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AN INTRODUCTION TO THE TIDES OF FLORIDA BAY

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ABSTRACT: *Water level records from 37 locations in Florida Bay are used to quantify semidiurnal, diurnal, fortnightly, monthly, semiannual and annual tidal constituents. Semidiurnal and diurnal waves enter primarily from the Gulf side of the bay, but also through tidal channels that connect Florida Bay with the Atlantic Ocean.* M_2 *amplitudes in the northwest corner of the bay are 35 cm; amplitudes in tidal channels along the southeast side of the bay are 15–20 cm.* S_2 *amplitudes decrease along the western boundary of the bay from 11 cm in the northwest corner to 2 cm at the southern end. Highest* S_2 *amplitudes in tidal channels are 4–6 cm.* K_1 *and* O_1 *constituents have highest amplitudes of 15 and 12 cm in the northwest corner of the bay. Semidiurnal and diurnal tidal waves converging toward the interior of the bay are heavily damped, and amplitudes are less than 1 cm in the northcentral and northeast parts of the bay. Long-period tides are damped less. Amplitudes of the fortnightly and monthly constituents are 1–3 cm at all stations. The amplitude of the annual tidal constituent is 8–10 cm throughout Florida Bay. Nontidal forcing introduces considerable station-to-station, and year-to-year variability in the phase angles of the semiannual and annual constituents. Semiannual constituent amplitudes are 3–5 cm and act to delay annual maximum water levels to late September.*

FLORIDA Bay lies directly south of Everglades National Park, at the southern end of the Florida peninsula. The bay is bounded on the east and south by the Florida Keys. Numerous tidal channels between keys exchange water between Florida Bay and continental shelf waters on the Atlantic side of the keys. The western boundary of Florida Bay cannot be defined by bottom topography, and the bay connects directly with the inner shelf of the Gulf of Mexico. Taking the 81°05′W meridian as the boundary, the surface area of Florida Bay is approximately 2,140 km^2. Water depth along this north-south line averages about 3 m; within the bay, water depth is characteristically 0.5 to 1.0 m. Mud banks and mangrove islands define a series of distinct basins that are connected by channels (Fourqurean et al., 1993).

The tides of Florida Bay represent the interaction of tidal waves in the eastern Gulf of Mexico and southwestern North Atlantic Ocean. Atlantic tides are primarily semidiurnal (Defant, 1958). Tides in the eastern Gulf are mixed semidiurnal (Zetler and Hansen, 1970). The earliest studies of tidal conditions in the Gulf of Mexico (Marmer, 1954; Zetler and Hansen, 1970) included harmonic constants from Key West, the Dry Torgugas and the southwest coast of the Florida peninsula, but no information was available from Florida Bay. Tidal conditions in Florida Bay were characterized in a qualitative way by Jones and co-workers (1973), who stated that tidal patterns at any given location can be extremely complex. Holmquist and co-workers (1989) recorded water levels at six sites on shallow mud banks and described tidal and seasonal water level ranges in the interior of the bay and around the fringe. Water level records were not analyzed for tidal constituents. A recent study by Wang and co-workers (1994) quantified amplitudes and phase angles of the principal tidal constituents at two stations. Results showed a west-to-east damping of tidal amplitudes, although spatial patterns could not be defined to describe the interaction of Gulf and Atlantic tidal waves.

The importance of tidal processes in Florida Bay is twofold. Tides provide a mechanism for exchanging water between the bay and the adjacent continental shelf on both the Atlantic and Gulf sides of the bay. Fourqurean and co-workers (1993) noted the importance of tidal exchanges for transporting phosphorus into the bay, as well as for reducing hypersaline conditions in the interior. The study by Wang and co-workers (1994) introduced the possibility that frictionally damped tidal waves entering Florida Bay from the Gulf of Mexico set up mean water levels within the bay and thus force an outflow of water through tidal channels along the southeast fringe of the bay. This would help explain why the observed net outflow is in a generally upwind direction (Smith, 1994). Residual transport induced by a tidal pumping mechanism is inversely related to water depth (van de Kreeke and Chiu, 1981).

The rise and fall of the tide is important also because it changes the depth significantly relative to the mean. Florida Bay is a macrophyte-dominated system, with approximately half of the bay's productivity occurring over the shallow mudbanks (Zieman et al., 1989). In view of the high turbidity of the water, even relatively small changes in water depth can have a profound effect on the amount of light available to support seagrass growth. In western parts of the bay, the semidiurnal tidal range can change the water depth by ±50 cm.

The purpose of this paper is to provide a clearer picture of the spatial variability of the semidiurnal and diurnal tides in Florida Bay by incorporating water level data from several sources. This is especially important along the western fringe of the bay where gradients are strongest, and in the northcentral and northeast parts of the bay where amplitudes are less than 1 cm. A second purpose of the paper is to extend earlier work by describing the long-period fortnightly, monthly, semiannual and annual tidal constituents.

DATA—The data base assembled for this paper includes harmonic constants from 37 study sites, obtained from four sources. Harbor Branch water level studies contributed time series from 13 locations along or to the west of the Everglades National Park boundary, and in tidal channels along the southeast perimeter of the bay (Stations 1–13 in Figure 1). Except for a float-and-counterweight tide gauge on the bay side of Long Key (Station 9), the Harbor Branch

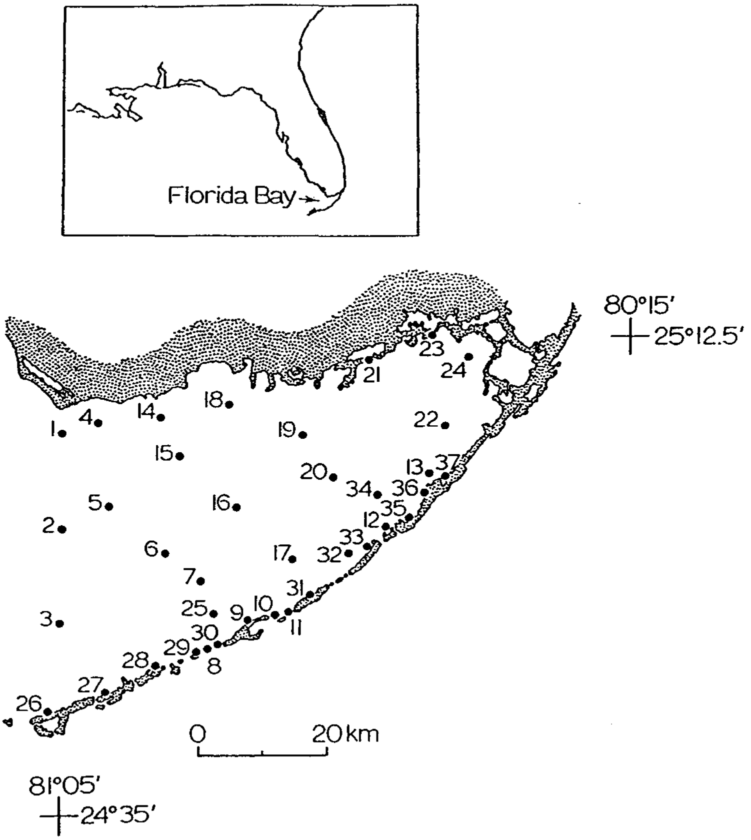

FIG. 1. Locations of the 37 study sites providing water level data from Florida Bay.

data are in the form of bottom pressure records. Pressure fluctuations have been converted to water level variations assuming a constant density of 1.024 gm cm^{-3}. A one decibar change in bottom pressure corresponds closely to a one meter change in water level. Individual readings are accurate to ±0.005 decibar (±0.5 cm), according to instrument specifications.

National Park Service personnel at Everglades National Park have maintained water level recorders on platforms in protected waters of the interior of Florida Bay as part of their Marine Monitoring Network since 1989. Data from 11 sites were used in this study (Stations 14–24). Water levels were tracked with a float-and-counterweight system, and the accuracy of the readings is ±0.3 cm.

Bottom pressure records from a National Data Buoy Center C-MAN weather station added data from Station 25 in the southern part of the bay. Finally, the National Ocean Service assembled water level records from throughout the Florida Keys south of Key Biscayne as part of their Marine Boundary and Coastal Mapping Program in the early 1970s (Martin, 1995). Harmonic constants of semidiurnal and diurnal constituents from 12 stations located along tidal channels, or on the Florida Bay side of the Keys were used in this study (Stations 26–37). Accuracy of the hourly observations is within ±0.3 cm.

The harmonic constants used to describe tidal conditions in Florida Bay include amplitudes, in cm, and local phase angles, in degrees. Local phase angles represent the interval, expressed in degrees, between the high water phase of an equilibrium tidal constituent at 75°

west longitude and the following high water of the same constituent in the tide observed at the study site (Schureman, 1958).

METHODS—Harmonic constants were quantified by one of two computer programs, depending on the length of the record. When the time series was shorter than a full year, a series of 29-day analyses (Dennis and Long, 1971) provided several amplitude and phase angle pairs for 24 diurnal, semidiurnal and shorter period tidal constituents. All harmonic constants for each of the principal tidal constituents were then vector averaged (Haurwitz and Cowley, 1975) to provide values more representative of the entire time series. Harmonic constants can be thought of as vectors, with the amplitude and local phase angle representing the magnitude and direction, respectively. Decomposing vectors into sine and cosine components, one can calculate the mean, as well as various measures of scatter about the mean. Comparison of the magnitude of the vector average with the probable error, for example, provides information on the statistical significance of the tidal constituent in question (Bartels, 1932).

When time series included a full year, a least squares analysis of the entire time series (Schureman, 1958) provided information on the fortnightly, monthly, semiannual and annual constituents, as well as on diurnal and semidiurnal constituents. The same computer program was used with a one-year record of surface pressure from Station 25 to investigate the effects that atmospheric tides might have on bottom pressure records obtained from Florida Bay.

The movement of individual tidal constituents through Florida Bay is traced using co-amplitude and co-phase charts. Both co-amplitude and co-phase charts were constructed by interpolating linearly between adjacent stations. With the combined data base, 21 of the 37 stations are from the interior of the bay, and the isopleths are much less subjective than they would be if water level records were from only the land-based stations surrounding the basin. Isopleths of local phase angles provide information on the speed and direction of tidal wave propagation. For semidiurnal constituents, a 30° phase lead or lag corresponds closely to a one hour time lead or lag. For diurnal constituents, a 15° phase difference corresponds to a one-hour time difference. Isopleths of amplitude provide information on how tidal waves are damped as they move through the bay. Phase angles have not been extended into the northcentral and northeast parts of the bay, where amplitudes are less than 1 cm. The 1 cm isopleth is used as an arbitrary boundary to define tideless parts of the bay for a given constituent.

RESULTS—Harmonic analysis identified six principal semidiurnal and diurnal tidal constituents: M_2, S_2, N_2, K_1, O_1 and P_1. Because of the microtidal conditions in Florida Bay, principal tidal constituents are defined to be those with amplitudes greater than 1 cm. Four tidal constituents, excluding N_2 and P_1, were selected for constructing co-amplitude and co-phase charts. The N_2 constituent is significant in the northwest corner with an amplitude of 7 cm at Station 1; the P_1 constituent is small throughout the bay (Table 1).

The co-amplitude chart for the M_2 tidal constituent shows a relatively uniform west-to-east decrease of about 2.0 cm km^{-1}, as the M_2 constituent enters the bay from the Gulf of Mexico and is damped in the shallow water (Fig. 2). Isolated pockets of locally significant M_2 amplitude are found along the southeastern fringe of Florida Bay, where connecting channels permit tidal waves to enter from the continental shelf on the Atlantic side of the keys. M_2 amplitudes are less than 1 cm in a 370 km^2 area in the northcentral and northeast parts of the bay. This represents about 17% of the total surface area if the bay is bounded by the 81°05′W meridian.

The interaction of converging tidal waves results in a complex co-phase chart (Fig. 3). The west-to-east increase in phase angle shows that semidi-

TABLE 1. Harmonic constants of the principal tidal constituents from Florida Bay water level recorders. Station numbers correspond to numbers shown in Figure 1. Amplitudes (η) are in centimeters; local phase angles (κ) are in degrees. An * indicates that the water level record was too short to quantify the amplitude and phase angle.

				Constituent										
Station	Lat. (N)	Lon. (W)		M_2	S_2	N_2	K_1	O_1	P_1	Mf	Msf	Mm	Ssa	Sa
1 8105 N	25°05.0′	81°05.0′	η	39.5	11.1	7.0	14.6	11.7	4.9	*	*	*	*	*
			κ	034	056	022	317	313	317	*	*	*	*	*
2 8105C	24°57.5′	81°05.0′	η	36.3	7.4	6.5	17.3	12.2	*	*	*	*	*	*
			κ	038	043	030	311	317	*	*	*	*	*	*
3 8105S	24°50.0′	81°05.0′	η	23.4	6.8	3.9	12.0	10.2	4.0	*	*	*	*	*
			κ	050	077	033	332	326	332	*	*	*	*	*
4 Marker 5	25°05.8′	81°01.9′	η	36.9	11.0	7.1	18.7	12.5	6.2	*	*	*	*	*
			κ	050	075	042	325	320	325	*	*	*	*	*
5 Oxfoot Bank	24°59.2′	81°00.7′	η	37.3	9.7	5.7	15.8	11.4	5.2	*	*	*	*	*
			κ	072	093	055	338	329	338	*	*	*	*	*
6 Sprigger Bank	24°54.8′	80°56.3′	η	23.4	7.0	3.8	11.9	10.1	3.9	*	*	*	*	*
			κ	061	092	040	325	324	325	*	*	*	*	*
7 Arsenic Bank	24°52.3′	80°53.0′	η	6.6	1.3	0.9	7.3	6.6	2.4	*	*	*	*	*
			κ	059	064	067	331	331	331	*	*	*	*	*
8 Long Key Channel	24°47.9′	80°52.2′	η	16.2	4.2	3.6	5.5	5.1	1.8	*	*	*	*	*
			κ	240	268	220	288	282	288	*	*	*	*	*
9 Keys Marine Lab	24°49.6′	80°48.9′	η	4.6	0.8	1.4	4.7	5.3	1.2	1.3	2.6	0.3	*	*
			κ	258	224	229	323	313	334	340	325	275	*	*
10 Channel Five	24°50.2′	80°46.3′	η	18.8	5.5	4.2	5.9	4.9	1.9	*	*	*	*	*
			κ	239	271	217	262	273	262	*	*	*	*	*
11 Channel Two	24°50.6′	80°45.1′	η	16.9	4.8	4.0	6.5	5.1	2.1	*	*	*	*	*
			κ	240	269	219	260	278	260	*	*	*	*	*
12 Windley Key	24°58.1′	80°36.6′	η	7.1	2.1	1.4	2.8	2.9	0.9	*	*	*	*	*
			κ	304	307	288	352	320	352	*	*	*	*	*

TABLE 1. Continued.

Station	Lat. (N)	Lon. (W)		Constituent										
				M_2	S_2	N_2	K_1	O_1	P_1	Mf	Msf	Mm	Ssa	Sa
13 Tavernier Creek	25°01.1′	80°33.1′	η	1.1	1.4	0.2	1.6	0.3	0.5	*	*	*	*	*
			κ	318	302	322	325	039	325	*	*	*	*	*
14 Murray Key	25°06.3′	80°56.5′	η	29.1	7.9	5.0	8.6	10.0	2.9	*	*	*	*	*
			κ	091	123	085	356	341	356	*	*	*	*	*
15 Johnson Key	25°03.1′	80°54.2′	η	13.9	4.1	2.3	6.6	5.7	1.8	1.4	3.3	0.7	0.5	7.6
			κ	110	132	095	019	012	027	296	043	034	139	145
16 Little Rabbit Key	24°58.9′	80°49.6′	η	1.5	0.5	0.2	2.2	2.3	0.8	0.4	2.5	2.1	3.0	8.2
			κ	113	173	080	045	030	057	312	048	037	068	172
17 Peterson Key	24°55.1′	80°44.8′	η	6.8	1.3	1.4	2.0	2.6	0.5	0.7	2.3	1.4	4.7	8.8
			κ	299	326	283	329	327	335	311	060	044	059	173
18 Buoy Key	25°07.3′	80°50.0′	η	2.4	0.7	0.4	1.8	1.8	0.7	0.2	2.5	2.2	3.2	8.4
			κ	168	196	139	088	076	108	275	070	037	052	151
19 Whipray Basin	25°04.7′	80°43.7′	η	0.5	0.3	0.1	1.3	1.2	0.5	0.5	2.4	2.3	2.3	8.8
			κ	228	234	210	093	081	103	289	062	051	064	165
20 Bob Allen Key	25°01.6′	80°40.9′	η	4.2	0.9	0.8	1.3	1.6	0.2	0.5	1.9	2.4	2.9	7.5
			κ	313	334	288	348	341	346	319	059	045	056	172
21 Little Madeira Bay	25°10.1′	80°37.9′	η	0.5	0.4	0.2	0.1	0.3	0.1	0.4	1.8	2.1	2.7	8.8
			κ	033	030	019	076	052	266	025	090	058	066	163
22 Butternut Key	25°05.1′	80°31.1′	η	0.4	0.1	0.1	0.3	0.3	0.1	1.0	1.7	1.8	2.5	9.0
			κ	035	162	352	073	062	060	311	092	051	037	161
23 Trout Cove	25°12.7′	80°32.0′	η	0.4	0.4	0.1	0.2	0.2	0.0	0.8	2.1	1.5	1.7	11.3
			κ	052	059	029	026	045	355	337	105	061	022	161
24 Duck Key	25°01.8′	80°29.4′	η	0.3	0.2	0.1	0.4	0.2	0.1	0.7	0.7	1.5	*	*
			κ	008	082	051	032	009	268	107	161	123	*	*

TABLE 1. Continued.

Station	Lat. (N)	Lon. (W)		Constituent										
				M_2	S_2	N_2	K_1	O_1	P_1	Mf	Msf	Mm	Ssa	Sa
25 NDBO C-MAN Station	24°50.6′	80°51.7′	η	1.4	0.4	0.7	5.1	5.6	1.7	*	*	*	*	*
			κ	273	151	249	324	321	324	*	*	*	*	*
26 Vaca Key, North	24°42.7′	81°06.1′	η	7.0	1.9	0.8	7.4	7.4	*	*	*	*	*	*
			κ	027	071	354	320	312	*	*	*	*	*	*
27 Fat Deer Key	24°44.0′	81°01.0′	η	15.4	4.0	2.3	7.9	8.3	*	*	*	*	*	*
			κ	061	085	022	345	329	*	*	*	*	*	*
28 Grassy Key	24°46.3′	80°56.4′	η	11.3	3.4	1.8	7.6	7.7	*	*	*	*	*	*
			κ	064	105	053	338	328	*	*	*	*	*	*
29 Conch Key	24°47.5′	80°53.0′	η	14.6	4.1	3.3	4.9	5.4	*	*	*	*	*	*
			κ	238	254	207	274	269	*	*	*	*	*	*
30 Long Key	24°48.1′	80°51.0′	η	15.5	3.5	3.5	4.2	4.7	*	*	*	*	*	*
			κ	235	259	217	255	267	*	*	*	*	*	*
31 Lower Matecumbe Key	24°51.9′	80°43.0′	η	10.9	1.9	2.5	3.1	4.0	*	*	*	*	*	*
			κ	256	263	235	317	314	*	*	*	*	*	*
32 Shell Key	24°55.4′	80°40.3′	η	8.4	1.4	1.7	1.4	2.3	*	*	*	*	*	*
			κ	284	316	267	311	312	*	*	*	*	*	*
33 Upper Matecumbe	24°55.5′	80°37.9′	η	6.7	1.3	1.4	1.5	2.0	*	*	*	*	*	*
			κ	297	315	269	327	319	*	*	*	*	*	*
34 East Key	24°59.8′	80°36.5′	η	7.0	1.3	1.7	0.9	1.6	*	*	*	*	*	*
			κ	305	347	282	313	313	*	*	*	*	*	*
35 Cowpens Anchorage	24°57.9′	80°34.1′	η	7.6	1.4	1.1	1.6	1.7	*	*	*	*	*	*
			κ	311	334	295	318	323	*	*	*	*	*	*
36 Plantation Key	25°00.1′	80°32.5′	η	1.0	0.1	0.1	0.9	0.6	*	*	*	*	*	*
			κ	321	246	344	195	105	*	*	*	*	*	*
37 Tavernier	25°00.9′	80°30.9′	η	0.5	0.4	0.2	0.6	0.3	*	*	*	*	*	*
			κ	342	192	123	157	174	*	*	*	*	*	*

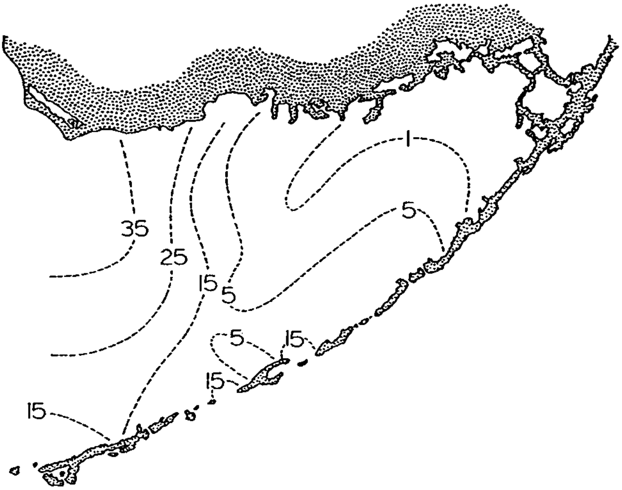

FIG. 2. Co-amplitude chart for the M_2 tidal constituent in Florida Bay. Isopleths are in centimeters.

urnal M_2 waves enter Florida Bay primarily from the Gulf of Mexico. Tidal waves entering the bay through tidal channels along the southeast fringe have a more local effect. In the southern part of the bay, isopleths of M_2 phase angles are tightly clustered, and a 180° phase difference occurs over a distance of less than 5 km just north of Long Key Channel (Station 8 in Fig. 1).

The spacing of the isopleths can be interpreted in terms of the speed of

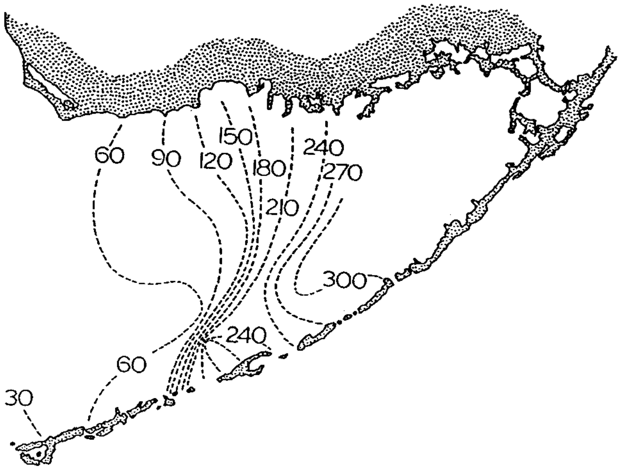

FIG. 3. Co-phase chart for the M_2 tidal constituent in Florida Bay. Local phase angles are in degrees.

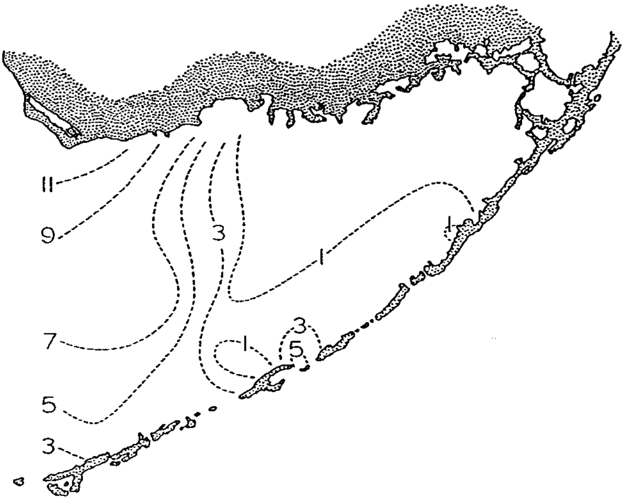

FIG. 4. Same as Figure 2, but for the S_2 constituent.

propagation of the tidal wave form. Tidal waves entering the bay from the Gulf of Mexico travel at speeds on the order of 5–10 km hr^{-1} in the northwestern part of the bay, then slow to 3–4 km hr^{-1} moving through the shallow water in the northcentral part of the bay (Fig. 3). In the southern part of the study area, tidal waves propagate from west to east at a speed of about 1 km hr^{-1}. This may represent the interaction of Gulf tidal waves with Atlantic tidal waves entering Florida Bay through tidal channels on either side of Long Key.

Highest amplitudes for the S_2 constituent are 11 cm in the northwest corner of the bay (Fig. 4). The west-to-east decrease is approximately 0.5 cm km^{-1}, and the 1 cm isopleth occurs just west of the northcentral part of the bay. The area within the 1 cm isopleth is approximately 830 km^2, which is 39% of the total surface area of Florida Bay. The north-to-south decrease in amplitude is 0.25 cm km^{-1}, and the S_2 amplitude at Station 26 (Fig. 1) is just under 2 cm. The S_2 co-phase chart (Fig. 5) shows waves entering from the Gulf and moving through the northern part of the bay at a speed of about 6 km h^{-1}. In the southern part of Florida Bay, the tightly compressed isopleths reveal a situation similar to that seen with the M_2 constituent. The 90° and 240° isopleths are only 5.2 km apart where Gulf and Atlantic S_2 tidal waves interact north of Long Key Channel.

The co-amplitude chart for the K_1 constituent (Fig. 6) contains maximum values of 15 cm in the northwestern corner of the bay; the 1 cm isopleth defines a 515 km^2 area in the northeast corner where the K_1 constituent is of negligible importance. Co-phase lines for the K_1 constituent (Fig. 7) indicate a convergent pattern with tidal waves moving into the northcentral part of the bay. The more closely spaced lines in the eastern part of the bay

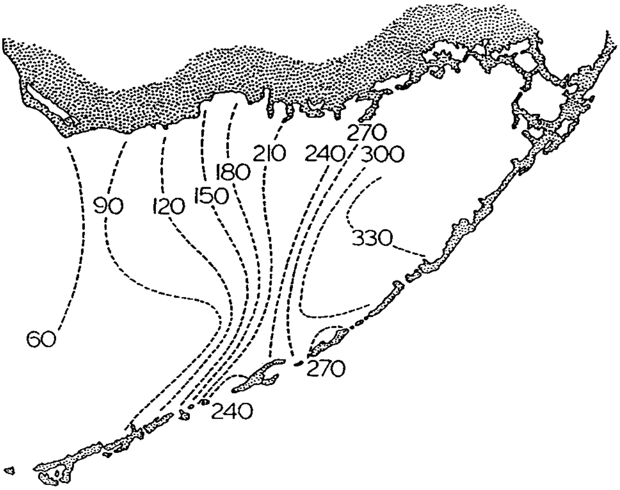

FIG. 5. Same as Figure 3, but for the S_2 constituent.

indicate that tidal waves move northward more slowly than they move eastward from the western side of the bay. The northward propagation speed is 1.1 km hr^{-1}, while the eastward propagation speed at the western end of the bay is 2.8 km hr^{-1}.

Highest O_1 amplitudes (Fig. 8) are near 12 cm in the northwest corner of the bay. Amplitudes decrease from west to east through the northcentral part of the bay at a rate of about 0.5 cm km^{-1}. Localized regions of relatively high amplitude are missing along the eastern and southeastern sides of the

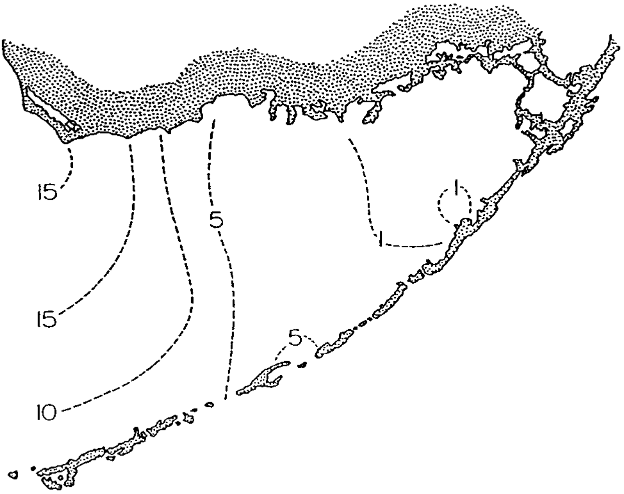

FIG. 6. Same as Figure 2, but for the K_1 constituent.

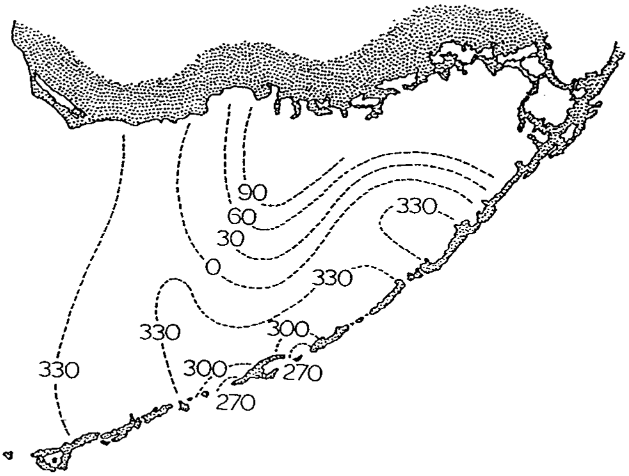

FIG. 7. Same as Figure 3, but for the K_1 constituent.

bay. The area with O_1 amplitudes less than 1 cm is 487 km^2, or about 23% of the total surface area of Florida Bay. The O_1 co-phase chart (Fig. 9) shows nearly uniform values along the western boundary. Tidal waves from both the Gulf of Mexico and from the Atlantic Ocean seem to be converging toward the northcentral part of the bay. O_1 propagation speeds are approximately 2–3 km h^{-1}.

The contaminating effect of atmospheric tides on bottom pressure records appears to be minimal for the semidiurnal and diurnal constituents. The principal atmospheric tidal constituent was S_2, but the amplitude was

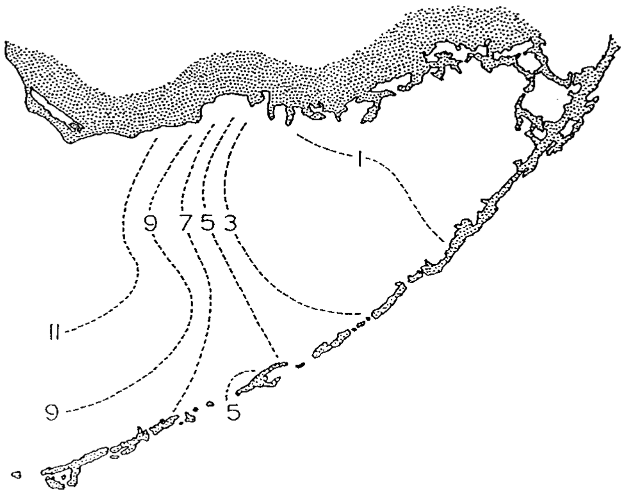

FIG. 8. Same as Figure 2, but for the O_1 constituent.

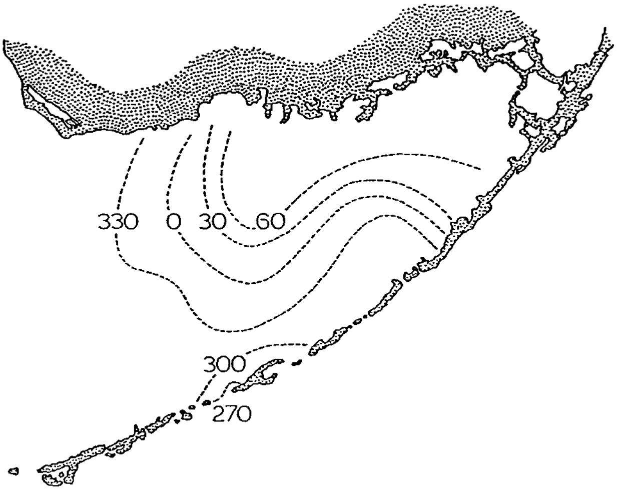

FIG. 9. Same as Figure 3, but for the O_1 constituent.

only 0.9 mb. The inverse barometer effect would translate this into a water level change of ±0.9 cm. Although this would be relatively large in the northeast corner of the bay, where all tidal constituent amplitudes are less than 1 cm, the perturbing effect of air pressure would be small throughout most of the study area. The amplitudes of the M_2, K_1 and O_1 constituents were 0.05, 0.02 and 0.03 mb, respectively.

Fourteen one-year time series from nine stations were used to quantify the amplitudes and local phase angles of the long-period tidal constituents. Harmonic constants were vector-averaged when a station had two or more one-year records. Amplitudes of the fortnightly and monthly tidal constituents are all within the range of 1–3 cm (Table 1). Msf and Mm amplitudes are slightly larger in the western part of the bay, but spatial gradients are weak. Lowest amplitudes in the northeast part of the bay are just under 2 cm. The Mf constituent is the smallest of the long-period constituents considered in this study. Amplitudes were less than 1.4 cm at all locations.

Figure 10 is a harmonic dial containing results of the 14 harmonic analyses that quantified the annual and semiannual constituents. Amplitudes of the Sa constituent are between 7 and 11 cm; phase angles are scattered between 140° and 210°. The vector average of the Sa harmonic constants assembled from Stations 14–24 has an amplitude of 8.6 cm and a phase angle of 163°, which produces a maximum water level in early September. The scatter for the Ssa constituent is similar to that for the Sa constituent, though amplitudes are smaller. The vector average of the Ssa constituent has an amplitude of 2.5 cm and a phase angle of 057°. The addition of the Ssa constituent to the Sa constituent raises the seasonal high water level to 9.8 cm above the annual mean, and it retards the occurrence of the year's highest water levels to the last week in September.

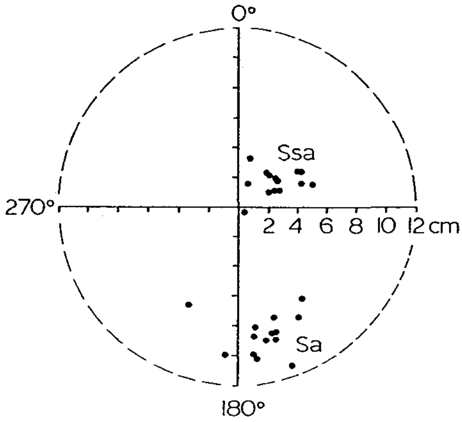

FIG. 10. Harmonic dial of Ssa and Sa constituent amplitudes and local phase angles from Florida Bay.

DISCUSSION—The picture that emerges from the integration of data from all stations within and bordering Florida Bay includes a rapid fringe-to-interior damping of semidiurnal and diurnal tidal constituents, and a large interior region dominated by long-period tidal constituents. Semidiurnal and diurnal tides are virtually absent in the northeast corner of the bay. Fortnightly and monthly tidal constituents contribute little to the total water level fluctuation at any location. Thus, the rise and fall in water level throughout much of the interior of the bay is restricted to nontidal fluctuations in response to meteorological forcing (outside the scope of this study), and the seasonal cycle, consisting of the combined effects of annual and semiannual constituents.

Given the data base available with the addition of stations 1–25 to the earlier NOS data, the harmonic constants of the principal semidiurnal and diurnal tidal constituents describe a spatially variable, but otherwise logical pattern. As a result of the interaction of Gulf and Atlantic tides, and because of the irregular bottom topography, harmonic constants do not vary uniformly across the bay. But the suggestion from earlier investigations that Florida Bay tides are extremely complex seems to be a reflection of the limited data base available at that time. In terms of spatial variability in the harmonic constants, Florida Bay is similar to other bodies of water that lie between seas with significantly different tidal conditions. Rocha and Clarke (1987) presented conceptually similar results from the Windward Islands, where Caribbean and Atlantic tides interact, and from the Strait of Gibraltar, where Atlantic and Mediterranean tides interact. Medeiros and Kjerfve (1988) found strong spatial gradients in the Strait of Magellan, where Atlantic tides interact with Pacific tides.

Nontidal forcing in two quite different forms influences the Sa and Ssa constituents in Florida Bay. Whitaker (1971) quantified the steric expansion and contraction of the water column over annual time scales using hydrographic data collected from throughout the Gulf of Mexico. Comparing Whitaker's results for the eastern Gulf of Mexico with the seasonal variation in water level for Florida Bay, as given by the sum of the Sa and Ssa constituents, it appears that steric effects explain approximately half of the midwinter seasonal low water, and about one-third of the autumn high water level.

Alternately, atmospheric pressure may have a significant effect on the seasonal sea level cycle of Florida Bay. Mean monthly surface pressures from Miami and Key West (NOAA, 1985) can be averaged to represent Florida Bay. If one assumes that the water surface rises and falls 1 cm for every 1 mb change in surface pressure (Smith, 1979), then the inverse barometer effect explains approximately 25% of the fall maximum and midwinter minimum water levels defined by the sum of the Sa and Ssa tidal constituents. One must invoke the inverse barometer effect with caution, however, because the deformation of sea level is in response to surface atmospheric pressure gradients, rather than the surface pressure at any given location. Without additional atmospheric pressure data from throughout the Gulf of Mexico, the importance of the inverse barometer effect cannot be quantified as a contribution to the seasonal cycle in Florida Bay. The available data, however, suggest that it may be a significant contributor.

The expanded data base used in this study is well suited for quantifying the longer period tidal constituents and for describing spatial variability in general terms. Additional data, however, will be useful for improving co-amplitude and co-phase charts in the southern part of the bay, especially near the major tidal channels. Spatial variability is greatest there as a result of interacting Gulf and Atlantic tidal waves. Nevertheless, incorporating the data collected over the past several years provides information needed to identify all the principal tidal constituents in Florida Bay, to define regions where these constituents are and are not important, and to reveal the spatial variability that results from the interaction of Gulf and Atlantic tidal waves.

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