Tides at Carrie Bow Cay, Belize

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ABSTRACT

The tide at Carrie Bow Cay, Belize, is microtidal (mean range of 15 cm) and is of the mixed semidiurnal type. Comparison with conditions at Key West, Florida, indicates that high and low waters off Carrie Bow occur earlier than at Key West by 45 and 2 minutes, respectively. Because of differences in tidal type and meteorological conditions, corrections for height and time difference applied to the predicted tide at Key West yield only approximate tide predictions for Carrie Bow Cay.

Introduction

Because the tide in the Caribbean Sea is microtidal, it might be expected to have little influence on the water flow regime. Velocity measurements indicate, on the contrary, that tidal forcing is a major cause of currents in coastal regions of the Caribbean (Roberts et al., 1975). Study of a shallow reef flat and back reef shows that even small tidal fluctuations have strong influence on the distribution and succession of organisms (Glynn, 1973; Rützler, in prep.). This note describes, characterizes, and predicts the tide at Carrie Bow Cay (16°48′N, 88°05′W), Belize, as a necessary first step in the investigation of flow and water exchange characteristics as well as intertidal and shallow subtidal communities at this barrier reef location.

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Measurements, Analyses, and Results

A Benthos 2820 submergible in situ tide recorder, which senses the hydrostatic pressure, was installed below the pier on the west side of Carrie Bow Cay in the barrier reef lagoon. This location is 120 m west of the reef crest, 24 km southeast of Dangriga (Stann Creek). Two major navigation cuts through the barrier reef, less than 1 km away, connect the barrier reef lagoon to the Caribbean Sea. The gauge intake was, on the average, 33 cm off the bottom, 59 cm below water, 153 cm below the top of the cement dock (the local reference datum) and has been operated intermittently since early 1976.

Several 29-day tide records were digitized to hourly intervals and subjected to harmonic anal-

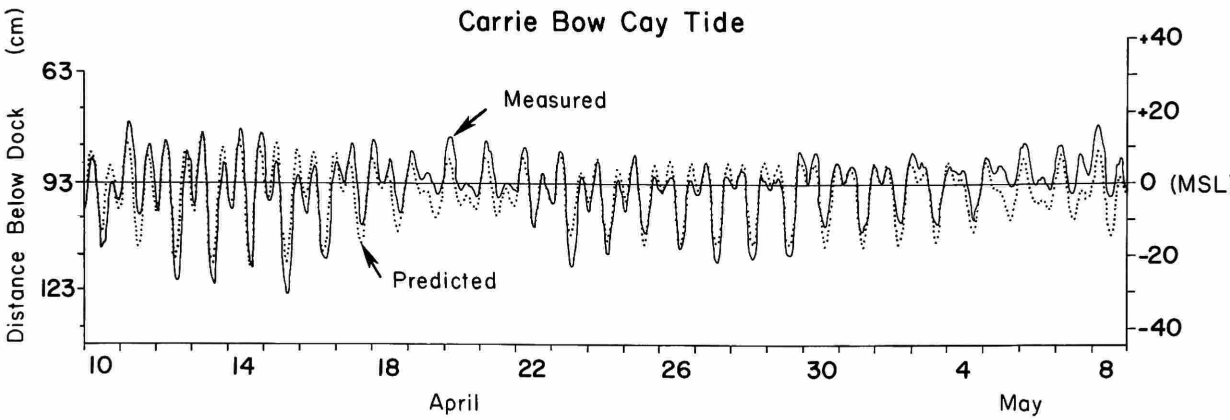

FIGURE 32.—Comparison of measured and computer-predicted tides at Carrie Bow Cay, Belize, 10 April–8 May 1976.

ysis (Schureman, 1940; Dennis and Long, 1971) for the purpose of computing amplitudes and epochs for the 24 major tidal constituents, which correspond to more than 99% of the actual amplitude. The nine constituents with the greatest amplitudes for a typical 29-day series are compared in Table 3 with the same constituents at Key West, Florida. The 24 amplitude and epoch values for Carrie Bow Cay were entered into the National Ocean Survey tide prediction computer program (Pore and Cummings, 1967), which allows monthly prediction of both hourly tidal height values and times and heights of high and low water. Results indicated reasonable agreement between measured and predicted tides for a 29-day test series (Figure 32). The prediction of time of high and low water is in general more successful than reproduction of water elevation.

The 29-day test record, 10 April–8 May 1976, was also tabulated and subjected to high-and-low water analysis on the basis of instructions for Form 2211 (National Ocean Survey, 1974:44-59).

TABLE 3.—Comparison of values for the nine major tidal constituents at Carrie Bow Cay, Belize, and Key West, Florida (symbol in parentheses follows each constituent; columns 1 and 2 computed for Carrie Bow Cay using Program "Harmonic" (Dennis and Long, 1971); columns 3 and 4 supplied by D. Simpson, Predictions Branch, National Ocean Survery; columns 5 and 6 from Defant, 1960: 267)

Tidal constituents		*Carrie Bow Cay*		*Key West*		*Period (mean solar hour)*	*Theoretical coefficient ratio (M_2 = 100)*
		Amplitude (cm)	*Epoch (°)*	*Amplitude (cm)*	*Epoch (°)*		
SEMIDIURNAL COMPONENTS							
Principal lunar	(M_2)	5.7	251	17.8	285	12.42	100.0
Principal solar	(S_2)	3.5	228	5.4	302	12.00	46.6
Larger lunar elliptic	(N_2)	2.5	243	3.5	269	12.66	19.2
Luni-solar	(K_2)	1.0	228	1.5	302	11.97	12.7
Larger lunar evectional	(ν_2)	0.5	244	0.7	271	12.63	3.6
DIURNAL COMPONENTS							
Luni-solar	(K_1)	7.9	185	8.9	282	23.93	58.4
Principal solar	(P_1)	2.6	185	2.9	287	24.07	19.4
Principal lunar	(O_1)	2.5	244	9.2	284	25.82	41.5
Larger lunar elliptic	(Q_1)	0.5	273	2.2	275	26.87	7.9

The pertinent results of this analysis are summarized in Table 4.

Discussion

The tide at Carrie Bow Cay is microtidal and of the mixed semidiurnal type. Its mean range is 15 cm and its semidiurnal and diurnal amplitudes are of approximately equal importance (Table 3). The form number F, an amplitude ratio between harmonic constituents, may be used to quantify the tide type (Defant, 1960:306–308). It is defined by $F = (K_1 + O_1)/(M_2 + S_2)$, where K_1 is the diurnal luni-solar, O_1 the diurnal principal lunar, M_2 the semidiurnal principal lunar, and S_2 the semidiurnal principal solar component (Table 3). If $F < 0.25$ the tide is semidiurnal; if $0.25 < F < 1.50$ the tide is mixed semidiurnal; if $1.50 \leq F < 3.0$ the tide is mixed diurnal; and $F \geq 3.0$ the tide is diurnal. The Carrie Bow Cay form number is 1.13 in comparison with 0.75 at Key West, Florida. Although both locations have the same tide type, the diurnal influence is greater at Carrie Bow Cay.

From the amplitude of the various harmonics (Table 3) it is possible to compute additional statistics (Marmer, 1954). With respect to the semidiurnal tidal constituents, the spring tide range is $2(M_2 + S_2)$ or 18.4 cm and the neap range approximately seven days later of $2(M_2 - S_2)$ or 4.4 cm. The mean semidiurnal tide is 2.2 M_2 or 12.5 cm. With respect to the diurnal constituents, the tropic tide range measures $2(K_1 + O_1)$ or 20.8 cm, the equatorial range is $2(K_1 - O_1)$ or 5.4 cm, and the mean diurnal tide is $1.5(K_1 - O_1)$ or 15.6 cm. The values above are only approximate as the P_1 and N_2 constituents show values significantly larger than could have been expected from the theoretical coefficient ratio based on the magnitude of the constituents' tide-producing forces (Table 3) at this location. Of course, such discrepancies between the magnitude of the tide-producing force and actual response of the water mass is quite common and is due to basin resonance characteristics.

The diurnal and semidiurnal partial tides are approximately equal; however, the spring-neap-spring cycle of the semidiurnal tide is 29.5 mean solar days (synodic month) and is related to the phase of the moon. The tropic-equatorial-tropic cycle of the diurnal tide is somewhat shorter, 27.3 mean solar days (sidereal month), and is related to the declination of the moon from the equator. Because of this time difference, several longer cycles are introduced. If the occasional times of high water in M_2, S_2, N_2, K_1, P_1, and O_1 occur simultaneously, the total tide range could be as great as 50 cm. Of course, wind tides are likely to cause extreme sea level changes more so than the astronomical forces.

The epoch or phase relative to the Greenwich meridian yields the following information about the inequality of the timing of highs and lows in the component tides (Marmer, 1949). If epochs are expressed in degrees, the difference $D = |M_2^0 - (K_1^0 + O_1^0)|$ indicates whether tidal inequality is entirely in the high waters ($D \approx 0°$), is equally great in the high and low waters ($D \approx 90°$), or is entirely in the low waters ($D \approx 180°$). If D is greater than 180°, its value is subtracted from 360°. For Carrie Bow Cay, the D value of 120° indicates inequality in both high and low waters, which is especially pronounced in the low water elevations (refer to Figure 32). This so-called diurnal inequality on the average measures 5.6 cm between low waters and 2.4 cm between high waters (Table 4).

The epoch also yields information about the phase age and the diurnal age. The phase age

TABLE 4.—Tide statistics for Carrie Bow Cay, corrected for the longitude of the moon's node and changes in the declination of the sun, based on computations using National Ocean Survey Form 2211 for 10 April–8 May 1976 (refer to Figure 32)

Tide datum (mean low water)[1]	0 cm
Mean range (Mn)	15.0 cm
Mean tide level (MTL)[2]	7.5 cm
Diurnal high water inequality (DHQ)	2.4 cm
Diurnal low water inequality (DLQ)	5.6 cm
Greenwich lunitidal high water interval	2.14 h
Greenwich lunitidal low water interval	8.44 h

[1] 101 cm below local reference datum.

[2] Marked "0" on Figure 32, right hand scale.

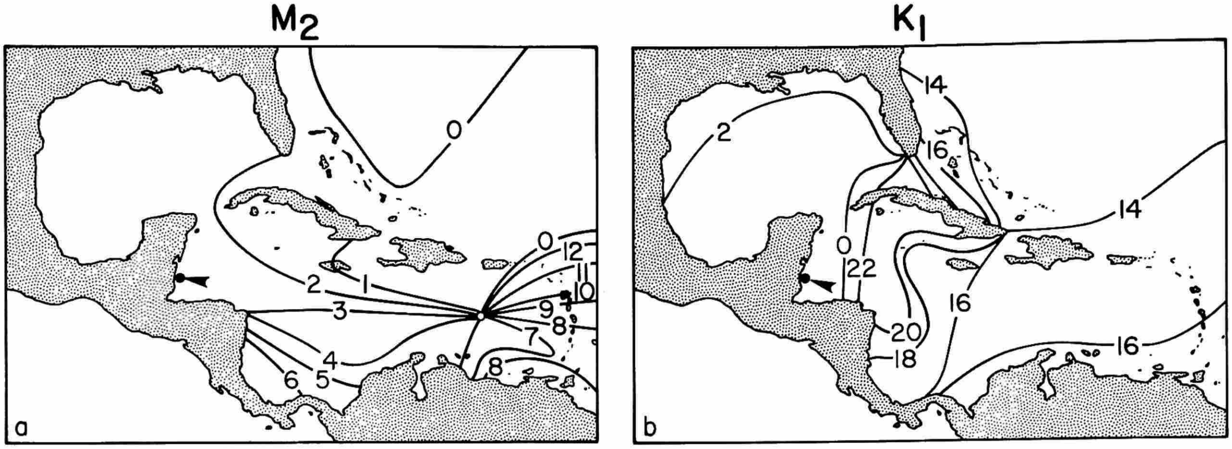

FIGURE 33.—Co-tidal lines of the predominant tides for the Caribbean Sea (after Defant, 1960); tide regression indicated by relative arrival time of high or low water, expressed in lunar hours: *a*, semidiurnal tide, M_2 constituent, progresses along the Belizean coast from north to south; *b*, diurnal tide, K_1 constituent, progresses along the Belizean coast from south to north. (Carrie Bow Cay indicated by arrow).

refers to the semidiurnal tide and is the lag of the spring tide relative to full or new moon. The phase age is computed as $0.98(S_2^0 - M_2^0)$ and equals -22 hours for Carrie Bow Cay, which indicates that spring tide leads the new and full moon by 22 hours. The diurnal age, on the other hand, is a measure of the timing of tropic tide relative to maximum declination of the moon. It is computed as $0.91(K_1^0 - O_1^0)$ and is 0 hours for Carrie Bow Cay, indicating a maximum diurnal tide range at the time of maximum lunar declination.

Figure 33, which shows the main Caribbean semidiurnal (M_2) and diurnal (K_1) amphidromic systems (Defant, 1960) indicates that the M_2 tide progresses from north to south along the Belizean barrier reef, whereas the K_1 tide progresses in the opposite direction, from south to north, along the reef crest.

Because it is inconvenient, though possible, to publish tidal predictions for Carrie Bow Cay, we instead computed correction factors and applied them to predicted tides for Key West, Florida, a National Ocean Survey reference gauge for which daily predictions are published. The Greenwich lunitidal intervals at Key West are 2.89 hours for high water (HW) and 8.48 hours for low water (LW) (D. Simpson, pers. comm.). Comparison of these figures with the lunitidal intervals for Carrie Bow (Table 4) indicates that on the average HW at Carrie Bow Cay leads HW at Key West by 45 minutes, and LW at Carrie Bow Cay leads LW at Key West by 2 minutes. Using the predicted tides for Key West for April and May 1976, we also found that HW at Carrie Bow Cay is 23 cm below HW at Key West and that LW at Carrie Bow Cay is 4 cm above LW at Key West on the average. However, because Carrie Bow Cay and Key West can be expected to experience different meteorological and oceanographic conditions at given times, the resulting tide predictions for Carrie Bow Cay now and then will deviate significantly from actual tide variations.

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