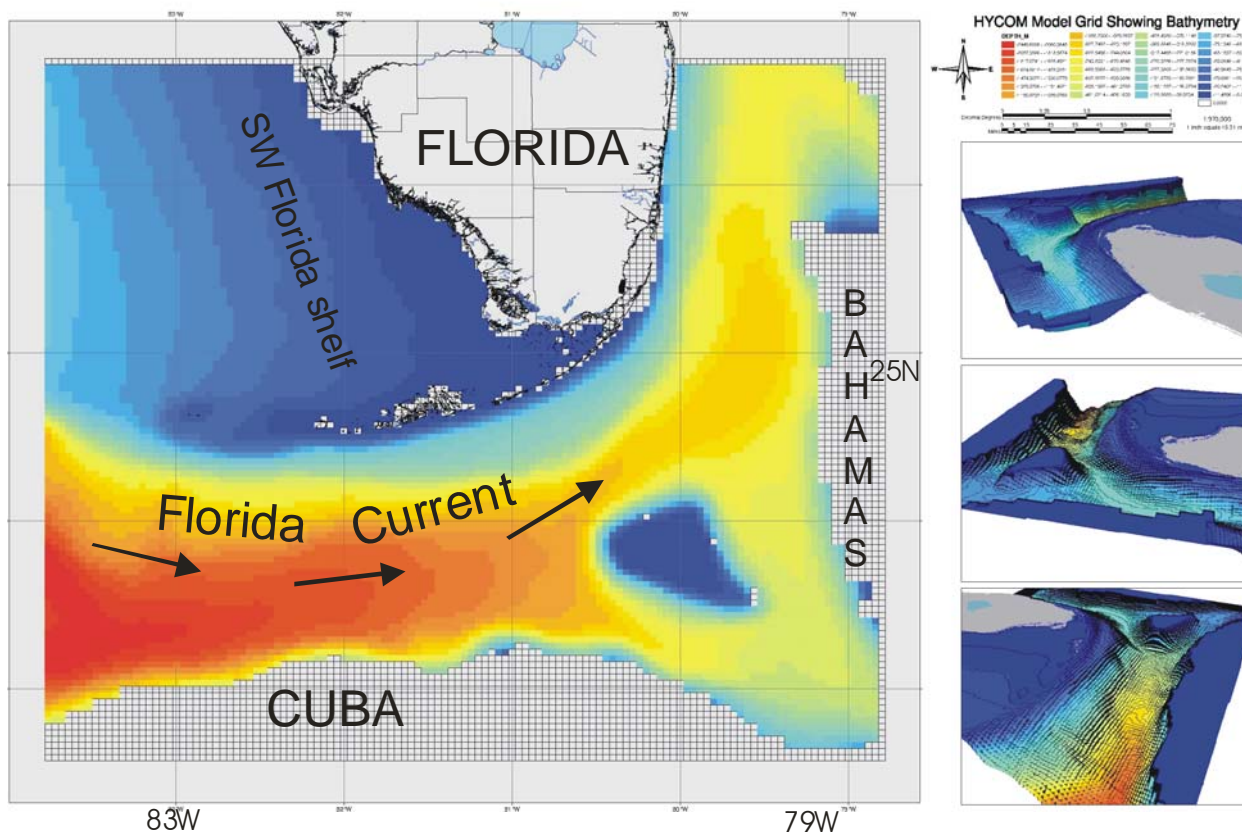# SoFLA-HYCOM (South Florida HYCOM)

# Regional Model around

# Florida Straits, Florida Bay and the Florida Keys:

# An overview

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# Background

The seas that surround the southern part of the Florida peninsula form a unique oceanographic environment that includes ecologically sensitive shallow areas (Florida Bay and the Florida Keys reef tract), shelf areas (the relatively broad southwest Florida shelf and the narrow shelf along the Atlantic side of the Florida Keys) and deep areas (Straits of Florida). The coastal seas around South Florida include Marine Protected Areas that are embedded in the Florida Keys Marine Sanctuary and the Dry Tortugas Ecological Reserve. The South Florida domain is the crossroads between the Gulf of Mexico and the North Atlantic and it has been the focus of long term, ongoing interdisciplinary surveys. The observations have provided concrete evidence that these distinct marine environments around South Florida are strongly inter-connected by circulation and biochemical exchange processes on a regional scale, while oceanic boundary currents connect them to remote regions of the Gulf of Mexico and the Caribbean. The coastal areas around South Florida will be the recipients of potentially drastic changes in freshwater flows associated with the Everglades Restoration Project. Observations and modeling have been employed to study the effects of such changes, in the context of natural disturbances associated with large scale flows, climatic variability and connectivity to remote reef systems.

The South Florida (SoFLA) Regional Model (details in Kourafalou et al., 2005) has been developed to address these challenging tasks so that coastal models of Florida Bay and the Florida Keys are linked together with the adjacent seas through suitable boundary conditions. A nested modeling approach has been employed to ensure the proper representation of such interactions. The modeling activities are supported by ancillary observational projects of NOAA/AOML and UM/RSMAS (see the NOAA South Florida Ecosystem Research and Monitoring Program (http://www.aoml.noaa.gov/sfp/).

## Model domain and set-up

The South Florida (SoFLA) Regional Model is an adaptation of the HYbrid Coordinate Ocean Model (HYCOM), thereafter called the SoFLA-HYCOM. The nesting of the SoFLA-HYCOM within a larger scale HYCOM model allows the accurate simulation of the interaction between shallow water dynamics around the Florida Bay and the Florida Keys reef tract with larger scale oceanic flows. The SoFLA-HYCOM performs simulations that are suitable to provide boundary conditions to coastal hydrodynamic, water quality and ecosystem models used in Florida Bay and the Florida Keys.

The SoFLA-HYCOM domain is shown in Fig. 1 and it extends from approximately $22.6^0$N to $27.4^0$N (west Florida coast) and to $26.7^0$N (east Florida coast) and from $78.8^0$W to $83.8^0$W. The model domain includes the south Florida coastal system and also covers the Straits of Florida between the Keys and Cuba including the Cay Sal Bank (Fig. 2) and the Bimini island (Bahamas). The horizontal resolution is 1/25 degree (about 3 to 3.5 km in latitude) and 19 vertical layers have been implemented with isopycnal layers in the deep Straits of Florida and a combination of sigma and z-layers on the shelf areas. The bathymetry (Fig. 2) has been adopted from the 2-minute NAVO/NRL DBDB2 global dataset. The depth values in shallow areas around the Florida Keys reef tract have been corrected so that topographic details are included; this is absent in the larger scale models that provide the boundary conditions (see below). Simulations with a 5m and a 3m minimum depth have been carried out.
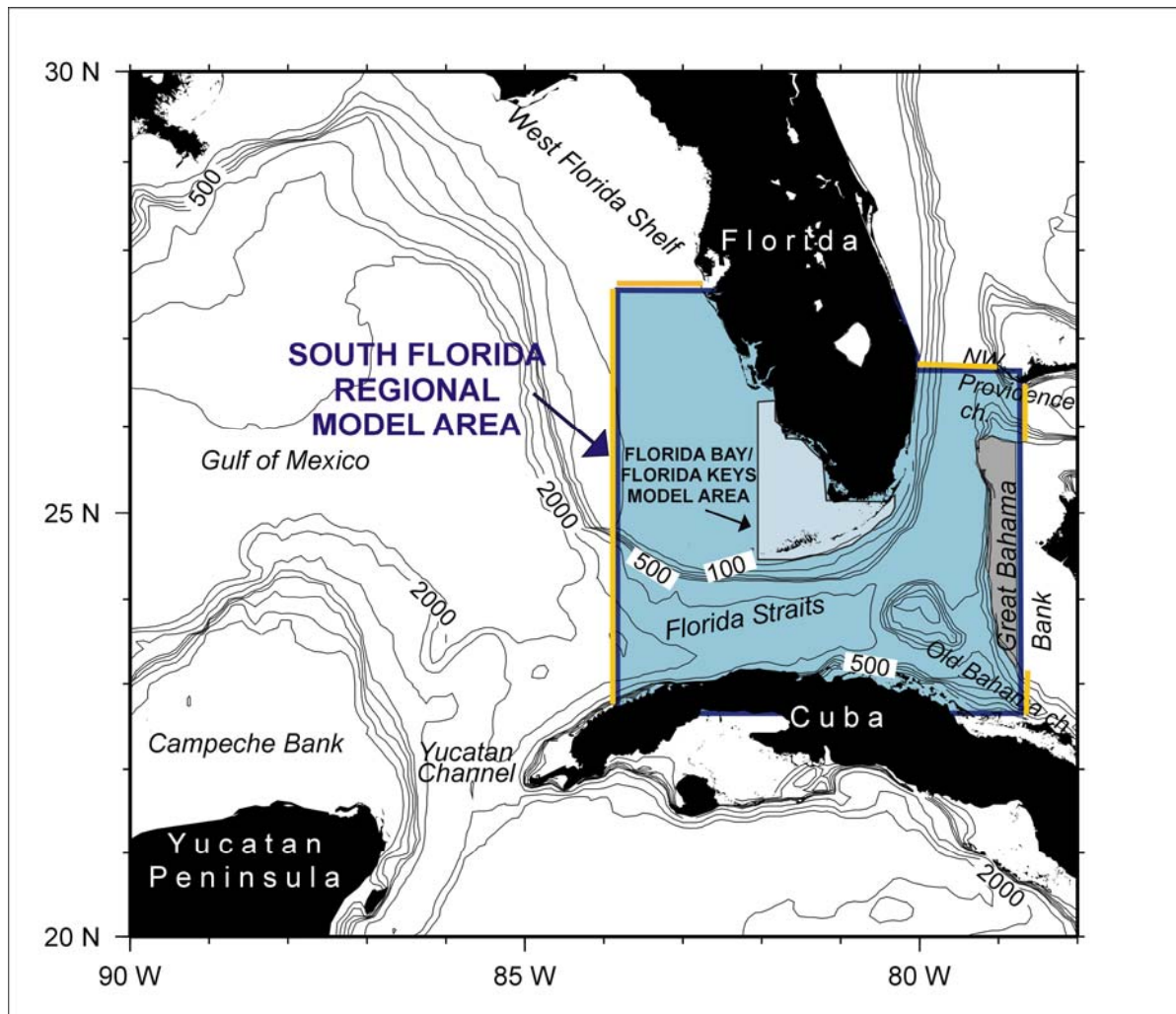
Figure 1: The SoFLA-HYCOM Regional Model domain (blue shaded); embedded is a sub-domain (light grey shaded) where model parameters (current Velocity, Temperature, Salinity and Sea Surface Elevation) are archived for use by coastal Florida Bay and Florida Keys models. The orange lines mark the open boundaries that are employed for nesting with the larger scale HYCOM; the shallow Great Bahama Bank (dark grey shaded) and the island of Cuba (plus smaller islands near the NE Cuban coast) are approximated as solid boundaries.
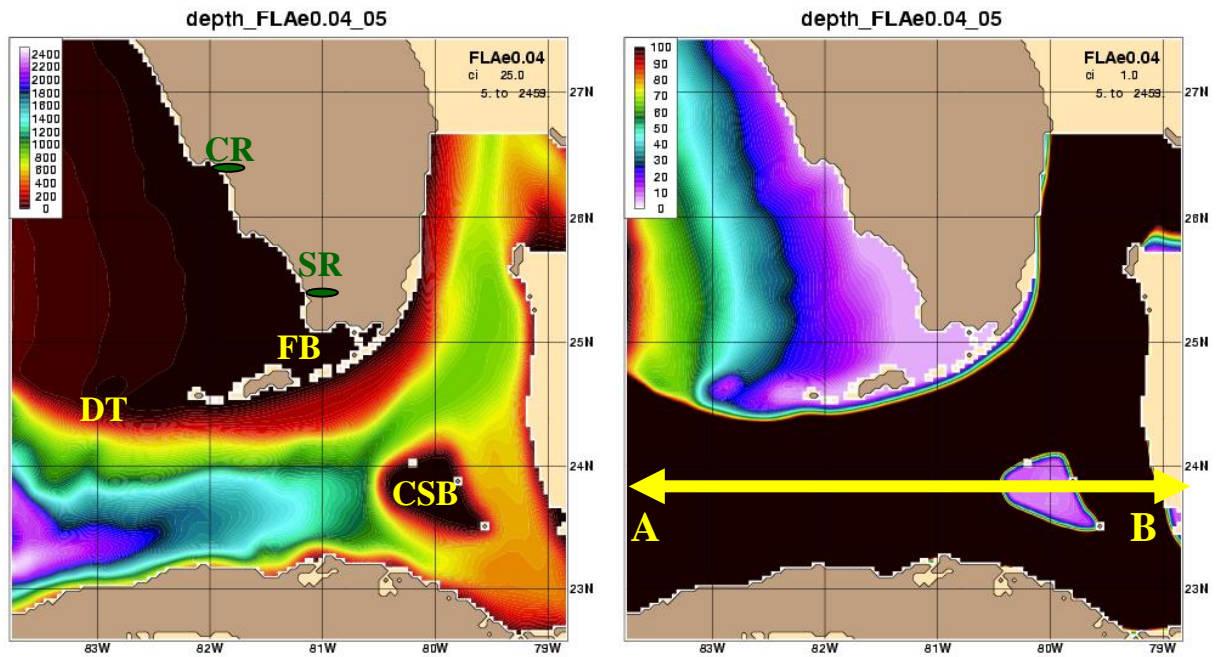
Figure 2: SoFLA-HYCOM bathymetry; details are shown for the deep (left) and shallow (right) depths. FB: Florida Bay; DT: Dry Tortugas; CSB: Cay Sal Bank; SR: Shark River; CR: Caloosahatchee River. The line AB is used in the cross-section of Fig. 3.

There are 4 distinct open boundaries of the domain (also marked on Fig. 1): the west Florida shelf to the north (west Florida coast), the Gulf of Mexico to the west, the Old Bahama Channel to the southeast and the NW Providence Channel to the east; the north boundary at the east Florida coast extends to the Grand Bahama island.

## Boundary conditions

The SoFLA-HYCOM domain has been nested within the NA-HYCOM (North Atlantic HYCOM) that has a resolution of 1/12 degree of latitude (~6-7 km grid size), minimum depth of 20m and includes the entire North Atlantic, the Caribbean and Gulf of Mexico, as well as global thermohaline circulation (through nesting within the global HYCOM). Two types of nesting have been implemented. First a double nest, where the SoFLA-HYCOM is nested within the IAS-HYCOM (Intra-Americas Sea) which has a 1/25 degree resolution and minimum depth of 10m. This setting was used for the climatological simulation and for sensitivity tests to assure the validity of the nesting procedure, since both IAS and SoFLA have the same resolution. The IAS nested runs also allowed the evaluation of improved flows simulated with SoFLA, due to the employment of detailed shallow topography and smaller minimum depth.

The final model set-up that is now used for the ongoing inter-annual simulation is a 1/25 degree SoFLA-HYCOM nested directly to the 1/12 degree NA-HYCOM. As mentioned above, the SoFLA-HYCOM resolves the Atlantic shelf along the Florida Keys reef tract and the major passages between the Florida Keys and Florida Bay. Furthermore, the SoFLA-HYCOM includes additional sources of freshwater inputs, namely the rivers on the Southwest Florida Shelf from the Shark River to the Caloosahatchee River, which are important sources of low salinity waters that can impact the water properties around and within Florida Bay, as well as the Florida Keys through the neighboring Keys passages.

## Simulations

### Climatological run

A long-term simulation has been completed with the nested configuration described above. The simulation is cyclic, using the same forcing each year. The employed perpetual year

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atmospheric forcing is from the European Center for Medium Range Weather Forecasting (ECMWF) and includes monthly mean fluxes of heat, precipitation and winds. In order to allow high frequency variability in the wind field, 6-hourly anomalies have been superimposed on the monthly mean fields, that were extracted from a "typical" (non El-Nino) year.
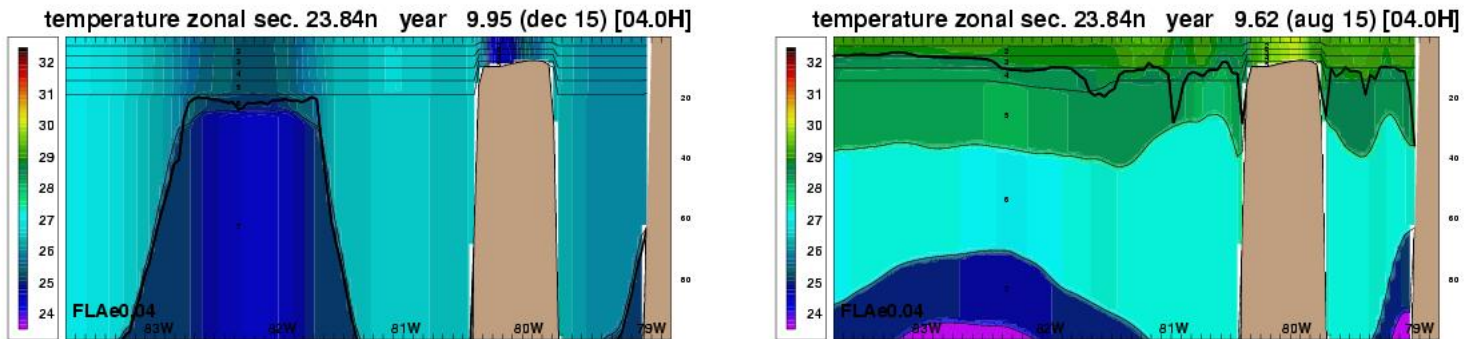


Figure 3: Model computed vertical temperature profiles along zonal section AB (marked in Fig. 2): (left) during summer (Aug 15); and (right) during winter (December 15). Thin lines mark the model layers and the thick line marks the model mixed layer depth.

The simulation shows the seasonal patterns in the circulation and water properties around the South Florida coastal areas. In particular, the salinity fields exhibit distinct differences between the "dry" (winter to spring) and "wet" (summer to fall) seasons, while the temperature field is dominated by seasonal changes in vertical stratification (Fig. 3), cold air outbreaks in winter and the passage of Florida Current eddies (Figs. 4 and 5). The Florida Bay domain, although not fully resolved in the regional model, exhibits reasonable patterns of salinity changes, as for instance the modification of the hypersaline conditions in the dry season caused by the influx of low salinity waters from the neighboring Southwest Florida shelf rivers.

The coastal flows are well resolved. A wind-driven flow along the Atlantic shelf of the Florida Keys that is southwestward (opposing the mean northeastward flow along the Florida Current

front) is evident in periods that are not dominated by eddy passages; this flow has been documented through drifter data and is absent from the larger scale IAS-HYCOM that does not include the shallow Keys topography.
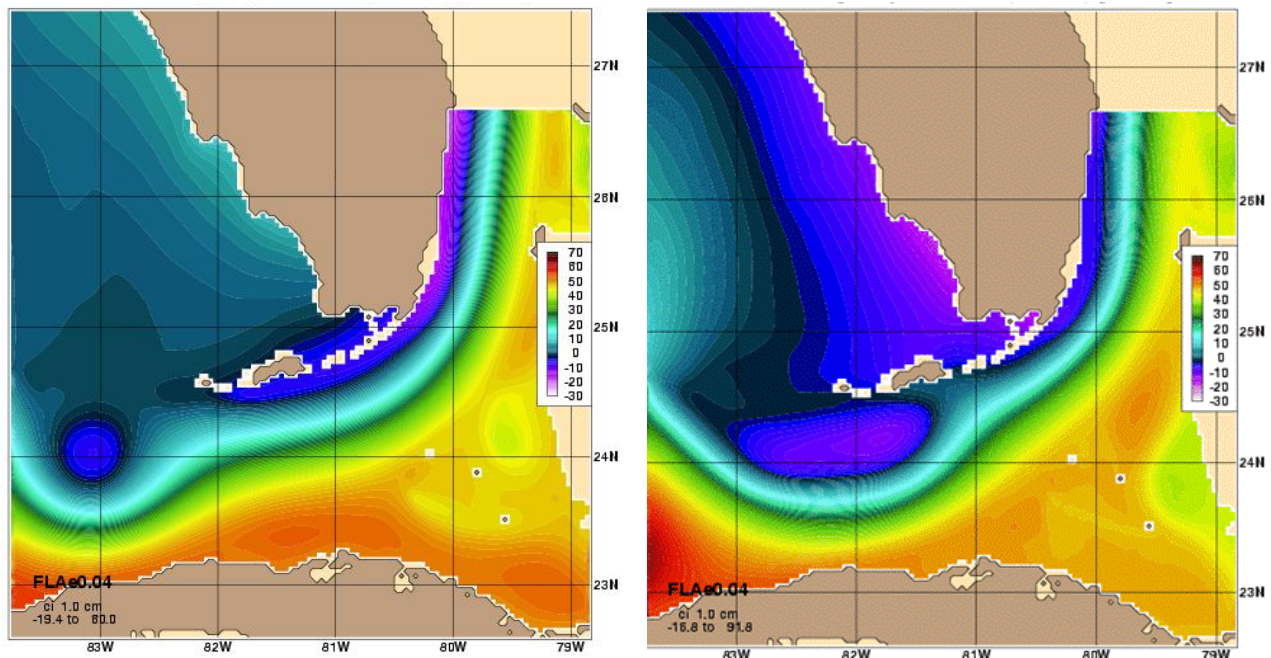


Figure 4: Sea surface elevation (scale in cm) during the formation of a Tortugas eddy (left) and eddy passage through the Straits of Florida (right).

Tracer experiments have been conducted with continuous release of passive tracers at different locations, to study the transport pathways around South Florida. An example is given in Fig. 6 from a release at the Dry Tortugas, that seeks to simulate prevailing recruitment pathways that larvae would be inclined to follow. When eddies are present, the tracer experiences higher rates

of retention and as the eddy enters the Straits of Florida and interacts with the Keys topography, there is evidence of tracer release on the Florida Keys reef tract and passage toward Florida Bay.
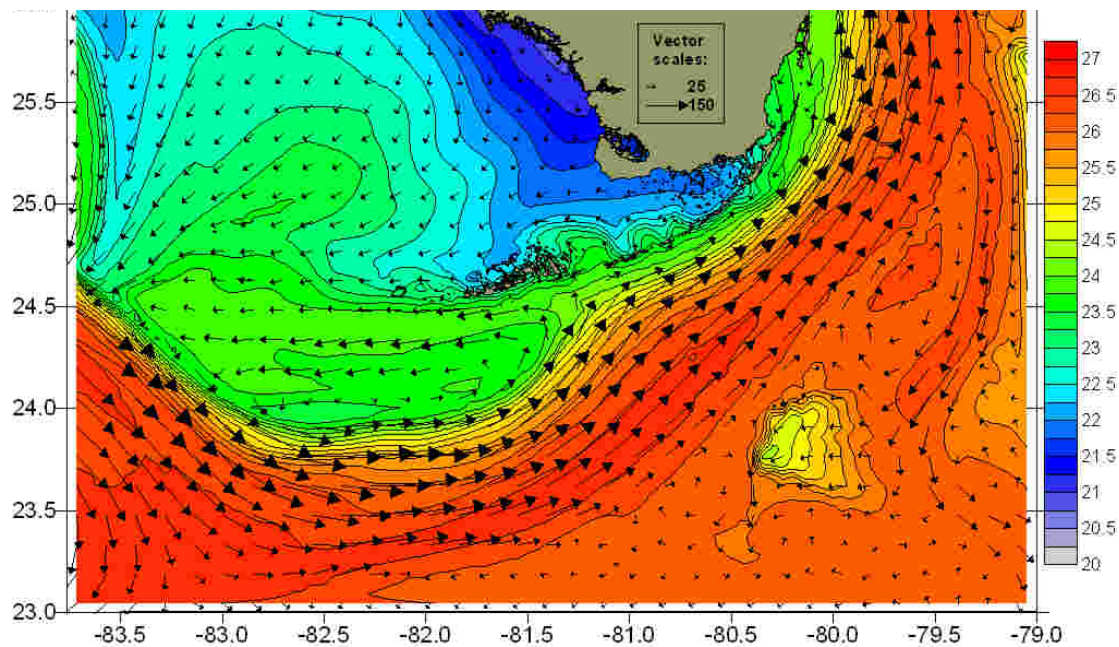


Figure 5: Near-surface temperature and current velocity (every 3ᵈ vector plotted; cm/s) during the passage of a mesoscale frontal eddy near the Florida Keys (see surface elevation field in Fig. 4). The model resolves temperature contrasts between cold shallow areas in and around Florida Bay and the warm Florida Current. Cool eddy waters are evident, circulating cyclonically inside the eddy, with clear intrusions toward the Keys passages; some warmer filaments within the eddy can be seen. The eddy was larger before entering the Straits of Florida and has begun to elongate as it is squeezed between the Florida Current and the Keys.
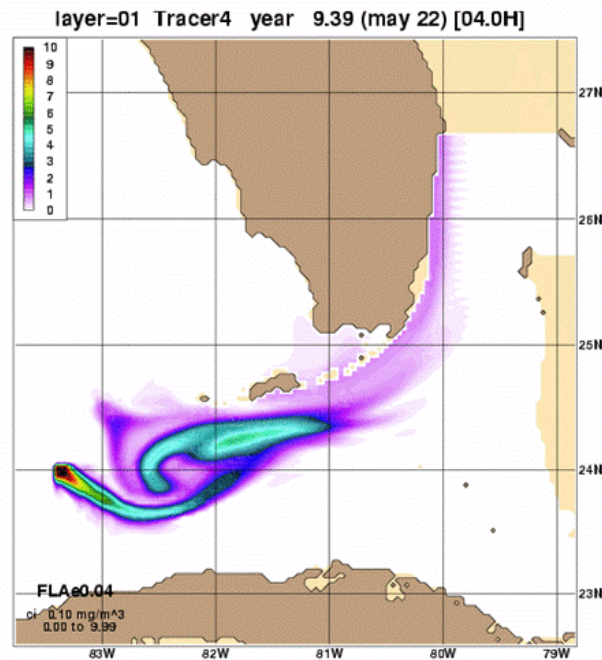
Figure 6: Tracer experiment showing recirculation by a mesoscale eddy and the westward flow along the Keys shelf that allows the tracer to be advected against the dominant Florida Current mean flow (May 22); the transport through the Keys passages and into Florida Bay is evident.

The SoFLA-HYCOM model computed fields of monthly averaged currents, sea elevation, salinity and temperature have been incorporated in the comprehensive GIS-based decision support system for the Florida Keys and reef tract. The system is a centerpiece of the work by the National Caribbean Coral Reef Institute (NCORE, http://www.ncoremiami.org/GIS/GIS_Main.htm) and it includes layers of socioeconomic

parameters, vegetation and habitat, legal and administrative boundaries, atmospheric and oceanographic data, among others. Results from the present study are adopted by NCORE to provide visualization and management tools for the Florida Keys reef tract.
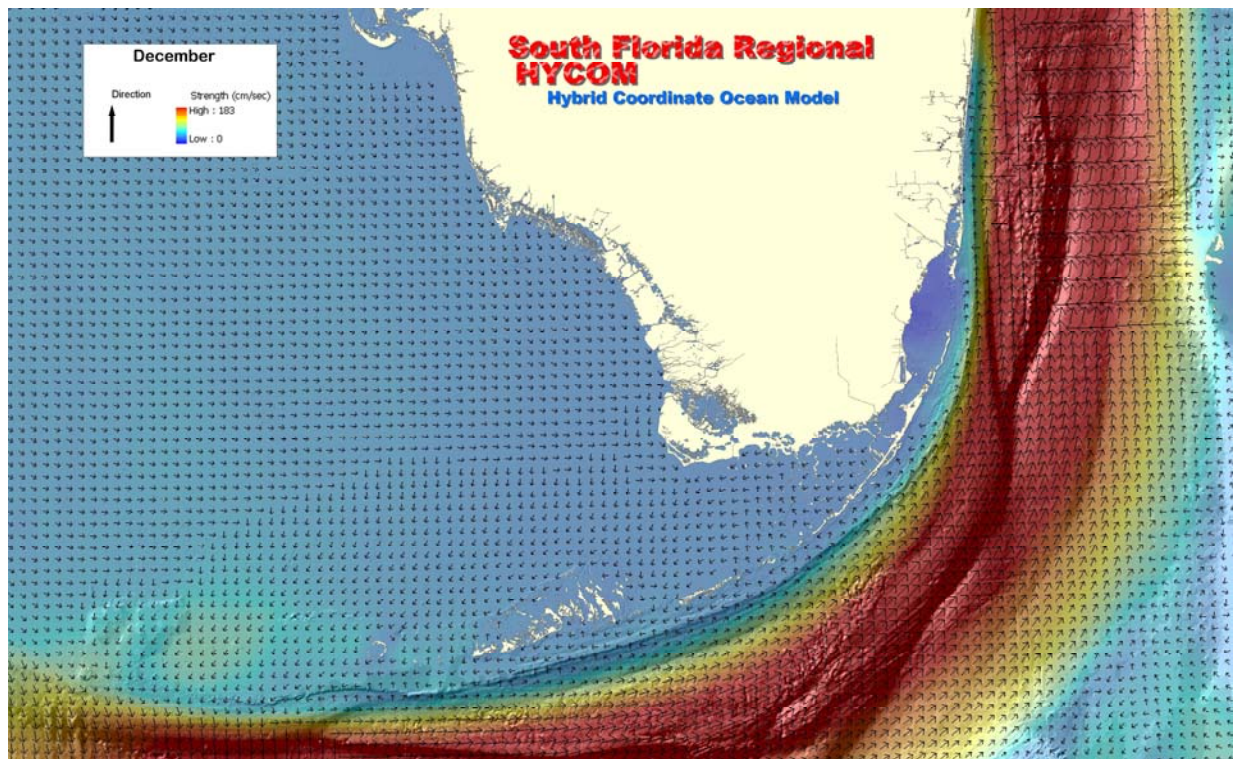


Figure 7: Model computed vertically averaged current layer of the GIS-based multi-layer management tool for the Florida Keys (monthly averaged for December); current direction in arrows, current strength in color.

Monthly mean climatological currents are overlaid on GIS topography to show topographic steering of mean currents. By overlaying the predictions of the nested simulation to a highly

accurate GIS surface topography, the mean flow patterns around the shallow Florida Keys and the reef tract can be better understood and interpreted by marine conservationists and park managers. An example is shown in Fig. 7 for the mean December current. The flow within the Straits of Florida is dominated by the Florida Current front, while, along the Keys, opposing coastal currents are directed southwesterly. Influences from the west Florida shelf through Florida Bay are evident through the Keys passages.

*Inter-annual run*

An inter-annual simulation is currently in progress, with the same 1/25 degree SoFLA-HYCOM configuration described above, but with boundary conditions from the 1/12 degree North Atlantic and Gulf of Mexico NA-HYCOM. The NA-HYCOM inter-annual run has been started from the multi-year climatological NA-HYCOM simulation at year 1999 with high-frequency atmospheric forcing from the Navy Operational Global Atmospheric Prediction System (NOGAPS). A careful evaluation of the wind forcing has been performed for the SoFLA-HYCOM region, by comparing time series of NOGAPS winds with measured values at C-MAN stations (Coastal-Marine Automated Network of the NOAA/National Buoy Center).

River discharge data for the Southwest Florida shelf rivers have been incorporated and salinity data have been employed to evaluate the model computed salinity patterns. Data for river inflows have been supplied by the U.S. Geological Survey, through an ancillary project with the South Florida Water Management District. The salinity data are from the long term bi-monthly surveys of South Florida hydrographic properties aboard the UM/RSMAS R/V Walton Smith (NOAA/AOML and UM/RSMAS collaboration under the NOAA South Florida Ecosystem Research and Monitoring Program (http://www.aoml.noaa.gov/sfp/). The surveys last about 10 days and cover the Atlantic Florida Keys shelf, the southwest Florida shelf from the Florida Bay entrance to the Caloosahatchee River and extending offshore to the Dry Tortugas area. The data have been employed for validation of model results.

The seasonal variability in salinity for the Southwest Florida shelf area that is in the immediate vicinity of the riverine inputs is depicted in Fig. 8. The monthly mean salinity over a subset of the model area that coincides with the monitoring sampling area is shown. The results from three years are employed (2000-2002) and a distinction between "wet" and "dry" seasons is apparent: salinities are generally highest in April-May and lowest in September-October. Furthermore, it is obvious from Fig. 8 that the overall salinity was highest in 2000 and lowest in 2002, reflecting inter-annual variability. The data derived salinity patterns (not shown) confirm that the year 2002 was generally "dry" as compared to a "wet" year 2000.
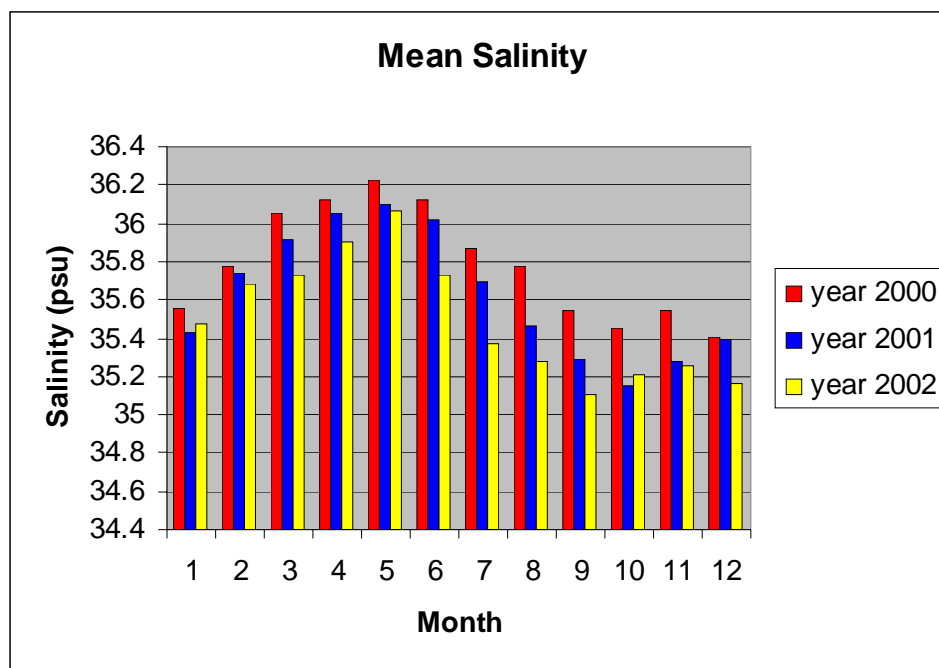


Figure 8: Model computed monthly mean salinity over an area sampled by the R/V Walton Smith showing a pattern of wet (summer) and dry (winter) seasons over three years (2000 to 2002).

An interesting process in the model is the simulation of salinity changes around the South Florida coastal areas and in the Straits of Florida through intrusions of substantial volume of low salinity waters that are of Mississippi origin. This is an important process that is included in the SoFLA-HYCOM simulations through the boundary conditions that are influenced by Gulf of Mexico circulation and water properties. Such intrusions are more frequent during the summer months, in accordance with observational findings. Interdisciplinary studies suggest that intrusions of Mississippi River waters have important implications on water quality for the South Florida coastal ecosystems.

## Summary

A comprehensive three-dimensional hydrodynamic ocean circulation model has been developed for the South Florida coastal system that includes Florida Bay, the Florida Keys reef tract and the Southwest Florida shelf. The South Florida (SoFLA) adaptation of the Hybrid Coordinate Ocean Model addresses the complex dynamics of this region and the intense coastal to offshore interactions through nesting with larger scale models of the North Atlantic and the Intra-Americas Sea. Important results include the effect of remote sources of low salinity waters reaching the Florida Keys, the prevailing northeastward Florida Current, the wind-driven southwestward flow along the Florida Keys shelf, the passage of eddies between the Florida Current front and the reef tract and the influence of rivers and weather systems on the Southwest Florida shelf and Florida Bay. Preliminary model validation with data shows reasonable agreement. Model results are provided to support modeling efforts in Florida Bay, associated with the Everglades Restoration Project. Modeling activities in the Florida Keys can also be supported by the SoFLA-HYCOM; an example is the incorporation of the model computed circulation patterns in a GIS-based decision support system for the Florida Keys reef tract.

# REFERENCES

Kourafalou, V.H., R.S. Balotro and T.N. Lee (2005). The SoFLA-HYCOM (South Florida HYCOM) Regional Model around the Straits of Florida, Florida Bay and the Florida Keys. UM/RSMAS Tech. Rep. 2005-03, 28 pp.

# ACKNOWLEDGEMENTS