Understanding Florida Bay Hypersalinity and Water Exchange

Nelson Melo[1], Thomas N. Lee[2], Elizabeth Johns[3], Ryan H. Smith[3], Chris Kelble[1] and Peter B. Ortner[2]

1 Cooperative Institute for Marine and Atmospheric Studies, U. of Miami, Miami, FL; 2 Rosenstiel School of Marine and Atmospheric Science, U. of Miami, Miami, FL; 3 NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, FL, USA

The Problem

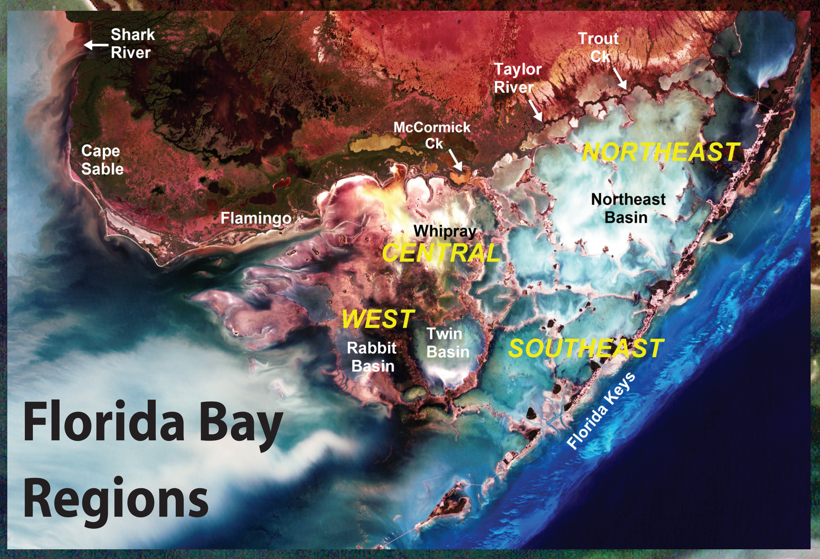
Florida Bay is made up of a collection of shallow basins separated by mud banks and mangrove islands lying at the receiving end of the Everglades discharge between the Florida mainland and the Florida Keys. Alteration of Everglades flow has led to reduced water delivery to Florida Bay and elevated salinities, especially in the north-central region of Whipray basin where extreme hypersalinity can develop with concurrent sea grass die-off and water quality degradation and potential downstream impacts on Florida Keys coral reef ecosystems.

The Question

How and at what rate do storms, changing fresh water flows, sea level rise and local evaporation-precipitation patterns influence circulation and salinity patterns within Florida Bay and exchanges between the bay and adjacent waters ?

Proposed Research Objectives

Multi-institutional study to resolve the volume and salt transports in Florida Bay. Compute volume transport, salt balances and resident times in the Bay.



Florida Bay Regions

The basins are separated from the southwest Florida shelf waters by 9-Mile Bank to the west and from the southeast sub-region of Florida Bay by Twin Key Bank. To the north lies a broad bank region separating the basins from the north-central region of the bay where hypersalinity is commonly observed during dry seasons.

Instrumentation

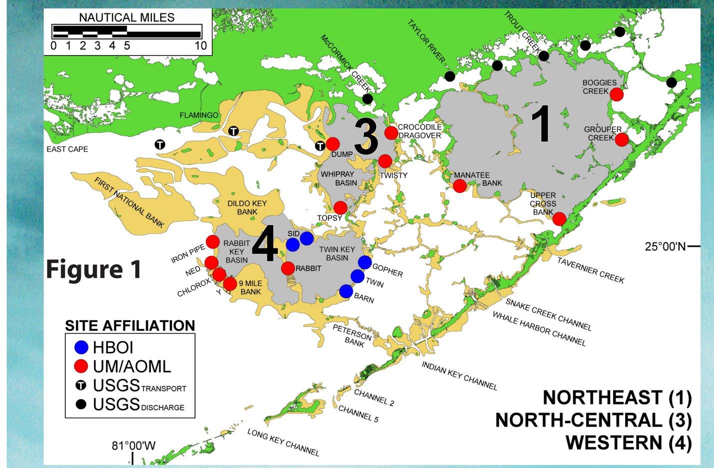
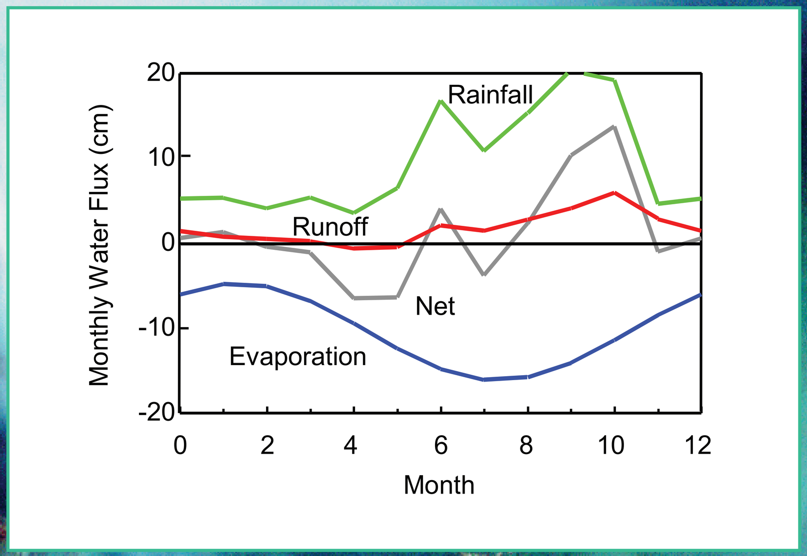


Figure 1

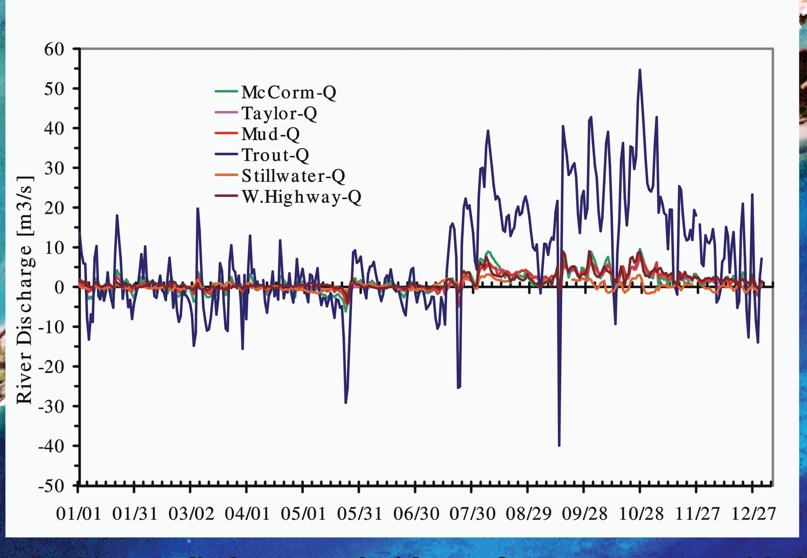
Figure 1. Moored instrumentation sites from recent studies of the inner basin circulation and exchange processes in sub-regions of Florida Bay. Also shown are USGS transport and river discharge measurement stations.

We have recently (2001 - 2005) conducted observational studies of water exchange and salinity variability within the north-central, northeast and western regions of Florida Bay (Fig. 1) to better understand the important physical processes and to provide flow and salinity data to aid development and calibration of the bay hydrodynamic model.

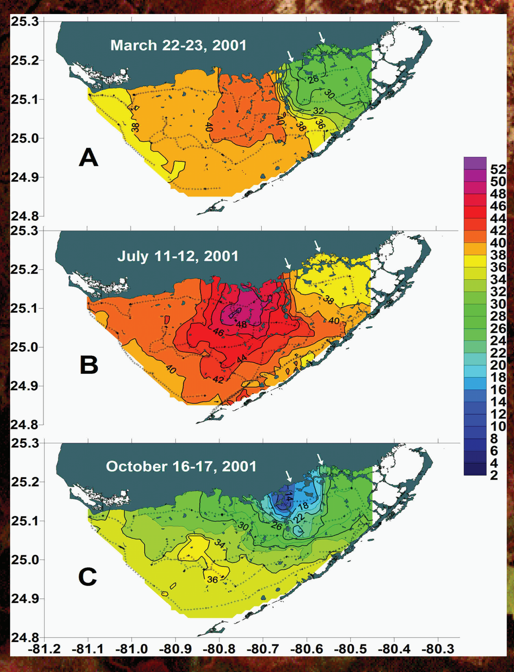
High resolution spatial salinity surveys were made at approximately 2 week intervals over the study period and sea level measurements were made continuously throughout both seasons.



Monthly average fresh water fluxes to Florida Bay from long-term measurements (from Nuttle et al., 2005).

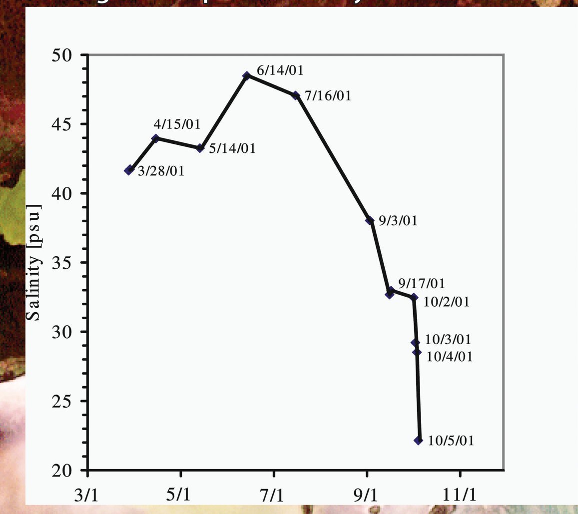


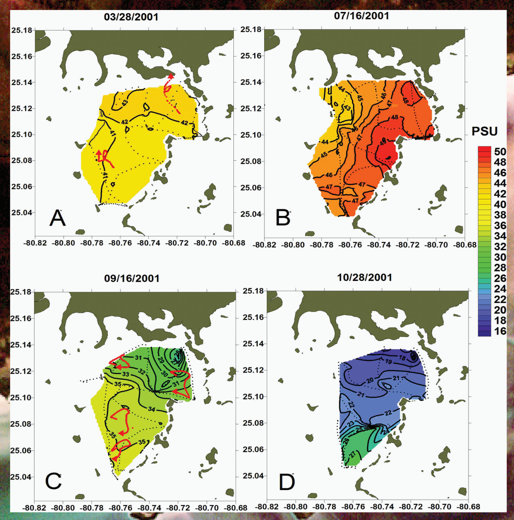
Daily average fresh water discharge to Florida Bay for 2001. Data provided by U.S Geological Survey, South Florida Ecosystem Program, Information Access Site (USGS, 2005).



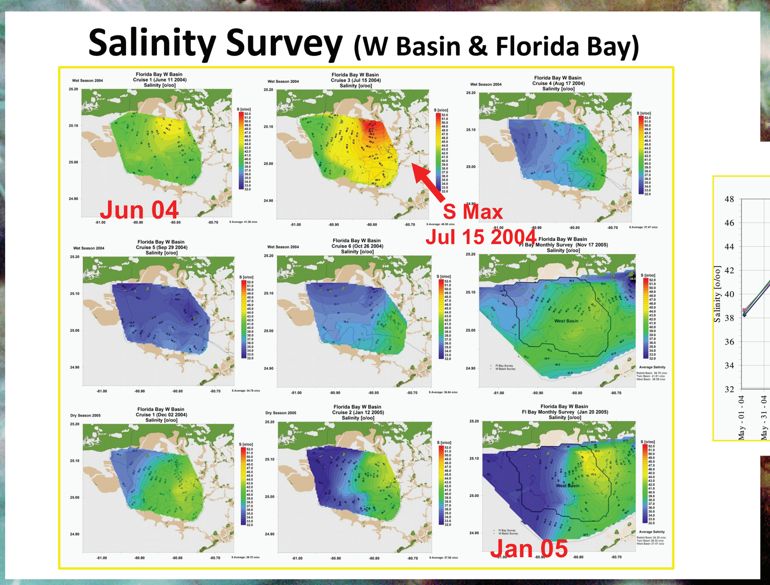
Florida Bay surface salinity from 2001 monthly surveys of the R/V Virginia K using continuous underway measurement for:
A) March 22-23 dry season;
B) July 11-12 near the end of the dry season;
C) October 16-17 wet season.

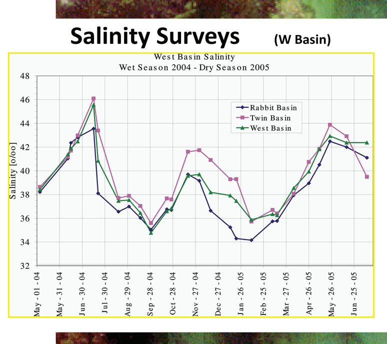
Time series of basin average salinity for WB during dry and wet seasons of 2001 from R/V Virginia K spatial surveys.



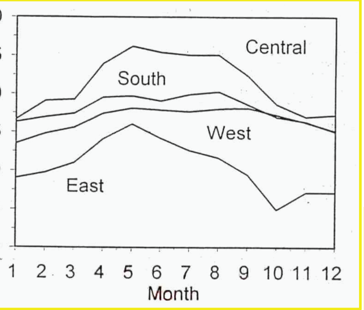


WB surface salinity from high-resolution surveys of the R/V Virginia K using continuous underway measurement for:
A) Mar. 28 dry season;
B) Jul. 16 near the end of the dry season;
C) Sept. 16 wet season;
D) Oct. 28 near the end of wet season 2001.
Vessel track shown with dotted line. Surface drifter trajectories shown with red arrows.

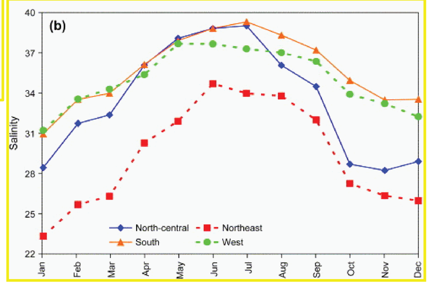




Seasonal cycle of monthly average salinity for the four regions of Florida Bay



from Nuttle et al., 2000
31 year data

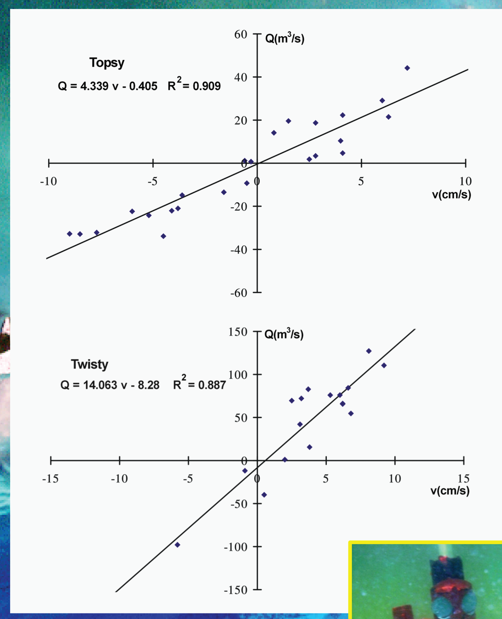


from Kelble et al., 2006
7 year data

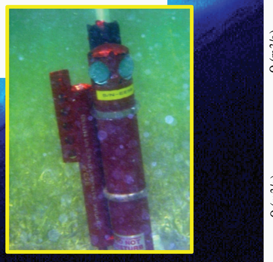
$$Q'_i = (\partial S_{WB}/\partial t + S_o R')/(S_i - S_o)$$

Terms used in the salt balance model for estimating the fractional rate of volume exchange (Q'i)/mo and water renewal time (T) for WB during dry and wet seasons 2001.
$Q'_i = Q_i/Vol$; $R = r + P - E$; $R' = R/Vol$; Vol = Whipray Basin mean volume.

Season	$\partial S_{WB}/\partial t$ (mo^{-1})	R' (mo^{-1})	S_i	S_o	Q'_i (mo^{-1})	T (mo.)
Dry	2.6	-0.078	42.7 to 41.7	44.69	0.44 to 0.3	2.3 to 3.4
Wet	-5.8	0.22	28.38	32.65	-0.32	3.1

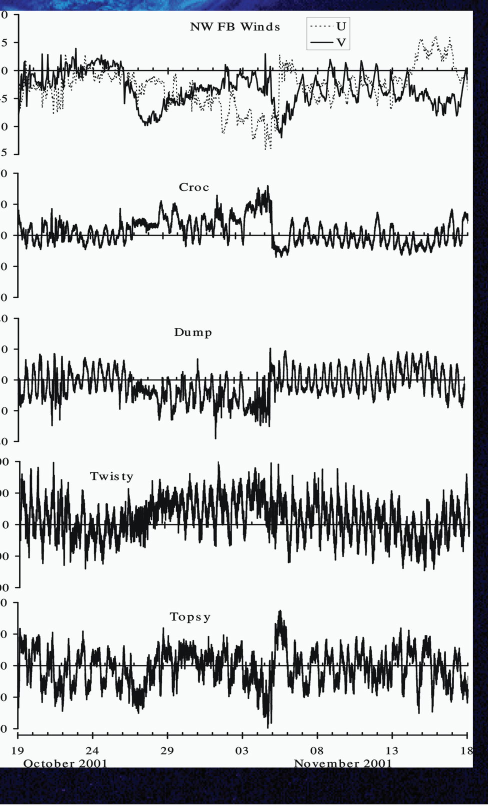


Linear regression of along-channel currents against volume transport measured with shipboard ADCP transects across the current meter sites at Topsy (top) and Twisty (bottom) transects during the wet season of 2001. Regression relationships used to convert current to transport and the squared correlation coefficient are shown.

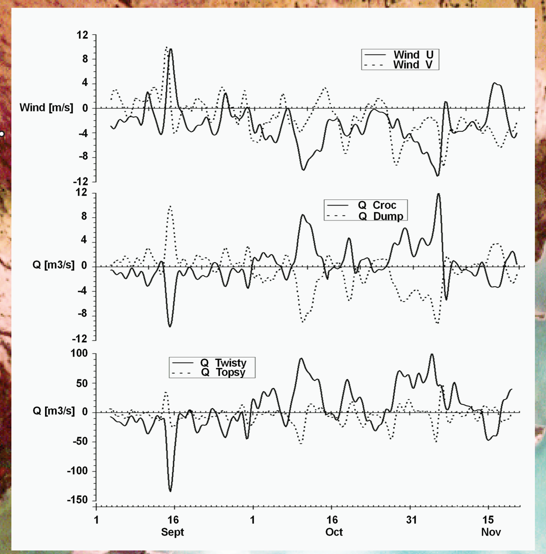


Channel Volume Transport
Wet Season 2001 (W BasinFl Bay)

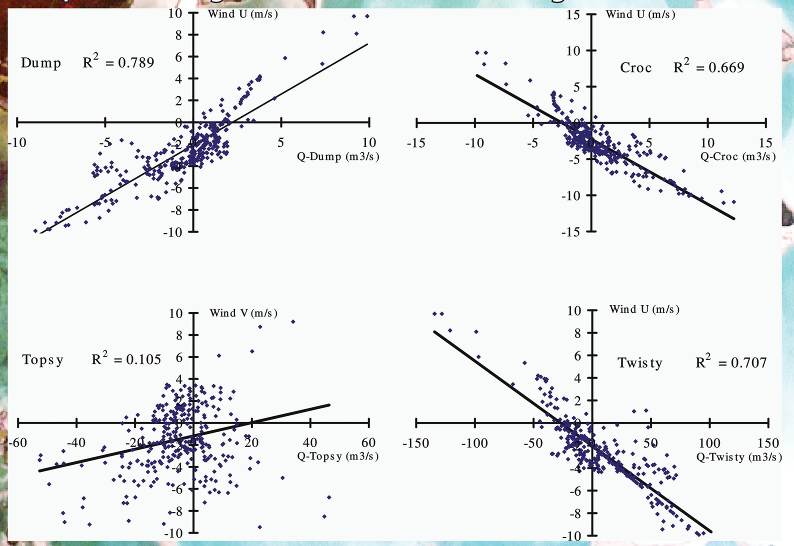
3 hour low-pass filtered volume transports derived for the major flow channels to WB Positive values are inflows and negative are outflows. Also shown are east-west and north-south wind components from the NWFB SeaKeys site.

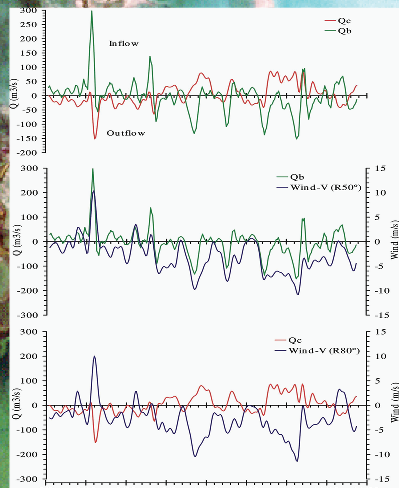


40 hour low-pass filtered NWFB wind components and volume transports through WB flow channels during wet season 2001. Positive values are inflows and negative are outflows.



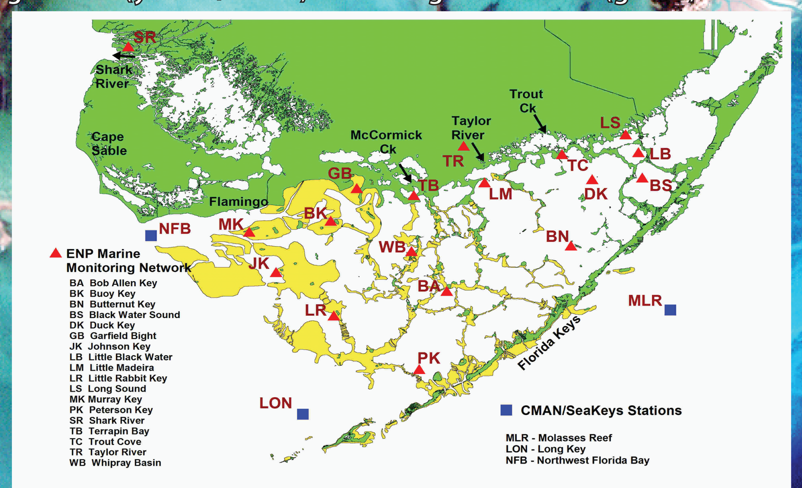
Linear regression between subtidal time series of east-west wind and transports through WB flow channels during the wet season 2001.

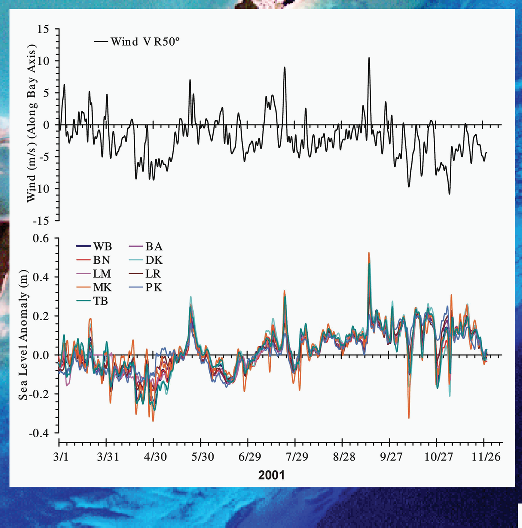




Wet season 2001 subtidal time series of the total channel flow (Qc) and total bank flow (Qb) (top panel); total bank flow plotted with along-axis winds (middle panel); and total channel flow plotted with winds rotated 80deg (bottom panel).

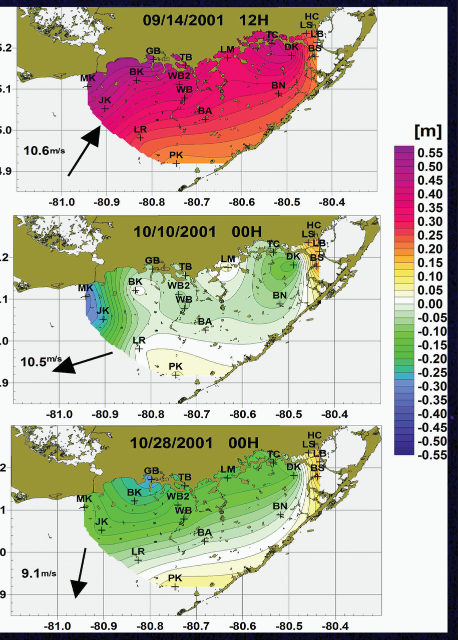
Location of ENP marine monitoring stations in Florida Bay (triangles), CMAN/SeaKeys wind stations (squares), and the location of fresh water discharge points (arrows) superimposed on the bays bank/basin configuration (yellow/white) and mangrove islands (green).



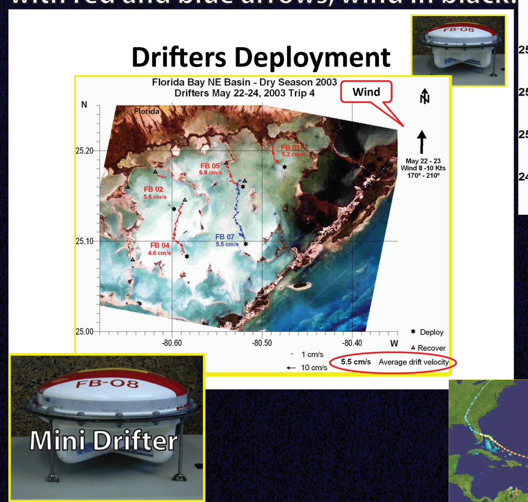


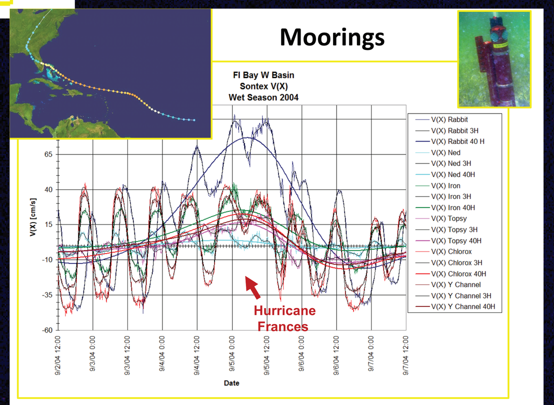
Subtidal sea level time series from selected stations of the ENP monitoring array and winds for the NWFB SeaKeys station, rotated 50° into along-bay axis (along-axis winds = toward 50°)

Gridded and Contoured Sea Level Fields derived from the ENP monitoring array for fall 2001 wind events.
Winds from the NWFB SeaKeys station are shown with black arrows.



Drifter Deployment
The drifter trajectories are shown with red and blue arrows, wind in black.





Transport Anomaly during Hurricane Frances in the Channels of the West Basin Florida Bay

Results

Physical data for the Central Basin and values for annual water balance model during wet and dry seasons of 2001.

Mean depth (m)	Surface area (km²)	Mean volume x 10^6 (m^3)
0.65	86.9	56.55

Seasonal and Annual Water Balance Model in m^3/s

$$Q_T = Q_w + Q_g + r + P + E$$

(Wind transport, Ground water inflow, River discharge, Precipitation, Evaporation, Total Transport)

	Q_w	$+Q_g$	$+r$	$+P$	$+E$	=	Q_T
Dry	0.8	1.65	-0.5	3.07	-4.25	=	0.77
Wet	-0.07	-4.67	3.5	4.81	-3.64	=	-0.07
Annual average	0.36	-1.51	1.5	3.94	-3.94	=	0.35

Conversion: 1 m^3/s = 2.98 cm/mo.

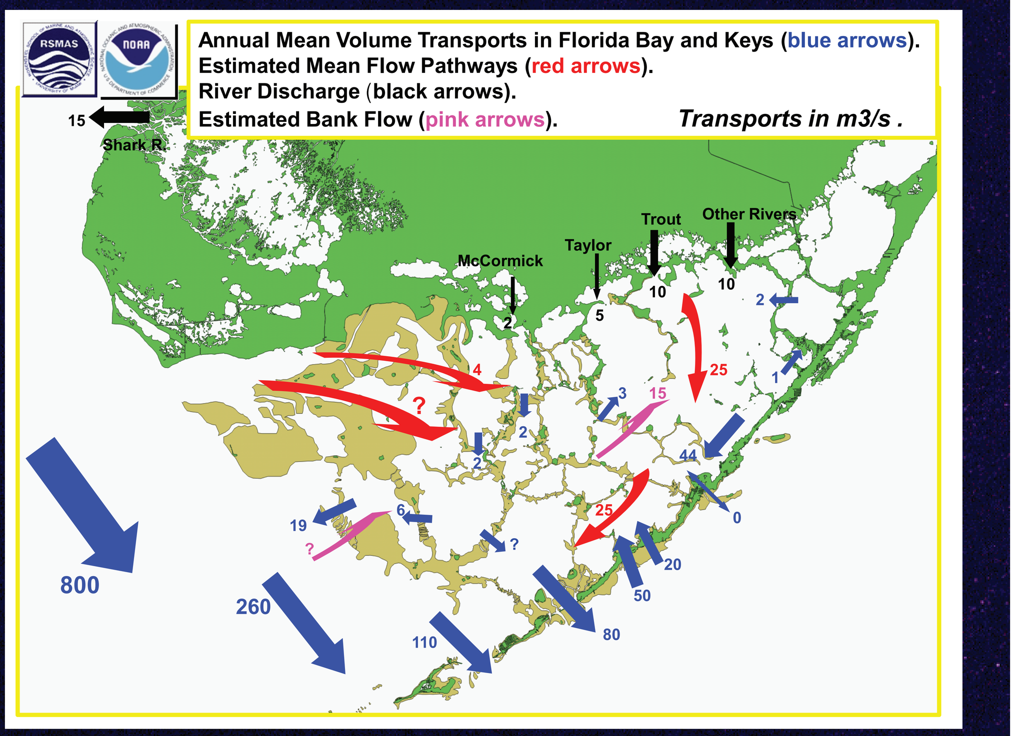
Seasonal and annual means of Total Transport (Q_T) from Central Basin sea level monitoring data, total measured channel transport (Q_c) and residual bank transport (Q_b) from
$Q_b = Q_T - Q_c$ in m^3/s for 2001.
[Mean volume of Central Basin is 56.55 x 10^6 (m^3).]

Transport	Dry Season	Wet Season	Annual Mean
Q_T	0.8	-0.1	0.4
Q_c	-10.48	3.2	-3.6
Q_b	11.2	-3.3	3.9
Basin Renewal Time (months)	2.1	6.8	6.1

Seasonal and annual means of Total Transport (Q_T) from NE Basin volume anomalies data, total measured channel transport (Q_c) and residual bank transport (Q_b) from
$Q_b = Q_T - Q_c$ in m^3/s
for 2002.
[Mean volume of NE Basin is 4.41 x 10^8 (m^3).]

Transport (m^3/s)	Wet Season	Dry Season	Annual Mean
Q_T	5.3	1.8	3.6
Q_c	-32.7	-77.8	-55.2
Q_b	38.8	79.6	58.8
Basin Renewal Time (months)	4.8	2.2	3.0

Florida Bay Transports



Conclusions

In the Central Basin 2001:

- Dry Season - eastward winds produce mean through-flow of 11 m^3/s and basin renewal times of 2-3 mo.
- Wet Season – westward winds cause mean through-flow of 3 m^3/s and basin renewal times of 6-7 mo.
- Flushing time for complete water renewal ~= 6-12 mo.

In the NE Basin 2002-2003:

- Dry Season - eastward winds produce mean through-flow of 31 m^3/s and basin renewal times of 5.5 mo.
- Wet Season – westward winds cause mean through-flow of 13 m^3/s and basin renewal times of 12 mo.
- Flushing time for complete water renewal ~= 6-12 mo.

Water renewal and residence times in Florida Bay are primarily controlled by local wind forcing.

- Hypersalinity development in north-central Florida Bay results from reduced fresh water inputs during the dry season coupled with poor exchange with surrounding regions.
- Hypersalinity development in Fl. Bay could be regulated by redirection of a portion of Everglades flow to Whipray Basin via McCormick Creek during the dry season.