, Del.	-3.47	0.57	+0.14
N	Easton, Md.	-1.88	0.64	-0.09
O	Elkridge, Md.	-1.10	0.38	-0.28
P	Elkton, Md.	-2.51	0.47	-0.12
Q	Ellendale, Del.	-3.16	0.55	+0.44
R	Fredericksburg, Va.	-1.23	0.59	-0.37
S	Golden Hill, Md.	-1.93	0.82	-0.06
M5	Hampton Roads, Va.	-2.42	0.50	+0.26
T	Harrington, Del.	-3.07	0.54	+0.25
U	Havre DeGrace, Md.	-2.51	0.47	-0.12
V	Kiptopeke, Va.	-1.06	0.71	-0.22
W	Lee Hall, Va.	-3.05	0.81	+0.19
X	Lewes, Del.	-2.84	0.49	+0.70
Y	Marlboro, Md.	-1.66	0.40	-0.40
Z	Milford, Del.	-3.11	0.55	+0.35
AA	Norfolk, Va.	-2.77	0.52	+0.37
BB	Piney Point, Md.	-2.00	0.58	-0.44
CC	Port Royal, Va.	-0.92	0.84	-0.28
M6	Portsmouth, Va.	-2.77	0.52	+0.37
DD	Princess Anne, Md.	-2.04	0.67	-0.05
EE	Providence Forge, Va.	-3.63	1.26	+0.17
FF	Queenstown, Md.	-2.75	0.58	-0.14
GG	Richmond, Va.	-1.86	1.92	+0.17
HH	Salisbury, Md.	-2.14	0.62	-0.01
II	Saluda, Va.	-3.06	0.95	+0.10
JJ	Smithfield, Va.	-3.25	0.71	+0.34
M4	Solomons, Md.	-2.45	0.48	-0.44
KK	Spring Grove, Va.	-1.61	0.91	+0.27
LL	St. Georges, Del.	-2.46	0.52	-0.04
NN	Tappahannock, Va.	-1.94	1.02	-0.10
OO	Toano, Va.	-2.05	0.87	+0.17
M3	Washington, D.C.	-1.11	0.40	-0.42
PP	Wenona, Md.	-0.64	0.91	-0.05
QQ	West Point, Va.	-3.76	0.95	+0.12
RR	Westland, Va.	-1.54	1.27	-0.10
SS	Whitehaven, Md.	-1.32	0.76	-0.01
TT	Williamsburg, Va.	-3.03	0.83	+0.18
UU	Yorktown, Va.	-3.09	0.83	+0.18

Note: A constant value of +0.10 mm/yr has been added to each velocity from Adjustment I prior to comparison with Adjustment II.

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