# Observations and Modeling of the West Florida Continental Shelf Circulation

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Grant #: N00014-98-1-0158

## LONG-TERM GOALS

My long-term goals are an improved understanding of how physical processes affect material property distributions on continental shelves and the ability to forecast property changes. Properties of interest include biological (red-tide algae and fish larvae), chemical (nutrients), and geological (resuspended sediments) variables, and the physical responses of sea level, currents, temperature and salinity.

## OBJECTIVES

To achieve these goals I must accomplish a related set of objectives. In logical order: 1) I am developing descriptions of the tidal, synoptic, seasonal, and inter-annual varying circulations on the West Florida Shelf (WFS). 2) Along with descriptions, I am developing quantitative understandings of how external forcing affects the WFS circulation. 3) I am determining what controls the along and across-shelf transports of materials, with emphasis on the frictional boundary layers. 4) Given both seasonal and inter-annual variations, I am assessing the relative importance of local and deep-ocean forcing in determining WFS water properties. 5) For local forcing, I am assessing the relative influences of the surface buoyancy (heat and fresh water) and momentum (wind stress) fluxes. 6) For deep-ocean forcing, I am assessing how and where the Gulf of Mexico Loop Current (LC) impacts the WFS. 7) I am relating these physical factors to questions of geological, biological, and chemical importance; for example, storm surges, sediment redistributions, nutrient distributions, species migrations, primary productivity, and how all of these factors affect inherent optical properties (IOPs). 8) Since these objectives require sampling over various time and length scales using an assortment of instruments, I am contributing toward a WFS Autonomous Ocean Sampling Network (AOSN) of use for Navy defense related experimentation and as a regional component of an integrated, Coastal Ocean Observing System (COOS). 9) To support AUV operations, sensor developments, prognostic physical and biological models, and to provide useful public data products, I am expanding the capability for real-time data through moorings, floats, high frequency radars, and other techniques.

## APPROACH

My approach is a coordinated program of *in-situ* measurements and numerical circulation models. With colleagues, I am marshaling resources from several projects. While the *in-situ* measurements change with programmatic needs they generally consist of moored arrays and hydrographic cruises. Array configurations include bottom and surface mounted acoustic Doppler current profilers (ADCP) for currents. Our bottom moorings generally have temperature/salinity (T/S), and pressure sensors, and a smaller subset of these have included sediment resuspension packages (near bottom acoustic

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



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|---|---|---|
| 1. REPORT DATE<br>**30 SEP 2003** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2003 to 00-00-2003** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Observations and Modeling of the West Florida Continental Shelf Circulation** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**College of Marine Science,,University of South Florida,140 7th Ave. S.,,St. Petersburg,,FL, 33701** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S)<br>11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **10** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

current profilers and optical instruments). The surface moorings generally have surface meteorological instruments and vertically distributed T/S sensors. At its peak a total of 13 moorings were deployed with emphasis on the inner-shelf. Ten moorings are presently deployed, four bottom mounted and six surface buoyed. The surface buoys all have real time telemetry, and the real time data are available at http://comps.marine.usf.edu. These data are also on the NDBC web page and are provided to NCEP. The figure below shows our present WFS array (including NOAA maintained sites).


The coordinated numerical modeling portion of our program is primarily based on applications of the primitive equation, Princeton Ocean Model (POM) of Blumberg and Mellor (1987). The model domain extends from the Mississippi River to the Florida Keys with one open boundary arching between. Horizontal resolution varies from about 6 km to 2 km, and 21 sigma layers span the vertical. Baroclinic hindcasts (quantitatively compared with data) use NCEP reanalysis winds [blended by optimal interpolation (OI) with coastal and buoy winds] and surface heat fluxes (with a flux correction to an OI satellite SST product) and river inputs. Nowcast/forecasts use ETA winds. Nowcast/forecasts are presently barotropic, awaiting an operational surface heat flux product to convert these to baroclinic. Along with POM we are also using ROMS (H. Arango, personal communication), a finite volume model (FVM) by Chen et al. (2003), and ECOM3D-si by Blumberg (1993).

## WORK COMPLETED

I initiated a WFS circulation study in 1993 in cooperation with the USGS Center for Coastal Geology. It expanded in 1995 with MMS and ONR support. The State of Florida approved a long-term plan for a Coastal Ocean Monitoring and Prediction System (COMPS) for real-time currents and surface fluxes offshore, and sea level and winds at the coast. USF, in partnership with others, was awarded an ECOHAB (Ecology of Harmful Algal Blooms) regional field study for the WFS by NOAA/COP, and this evolution helped to facilitate the present efforts.

Measurements began with a mid-shelf ADCP mooring (10/93-1/95) that defined relevant time scales and a seasonal circulation cycle (Weisberg et al., 1996a,b and Black, 1998). A trans-shelf array was then deployed (1/95-2/96) showing an inner-shelf region where responses to synoptic weather forcing are well-defined, contrasted with an outer-shelf region where interactions with the deep-ocean may be controlling (Weisberg et al., 1997, Siegel, 1998, and Meyers et al., 2001). To focus on the inner-shelf, ADCPs were deployed off Sarasota, FL on the 20m and 25m isobaths in 11/96 showing the three-dimensionality of the circulation and the importance of baroclinicity, even in shallow water. The across-shelf transports in response to winds are seasonally modulated as the surface and bottom Ekman layers adjust to stratification, and Weisberg et al. (2000a) identify an upwelling/downwelling response asymmetry through a comparison of *in-situ* data with a numerical model simulation for April 1998. Upwelling favorable winds produce disproportionately larger responses in sea level and currents than downwelling favorable winds, and this is explained through thermal wind effects across the bottom Ekman layer. For downwelling favorable winds, the buoyancy torque by isopycnals bending into the sloping bottom opposes the tendency by the tilting of planetary vorticity filaments by the vertically sheared coastal jet. This thermal wind effect negates the need for large dissipation of relative vorticity by the across-shelf flow in the bottom Ekman layer. The opposite occurs for upwelling favorable winds. Buoyancy torque adds constructively with the planetary vorticity tilting tendency requiring larger dissipation of relative vorticity in the bottom Ekman layer. This enhancement or suppression of the bottom Ekman Layer by thermal wind accounts for the response asymmetry.

Satellite imagery is important to our work. Weisberg (1994) related SST patterns to LC influence on the WFS. Weisberg, et al. (2000b) provides an upwelling case study using satellite imagery, *in-situ* data, and a numerical model simulation. As an initial value problem we document the Ekman/geostrophic route to spin-up, and supporting dynamical analyses show the ageostrophic boundary layer effects under stratified and constant density settings. With coastline geometry changes causing three-dimensional effects, the findings of this paper provided a physical basis for our WFS ECOHAB proposal hypothesis. Stratified versus constant density effects on upwelling outcrops are further borne out by recent observations (Weisberg et al., in preparation, and Jolliff et al., 2003).

Our numerical model applications began with preliminary exercises (Yang and Weisberg, 1999; Yang et al., 1999; Li and Weisberg, 1999a,b; Yang and Weisberg, 2000), and we are subsequently engaging in more realistic simulations, most of which are quantitatively gauged against *in-situ* data. He and Weisberg (2001, 2003a) consider the WFS circulation and temperature budget for the 1999 spring and the 1998 fall transitions, respectively. We confirm the Weisberg et al. (1996) hypothesis that surface heat flux is an important contributor to the seasonally varying currents, and we account for the Gilbes et al. (1997) "Green River" phenomenon of on the basis of local forcing, independent of the LC. We also show why this is a spring versus fall phenomenon since the wind-driven currents drive Mississippi River water westward in fall. He and Weisberg (2002) provide a regional WFS tides model gauged against *in-situ* data. He and Weisberg (2003b) consider a LC intrusion case study demonstrating the Taylor-Proudman theorem constraint on across-slope penetration. The LC does significantly impact the shelf currents under special conditions, however. Weisberg and He (2003) consider the relative importance of local versus deep-ocean forcing in accounting for the anomalous water properties during spring through fall, 1998. By systematic experimentation, with and without LC influence, we show how and where deep, nutrient rich water upwells onto the WFS and how this water is transported to the near-shore. We confirm the Hetland et al. (1999) hypothesis on LC southwest corner impact importance owing to isobath convergence there. We also provide the basis for our first, fully baroclinic, coupled physical/biological model for the WFS (Walsh et al., 2003).

Given quantitative assessments of the regional model veracity (and limitations) our attention is refocusing on the nowcast/forecast objectives that require improved surface forcing fields, open boundary values, and data assimilation. Baroclinic nowcast/forecasts require surface heat flux specification. Virmani et al. (2003) gives a WFS overview on this topic. To correct heat flux fields to observed SST by relaxation we need a gridded, cloud-free, daily SST product. He et al. (2003a) produce this by an OI blend of NOAA AVHRR (high resolution, but cloud-contaminated) and NASA TMI (low resolution but cloud-free) SST. Surface winds are also limiting. He et al. (2003b) provide an improved wind product by an OI blend of the NOAA EDAS model winds offshore and observed buoy and coastal winds near-shore. By comparing coastal ocean model runs driven by the original EDAS winds and those driven by the blended winds we achieve significant improvement in the coastal ocean model performance when gauged against *in-situ* data.

With a better understanding of model limitations we are now better poised for adding data assimilation to our program. Our approach involves: 1) improving surface boundary values via OI, 2) improving open boundary values via interactions with other larger scale modeling groups (e.g., we are now formally part of the HYCOM team, and we are drawing associations with NCOM modelers), and 3) applying OI to blend model and data as data become increasingly available (through our moorings, our newly acquired HF-radar for surface currents, and our related profiling float program). Additionally, by implementing other model codes for which adjoints are being written (e.g., ROMS) we will in the future be able to consider other forms of data assimilation not presently available to POM.

Other works completed include modeling studies on the Charlotte Harbor estuary (CH) and a hurricane storm surge simulation for the Tampa Bay region (TB). Both of these estuaries are important for our long-term goals (material property distributions), especially with respect to red-tide. As preliminary work toward including the CH in our WFS FVM development we engaged in a regional model study using ECOM3D-si. Weisberg and Zheng (2003) provides an analysis on how energy, input by rivers, tides, and winds, partitions between buoyancy work and dissipation to account for the gravitational convection part of the net estuarine circulation, and Zheng and Weisberg (2003) provide a more general exposition of the CH circulation in response to rivers, tides, and winds. For TB we combined the high resolution and flooding/drying attributes of the FVM with a high resolution, merged topographic/hydrographic data set (USGS/NOAA) to simulate surge response for category 2 and 4 hurricanes approaching from different directions, over a range of approach speeds, and making landfall at several different locations.

In summary: 1) We are maintaining a long-term monitoring array for the WFS in coordination with our modeling studies. 2) This year we published seven refereed papers, have three in press, and submitted two other manuscripts. Additionally, four articles were published in non-refereed media and one is in press. 3) We maintain an operational, web-based, nowcast/forecast model. 4) We have a FVM that links the TB and CH estuaries with the WFS that is presently being run baroclinically for comparison with previous POM simulations (and we are preparing to do similar comparisons with ROMS). 5) We are actively engaged with larger-scale modelers for the purpose of open boundary values and for developing improved strategies for modeling the coastal ocean. 6) We are actively pursuing the continuation of our WFS work as part of the emergent COOS community, as a Southeast Atlantic Coastal Ocean Observing System (SEA-COOS) founding partner and in coordination with both GCOOS and SURA-SCOOP.

## RESULTS

Significant new findings over the past year are as follows. 1) We accounted for the anomalous water properties on the WFS in 1998, and our circulation simulations supported a coupled physical/biological model simulation of primary productivity. As a result we have a better understanding of how deep-ocean and estuarine nutrient sources fuel plankton blooms. 2) We advanced our understanding on across-shelf transport and the importance of the bottom Ekman layer on a gently sloping shelf. 3) We demonstrated that the primary limitation to coastal ocean modeling is in the forcing fields and offered a reasonable way toward improving this through blending of modeled and observed wind fields. These findings further justify the COOS concept, and our results are important for COOS design.

## IMPACT/APPLICATIONS

WFS physical oceanography is essential to WFS biology and optics. The 3-D, time dependent WFS circulation responses to local and deep-ocean forcing sets the stage for chemical, geological, and biological properties sampled by sensors aboard AUVs, or flown on aircraft or satellites. Moreover, the bottom Ekman layer, generally not sampled by remote techniques, is the principle conduit for the across-shelf transport of biologically important materials. Our work has significantly impacted WFS coupled physical/biological models and multidisciplinary sampling strategies. With the 1998 results successful and published our hindcast simulations for the subsequent HYCODE field years are presently being used for additional coupled physical/biological model experiments.

## TRANSITIONS

The physical/biological modeling efforts will eventually transition to a WFS red-tide forecast model as part of the NOAA MERHAB Program. Real time, internet accessible measurements and models are also being used for emergency preparedness as part of the USF COMPS. We are steadily engaging local officials in our programs through outreach. We believe that the long-term health of any COOS will depend on local user involvements.

## RELATED PROJECTS

Our interactions continue to expand with the emergence of COOS and with related modeling and monitoring programs. At USF and among HYCODE P.I.s we continue to interact toward achievement of common objectives. Many of the former NOAA/ECOHAB P.I.s remain engaged through a NOAA/MERHAB. We are part of SEA-COOS, a consortium of COOS scientists from NC, SC, GA, and FL, and we are coordinating our efforts with a related Gulf of Mexico COOS group. Both MERHAB and SEA-COOS are incrementally adding to our COMPS/HYCODE efforts. In particular through SEA-COOS we have now added HF-radar (long-range CODAR) to our measurement suite. A parallel development at USF (C. Lembke, R. Byrne, and R. Weisberg) is the Bottom Stationed Ocean Profiler (BSOP) for mapping hydrographic fields using profiling floats. Between the HF-radar for surface currents and internal T/S from BSOP, we anticipate having real-time data fields along with our present point measurements for assimilation into our models. New this year is a formal involvement with the HYCOM modeling team through a recently funded NOPP grant. We will use this to advance both our open boundary value specifications and our data assimilation applications.

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**HONORS/AWARDS/PRIZES**

Robert H. Weisberg received a Presidents Award for Faculty Excellence from the University of South Florida in January 2003.