Observations and Modeling of the West Florida Continental Shelf Circulation

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LONG-TERM GOALS

My long-term goal is improved understanding of how physical processes affect material property distributions on continental shelves. These include biological (red-tide algae and fish larvae), chemical (nutrients), and geological (sediment resuspension/transport) measures, and the physical responses of the currents and sea level.

OBJECTIVES

To achieve this goal I must accomplish a related set of objectives. In logical order, these are. 1) I am developing a description of the seasonally varying circulation on the West Florida Continental Shelf (WFS) using a combination of *in-situ* measurements and numerical circulation models. 2) Along with description, I am developing a quantitative understanding of how the various forcing functions: tides; synoptic weather; and surface, coastal, and offshore buoyancy fluxes affect the WFS circulation. 3) I am determining how these processes affect along and across-shelf material property transports, with emphasis on the frictional boundary layers. 4) Given large seasonal transitions, I am assessing the relative importances of the surface heat and fresh water fluxes and the coastal ocean dynamics in determining WFS water properties. 5) I want to relate these foregoing physical factors to questions of geological, biological, and chemical importance; for example, storm surges, sediment redistributions, nutrient distributions, species migrations and successions, primary productivity, red-tides, and how all of these factors affect inherent optical properties (IOPs). 6) Since these objectives require sampling over various time and length scales using an assortment of instruments, I am working toward a WFS Autonomous Ocean Sampling Network (AOSN) site south of Tampa Bay that may be useful for naval defense related experimentation. 7) The support of AUV operations, testing of sensors, developing prognostic physical and biological models, and providing useful public data products, requires the capability for real-time data through moorings and floats, which is an important continuing objective. 8) An aspect of near real-time data retrieval is an optical transmission link between an AUV and a mooring for quick data transfer without docking. 9) Finally, I want to observe the responses of the near bottom log-layer region across the inner shelf to assess sediment resuspension events and their effects upon water column IOPs.

APPROACH

My approach combines *in situ* measurements, remote sensing, and numerical circulation modeling. Along with colleagues, I marshaled resources from several projects. The *in-situ* measurements consist

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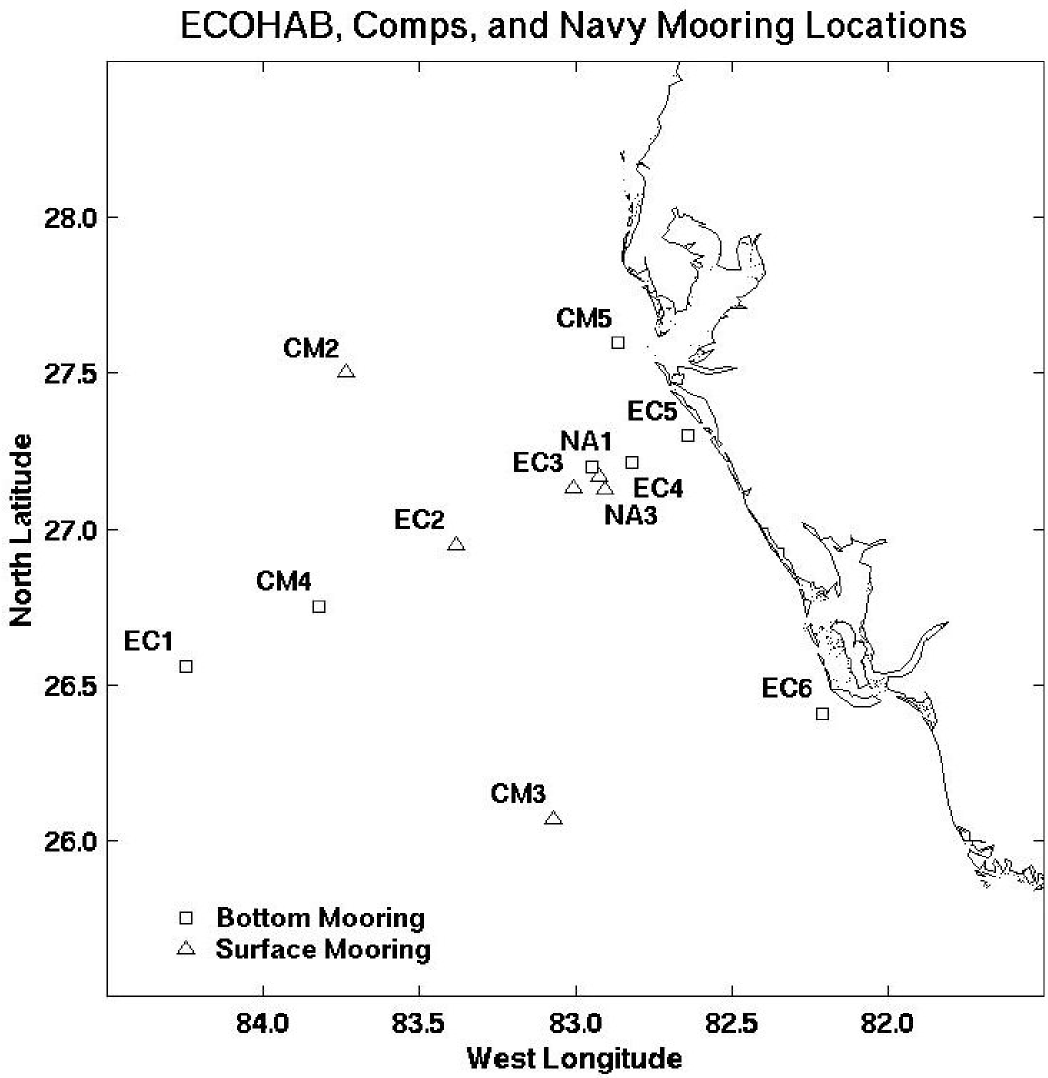
of a moored array complemented by monthly hydrographic cruises. The array uses bottom and surface mounted acoustic Doppler current profilers (ADCP) for currents. The bottom moorings include temperature/salinity (T/S), and pressure sensors, and a smaller subset of these will include sediment resuspension packages (near bottom acoustic current meters and optical instruments) deployed on an experiment specific basis. The surface moorings include surface meteorological instruments and a vertically distributed set of either T/S or T sensors. The array shown in Figure 1 (with 13 moorings: 6 surface and 7 subsurface) is presently being maintained.



The array samples the inner-shelf and the spatial transitions occurring across the mid-shelf to shelf break. The main sampling line (offshore from Sarasota, FL) is bounded by a control volume encompassing the Tampa Bay to Charlotte Harbor region. All Figure 1 measurements are by my USF Ocean Circulation Group (OCG). Additional sites (not shown) exist to the north in the Florida Big Bend (W. Sturges, FSU), and to the south in Florida Bay (T. Lee, RSMAS). I am interacting with P. Howd and other USF geologists on sediment resuspension studies. Our initial 10m isobath deployments will be expanded to other sites. Our monthly hydrographic cruises extend to the shelf break with lines running offshore from Tampa Bay, Sarasota, and Charlotte Harbor (with G. Vargo and J. Walsh, USF).

These are augmented by bi-weekly cruises offshore of Sarasota to the 30m isobath (G. Kirkpatrick, Mote Marine Laboratory). Remote sensing includes satellite AVHRR and ocean color imagery (F. Muller Karger, USF). Numerical circulation modeling (by my OCG assisted by H. Yang and Z. Li) includes two regional versions of the Princeton Ocean Model. These models are limited to either the eastern Gulf of Mexico or the WFS so collaborations are underway with groups that model either the entire Gulf of Mexico (R. Patchen, Dynalysis and G. Mellor, Princeton University) or smaller scales (R. Garwood, NPS). Also at USF, J. Walsh leads the biological modeling, K. Fanning provides nutrient data, K. Carder plans to deploy optics on the moorings, L. Langebrake [Center for Ocean Technology (COT)] developed the optical data transmission link, and my co-investigator M. Luther assists with our Florida COMPS and our real-time internet capabilites. New this year is the addition of optics on three of my moorings by R. Maffione, HobiLabs.

WORK COMPLETED

I initiated a WFS circulation study in 1993 in cooperation with the USGS Center for Coastal Geology. This 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 allowed the development of the present efforts.

Measurements began with a mid-shelf ADCP from 10/93 to 1/95. These data defined the relevant time scales of motion and showed a seasonal cycle in the circulation. Weisberg et al. (1996a, b) and Black (1998) present some of these findings. This was followed by a trans-shelf array of ADCPs deployed between the 300m and the 30m isobaths over the 8-12 month period 1/95-2/96. Data are reported in Weisberg et al. (1997) and Siegel (1998). They show 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 are controlling. Meyers et al. (2000) describes the outer-shelf features.

To look more closely at the inner-shelf, ADCPs were deployed off Sarasota, FL on the 20m and 25m isobaths in 11/96. They show the three-dimensional nature of the inner-shelf and the importance of baroclinicity even in shallow water. Seasonally, we observe a modulation of the across-shelf transports in response to wind forcing as the surface and bottom Ekman layers are affected by stratification. A seasonal cycle is also evident in the alongshore currents. Weisberg et al. (2000b) compare the *in-situ* data with a numerical model simulation for the seasonal transition month of 4/98 when stratification was well developed. A new and important finding is a rectification of the inner-shelf responses to synoptic wind forcing. Upwelling favorable winds produce disproportionately larger responses in both the sea level and currents than downwelling favorable winds. Stratification provides the explanation, most readily understood from the streamwise component of relative vorticity. For downwelling favorable winds, the buoyancy torque due to isopycnals bending into the sloping bottom opposes the tendency by the tilting of planetary vorticity filaments due to 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 planetary vorticity filament tilting requiring larger dissipation of relative vorticity by the bottom Ekman layer. By enhancing (upwelling) or suppressing (downwelling) the bottom Ekman layer the entire response is reduced or increased, respectively. This rectification is clearly evident on the WFS, both in the *in-situ* data and the model, because the WFS is wide enough to distinguish the frictional inner-shelf region from the shelf break.

Satellite imagery plays an important role. Weisberg (1994) related SST patterns to Loop Current influence on the WFS, and Siegel et al. (1999) expands on this. Weisberg, et al. (2000a) report on a specific upwelling case study using satellite imagery, *in-situ* data, and a numerical model simulation. The case study winds were calm for several days prior to a wind-driven upwelling event, and this allowed us to view the response as an initial value problem. The observed Ekman/geostrophic spin-up, supported by dynamical analyses, shows the ageostrophic effects of the boundary layers under either stratified or constant density settings. Coastline geometry changes have large three-dimensional effects.

Our numerical model applications are based on the Princeton Ocean Model of Blumberg and Mellor (1987). They include Lagrangian and Eulerian studies. Yang et al. (1999) describes Lagrangian experiments in an attempt to explain why surface drifters deployed in the northern WFS avoided the inner-shelf region south of Tampa Bay. Li and Weisberg (1999a, b) describe model responses to upwelling favorable winds under constant density settings. The flow field kinematics are fully three-dimensional with important regionality due to coastline and isobath geometries, and the flow field dynamics define the inner shelf and the momentum balance variations. These manuscripts also show that the across-shelf component of wind stress has importance in the inner-shelf responses, as borne out by the *in-situ* data. We are beginning to explore (with J. Walsh) coupled physical/biological models of red-tide dinoflagellates. Walsh et al. (2000), describing the red tide event of 1979, is the first of our coupled model manuscript submittals.

The foregoing transitions directly into the present research. The moorings shown in Figure 1 are presently being maintained, the data returns are excellent, and we are achieving our measurement goals. The array elements either record internally or telemeter data in real time. Our most complete telemetering mooring (on the 25m isobath) provides full surface heat and momentum flux information, water column currents, and T/S at six depths transmitted hourly via GOES satellite and available to the general public on the internet (http://comps.marine.usf.edu). Along with the large scale array we are measuring currents and sediment resuspension in the bottom log-layer. After testing the new SonTec acoustic Doppler profiler (ADP) coupled with optical devices (LISST100 and OBS), we opted to purchase ADPs as opposed to the single point ADV. While this delayed our proposed multiple site bottom log-layer work, equipment is now arriving, and we will be on target for the present year of field activities. We supported the July 2000 SF_6 tracer experiment by R. Wanninkhof (AOML) and colleagues by the *in-situ* measurements proposed last year, including bottom log-layer measurements at the 10m isobath and surface moorings with additional T/S sensors. Data from the SF_6 tracer experiment time period were just retrieved in September 2000, and are presently being analyzed. Our *in-situ* measurements will also be in place for the November 2000 tracer release, as proposed. Using a density field initialization from the June 2000 ECOHAB hydrography cruise and the real time winds from our mooring, we ran a nowcast model in support of the experiment. Subsequent hydrography now provides an improved retrospective model analysis that will be beneficial for interpreting the SF_6 tracer experiment results. Net surface heat flux inclusion should also give improved nowcasts for future experiments

Unable to schedule AUV time for in-water field tests of the optical data transmission link previously designed by the USF/COT leaves this element incomplete. In air laboratory tests give reliable transfer rates of 57600 baud at distances of 20m, suggesting that we can achieve rapid data transference between a mooring and an AUV without docking. We will attempt in-water testing next year.

RESULTS

FY00 results were achieved in all proposed areas. 1) The WFS array is in place and with the additions proposed last year. We are assisting R. Maffione (Hobilabs) with optics measurements on our moorings. 2) Real time satellite telemetry capabilities are improved and we are building long time series of *in-situ* surface fluxes, so critical for shelf modeling. 3) Groundwork is laid for near bottom log-layer experiments using the latest optics and velocity profiling techniques. 4) Numerical model experimentation is advancing for considering deep ocean/shelf interactions, the seasonal cycle by local air sea fluxes, the seasonal modulation of inner-shelf responses to synoptic weather forcing, coupled biological/physical modeling, and along a separate vein - hurricane storm surge simulation.

Significant findings are as follows. 1) The WFS is wide enough for its inner-shelf to be resolved separately from its shelf break. 2) A seasonal cycle exists in response to local forcing, but modulated by Loop Current influence. 3) The inner-shelf response to synoptic weather forcing is critically controlled by stratification; specifically the buoyancy torque by isopycnals relative to the sloping bottom. These bottom Ekman layer physics cause rectification favoring upwelling responses. 4) The bottom Ekman layer controls the biology of the WFS to large measure and hence IOPs. 5) Modeling the inner-shelf requires substantial *in-situ* data. Along with moorings, these must include surface, coastal, and offshore buoyancy fluxes, and sufficient interior T/S, since without the density field the model circulation will be incorrect. If the circulation is incorrect then any model quantity depending on the circulation (nutrients, primary productivity, larvae distributions, IOPs, sediment transport, etc.) will also be incorrect. 6) It is difficult to separate synoptic from the seasonal variability since both depend on each other. Synoptic responses depend on the seasonal stratification, and the seasonal cycle depends on heat fluxes that are governed to large degree by the synoptic scale.

IMPACT/APPLICATIONS

Our physical oceanographic results are necessary inputs to biological/optical models. The 3-D, time dependent WFS circulation responses largely determines the chemical, geological, and biological properties to be sampled by sensors aboard AUVs, or flown on aircraft or satellites. Satellite sensors may offer only a limited view of inner-shelf workings. *In-situ* physical oceanographic data are necessary for interpreting ocean optical measurements made either *in-situ* or by remote techniques.

TRANSITIONS

The physical/biological modeling efforts will transition to a WFS red-tide forecast model as part of the NOAA/EPA ECOHAB Program. Real time, internet accessible measurements and models (e.g., hurricane storm surge) are also being used for emergency preparedness as part of the USF COMPS.

RELATED PROJECTS

We are interacting with NOAA sponsored scientists to the south in Florida Bay (T. Lee) and with MMS sponsored scientists to the north in the Florida Big Bend (W. Sturges). The NOAA/EPA ECOHAB Program is co-located with our work (other P.I.s include J. Walsh, G. Vargo, K. Steidinger, G. Kirkpatrick). For HyCODE we are also interacting with K. Carder, R. Maffione, and others, and for the larger Gulf of Mexico arena we are interacting with Dynalysis (R. Patchen), Princeton (G. Mellor), and RSMAS (C. Moorers).

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