Using ROMS to Study Storm Impacts on Coastal Circulation
in Long Bay, South Carolina, USA

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1. Background

The United States eastern border is prone to many storm activities due to its geographic setup combined with the Jet Stream dynamics. Based on a study of cyclogenesis occurrences for a 4-decade period from 1958 to 2000 (Bradbury *et al.*, 2003), almost 50% of the total occurrence took place in the South Carolina coast (Fig.1). In a recent study, however, it is expected not only the number of occurrence but also its strength will grow.

This heavily-developed coastal region supports a large tourism industry. Local economies are often adversely impacted by damage and loss of property due to coastal erosion and storm events. Hence, beach re-nourishment is important for mitigating coastal erosion in the region, and its success and coast depend on the availability of quality and resources.

It is reported in Atkinson *et al*. (1983) and Lee *et al*. (1985) that rates and pathways of sediment transport on the inner shelf of Long Bay are influenced by local winds associated with the passage of storms. This study is motivated to assist decision makers in mitigation of property damages and losses and management of coastal resources (1st ***motivation)***. The 2nd ***motivation*** is derived from a discovery of a large sand deposit at 4.5 km off Myrtle Beach, during the South Carolina Coastal Erosion Study (Hansen, 1998). This sand bar is an elongated shape in a dimension of 10-km long, 20-km wide and about 3-m thick (Fig. 2). Analysis of sediment grab sampling taken from the Study has indicated the feature is dated 10,000 years (Holocene).

The ***objectives*** of this study are:

A. Understand the primary processes leading to coastal change in Long Bay, SC

B. Quantify interactions between the underlying geological and physical processes that result in coastal erosion and shoreline change, and the mechanisms responsible for maintaining the offshore feature

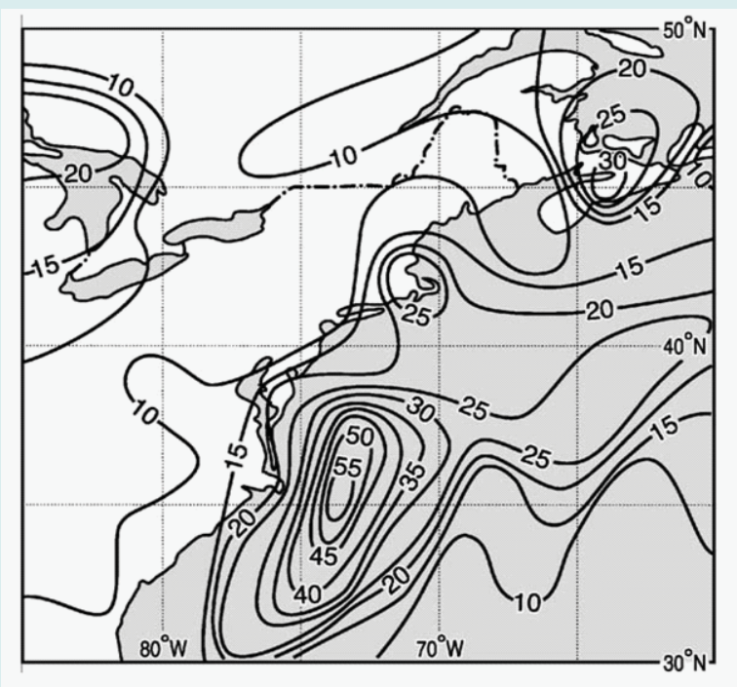


Figure 1. Total cyclogenesis occurrences (1958-2000) along the northeastern coast of the United States (Bradbury et al., 2003)

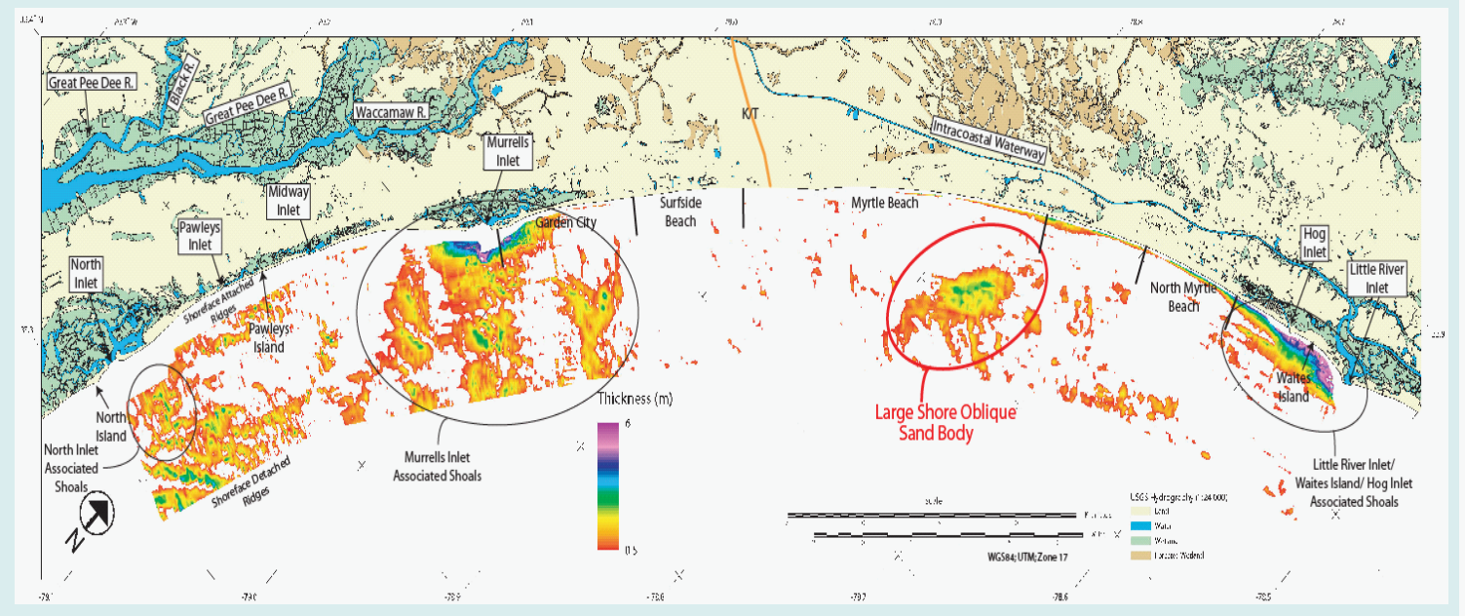


Figure 2. The thickness of Holocene sediment as defined through seismic profiles. Sediment thickness ranges from 0.5 (orange) to more than 6 meters (purple), and the thickest deposits are near tidal inlets. An exception is the sand bar 4.5-km offshore of Myrtle Beach.

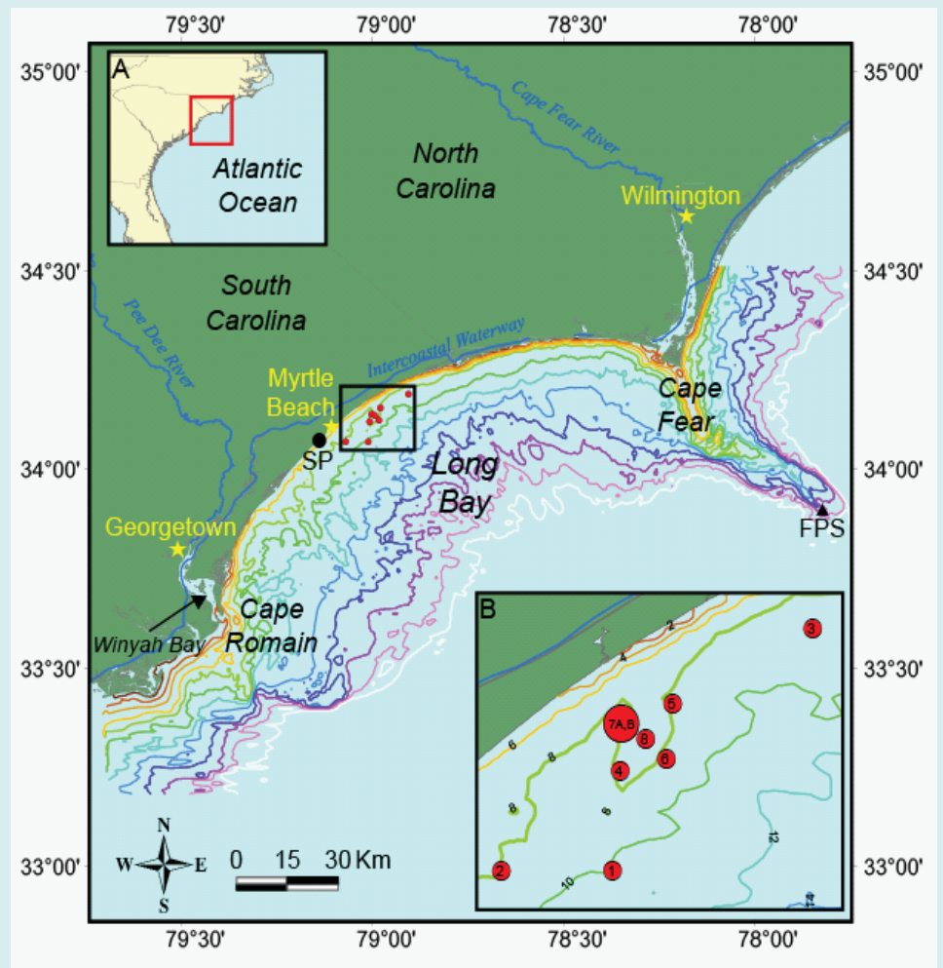


Figure 3. The Long Bay, South Carolina, study area: Eight mooring sites are in solid red dots. Site 8 is at the middle of a shore-oblique sand bar. Superimposed are bathymetric contours at 2-m intervals.

2. Field Study

A data collection was conducted for approximately 6-month from October 2003 to April 2004, in the inner shelf of Long Bay, South Carolina (Fig. 3). Specific measurements are:

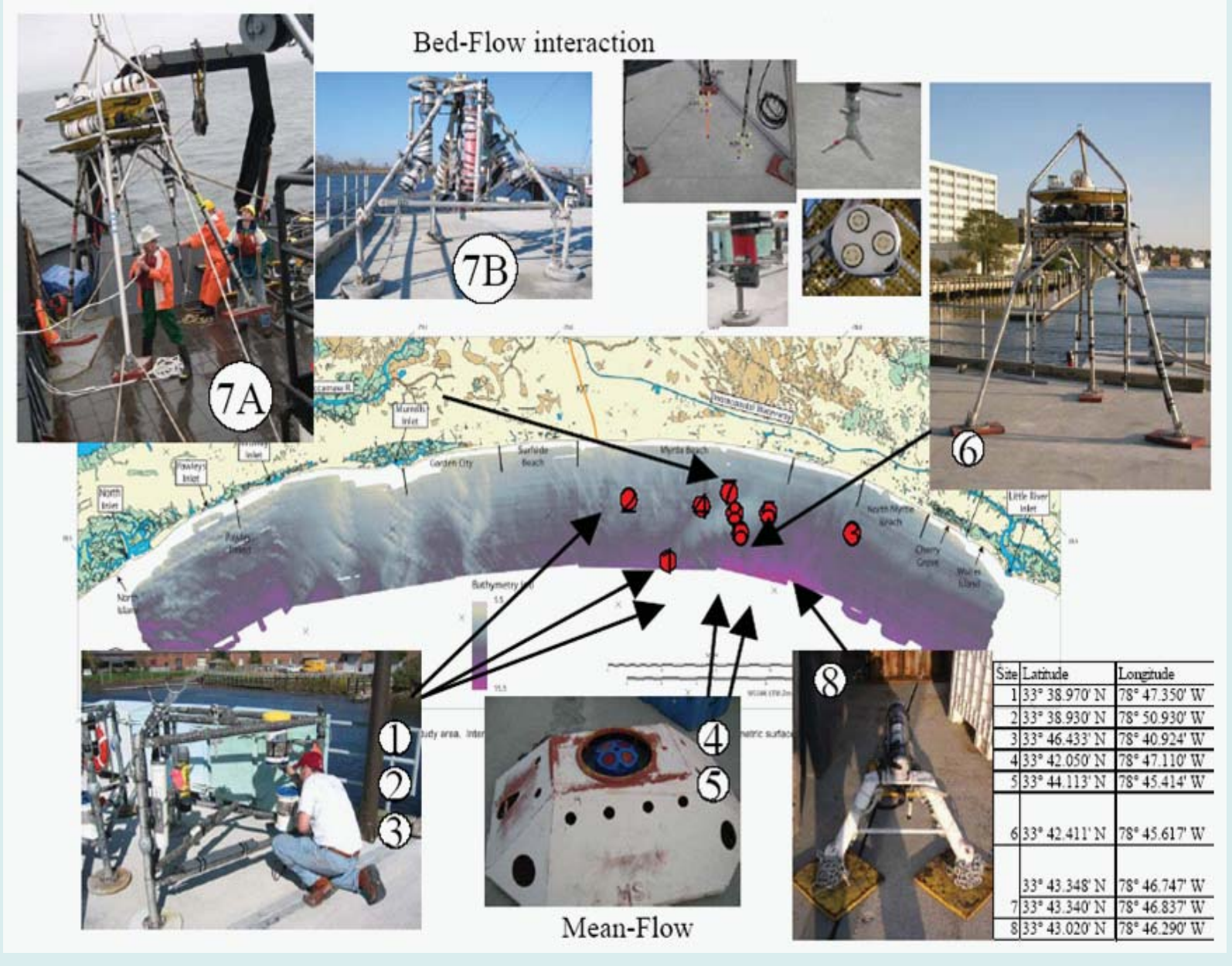
- Pressures
- Surface waves
- Currents
- Temperature & Salinity
- Suspended sediment concentrations (SSC)
- Sea floor bedforms

Moorings and Instruments (Fig. 4) – ADCP, Sea-Bird SEACAT, MicroCAT, Acoustic Doppler Velocimeter, Pulse-Coherent Acoustic Doppler Profiler, OBS, ABS, Rotating Sonar, and pressure sensor.

Deployment periods:

1. October 2003 – December 2003
2. January 2004 – April 2004

In addition,
Tides data from NOAA/NOS CO-OPS tidal stations;
Meteorological data from NOAA NDBC buoys - FPSN7 and 41013



Site	Latitude	Longitude
1	33° 38.970' N	78° 47.350' W
2	33° 38.930' N	78° 50.930' W
3	33° 46.433' N	78° 40.924' W
4	33° 42.050' N	78° 47.110' W
5	33° 44.113' N	78° 45.414' W
6	33° 42.411' N	78° 45.617' W
	33° 43.348' N	78° 46.747' W
7	33° 43.340' N	78° 46.837' W
8	33° 43.020' N	78° 46.290' W

Figure 4. Mooring locations and sets of images of tripods with a variety of oceanographic instruments. A set of pictures in the upper portion is designed to measure bed-flow interactions, and in the lower portion to observe mean-flow.

3. Time series of data

Response to a large scale weather system

3 major different types of storms in the study area (Austin and Lentz, 1999):

1. Tropical storm ("T" & shaded in yellow)
2. Cold front ("C" & shaded in blue)
3. Warm front ("W" & shaded in pink)

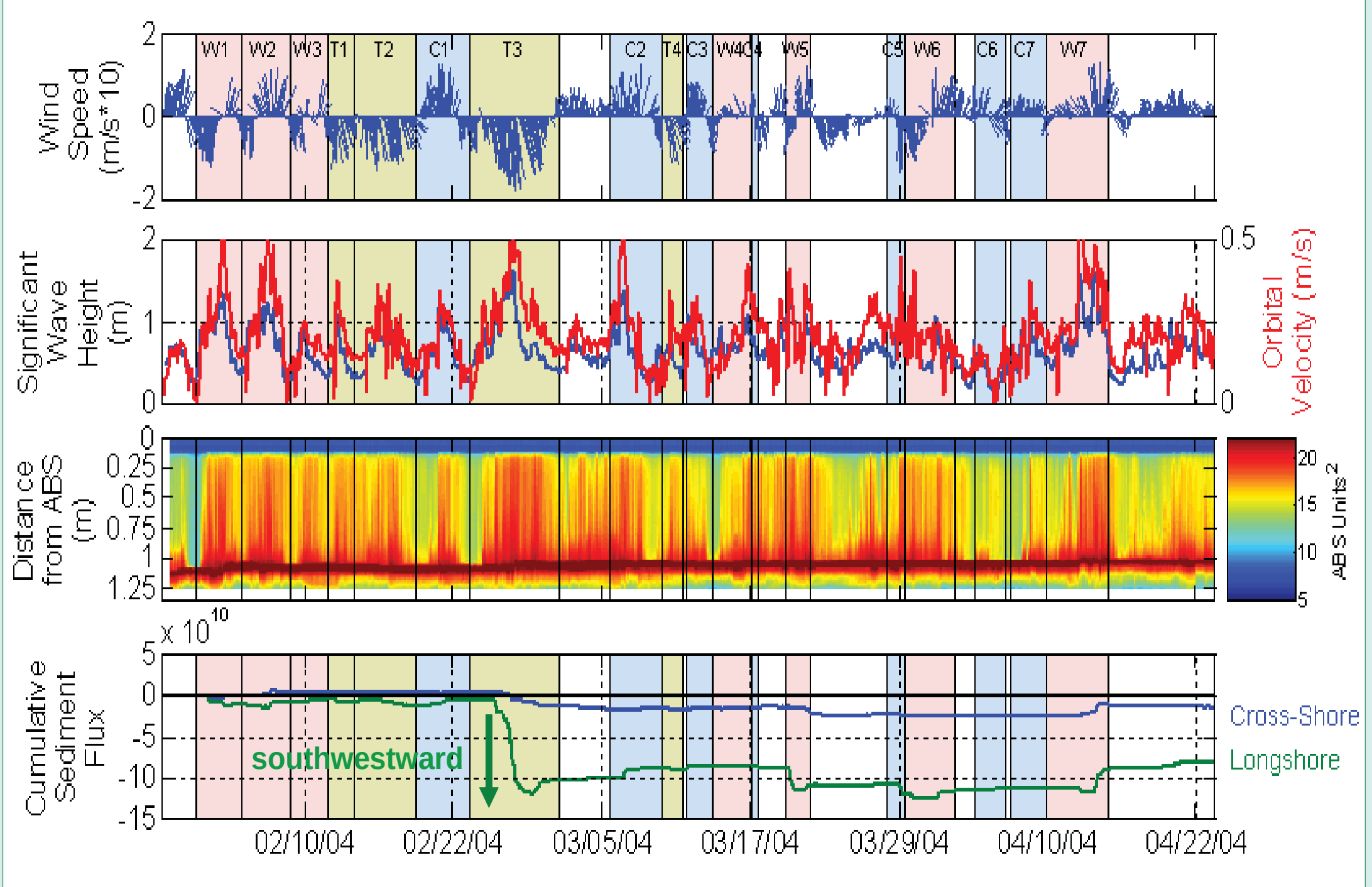


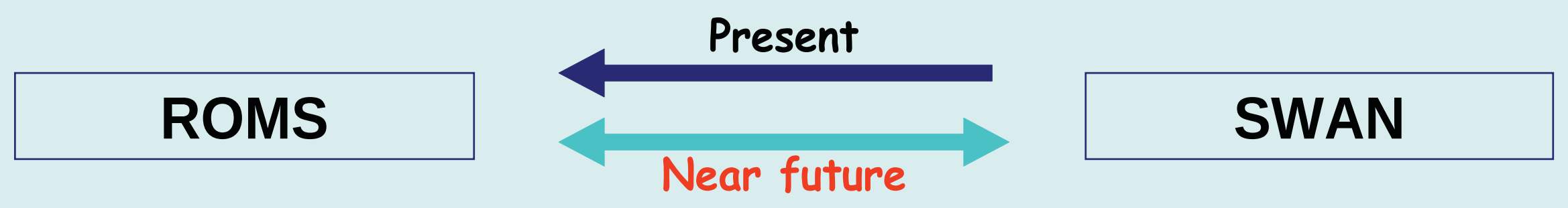
Figure 4. observations from February 2 to April 24, 2004: Wind at FPSN7 in the 1st panel; Significant wave height (blue) and Orbital velocity (red) in the 2nd panel; Uncalibrated suspended sediment concentration (SSC) in the bottom 1-m layer in the 3rd panel; Cumulative sediment flux (m^3/hr) in the cross-shore (blue) and along-shore (green) directions. Vertical partitions in each panel represent the duration of each storm events in yellow for a tropical storm, light blue for a cold front and pink for a warm front.

Wind forcing predominantly varies at a weather band frequency (3-10 days). There are strong correlations at the frequency between wave energy and wind forcing, and between SSC and wind forcing. It appears a certain wind direction such as northeastward and southwestward winds, makes more impacts on significant wave height. Over this 12-week period of observations, significant wave height was as high as 2 m, and a maximum orbital velocity was 0.4 m/s. Estimates of cumulative sediment flux show that the along-shore variations are approximately 10 times larger than the cross-shore transport. A significant loss occurred during a tropical storm which stayed in the area almost 8 days between Feb 23 and Mar 1. Powerful tropical storms will transport sediments southwestward. However, both warm and cold fronts also provide a mechanism by which sediments are transported northeastward, instead. The magnitude and frequency with which warm fronts, cold fronts and tropical storms pass through Long Bay, SC, may therefore be of great significance to the development of regional sediment budgets.

4. Modeling Work

Investigate oceanic response to storm events, using ROMS and SWAN (Simulating WAves Neashore) model.

4-A. Modeling Components (Warner et al., 2006)



ROMS

Present

Near future

SWAN

- ✓ 3-D primitive, free surface equations
- ✓ using 2 time-split method
- ✓ curvilinear & terrain-following coordinates
- ✓ coupled bottom boundary layer dynamics
- ✓ coupled sediment dynamics

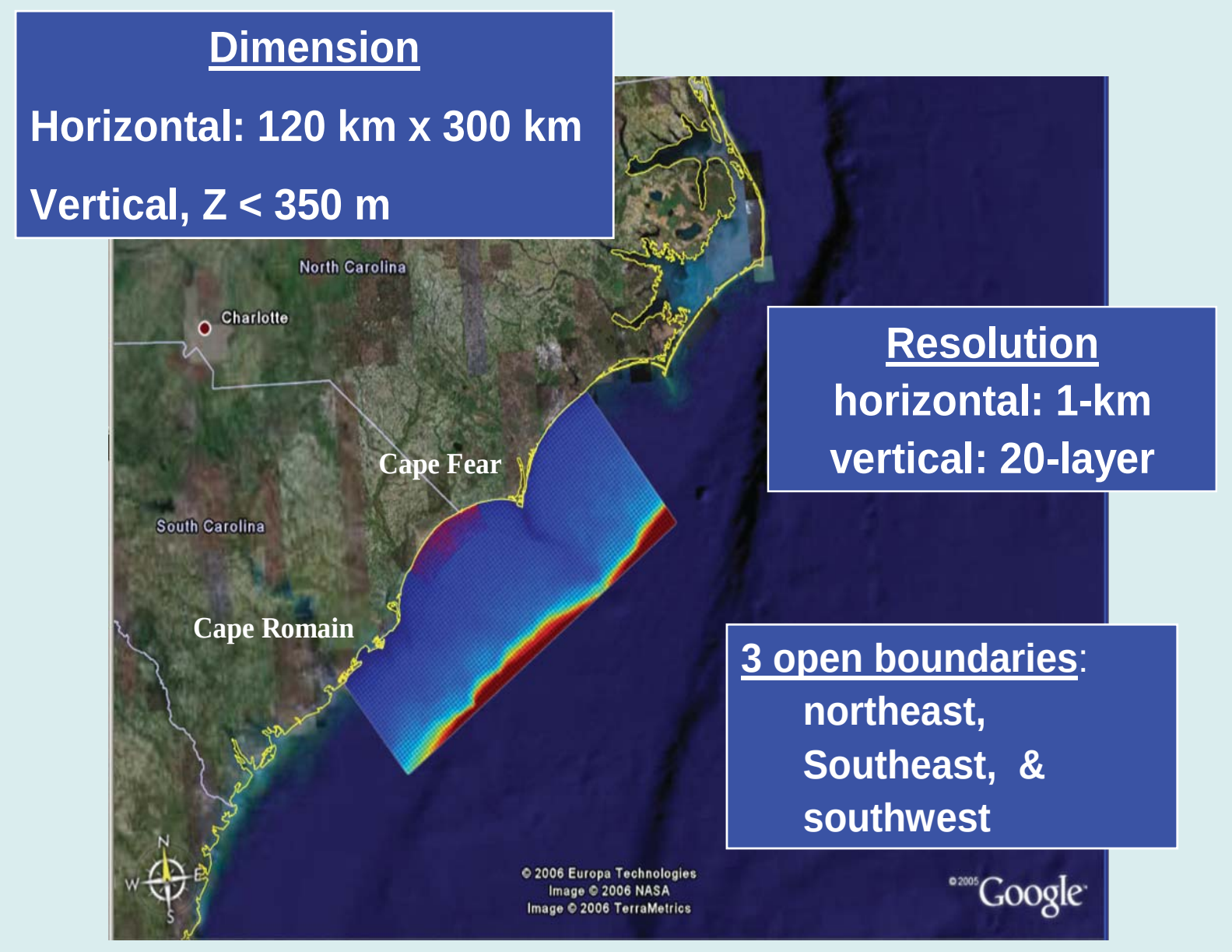
- ✓ solves a transport equation for wave action density N,

$$N = \frac{\text{energy density}}{\text{Relative frequency}}$$

- ✓ output: wave height, direction, wave length, bottom orbital velocity, surface and bottom wave periods.

4-B. South Carolina Modeling Domain & Configurations

Dimension
Horizontal: 120 km x 300 km
Vertical, Z < 350 m



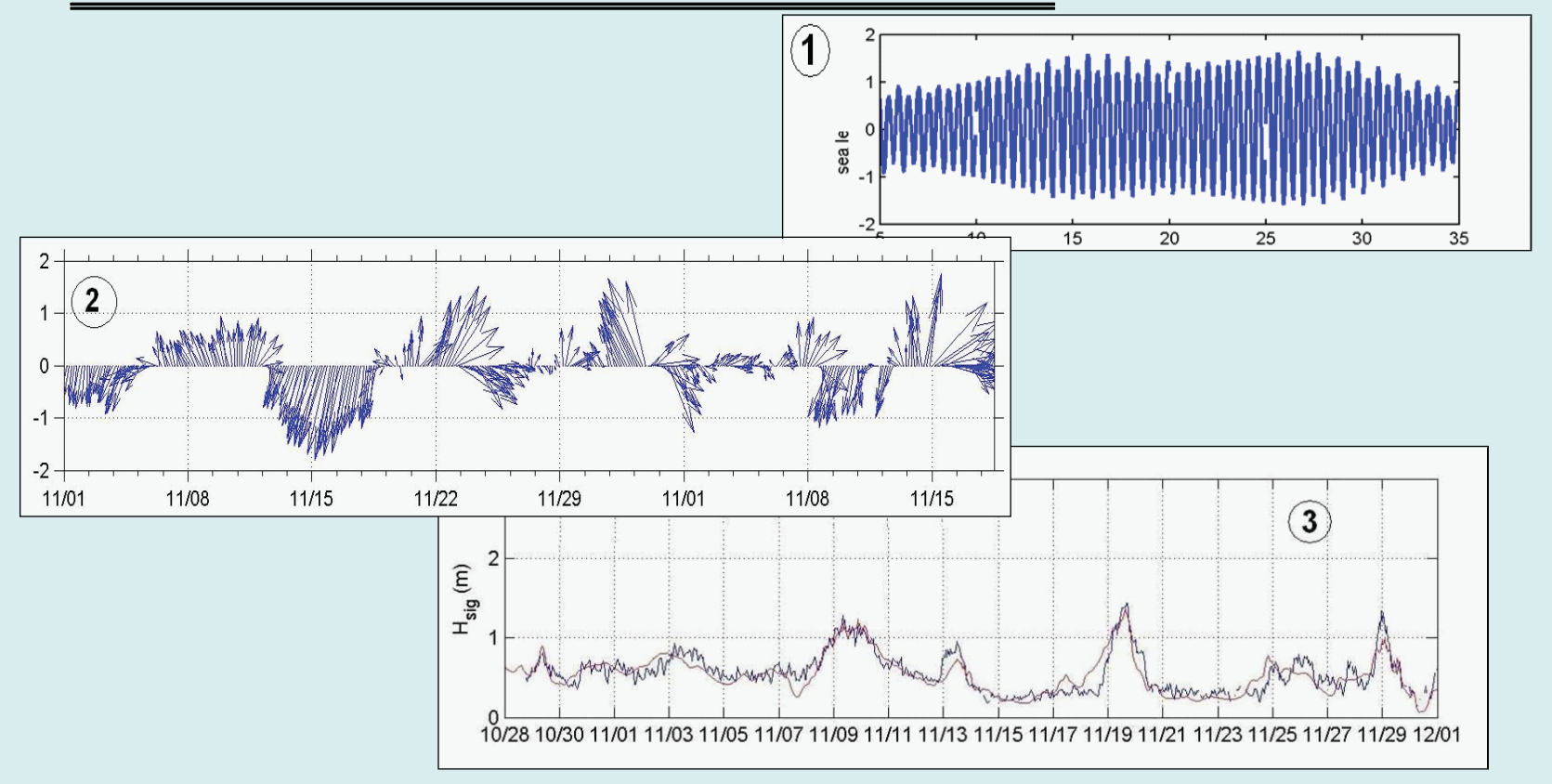
Resolution
horizontal: 1-km
vertical: 20-layer

3 open boundaries:
northeast,
Southeast, &
southwest

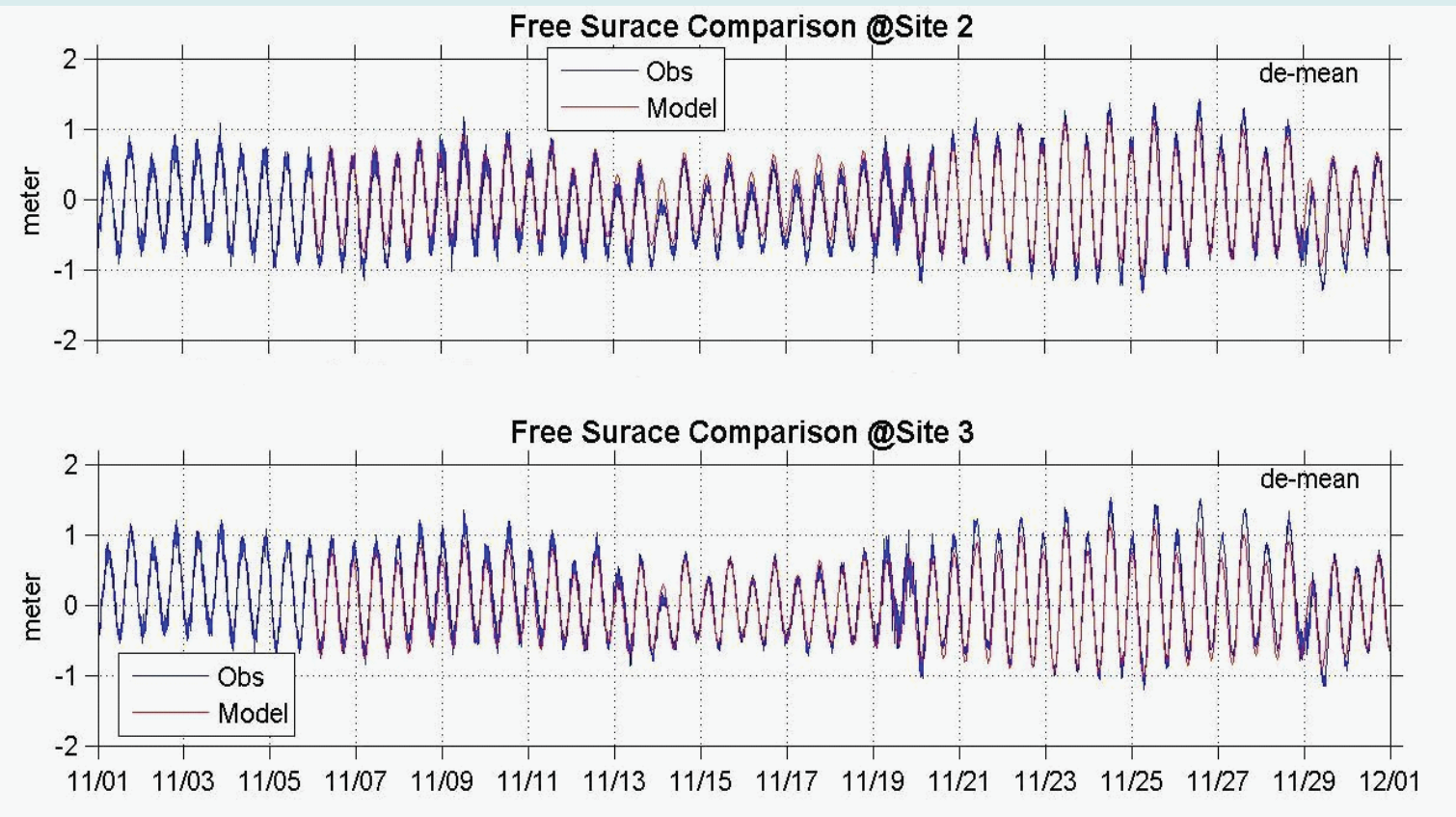
4-C. Forcing & BC values

Parameter	Source
1. Tides	**ADCIRC**
2. Wind	**NARR (NCEP)**
3. Waves	**SWAN* for ROMS**
3'. Waves	**WW3 for SWAN**

*****: separate run for now, ROMS + SWAN coupling in the near future



5. Smoke Check



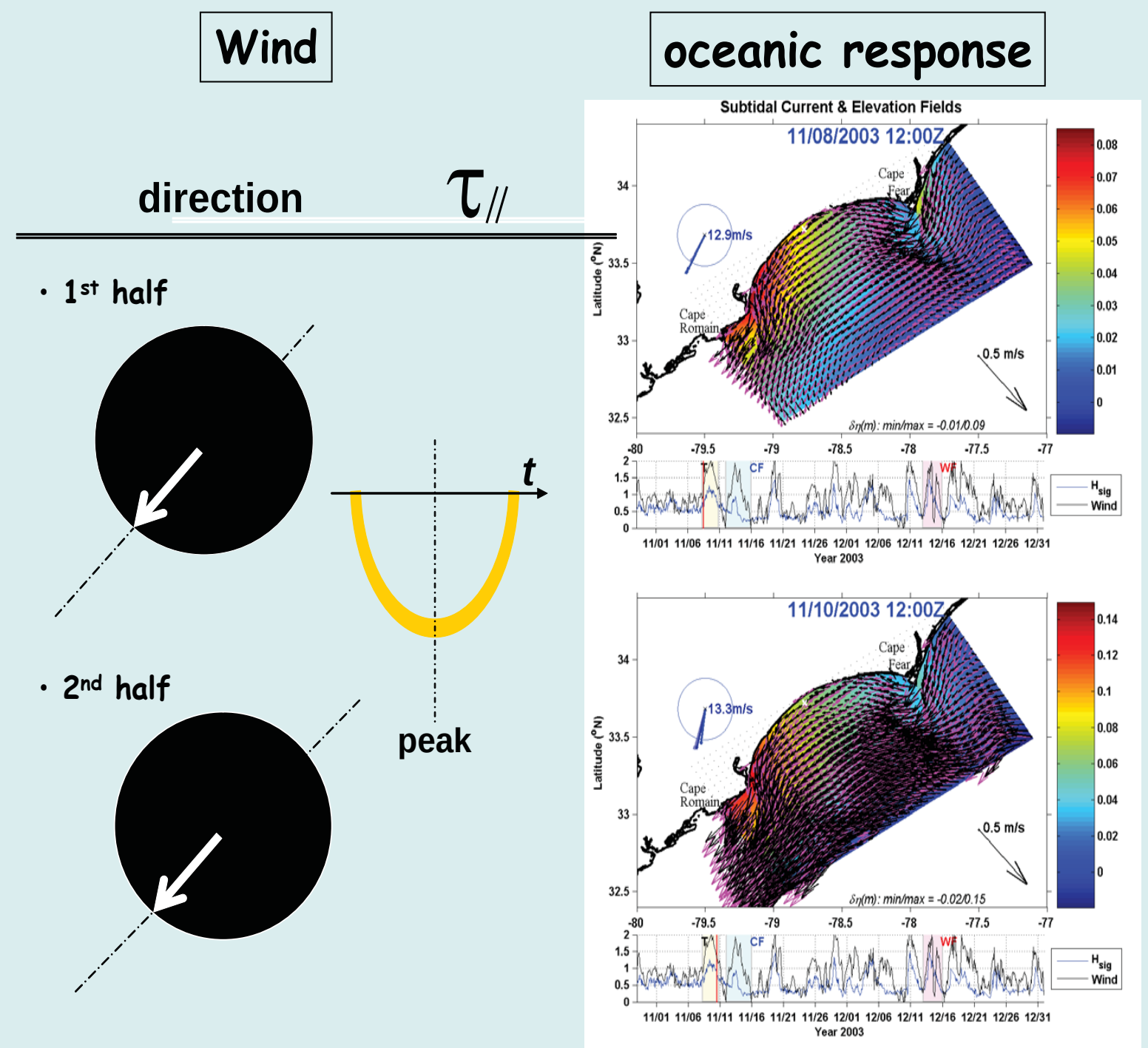
site ID	mean diff. (m)	rms diff. (m)
2	– 0.02	0.16
3	– 0.01	0.15

Quick model validation

Comparisons of water level elevations at site 2 and 3 show that both tidal amplitudes and phases are in a good agreement between observation and model.

6. Simulation Results

Characteristics of Tropical Storms

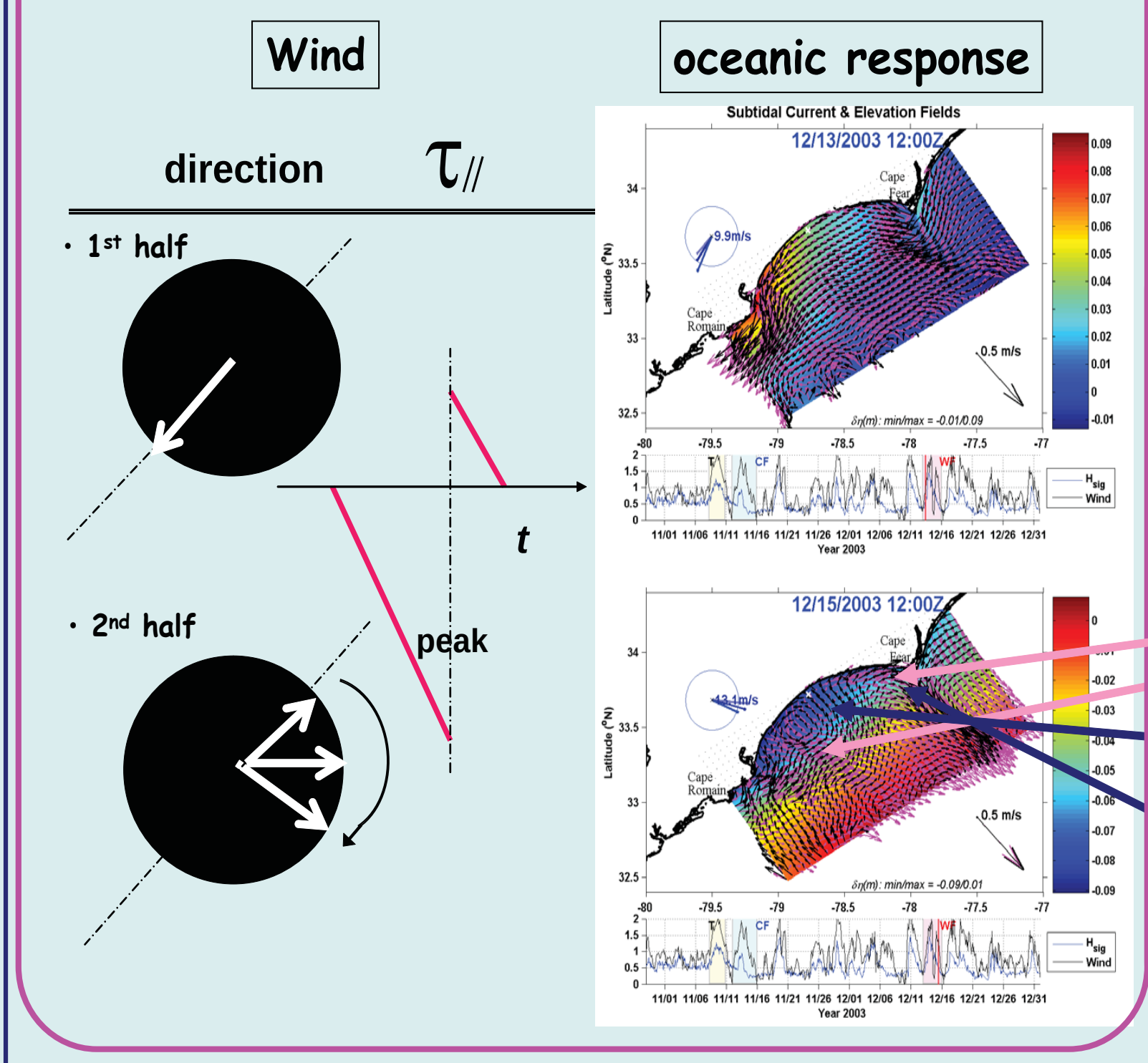


Throughout the storm event, winds blow southwestward constantly. There is no particularly notable peak of the event.

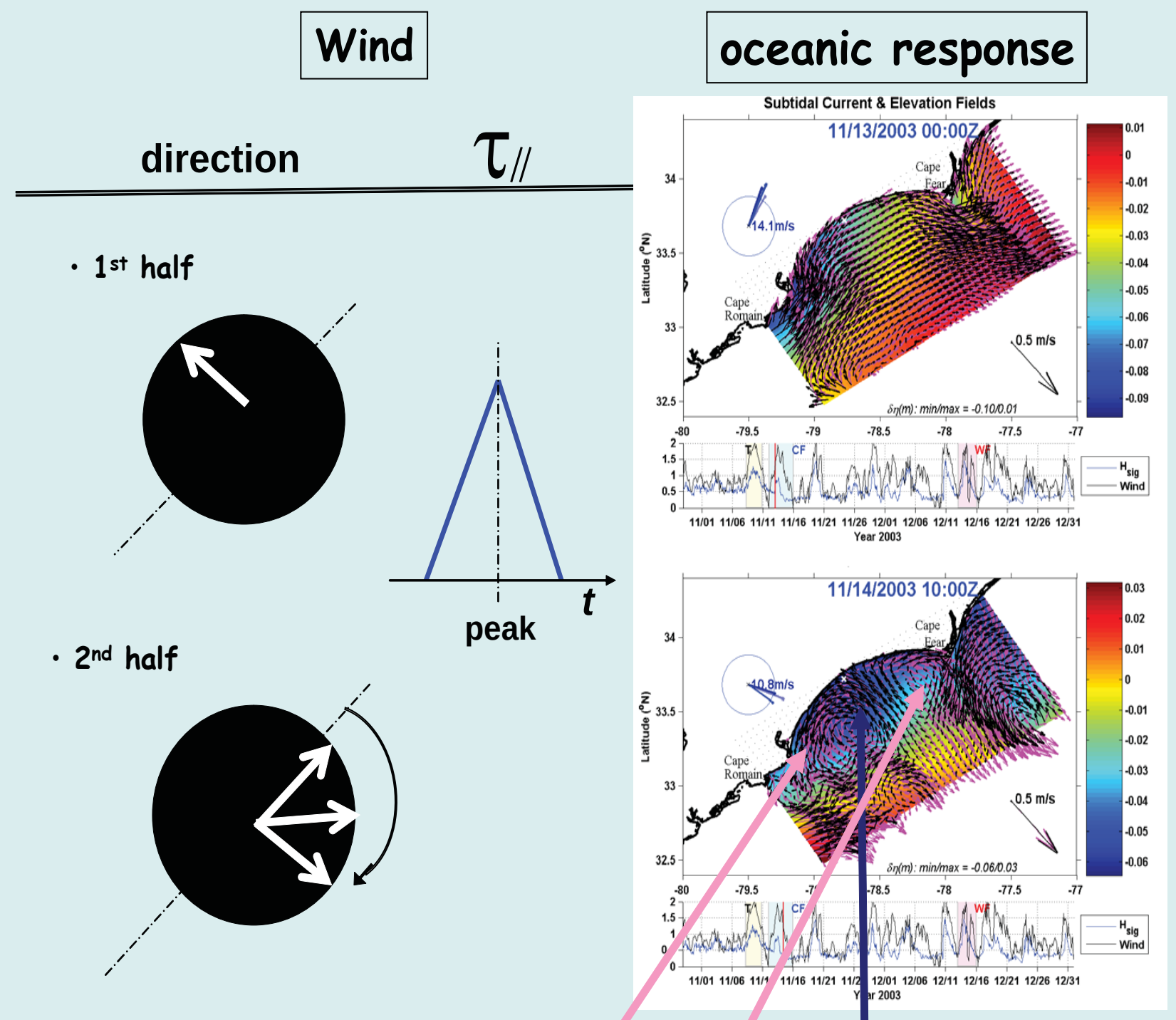
Subtidal circulations in the sea surface and bottom layers are mainly southwestward, the same direction as winds, before and after the passing of the storm. Currents are relatively weak at the center of the Bay.

Higher pressure sets up the southwestern portion of the Bay.

Characteristics of Warm Fronts



Characteristics of Cold Fronts



Winds shift from northeastward for the 1st half of to northeastward/southeastward for the 2nd half of the event. The profile of wind shift progression is almost symmetric.

Subtidal coastal circulations are northeastward for the both sea surface and bottom layers prior to the passing of the front. However, the circulation patterns are drastically different, forming strong coastal currents near Cape Romain and Fears in the surface whereas strong on-shore currents at the center of the Bay in the bottom layer, named ***"mushroom-cap circulation"*****.** Hence, there are two cells are developed – cyclonic gyre in the southwestern portion and anti-cyclonic gyre in the northeastern part of the Bay.

The pressure set-up is more complicated for the 2nd half of the event than the 1st, in which the whole inner-shelf is depressed, especially near Myrtle beach.

Winds blow southwestward persistently prior to the passing of a warm front, and then change to northeastward or southeastward post to the passing of the front. The progression profile of wind shift is asymmetric, having longer duration for the 1st part of the event.

Before the passing of the front, the surface and bottom-layer currents flow in the same direction as winds. After the front passage, the surface currents form strong coastally-intensified flows south of Cape Fear and relatively weak flows else-where except an area with steep topography. The currents at the bottom layer develop a cyclonic circulation the most of Long Bay interior, with relatively strong speed at the axis of the Bay. The currents south of Cape Fear flow parallel to shoreline with the surface currents.

Pressure is low for the most part of bay, except around Cape Romain for the 1st half. The pattern becomes almost opposite for the latter part of the event.

7. Summary of Findings

7-1. Strong correlation in oceanic response to storms. However, the response is different to different types of storms:

Topical storm (TS) – constant **southwestward** flow and upwelling

Cold front (CF) – **northeastward** flow for the 1st half of the event; a very definitive **mushroom-cap shape of circulation** for the 2nd half.

Warm front (WF) – persistent **southwestward** flow, followed by **a pair of cyclonic and anti-cyclonic circulation patterns** for the later part of the event.

7-2. A total of 12 storms over a 2-month period in 2003: 2 TS, 7 CF & 2 WF

Each storm plays a significant role in the coastal circulation. Two-layer (sea surface and bottom layers) analysis indicates that upwelling/downwelling is a local phenomenon, and they are not directly driven by local wind forcing. Rather, it seems to be caused by basin-scale pressure setup/setdown. Potentially this secondary circulation play a role in sediment transport. A total of 11 storm events has been observed over a 2-month duration. Sediment scouring/deposit can be substantial, if integrated over these storm episodes.

8. Feature Works

- Numerical study on sediment transport
- Numerical study on wave-current interactions
- Coupling ROMS-SWAN

9. Acknowledgements

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