8-1996

Seasonal Modulation of the West Florida Continental Shelf Circulation

Robert H. Weisberg
University of South Florida, weisberg@marine.usf.edu

Bryan D. Black
University of South Florida

Huijun Yang
University of South Florida

GEOPHYSICAL RESEARCH LETTERS, VOL. 23, NO. 17, PAGES 2247-2250, AUGUST 15, 1996

Seasonal modulation of the west Florida continental shelf circulation

Robert H. Weisberg, Bryan D. Black, and Huijun Yang

Department of Marine Science, University of South Florida, St. Petersburg, Florida

Abstract. Velocity data from 28°N, 84°W on the west Florida continental shelf are presented. The data were sampled from October 1993 through January 1995 at 1 m intervals between 3 m and 42 m in a total water depth of 47 m. Their monthly means suggest an annual cycle hypothesized to be driven by a seasonally varying shelf-wide baroclinic structure. Motions at semi-diurnal, diurnal and synoptic time scales are seasonally modulated, both by wind forcing and stratification that decouples fluid motions from the damping effects of bottom friction. These motions are presented in the form of progressive vector plots. With 16 months of data, probability density and distribution functions for along-shore and across-shore particle displacements over specific time intervals are constructed. For daily intervals, particles are equally likely to travel approximately 5 km (depending upon confidence interval) in any direction. For monthly intervals, particles may travel a few hundred km, primarily along-shore.

Introduction

The west Florida continental shelf is a broad, gently sloping region of width equal to that of the sub-areal state of Florida. Its isobaths generally parallel the coastline which at mid-shelf is oriented approximately along 333°T, and the 100m isobath is located some 150-200 km offshore. The circulation on the west Florida shelf is driven by tides, winds and buoyancy fluxes, and it is steered by the joint affects of the earth's rotation and topography. The circulation is also influenced by the Gulf of Mexico's Loop Current that enters through the Yucatan Straits and exits as the Gulf Stream through the Straits of Florida, sidling close to the west Florida shelf break at times during its Gulf of Mexico transit.

Recognizing that the circulation is an important contributor to the distribution of bio-geochemical material properties, a study was initiated in fall, 1993 for the purposes of improving upon the description of the shelf circulation and its seasonal and synoptic variability. This study builds upon earlier measurements such as Niiler (1976), Koblinsky (1981), Mitchum and Sturges (1982), Marmorino (1983) and Halper and Schroeder (1990) that were either of short duration or located relatively far offshore. As a precursor to a shelf-wide array of currents measurements, an RD Instruments 600 kHz acoustic Doppler current profiler (ADCP) was deployed mid-shelf on the 47 m isobath, as shown in Figure 1. The ADCP (with 30° transducer configuration) was surface moored in a downward-looking mode and it recorded hourly velocities (vector averaged over 500 samples, each 1 second apart) at 1 m intervals between depths of 3 m to 42 m from October 5, 1993 to January 26, 1995 (approximately 16 months). The present letter briefly describes the seasonal modulation of the observed circulation features, and it proceeds as follows. We first describe the means for both the entire 16 month deployment and for each month. Progressive vectors by month are then developed for motions occurring at semi-diurnal, diurnal and synoptic time scales as well as for motions inclusive of all time scales, and the seasonal modulation of these hypothesized particle displacements is given. Based upon the progressive vector analysis, a set of probability density and distribution functions for along-shore and across-shore particle displacements over specific time intervals is then presented followed by a discussion and summary.

Paper number 96GL02184
0094-8534/96/96GL-02184$05.00

Record-length and Monthly Means

The record-length (16 months) means and standard deviations for the along-shore (333°T) and the across-shore (63°T) components of flow are shown as a function of depth in Figure 2. The means for both components are essentially zero at all depths and the standard deviations for either component are about 10 cm sec^{-1}, being only slightly larger near the surface. The implication is a rather sluggish, barotropic circulation on average. The monthly means, however, given as horizontal velocity vectors at 10, 20, 30 and 40 m depths in Figure 3, present a much different picture, in which the circulation is large and seasonally reversing. The monthly mean vectors tend to be oriented along-shore with largest magnitudes (about 10 cm sec^{-1}) directed toward the southeast (northwest) in spring (late summer/early fall). During other months the means are of smaller magnitude. When the monthly means are largest; for example, 10/93, 4/94, 9/94, they also show a systematic decrease with depth in the along-shore component consistent with a thermal wind balance.

Progressive Vector Diagrams

A progressive vector approximation is adopted for estimating the particle excursions at 3 m depth based upon the Eulerian observations. Position time series in the east and north coordinate directions [x(t), y(t)] were calculated according to: $dx/dt=u(t)$ and $dy/dt=v(t)$, where (u, v) are the Eulerian velocity components in (x, y). This was done by month for the semi-diurnal, diurnal and synoptic time scales after bandpass filtering the original hourly data set and for the original unfiltered hourly data set. The results are shown in Figure 4 for the months of January, April, July and October, 1994. The format in each set of panels is similar, the only difference being the spatial scale which increases with the time scale from semi-diurnal at the top to inclusive of all time scales at the bottom. At the semi-diurnal time scale, well-defined, eccentric ellipses are observed each month owing to primarily deterministic forcing provided by the M_2 and S_2 tidal constituents. These ellipses are oriented with semi-major axes in the across-shelf direction and their associated particle

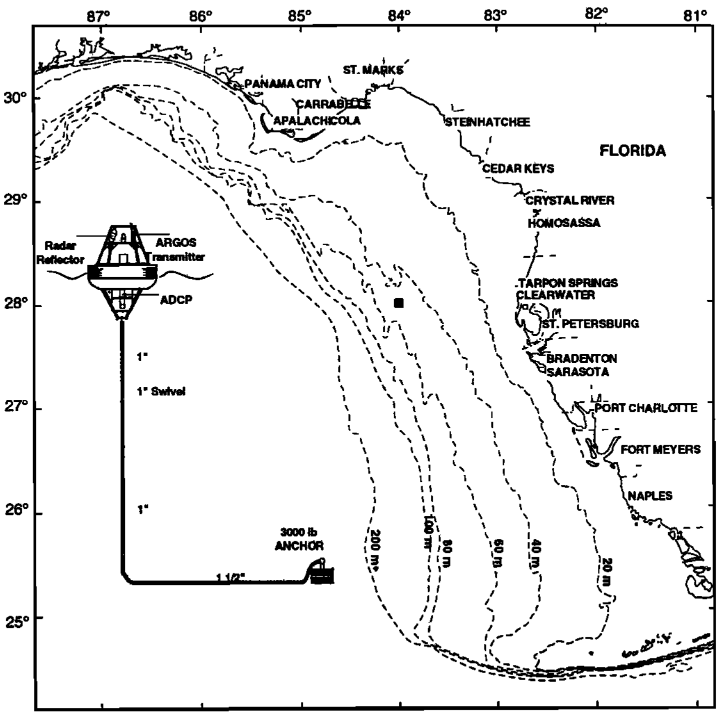

Figure 1. The west Florida continental shelf showing the mid-shelf ADCP mooring at 28°N, 84°W on the 47 m isobath.

excursions over a tidal cycle are about plus and minus 1 km in the across-shelf direction. The exception is in the summer months when stratification permits internal tides, adding a small random modulation about an otherwise deterministic, barotropic semi-diurnal tide. The diurnal time scale shows a much larger seasonal modulation. With the mooring at 28°N the inertial and diurnal time scales are very close to each other. During winter months the diurnal ellipses are well-defined and forced primarily by the deterministic O_1 and K_1 tidal constituents, resulting in across-shelf oriented (but less eccentric) ellipses having particle displacements similar in magnitude as the semi-diurnal tides. Once the water column stratifies, permitting internal waves and decoupling the inertial motions from the frictional affects of the bottom, the diurnal ellipses become random, nearly circular and large, with particle displacements having 5 km radii in July. The diurnal time scale is therefore both tide and wind forced, but the wind forced response is largest when the wind (measured at a NOAA buoy located at 28.5° N, 84.5° W) is smallest in summer, and conversely in winter, owing to the effects of stratification.

At synoptic time scales, the particle motions are primarily wind-forced. Since frontal systems are most pronounced in fall and winter, the synoptic time scale displacements are largest during those times. Due to the steering effects of topography, these displacements tend to align with the along-shore direction. Typical frontal passage in winter can therefore result in along-shore displacements of plus and minus 10 km, as compared to less than half that amount in summer. Along with the semi-diurnal, diurnal and synoptic fluctuations, there are also the monthly varying mean flows (Figure 3). Thus, monthly particle displacements, inclusive of motions at all time scales, can be very large (the bottom panels of Figure 4), with the seasonally varying background circulation resulting in primarily along-shore displacements of 100-300 km.

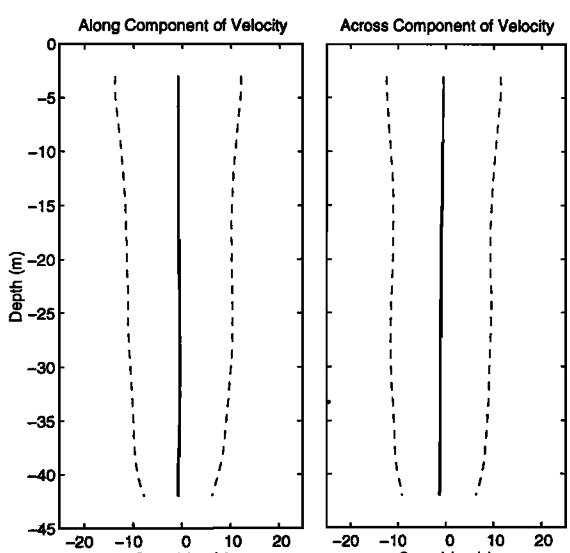

Figure 2. Vertical distributions of the record-length means and standard deviations for the along-shore and the across-shore velocity components measured at 28°N, 84°W.

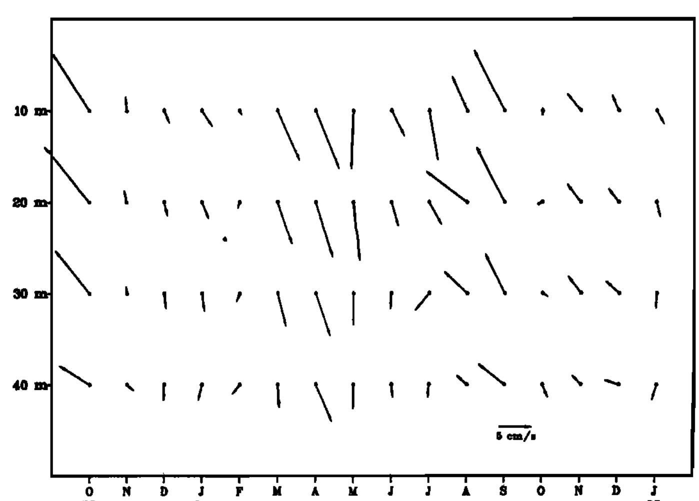

Figure 3. Monthly mean horizontal velocity vectors (north vertically up) at 10 m, 20 m, 30 m and 40 m depths at 28°N, 84°W.

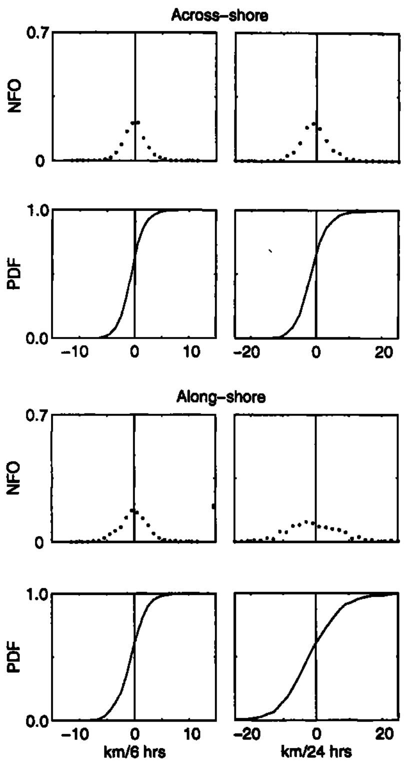

Figure 4. Monthly progressive vector diagrams (north vertically up) calculated from the Eulerian time series band-pass filtered about semi-diurnal (0.0769-0.0841 cph), diurnal (0.0370-0.0435 cph) and synoptic (0.00417-0.0125 cph) time scales and unfiltered to include all time scales. The data are from 3 m depth and the months of January, April, July and October, 1994 are representative of the seasonal modulation.

Particle Displacement Probabilities

The data allow for the construction of probability density and distribution functions for along-shore and across-shore particle displacements over specific time intervals. The intervals chosen are 6 hrs (a typical time between satellite fixes for tracking drifting buoys) and 1 day (to average out tidal and inertial oscillations). The procedure consisted of calculating along-shore and across-shore displacements for each independent time interval (1912 at 6 hrs and 478 at 1 day), forming normalized frequency of occurrence diagrams (probability density functions) and then integrating these to get probability distribution functions. The results are shown in Figure 5. At these intervals the along-shore and the across-shore displacements are nearly Gaussian. Assuming (on average over the annual cycle) stationarity and homogeneity, Figure 5 may be used for making probabilistic statements regarding particle displacements at mid-shelf. For example, in the across-shelf direction, for a 1 day interval, there exists an equal probability that a particle will be displaced either on-shore or off-shore and that the displacement magnitude with 90% confidence will be less than about 5 km.

Discussion and Summary

Long term measurements of currents on the west Florida continental shelf reveal a seasonally varying background circulation and a seasonal modulation to the velocity fluctuations occurring in response to the shelf's primary forcing functions (i. e., the semi-diurnal and diurnal tides and the wind-forced motions at inertial and synoptic time scales). While the record-length mean flows in both the along-shore and across-shore directions are nil, the monthly means are relatively large at times (10 cm sec^{-1}), reversing direction from

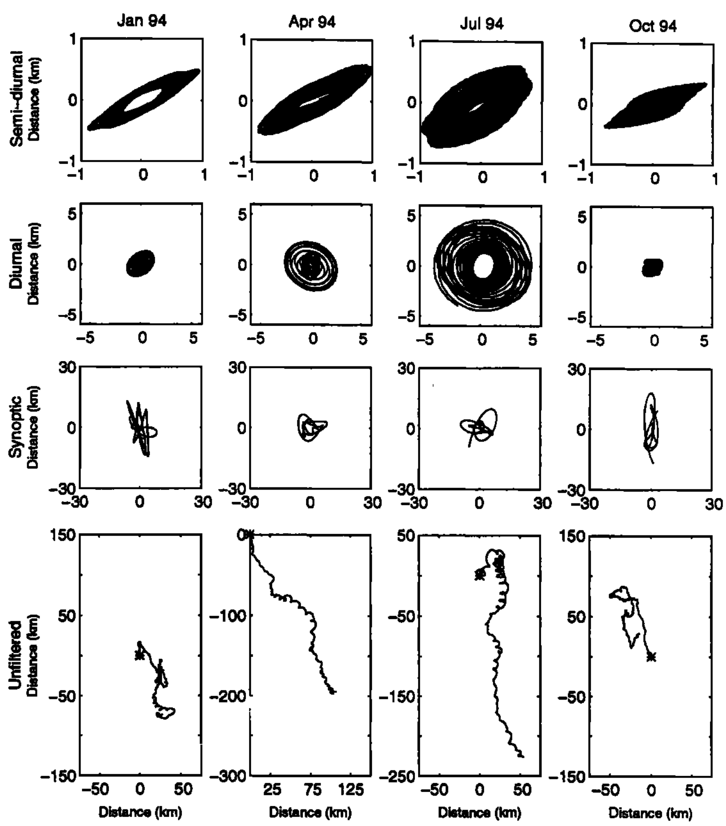

Figure 5. Probability density and distribution functions for particle displacements in the along-shore and the across-shore directions over time intervals of 6 hrs and 1day inferred from the progressive vector analysis of 16 months of Eulerian velocity data observed mid-shelf at 3 m depth.

primarily along-shore toward the northwest with maximum values in late summer/early fall to along-shore toward the southeast with maximum values in spring.

At the times of maximum monthly means, the vertical shear suggests a baroclinic origin via the thermal wind relationship. A simplistic way of thinking about this is to recognize that during winter (summer) months the waters at the shelf break are relatively warm (cold) compared with the waters on the shelf. From this one can hypothesize a reversal in the across-shore density gradient (and therefore the across-shore pressure gradient) consistent with a geostrophic reversal in the currents. This conceptual model appears to work in late summer/early fall when the near coastal waters are warmer and also fresher (the rainy season) than the waters farther offshore resulting in a northwestward along-shore geostrophic current. Indeed the seasonal maximum in sea level at the coast occurs at this time (e. g., Blaha and Sturges, 1981). The strongest southeastward directed currents occurring in spring, rather than winter, are more difficult to explain. Inspection of satellite AVHRR images shows a local SST minimum occurring between the mooring location and the coast (e. g. Vukovich, 1986) in spring as the shelf warms from south to north and offshore from the coast. This would effectively increase the across-shore pressure gradient. Developing a better understanding of this seasonal baroclinic portion of the west Florida shelf circulation remains an important objective of our studies and it must be recognized that an improved, systematically collected hydrographic data set is required. It is also noted that these times series measurements help to explain the drift bottle retrievals under the "Hourglass Project" (Williams, 1977).

The findings that the semi-diurnal tidal currents may be described as well-defined, stable, barotropic ellipses, oriented across-shelf, are consistent with observations reported by Koblinsky (1981) and model predictions of Battisti and Clark (1982). Stratification during summer months, however, adds a small, random internal tide contribution.

In contrast to the semi-diurnal tides, diurnal period motions show a pronounced seasonal modulation due to the generation of random inertial oscillations that add to the deterministic, barotropic diurnal tides in summer months when the shelf is stratified. This contradicts the conclusion of Marmorino (1983) whose measurements were in winter when the inertial oscillations are critically damped by bottom friction.

The estimation of probability density and distribution functions for the hypothesized (using progressive vectors) along-shore and across-shore particle displacements show that particles, over time scales of 6 hrs and 1 day, have nearly equal probability of flowing in any direction with daily displacements (depending upon confidence interval) being about 5 km.

The complete record of currents reported herein along with the ancillary wind, sea level and temperature data are available in Weisberg et al. (1996). Future correspondences will include data from a recently recovered trans-shelf array of instruments.

Acknowledgments. Support was provided as part of the west central Florida coastal erosion study by a cooperative agreement between the USGS (Center for Coastal Geology, St. Petersburg, FL.) and the University of South Florida, with equipment matching from the USF Division of Sponsored Research, and with additional support from the Florida DEP, FMRI, St. Petersburg, FL. We thank the Florida Institute of Oceanography, the USGS and the respective crews of the *R/V Suncoaster, R/V Bellows* and *R/V Gilbert* for ship support. R. Cole and J. Donovan assisted with the field work and data analysis.

References

Battisti, D. S., and A. J. Clarke, Estimation of nearshore tidal currents on non-smooth continental shelves, *J. Geophysical Res.*, **87**, 7873-7878, 1982.

Blaha, J., and W. Sturges, Evidence for wind-forced circulation in the Gulf of Mexico, *J. Marine Res.*, **39**, 711-733, 1981.

Halper, F. B., and W. W. Schroeder, The response of shelf waters to the passage of tropical cyclones- observations from the Gulf of Mexico, *Continental Shelf Res.*, **10**, 777-793, 1990.

Koblinsky, C. J., The M_2 tide of the west Florida shelf, *Deep Sea Res.*, **28A**, 1517-1532, 1981.

Marmorino, G. O., Variability of current, temperature, and bottom pressure across the west Florida shelf, winter 1981-1982, *J. Geophysical Res.*, **88** 4439-4457, 1983.

Mitchum, G. T., and W. Sturges, Wind-driven currents on the west Florida shelf, *J. Phys. Oceanogr.*, **12**, 1310-1317, 1982.

Niiler, P. P., Observations of low-frequency currents on the west Florida continental shelf, *Mem. Soc. Roy. Sciences de Liege*, **6**, 331-359, 1976.

Vukovich, F. M., Aspects of behavior of cold perturbations in the eastern Gulf of Mexico: a case study, *J. Phys. Oceanogr.*, **16**, 176-188, 1986.

Weisberg, R. H., B. D. Black, J. C. Donovan and R. D. Cole, The west-central Florida shelf hydrography and circulation study: a report on data collected using a surface moored acoustic Doppler current profiler, 129 pp.,Department of Marine Science, University of South Florida, St. Petersburg, FL, 1996.

Williams, J., W. F. Grey, E. B. Murphy, and J. J. Crane, Memoirs of the Hourglass Cruises, Volume 4 Part 3, Florida Department of Natural Resources, 133pp., 1977.

B. D. Black, R. H. Weisberg, H. Yang, Department of Marine Science, University of South Florida, 140 7th Avenue South, St. Petersburg, FL 33701. (e-mail: black@ocg6.marine.usf.edu; weisberg@ocg6.marine.usf.edu; yang@ocg6.marine.usf.edu)

(Received March 28, 1996; revised June 18, 1996;
accepted June 24, 1996.)