Current Meter Observations on the Continental Slope at Two Sites in the Eastern Gulf of Mexico

ROBERT L. MOLINARI AND DENNIS A. MAYER

Atlantic Oceanographic and Meteorological Laboratories, NOAA, Miami, FL 33149

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ABSTRACT

Current-meter observations obtained at two sites on the continental slope of the eastern Gulf of Mexico, at nominal positions of 29°N, 88°W (the Mobile site) and 27.5°N, 85.5°W (the Tampa site) are presented. Data were collected at three levels at Mobile (90, 190 and 980 m) from July 1977 through August 1978 and at four levels at Tampa (150, 250, 550 and 950 m) from June 1978 through June 1979. At 90 and 190 m, the flow at Mobile was on the average to the east. Sustained periods of flow to the west were observed during the summer 1977 and spring 1978. During the periods of eastward flow, the wind was generally out of the north and during the periods of westward flow, the wind was out of the east. The flow at the top meter at Tampa was on the average to the west, in the same direction as the average wind. At both sites, the motions are perturbed by events associated with the Loop Current. These events make it difficult to define any seasonal variability in the upper layers. The flow at the bottom meters is strongly aligned with the bottom topography and lacks a strong seasonal signal. Little barotropic tidal energy was observed at either site. At both sites, maximum diurnal energy occurred near the local inertial frequency at the upper levels. These motions are probably induced by either cold-front passages or other atmospheric events. At the bottom meters, maximum diurnal-band energy occurred near the K_1-tidal constituent. These motions are strongly time-dependent and they may be related to internal tides.

1. Introduction

Few direct current observations are available in the Gulf of Mexico, other than on the west Florida continental shelf (Niiler, 1976; Price, 1976). Therefore, to satisfy a Department of Energy need for such observations at two sites in the eastern Gulf, current-meter arrays were deployed at a nominal position of 29°N, 88°W, hereinafter referred to as the Mobile site, and a nominal position of 27.5°N, 85.5°W, hereinafter referred to as the Tampa site (Fig. 1). Both sites are located in ~1000 m of water on very steep continental slopes. The Mobile site, near the head of the DeSoto Canyon, is located in an area where bottom slopes average 50 m km^{-1}. The Tampa site, on the Florida Escarpment, is located in an area where bottom slopes range from 40 to 240 m km^{-1}.

Table 1 lists exact mooring positions and data availability. In addition to the current meter observations, bi-monthly and ship-of-opportunity site visits were made to collect other environmental data. Results from preliminary analyses of these data are given in unpublished manuscripts by Molinari *et al.* (1979a) for Mobile and by Molinari and Mayer (1980) for Tampa. Here, we quantify further the variability observed in the current-meter records at both sites. Because the moorings were not deployed to test specific theories relative to continental slope motions and because there is little overlap between records taken at the two sites (Table 1), relationships between possible forcing mechanisms and the observed variability cannot be quantified. However, some qualitative analyses relating forcing and variability are attempted; e.g., tide generating forces, the Loop Current and wind stress are considered in analysis of the motions at both sites.

Few direct observations of the deep-basin tidal components of the Gulf of Mexico exist. Mofjeld and Wimbush (1977) report on the results of an analysis of a three-month-long, bottom-pressure record from the center of the Gulf. They find elevations associated with the major diurnal tidal components to be an order of magnitude greater than the semi-diurnal components. Koblinsky (1979) and Leaman (1980) report on different aspects of tidal motions on the continental shelf to the south and east of the Tampa site.

The Loop Current is the major circulation feature in the eastern Gulf of Mexico. The Loop is an anticyclonic gyre, which extends from the Yucatan Straits, north into the Gulf, to the Straits of Florida. The northernmost position of the Loop translates in a systematic fashion, with northward intrusions, followed by an eddy separation and a repeat of the cycle. The timing of any particular phase of the Loop penetration cycle is quite variable [see Molinari (1980), for instance]. The few studies completed to date on the interaction of the Loop with slope and shelf waters

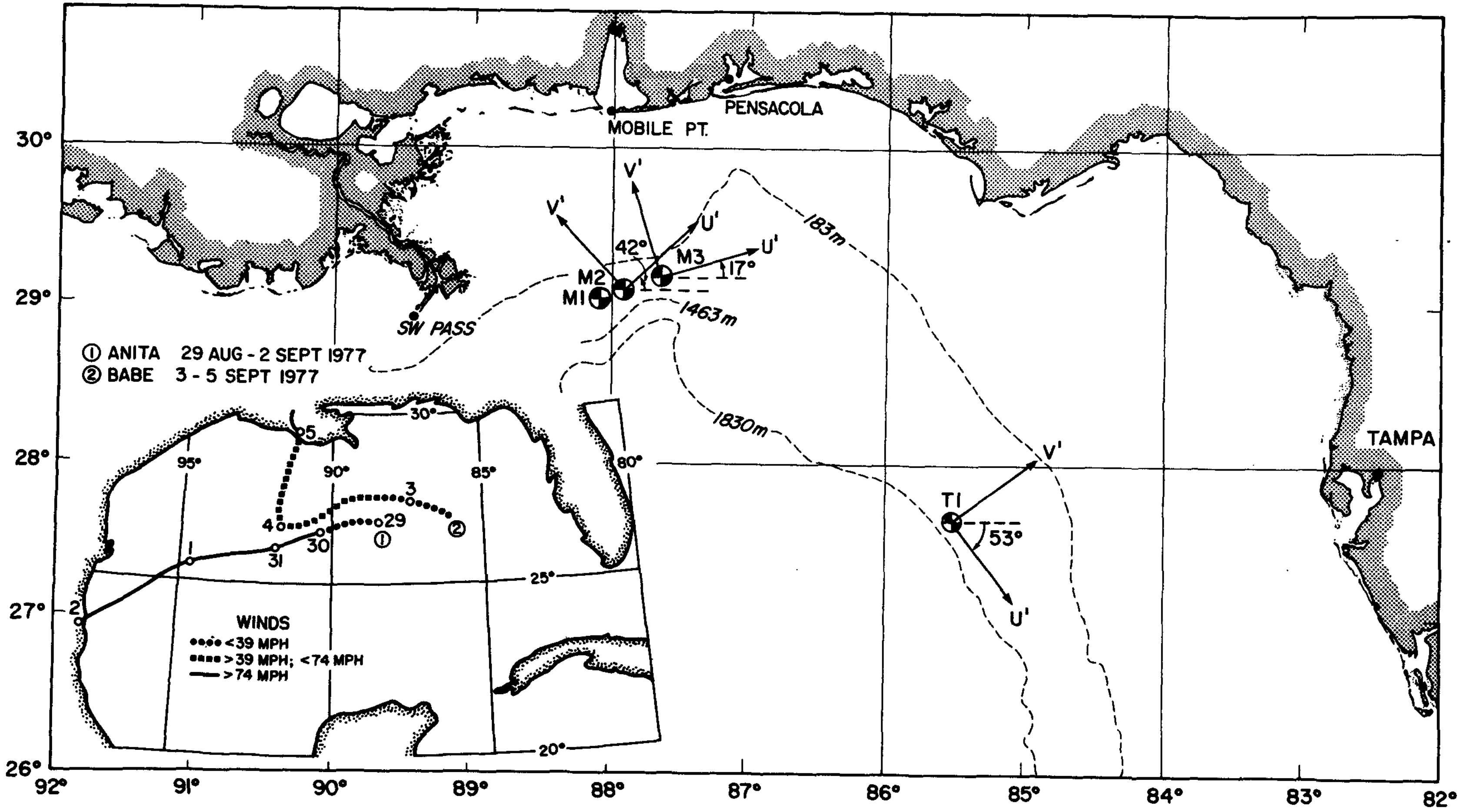

FIG. 1. Locations of current-meter moorings and ship operations. Principal-axis-oriented coordinate systems computed for the bottom meters at each site indicate the dominant flow direction. Tracklines of Hurricane Anita and tropical storm Babe are given in the inset.

TABLE 1. Data availability.

	Position		Water depth	Meter depth	Start time	End time	
Mooring	(°N)	(°W)	(m)	(m)	Julian Day/Year		Days
M1	29°02.3′	88°06.8′	1047	130	199/1977	328/1977	129
				215	199/1977	320/1977	121
M2	29°06.5′	87°55.1′	1050	90	200/1977	291/1977	91
				190	200/1977	291/1977	91
				985	200/1977	291/1977	91
M3	*29°11.4′	87°38.2′	1047	90	292/1977	168/1978	241
				190	292/1977	124/1978	197
				985	292/1977	166/1978	239
	*29°11.9′	87°38.3′	1033	70	169/1978	236/1978	67
				168	169/1978	236/1978	67
				970	169/1978	236/1978	67
T1	27°39.9′	85°31.3′	1050	150	164/1978	43/1979	244
					300/1978	349/1978	49
				250	45/1979	119/1979	74
				550	164/1978	298/1978	134
					45/1979	177/1979	132
				950	164/1978	157/1979	358

* Records at top and bottom meters joined.

suggest that interactions between these regions may be significant in the eastern Gulf (e.g., Niiler, 1976; Huh *et al.* 1981).

In the absence of extreme events, the winds of the eastern Gulf of Mexico are affected by the position of the atmospheric North Atlantic anticyclone (Jordan, 1973). The winds are generally northwestward in the summer. During the winter, a secondary high cell forms on the western side of the North Atlantic anticyclone, producing a stronger southward component. The eastern Gulf is affected by continental weather systems, in the form of fronts and cold-air outbreaks, during the winter, and by tropical weather systems, in the form of tropical storms and hurricanes, during the summer.

In the following discussions, we first give a description of sampling procedure and data-analysis techniques (Section 2). Current-meter results are described in Section 3. The relation of the mean currents and time-dependent motions to large-scale oceanic and atmospheric conditions are discussed qualitatively in Section 4. Finally, a summary of results is offered in Section 5.

2. Sampling procedures and data analysis techniques

The entire Mobile data set is listed by Thomas *et al.* (1979) and Molinari *et al.* (1979b). For Tampa, the June 1978 through October 1978 current meter data and March 1978 through December 1978 STD and XBT data are also listed in Molinari *et al.* (1979b). Both reports describe data-collection and calibration techniques, so only a brief review is given here.

The spatial and temporal availability of current-meter data is summarized in Table 1. At both sites, Aanderaa current meters were attached to taut-wire subsurface moorings. Observations of temperature, pressure, current speed and current direction were obtained every 20 min at Mobile and every 30 min at Tampa. The raw current-meter records were edited to remove spurious values. These edited data were then smoothed by applying a 3 h low-pass filter to the series. The characteristics of this filter and other filters used in the analyses are summarized in Table 2. The records resulting from the application of the 3 h low-pass filter were resampled hourly to construct the time series on which all other operations were performed.

A principal-axis-oriented coordinate system is frequently used since, as will be described, the motions are strongly influenced by bottom topography. The rotated system was determined by defining a coordinate system for each record which minimized the covariance between velocity components. This operation is equivalent to finding the principal axes of

TABLE 2. Filter characteristics.

Lanczos filter	Energy rejection and frequency response
3 h low-pass	6 db at 2.5 h 20 db at 2.0 h
40 h low-pass	6 db at 36.9 h 20 db at 30.0 h
60 h low-pass	6 db at 58.0 h 20 db at 48.0 h
40 h high-pass	6 db at 36.9 h 20 db at 48.7 h

a scattergram whose points are the east-north velocity components on the hodograph plane. The principal axes at the bottom meters are shown in Fig. 1. Rotary spectra computations as described by Gonella (1972), for instance, were also performed on the data.

STD data were collected during the July 1977 cruise using a Plessey Environmental Systems Model 9040 unit. A Plessey Model 9060 was used on all other cruises. On the average, the salinities resulting from the calibration of the raw data from the Model 9040 are accurate to within ±0.02‰ and the temperatures to ±0.01°C. The salinities resulting from the calibration of the raw data from the Model 9060 are accurate to within ±0.1‰ and temperatures to ±0.05°C.

Time series of daily surface air and dew-point temperatures and wind speed and direction were generated for each site. The time series were determined from daily 1200 GMT weather maps by Mr. Jose Fernandez-Partagas. A description of the technique is given by Mooers *et al.* (1975). A qualitative comparison of ship and interpolated winds indicates that interpolated wind speeds are within 1–2 m s^{-1} of observed speeds, during average wind-speed conditions. Wind-stress values were computed from the wind data using a quadratic stress law with variable drag coefficient. Cold-front passages were determined visually from the 1200 GMT weather maps. Therefore, the time of frontal passage is accurate to ±1 day.

Weekly maps of sea-surface-temperature (SST) fronts generated by the Miami Field Station of the National Environmental Satellite Service were used to determine the position of the Loop Current relative to the two sites. The technique for determining these fronts is described by Maul *et al.* (1978).

Maul and Gordon (1975) have shown that the speed maximum of the Loop Current is located on the average 15 km to the right, looking downstream, of the SST front. Since no significant SST fronts occur in the summer, this approach is only useful during other times of the year.

The baroclinic nature of the Loop is such that subsurface temperature distributions within the thermocline can also be used to define its position (Leipper, 1970). In particular, the location of the 20°C isotherm at 150 m is approximately coincident with the axis of the Loop. Thus, the closest position of this isotherm at 150 m to the two sites is also used both to define the position of the Loop during the summer and as a verification of the satellite results.

3. Current-meter results

a. *Vertical and horizontal coherence*

Progressive vector diagrams (PVD's) derived from the current-meter records are given in Fig. 2. At Mobile, the visual coherence between the top and middle records is high. A 60 h, low-pass filter (Table 2) was applied to the 3 h, low-passed series and vertical coherences were computed from these new series. Vertical coherence between the 90 and 190 m records from 180 days of observations at M3 is significant (>95%) only for periods > 6 days.

Since visual coherence between the top and bottom records is poor over the length of the data set, records are broken into shorter subsets to ascertain if coherence exists on shorter time scales. Coherence is poor except for the time period from May through August 1978. For this period, coherence squared for the along-isobath component exceeds the 95% level at a period of 6 days. The phase between the two motions is 180°.

The 250 m record at Tampa is too short for computation of cross-spectral analysis with other records (Table 1). The visual coherence between the top two records is good at low frequencies for the 49 days available for comparison (not shown). Comparing the top two records with the record at 550 m suggests some visual coherence for periods > 15 days. Motions in the upper and lower portions of the water column do not appear to be correlated (Fig. 2), so vertical coherence was not computed.

Horizontal coherences can be computed for two short periods during which records are available at different geographical positions. Initially, two moorings were deployed at Mobile, but only one was redeployed after the first servicing of the arrays. There is also some temporal overlap between Mobile and Tampa records.

Rotary spectral computations were performed on the 71 days of record overlap at meters M1 and M2 (Table 1), which are separated by 24.5 km (Fig. 1). The results show no significant coherence between the two Mobile sites at any frequency that can be resolved by these limited record lengths. However, visual inspection of the records suggests some coherence may exist near the end of the overlap period. Forty-hour, low-passed vector time series for the July–August overlap period are shown in Fig. 3. Days of peak speed are observed at the top current meters beginning at 27 August [Julian day (J.D.) 239] to occur on the average every 6–7 days. The peaks at the northeastern site (M2) lead the peaks at the southwestern site (M1) by 2–3 days.

The records at Mobile and Tampa also overlap for 71 days during the summer 1978. Rotary-spectra computations reveal no significant correlations between the motions at the two sites. However, some visual coherence was observed between the top two meters (not shown), but the structure and cause of this coherence can not be determined from this short data set.

b. *Energy levels*

Motions with periods greater than 1–2 weeks cannot be resolved statistically because of the short length of the current-meter records. The motions at these frequencies can be described qualitatively. The energy at higher frequencies can be resolved statistically.

Results of rotary spectral analysis of longer records are given in Fig. 4. For purposes of this discussion low-frequency motions are those with periods > 3 days and diurnal-band motions those with periods between 22 and 27 h. At both sites, the diurnal band includes inertial as well as tidal motions.

At Mobile, approximately 80% of the total energy is contained, throughout the water column, in the low frequencies. At both sites, spectra for current components oriented along principal axes (not shown) indicate that most of the low-frequency energy is in the along-isobath flow. This is apparent in the progressive vector diagrams as the average current vectors are aligned with the bottom topography (Fig. 2). The along-isobath (almost rectilinear flow) low-frequency structure is manifest in the unpolarized rotary spectra (Fig. 4), i.e., almost as much clockwise as anticlockwise energy. Polarized spectra, on the other hand, would show a large bias of energy that would

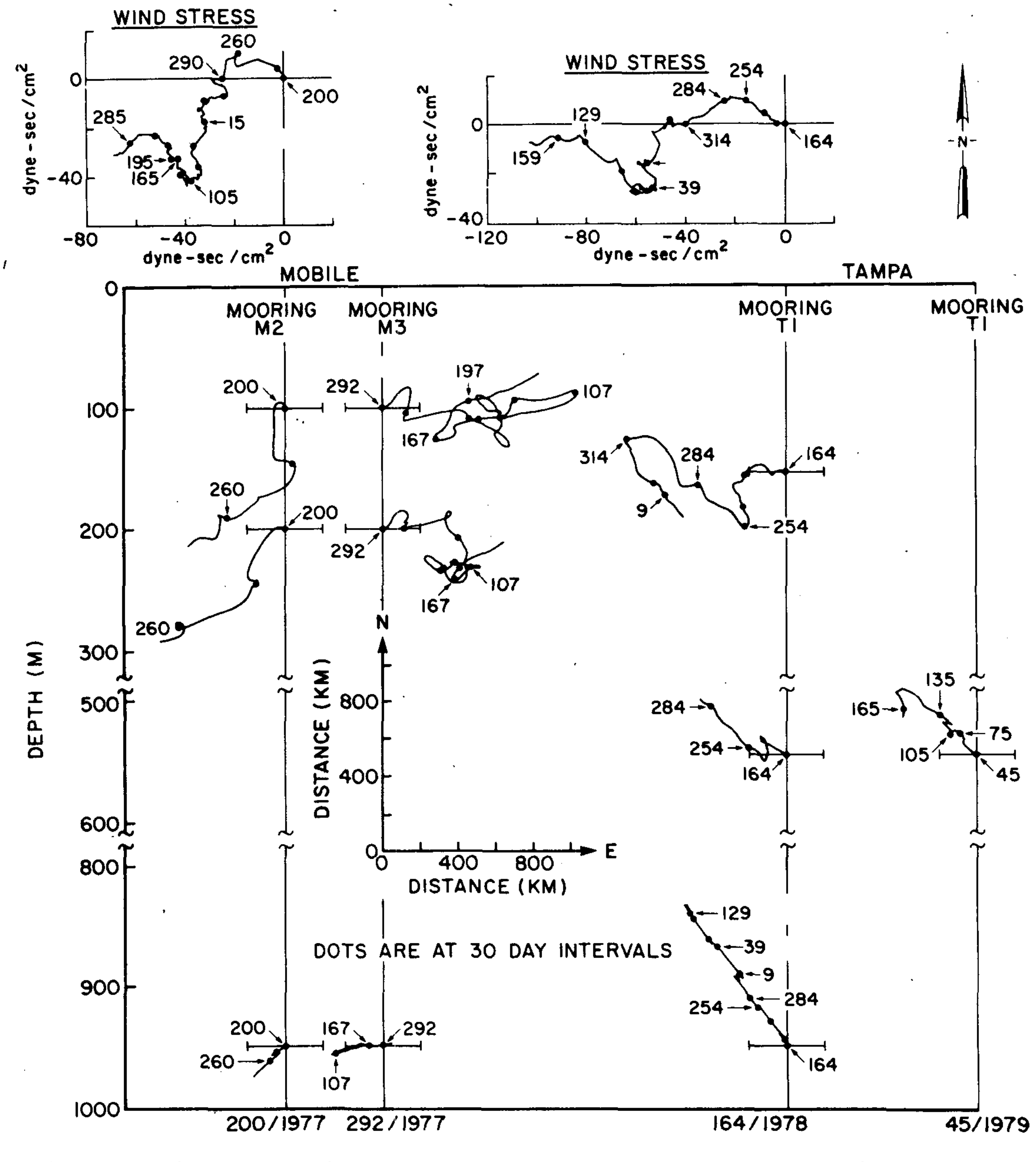

FIG. 2. Progressive current and wind-stress vector diagrams. The current-meter data have been filtered with a 60 h, low-pass filter (Table 2). Julian days are given; day 200 is equivalent to 19 July 1977, day 164, 13 June 1978 and day 45, 14 February 1979.

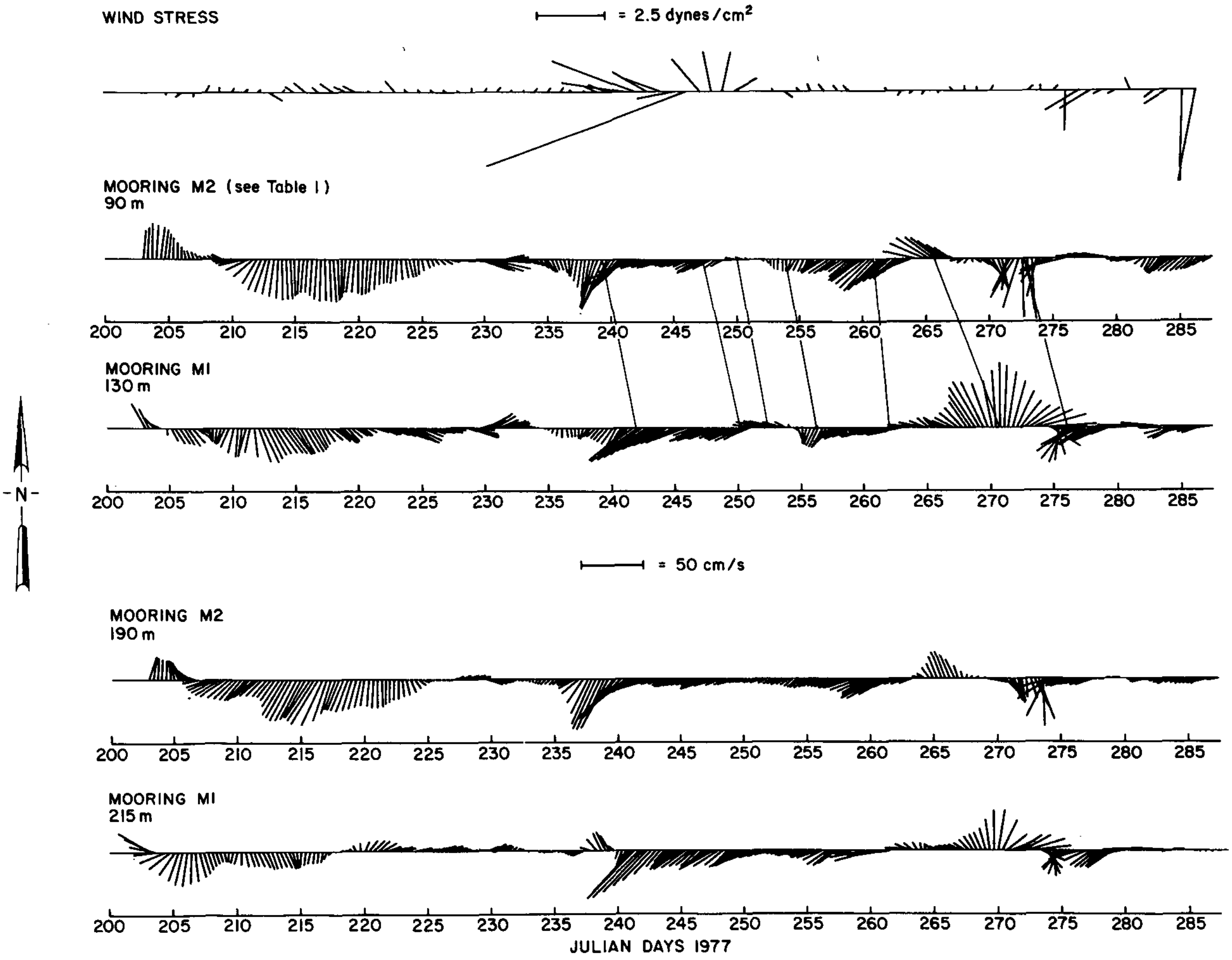

FIG. 3. Forty-hour, low-passed vector time series for periods of overlap between two Mobile current-meter records. Daily wind-stress vectors are also shown.

lie in either the clockwise or anticlockwise spectrum; e.g., almost circular or near-inertial motions in the Northern Hemisphere would contain almost all clockwise energy with very little anticlockwise energy.

There are no distinct peaks between the lowest-frequency bands and the diurnal frequency band (Fig. 4). The diurnal band is the most energetic in the high frequencies and represents, on the average, 3–6% of the total energy at Mobile. The energy in the diurnal band is an order of magnitude less at the bottom than in the upper part of the water column. The peak in diurnal energy is found at higher frequencies near the bottom (Fig. 4). In contrast to the low-frequency structure, the diurnal motions are highly polarized, i.e., almost all of the motion is clockwise and thus nearly circular.

At Tampa, the low-frequency variance (Fig. 4) contains 85% of the total energy at the top meter and 64% at the bottom. As at Mobile, most of the low-frequency energy is in the along-isobath flow. No maxima in energy distribution appear between the lowest-frequency band and the diurnal band. The diurnal energy band is somewhat more energetic at Tampa than at Mobile, particularly at the bottom, representing 10–20% of the total energy. The energy in the diurnal band is approximately uniform throughout the water column, although, as at Mobile, the peak in this band is found at higher frequencies near the bottom.

c. Seasonality

Spectra were computed for a number of 60-day subsets defined in Table 3 to study seasonal variability of energy distribution. The variances associated with each subset for the top and bottom records are given for both the low-frequency (periods > 3 days) and diurnal bands (22–27 h). At Mobile, there is higher energy in the near-surface low-frequency band during late summer and early fall 1977 and winter 1978. Smallest values of low-frequency energy are observed during summer 1978. The energy in the low-fre-

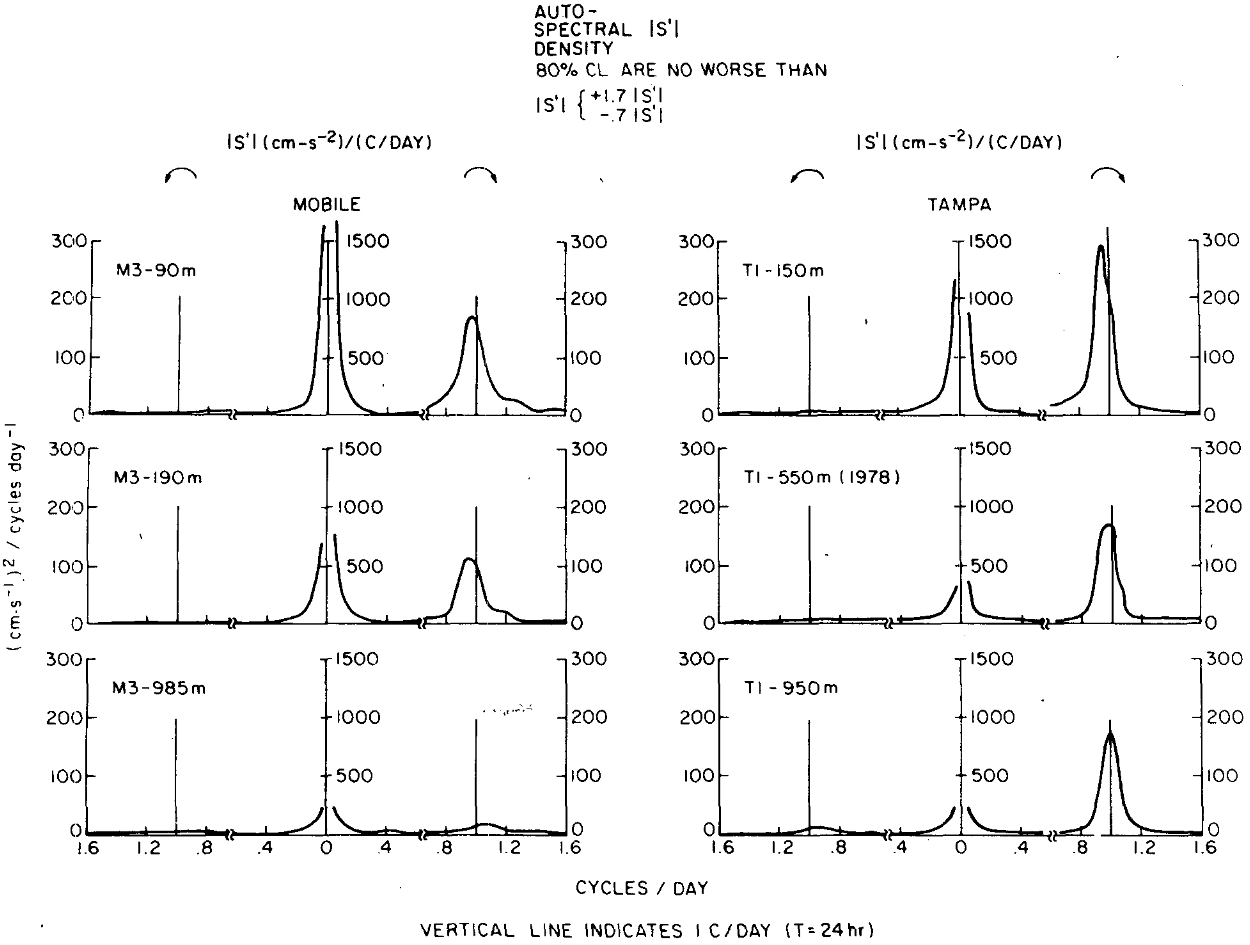

FIG. 4. Rotary auto-spectra, computed from longer records (Table 1).

quency band exhibits no clear annual signal at the bottom. Furthermore, no obvious seasonal signal is observed in the diurnal band at either the top or bottom meter.

At Tampa, there is a distinct maximum in low-frequency energy at the top meter during the fall (Table 3), while at the bottom meter no distinct maximum is observed. At the top meter highest diurnal-band energy occurs in the winter.

4. Observations of current-generating forces in relation to site-specific current measurements

The local wind stress, the Loop Current and the tide-generating forces are considered as possible current-generating forces. We now attempt to relate observations of these features to the current-meter observations.

a. Wind-stress forcing

Wind-stress PVD's are given in Fig. 2. Over most of the record the winds at Mobile have a northerly component. Largest easterly wind-stress components are observed during summer 1977 (J.D. 200–260) and spring–summer 1978 (J.D. 75–255). During most of these periods of easterly wind stress, the along-isobath component of flow is to the south and west (Fig. 2). However, after J.D. 167 (1978) the flow is to the north and east in opposition to the wind. The northeastward flow is probably related to the passage of an eddy detached from the Loop Current close to the site, as will be described shortly.

Historical data suggest that the flow during the summer is frequently to the west. In particular, returns from drift bottles released in the Mobile area during the early and mid-1960's (Drennan, 1963, 1968; Gaul, 1967) suggest eastward surface flow for all seasons except for westward surface flow in the summer. During several of these years, westward flow can be inferred as early as April.

Thus, on the average, it appears that the near-surface flow in the area is to the west during the summer. The increase in the southeasterly trade winds during this period probably provides the driving mechanism

TABLE 3. Energy (variances, cm^2 s^{-2}) of low-frequency band ($T > 3$ days) and diurnal band (22–27 h).

	Mobile					Tampa			
	90 m record		985 m record			150 m record		950 m record	
Center of 60-day subset	Low-frequency band	Diurnal band	Low-frequency band	Diurnal band	Center of 60-day subset	Low-frequency band	Diurnal band	Low-frequency band	Diurnal band
11 Sep 1977	256	16	49	1	13 Jul 1978	65	10	47	13
18 Nov 1977	153	17	45	1	11 Sep 1978	47	20	31	6
17 Jan 1978	280	18	60	3	10 Nov 1978	304	5	32	8
18 Mar 1978	117	5	58	3	9 Jan 1979	83	39	35	18
17 May 1978	157	15	38	1	10 Mar 1979			33	9
16 Jul 1978	66	15	19	1					

for the westward flow. The data are inadequate to determine if the flow is directly wind-driven or dependent on the wind-stress curl, for instance. The cause of the eastward flow during the other seasons is unclear.

At Mobile the current-vector time series given in Fig. 3 suggest the presence of waves with a period of about 6–7 days. The absence of a distinct peak in the energy spectra at these periods (Fig. 4) indicates that these features are intermittent. The vertical-coherence calculations suggest that motions at these time scales are coherent between 90 and 190 m. However, the motions do not appear to be coherent to the bottom. The variability shown in Fig. 3 occurs about the time increased wind stress related to the passage of both a tropical storm and depression to the south of the Mobile site (Fig. 1) is observed. However, a causal relation between the wind and current cannot be established.

At Tampa, mean-wind-stress and top-current-meter vectors are in the same direction and across the isobaths (Fig. 2) suggesting a directly wind-driven near-surface layer for long time scales. However, there are several intervals when the wind and current vectors are not correlated. As will be described shortly, the currents during these intervals are probably related to the Loop Current.

b. Loop Current forcing

Time series of Loop Current distances from both sites are given in Fig. 5. The Loop Current (or a detached eddy) was close to the Mobile site during the late summer, 1978. The northeastward flow observed at the top meters during this time (Fig. 2) is consistent with the flow associated with the northern boundary of the Loop. The 1978 Loop intrusion is apparently responsible for the reversal of the westward flow that had been established during the spring.

The Loop Current also appears to influence the current distribution at the Tampa site. For instance, from early September to early November 1978 [J.D. 254–314 (Fig. 2)] the flow in the upper layer has a large northwestward component while the wind has a small southward component. The current is also to the northwest at the bottom. Similarly, strong northwestward flow at the middle current meter is observed during February–March 1979 at a time of small average southward wind stress (Fig. 2). During the fall event, the energy in the low-frequency band at the top meter increases by almost an order of magnitude (Table 3). The February event is not resolved at the top meter.

Several pieces of evidence suggest that this northward flow is associated with Loop Current waters. A large tongue of warm water extends north from the area where the Loop Current runs onto the west Florida Shelf at 25°N (Fig. 6, derived from an infrared satellite image of the Gulf of Mexico as described previously). Furthermore, although the differences are close to the resolution of the Model 9060 STD units, salinity data collected in October 1978 (Fig. 7) reveal salinities in the upper layers characteristic of Loop Current water [i.e., a salinity maximum at 22°C approaching 36.5‰, characteristic of Subtropical Underwater (Nowlin and McLellan, 1967)]. The continuity of the tongue of warm saline water suggests that the northward flow is transporting Loop Current water to the site. Finally, Molinari and Mayer (1980) observe a surface patch of Loop Current Water at the site during the February period of northward flow.

Molinari (1980) describes a cyclonic gyre which is frequently observed to the north of the Loop Current. The topography of the 20°C isotherm obtained during February (Fig. 6) shows the Loop Current running onto the Shelf south of the Tampa site. Some suggestion of cyclonic flow to the north of the Loop Current is evident. Although the above evidence is far from conclusive, it does suggest that a gyre may exist when the Loop Current runs onto the shelf and the current bifurcates with the greater part of the Loop Current waters transported south but some transported north. These events were responsible for the most energetic flows observed at the Tampa site.

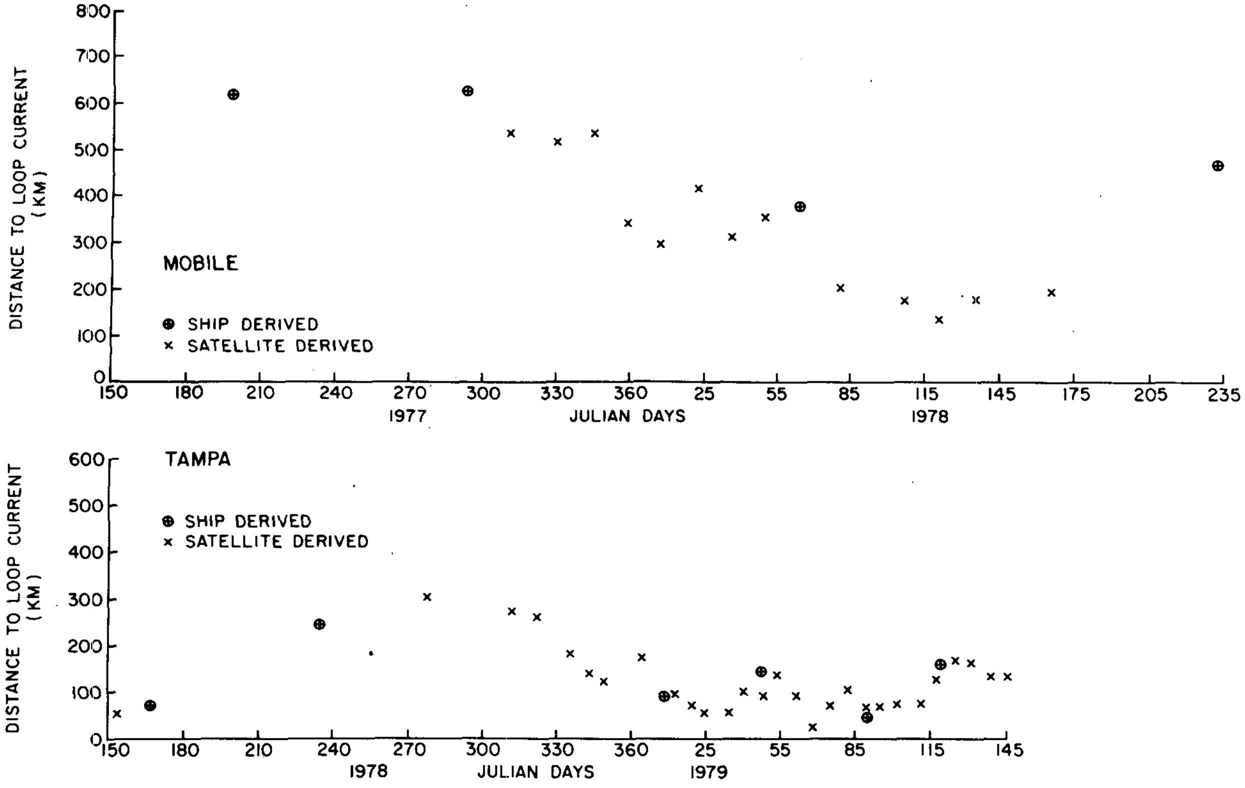

FIG. 5. Time series of Loop Current position relative to the sites given as closest distance to the axes of the Loop.

c. Forcing at tidal periods

Periods of the principal diurnal tidal constituents from nearby coastal stations and inertial periods at both sites are given in Table 4. At these latitudes the diurnal band includes tidal as well as inertial motions. The barotropic tide does not appear to contribute significantly to the energy level in the near-surface waters at either site. For instance, the energy within the diurnal band at Mobile is an order of magnitude less at the bottom than at the top current meter (Table 3). If all the bottom velocity variability is related to

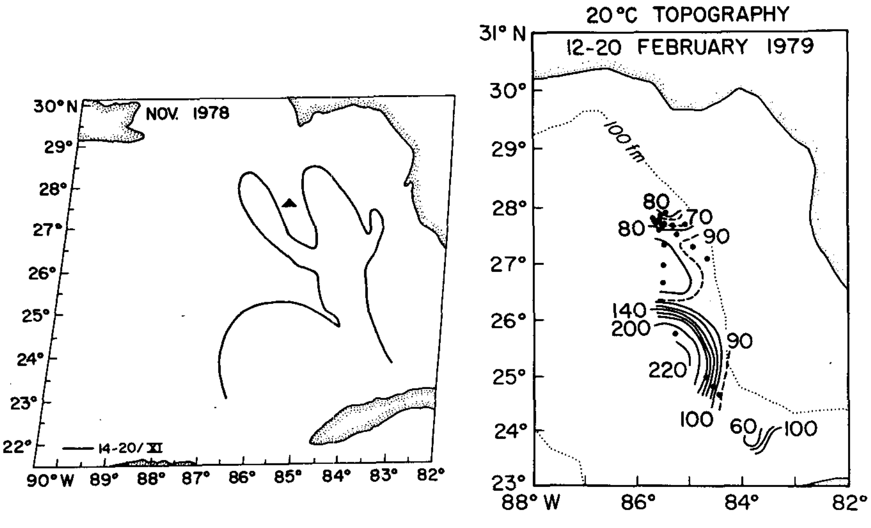

FIG. 6. Left panel: location of sea-surface-temperature front derived from satellite imagery of Gulf surface by the National Environmental Satellite Service (see text). Right panel: topography (m) of the 20°C isothermal surface.

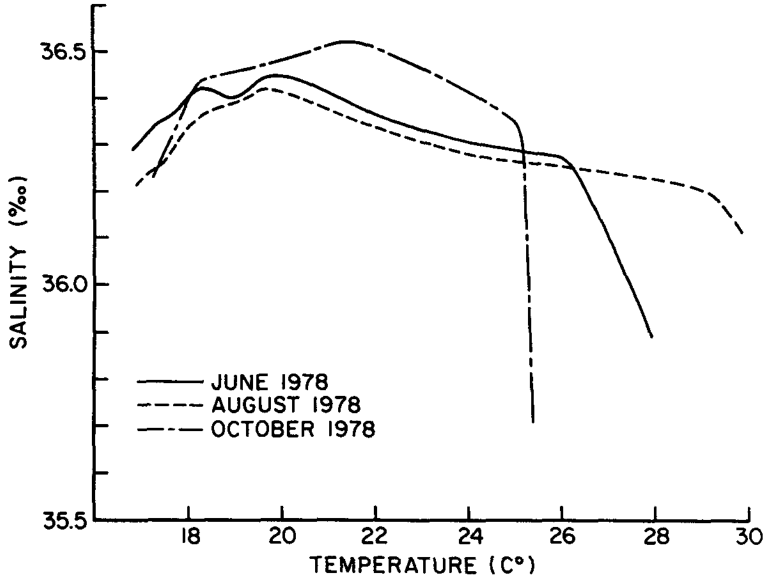

FIG. 7. *T-S* curves obtained during occupations of the Tampa site by research vessels.

barotropic tides, the tidal signal is only about 1 cm s^{-1}. At Tampa, although the diurnal energies at top and bottom are similar, the variability in bottom-meter diurnal energy suggests that barotropic tides do not contribute significantly to this variability (at most 2–2.5 cm s^{-1}).

At both sites, energy peaks within the diurnal band occur at longer periods at the upper levels than at the lower level (Fig. 4). At Mobile the top and the bottom energy peaks occur at 25.04 and 23.04 h, respectively; and similarly at Tampa, peaks occur at 25.04 and 24.00 h, respectively. Thus, near the surface at Mobile, the period of peak energy is closer to the inertial period than to the periods of either diurnal tidal constituent (Table 4), while near the bottom the peak occurs closest to the K_1 constituent. At Tampa, the O_1 and inertial periods are almost identical (Table 4) and the maximum diurnal energy near the surface occurs closest to these frequencies. As at Mobile, the peak in diurnal energy near the bottom occurs at frequencies closest to the K_1 constituent.

Plots of high-passed current-meter data for portions of the top and bottom current-meter records at both sites are given in Fig. 8. The diurnal energy appears as bursts of variable duration. As described above, near the surface at Mobile, the energy in this band is primarily inertial and most likely related to the passage of cold fronts or other wind events, as described for the Gulf of Mexico by Price (1976, 1981), for instance. There is no apparent seasonal signal in the intensity of the energy within this band at Mobile (Table 3). The absence of data closer to the surface and the poor resolution of the wind field precludes quantification of the relationship between wind forcing and current response at this site.

At Tampa, near the surface, the energy within this band is either inertial or tidal (O_1). There is considerably more diurnal energy during the winter (Table 3) when cold fronts are most numerous, suggesting that a portion of the energy is inertial. A much longer current-meter record is required to differentiate between the inertial and tidal frequencies.

The bottom current meter at Mobile does not have significant energy in the diurnal band (Table 3). At Tampa, much higher diurnal energies are observed. Although the maximum occurs near the K_1 tidal frequency, the magnitude of this energy varies throughout the year (Table 3). Analysis of 7-day chunks of data shows that the energy at this period varies considerably at both the top and bottom meters (Fig. 9). This is not consistent with directly forced barotropic tidal motion.

TABLE 4. Periods of the major diurnal tidal constituents at Mobile and Tampa coastal stations and inertial periods at 29°N (Mobile site) and 27.5°N (Tampa site). Also listed are the periods of peak diurnal energy at the top and bottom meters.

	Period (h)	
Tidal constituent	Mobile	Tampa
K_1	23.93	23.93
O_1	25.82	25.82
Inertial period	24.68	25.91
Diurnal energy peak (top)	25.04	25.04
Diurnal energy peak (bottom)	23.04	24.00

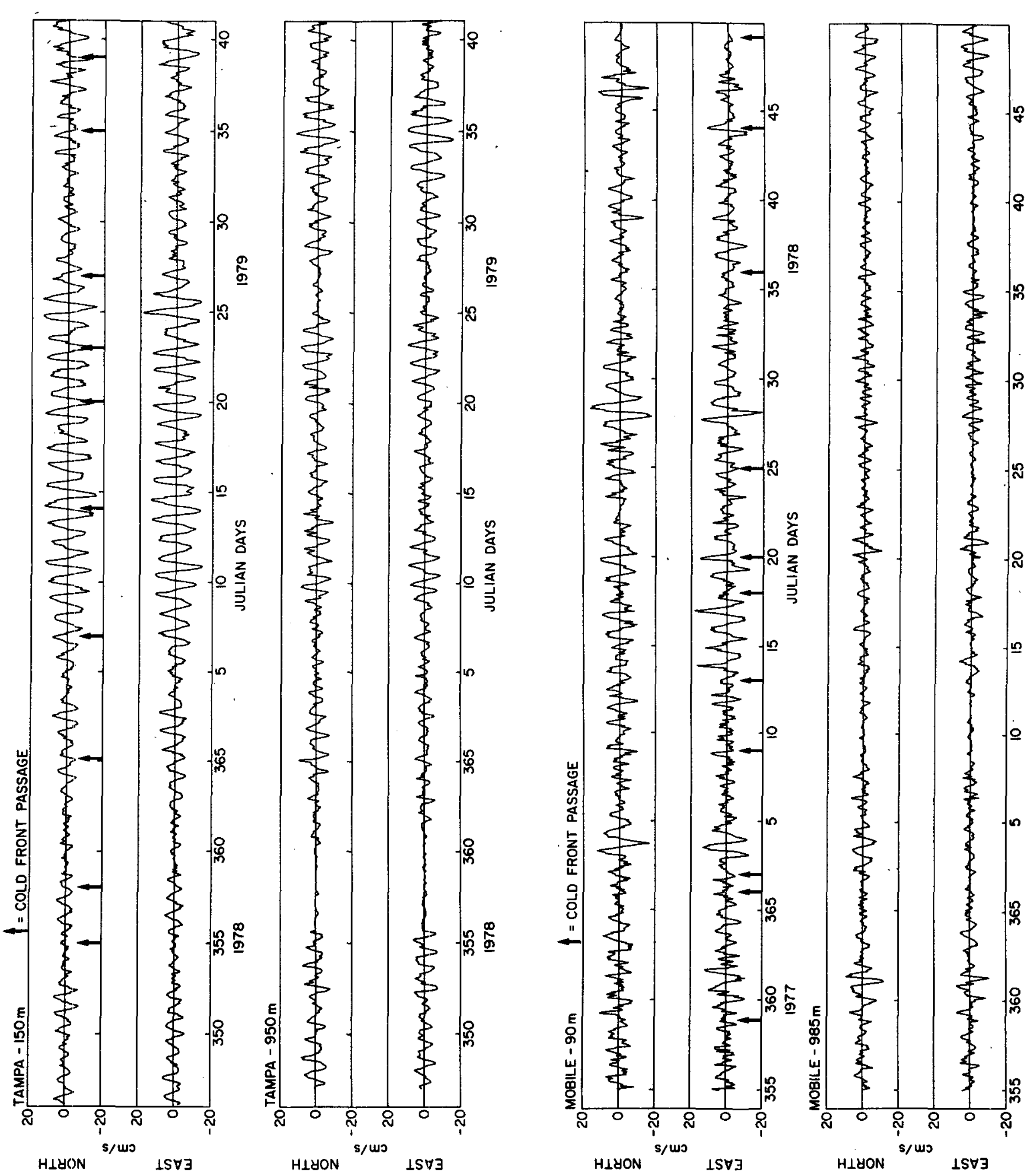

FIG. 8. Forty-hour, high-passed records from winter months. Cold-front passages are also indicated.

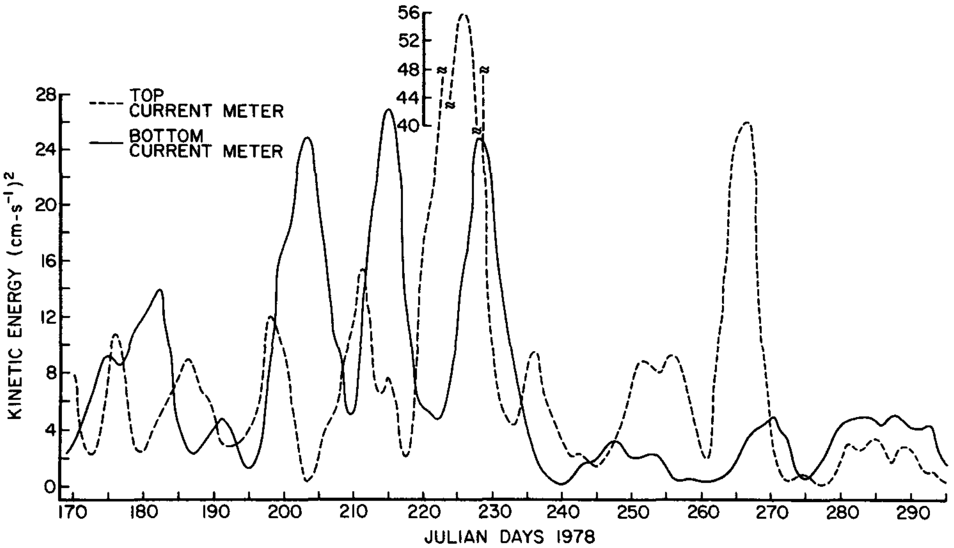

FIG. 9. Daily estimates of energy in the diurnal band from least-squares analysis of 7-day chunks of data, computed from 40 h, high-passed current-meter data at Tampa.

Leaman (1980) observes similar modulation at tidal periods on the west Florida shelf. He explains the variability in terms of generation of internal tides by interaction of barotropic tides with the density distribution and continental shelf. Under certain stratification distributions, slight changes in the vertical density structure can cause large changes in the propagation of internal tides, resulting in large changes in the amplitude of various tidal-current constituents. The mechanism also results in seaward propagation of tidal energy as described by Torgumson and Hickey (1979) off the Oregon shelf, for instance. The data are inadequate to ascertain either why the modulation is so dramatic at Tampa and not at Mobile or what the horizontal and vertical structures of these features are.

5. Summary

The following statements can be made relative to the mean currents at the Mobile site. In the upper 190 m, historical data and the current-meter results suggest that the mean flow at Mobile is eastward, except for mean westward flow observed during the summer. The summer flow is in the same direction as the mean wind-stress vector, suggesting a causal relation, but the flow at other times is opposite to the mean stress vector. The seasonal cycle of the mean flow can be perturbed by Loop Current events, which, during the summer of 1978, caused eastward surface flow.

At Tampa, although the mean flow is in the direction of the wind, the currents are strongly influenced by Loop Current events. In particular, apparent bifurcations of the Loop Current to the south of the site can cause long periods of energetic northward flow. Any seasonal signal in the upper-layer motions can easily be masked by these energetic events, possibly accounting for the lack of seasonal signal in the current-meter results of Koblinsky and Niiler (1979) which were obtained farther to the south and east.

In the diurnal frequency band, little energy is associated with barotropic tides. Inertial oscillations in the near-surface layers appear related to the passage of cold fronts or other wind events. Large modulations in the amplitude of the K_1 tidal current are probably related to internal tides (although the possibility of bursts of energetic near-inertial currents cannot be discounted) and are more dramatic at Tampa than at Mobile.

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