Supplemental Environmental Impact Statement for the Designation of Dredged Material Disposal Site(s) in Eastern Long Island Sound, Connecticut and New York

# Physical Oceanography of Eastern Long Island Sound Region

Prepared for: **U.S. Environmental Protection Agency**

Sponsored by: **Connecticut Department of Transportation**

Prepared by: **University of Connecticut**

with support from: **Louis Berger**

## Public Meetings 5+6 (December 8+9, 2014)

# Outline

1. Physical Oceanography in the ZSF – Purpose
2. Model: *Configure and test*
3. Evaluation of Simulations
   - Field Program: *Collect data (currents and stress etc.) at a set of stations that are expected to exhibit a wide range of conditions*
   - Model Performance: *Evaluate predictions of model with new data*
4. Analysis
5. Summary

# Physical Oceanography

- Physical oceanography is the science that explains the patterns of ocean circulation and the distribution of properties such as temperature and salinity. Elements of physical oceanography include tides, currents, waves, and sediment transport.

Of particular importance within this study are the factors governing boundary shear stress



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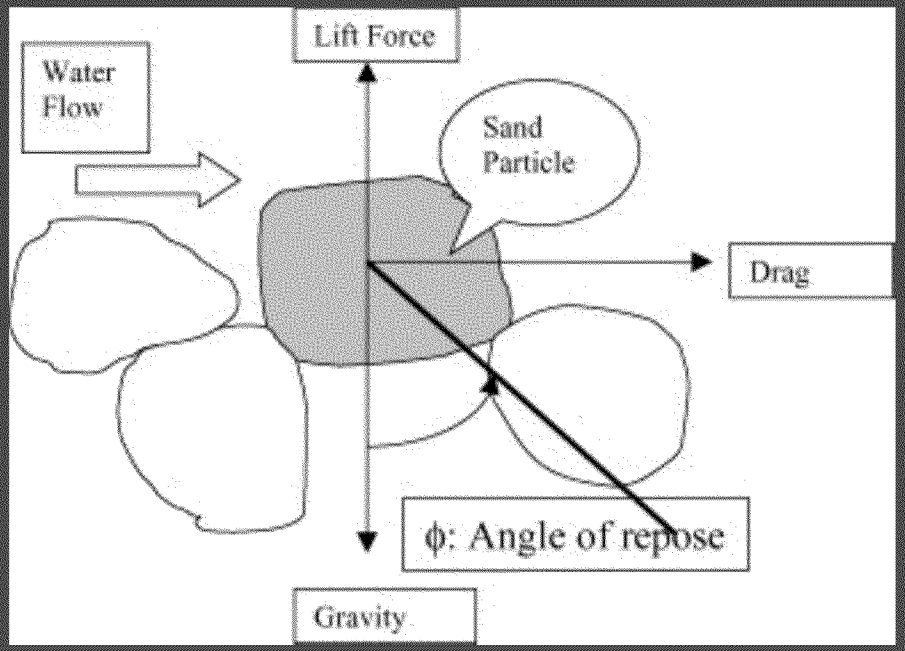
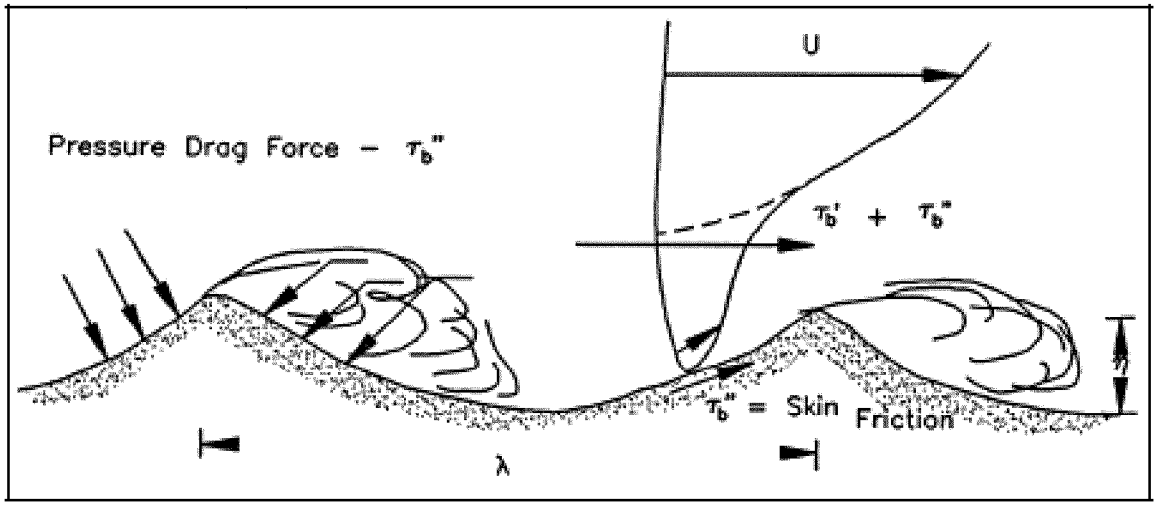
# Sediment Transport

For sediment resuspension the lift force due to the flow around it must exceed the gravity force.

The lift and drag forces slow the water and this effective force per unit area is called the **shear stress**.

Bedforms have a similar effect on the flow… they slow it down.



# Critical Erosion Stress

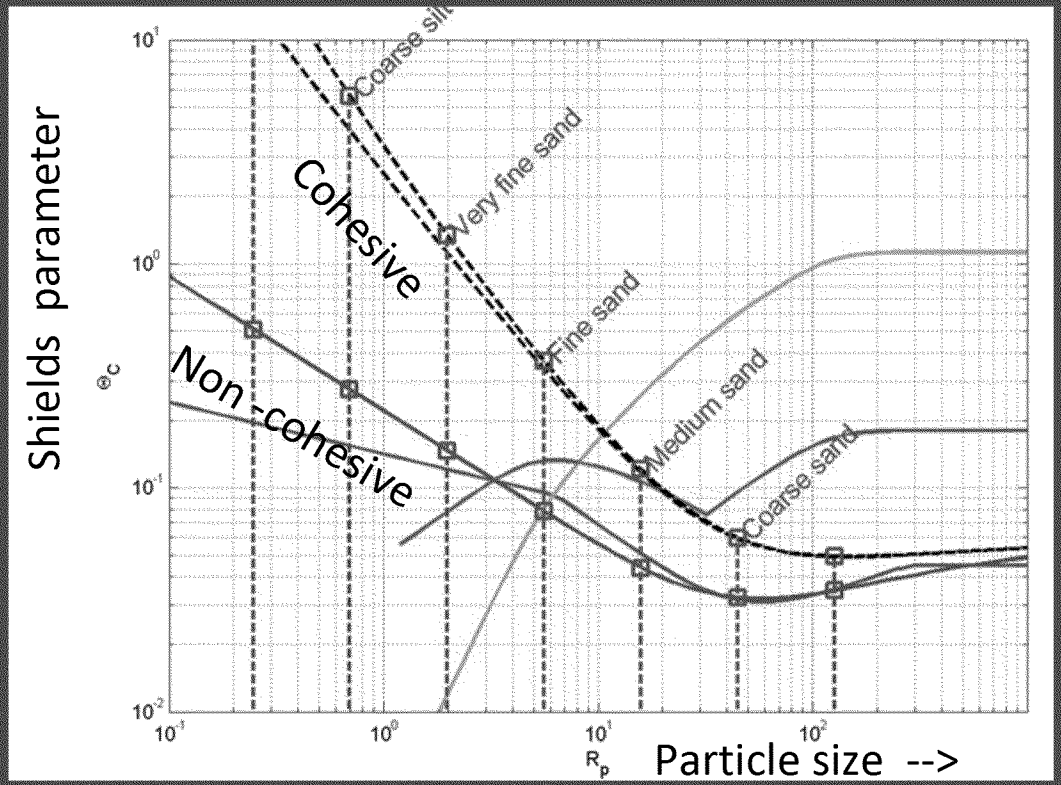



**Figure 34.** A graphical representation of the relationship between sediment particle size for cohesive and non-cohesive particles.

The red and blue solid lines are analytical representations of the critical Shields parameter, $\Theta_{c0} = \tau_{c0}/\rho_w sgd$, for non-cohesive sediments as a function of the particle Reynolds number. The black dashed lines show the influence of cohesion and adhesion on the critical value for the onset of particle motion.

The green and magenta lines show the critical values for the onset of sediment suspension as predicted by Bagnold (1966) and van Rijn (1984), respectively. The lower boundaries of the particle Reynolds numbers for traditional sediment classes (see Table 7) are shown by the blue dashed lines.

# Particle Size and Critical Stress for Cohesive and Non-cohesive Sediments

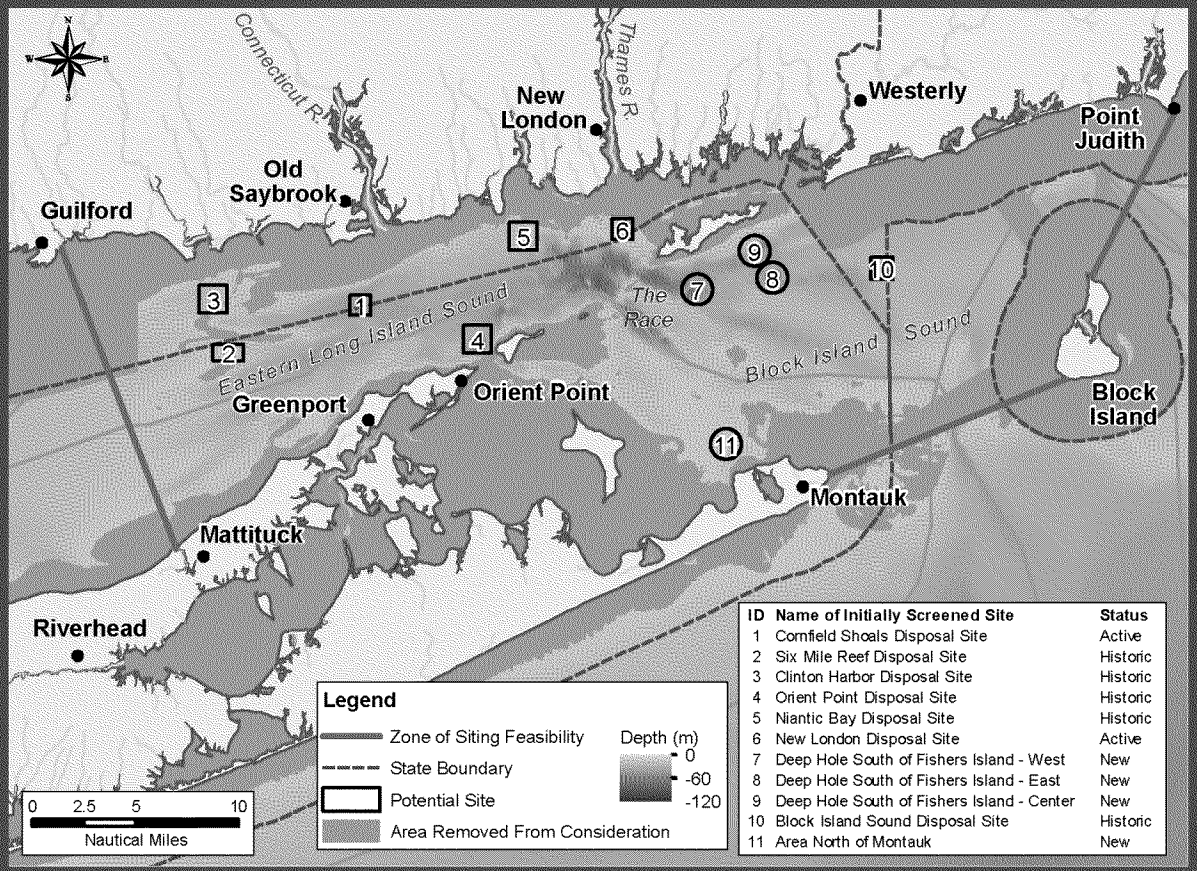
| Size | | | | Non-Cohesive Sediments | | | Cohesive Sediments | | |
|---|---|---|---|---|---|---|---|---|---|
| | Particle Size | | Reynolds Number | Critical Shields Parameter | Critical Stress | Critical Velocity | Critical Shields Parameter | Stress at the Initiation of Motion | Critical Velocity |
| Classification | Phi | d (mm) | $R_p$ | $\Theta_{c0}$ | $\tau_{c0}$ (Pa) | $u_{1,0}$ (m/s) | $\Theta_c$ | $\tau_c$ (Pa) | $u_1$ (m/s) |
| *Column No.* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
| Coarse sand | 1-0 | 0.50 | 44.96 | 0.03 | 0.26 | 0.32 | 0.06 | 0.48 | 0.44 |
| Medium sand | 2-1 | 0.25 | 15.90 | 0.04 | 0.18 | 0.27 | 0.12 | 0.49 | 0.44 |
| Fine sand | 3-2 | 0.13 | 5.62 | 0.08 | 0.16 | 0.25 | 0.37 | 0.74 | 0.54 |
| Very fine sand | 4-3 | 0.06 | 1.99 | 0.15 | 0.15 | 0.24 | 1.33 | 1.35 | 0.73 |
| Coarse silt | 5-4 | 0.03 | 0.69 | 0.27 | 0.14 | 0.23 | 5.62 | 2.81 | 1.06 |
| Medium silt | 6-5 | 0.02 | 0.25 | 0.51 | 0.13 | 0.23 | 26.33 | 6.64 | 1.63 |
| Fine silt | 7-6 | 0.01 | 0.09 | 0.95 | 0.12 | 0.22 | 143.41 | 18.09 | 2.69 |

*Notes:* Columns 5 to 7 provide example magnitudes of the critical shields parameter, $\Theta_{c0}$, for non-cohesive sediments and the stress $\tau_{c0}$ at the initiation of motion for the lower bounds for specific particle size classes listed on the left. An estimate of the magnitude of the required current at 1m above the sea floor required to create the critical stress for non-cohesive sediments is provided as $u_{1,0} = \sqrt{\tau_{c0} / \rho C_d}$ where $C_d = 2.5 \times 10^{-3}$ is assumed. Analogous estimates for cohesive sediments are provided Columns 8 to 10 based on the theory presented by Righetti and Lucarelli (2007). Values shaded in blue are extrapolations beyond the range of particle sizes used in parameterization.

# Objective of PO Study

## Support evaluation and selection of potential dredged material disposal sites within the Zone of Siting Feasibility (ZSF)

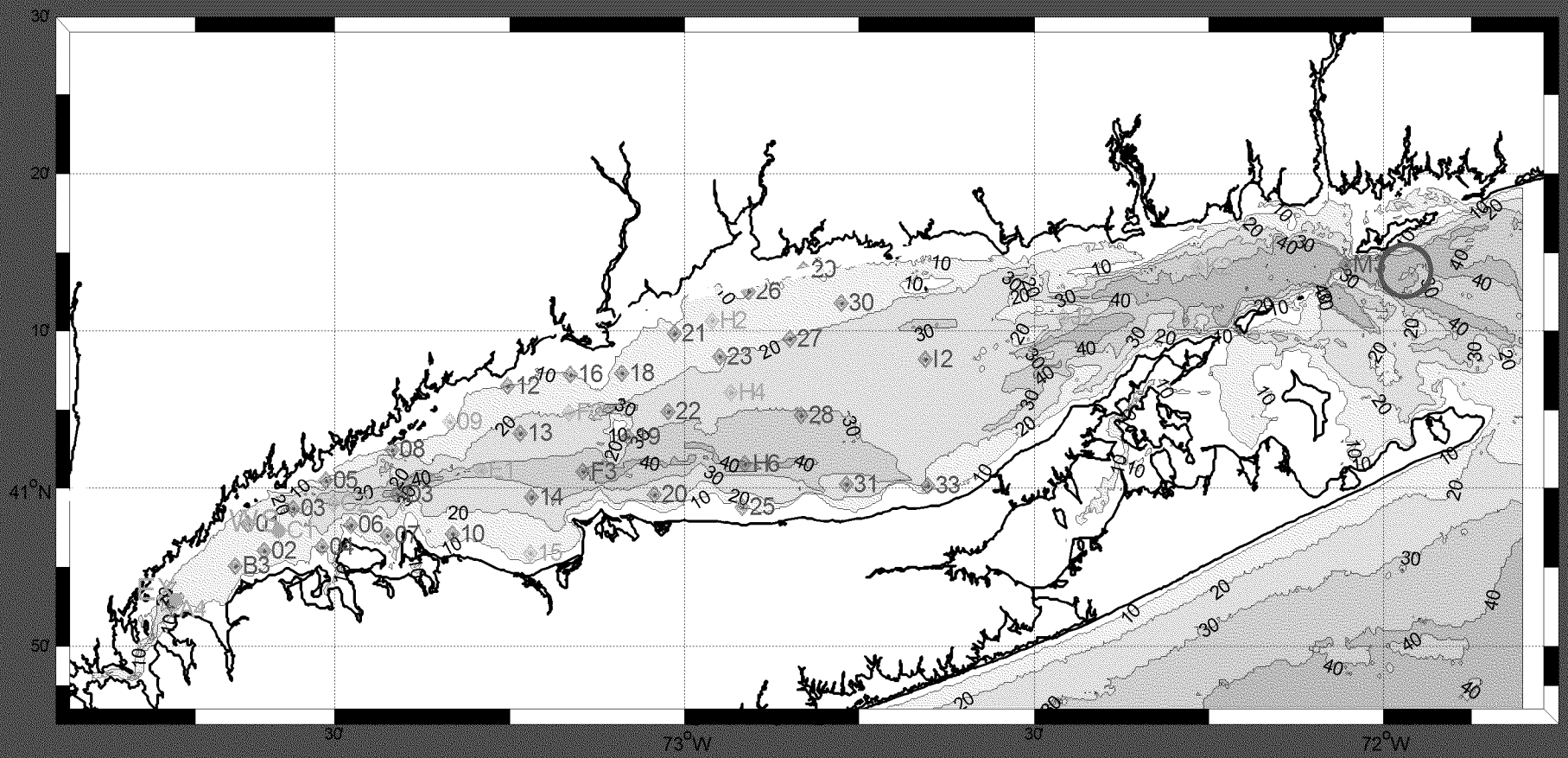
- Describe distribution of maximum bottom stress magnitudes expected in the ZSF including 'Superstorm Sandy' conditions (100-year storm)
- Characterize circulation in the ZSF to support assessment of potential off-site effects
- Acquire physical oceanography data to support future modeling of sediment transport at potential dredged material disposal sites




*Zone of Siting Feasibility (ZSF). Initial screening identified (1) areas not suitable for locating dredged material disposal sites due to various constraints (gray zone), and (2) 11 sites for further investigation as potential disposal sites; these sites include two active and five historic disposal sites, and six 'new' sites not previously used for dredged material disposal. The background represents water depth.*

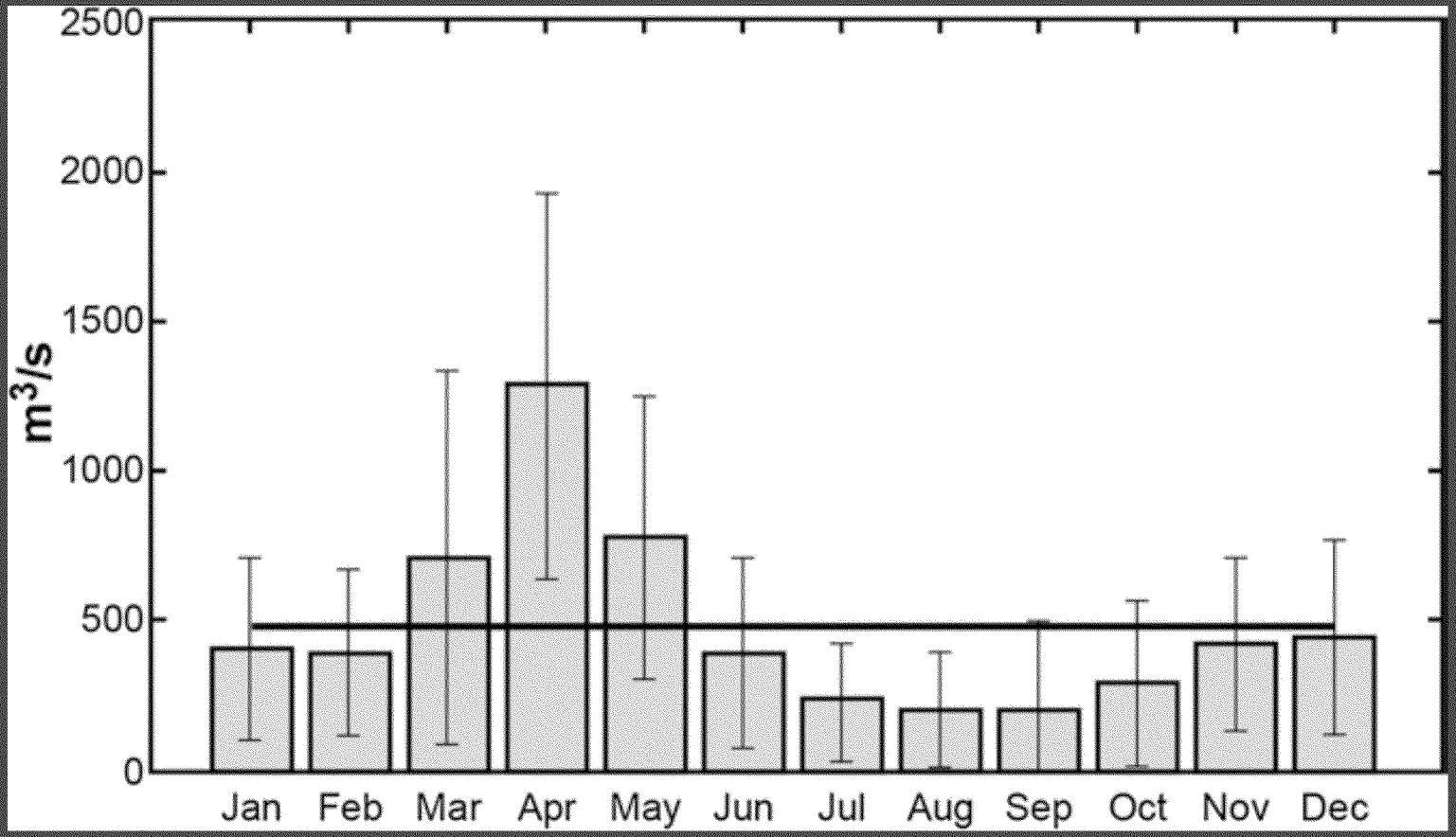
# Regional Temperature and Salinity

## CTDEEP – EPA Long Island Sound Study Ship Survey Stations



# River Inflow

Monthly Discharge of Connecticut Rivers (~80% of total inflow to Long Island Sound)



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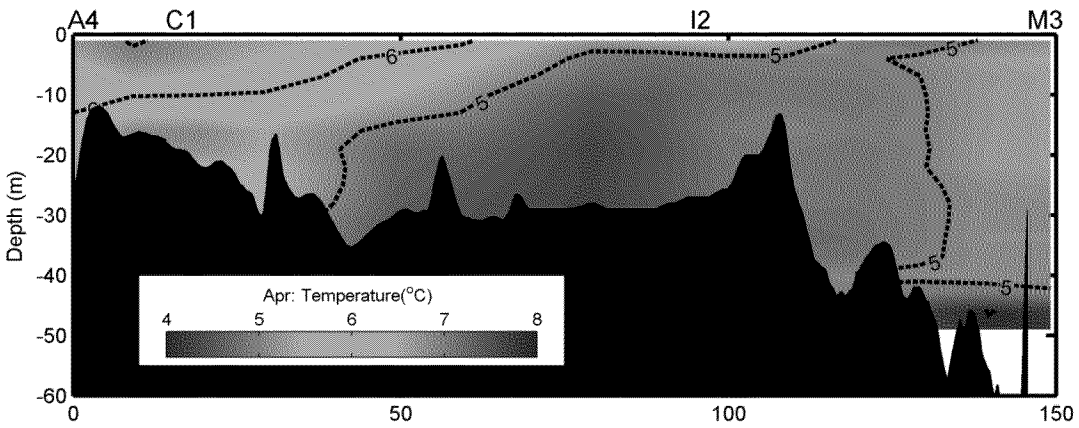
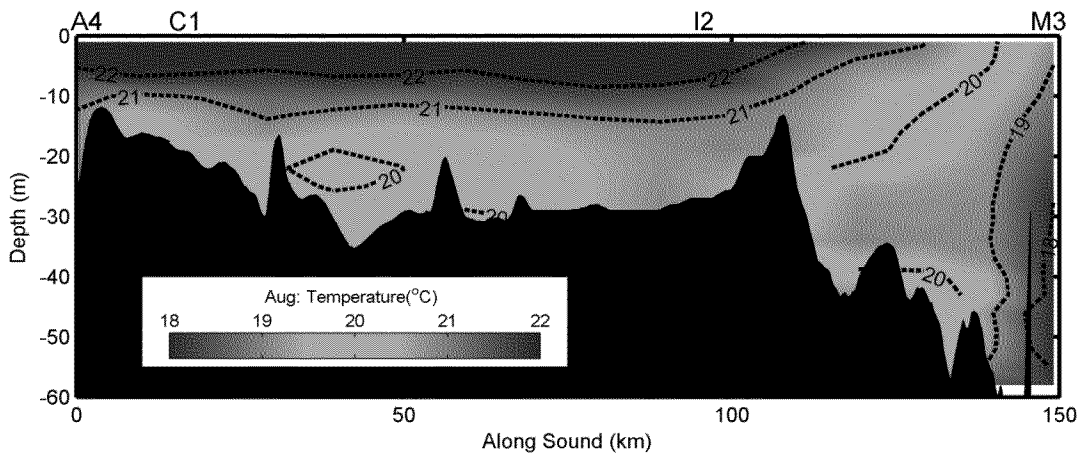
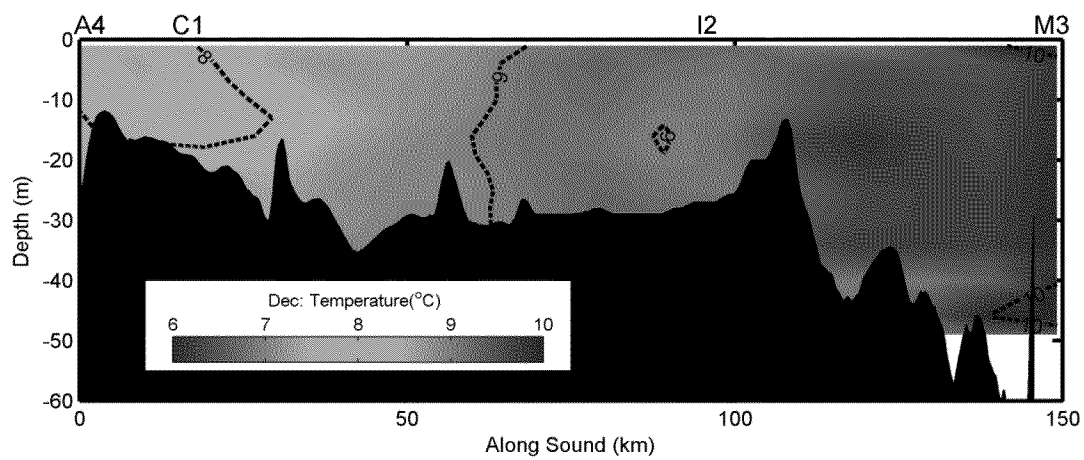
# Water Tempe-rature




(a)

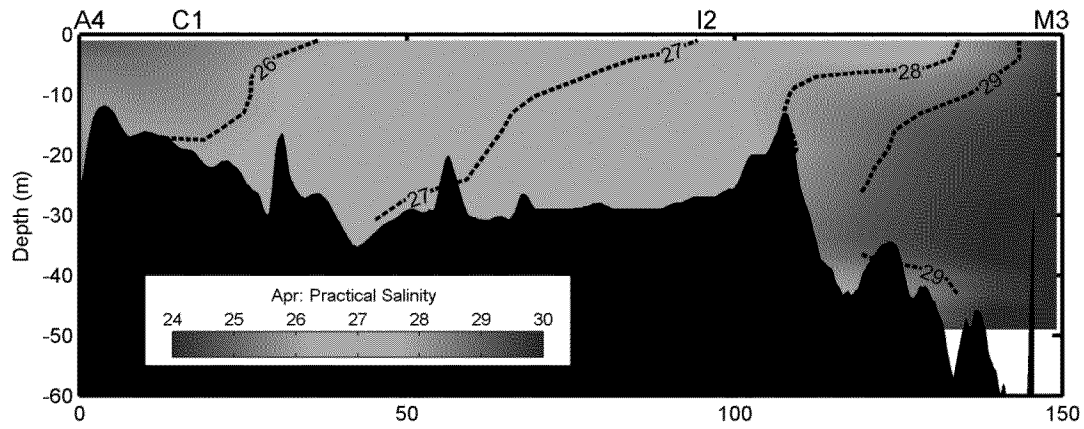



(b)

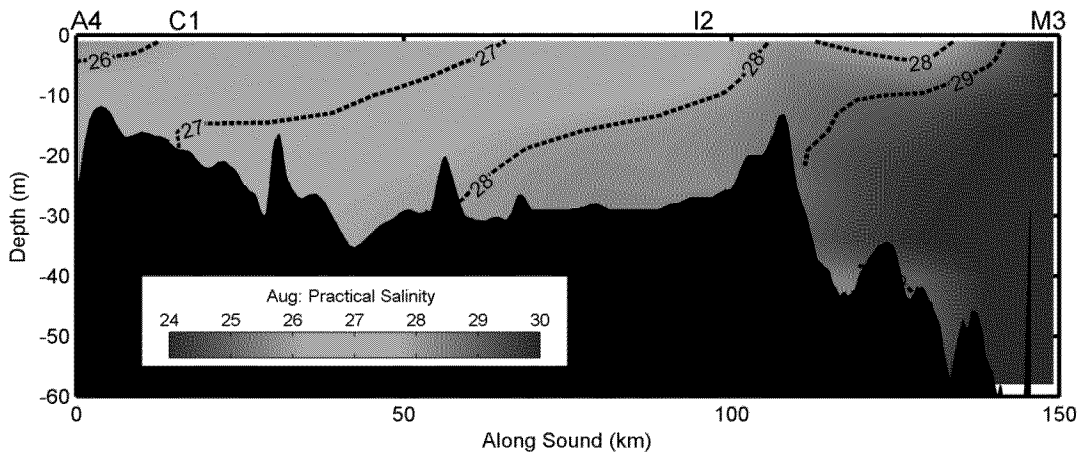



(c)

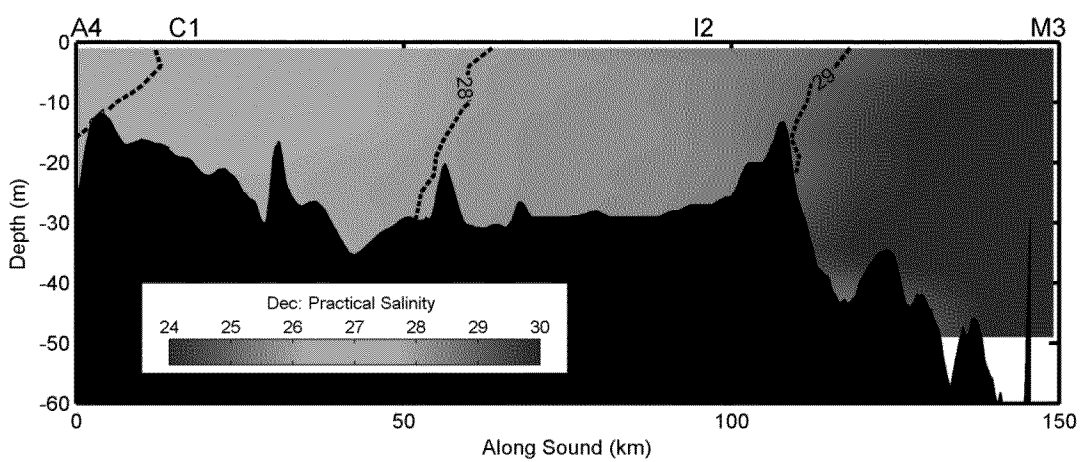
# Salinity




(a)



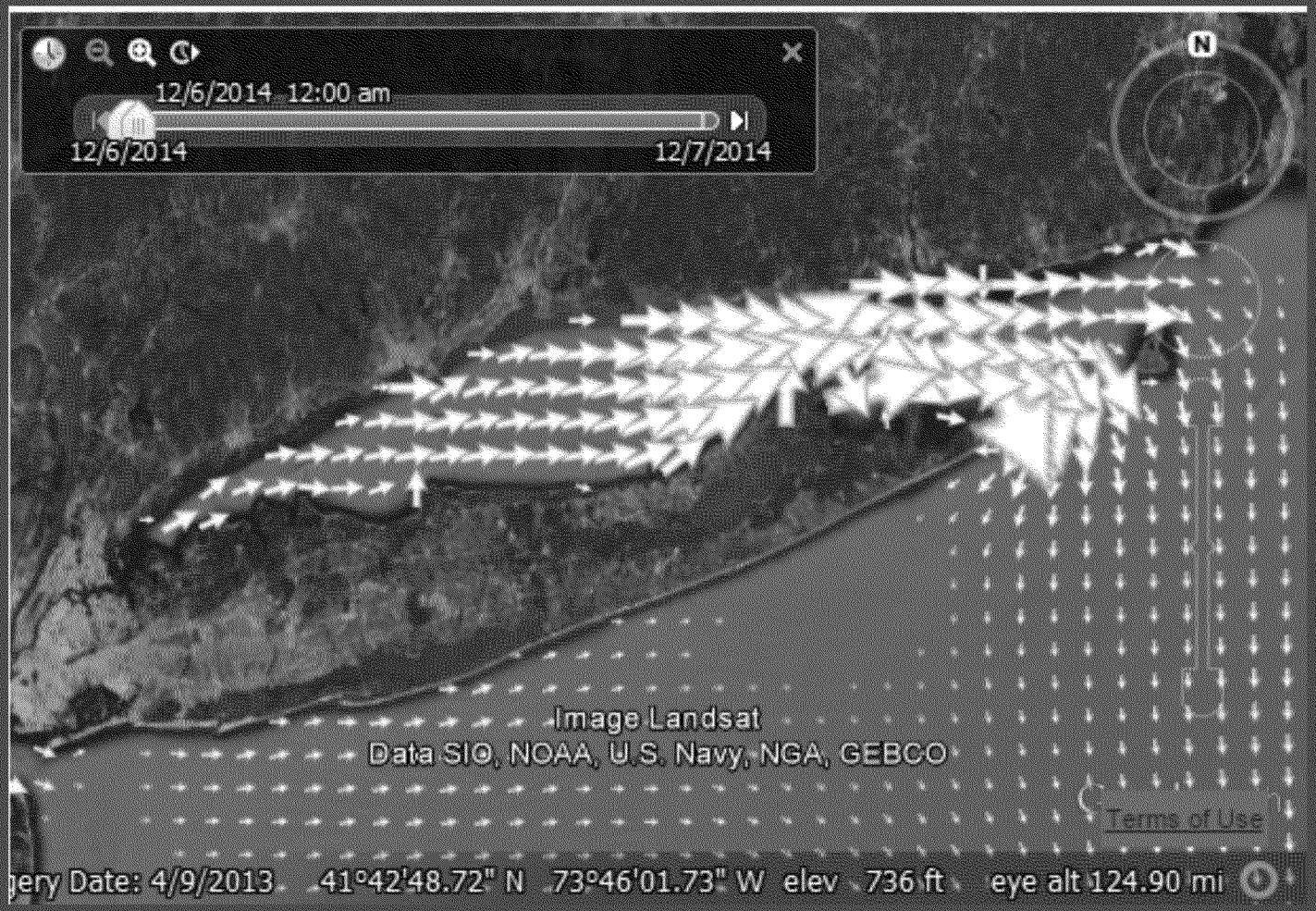

(b)




(c)

# Tidal Current Oscillations

- 00:00 AM

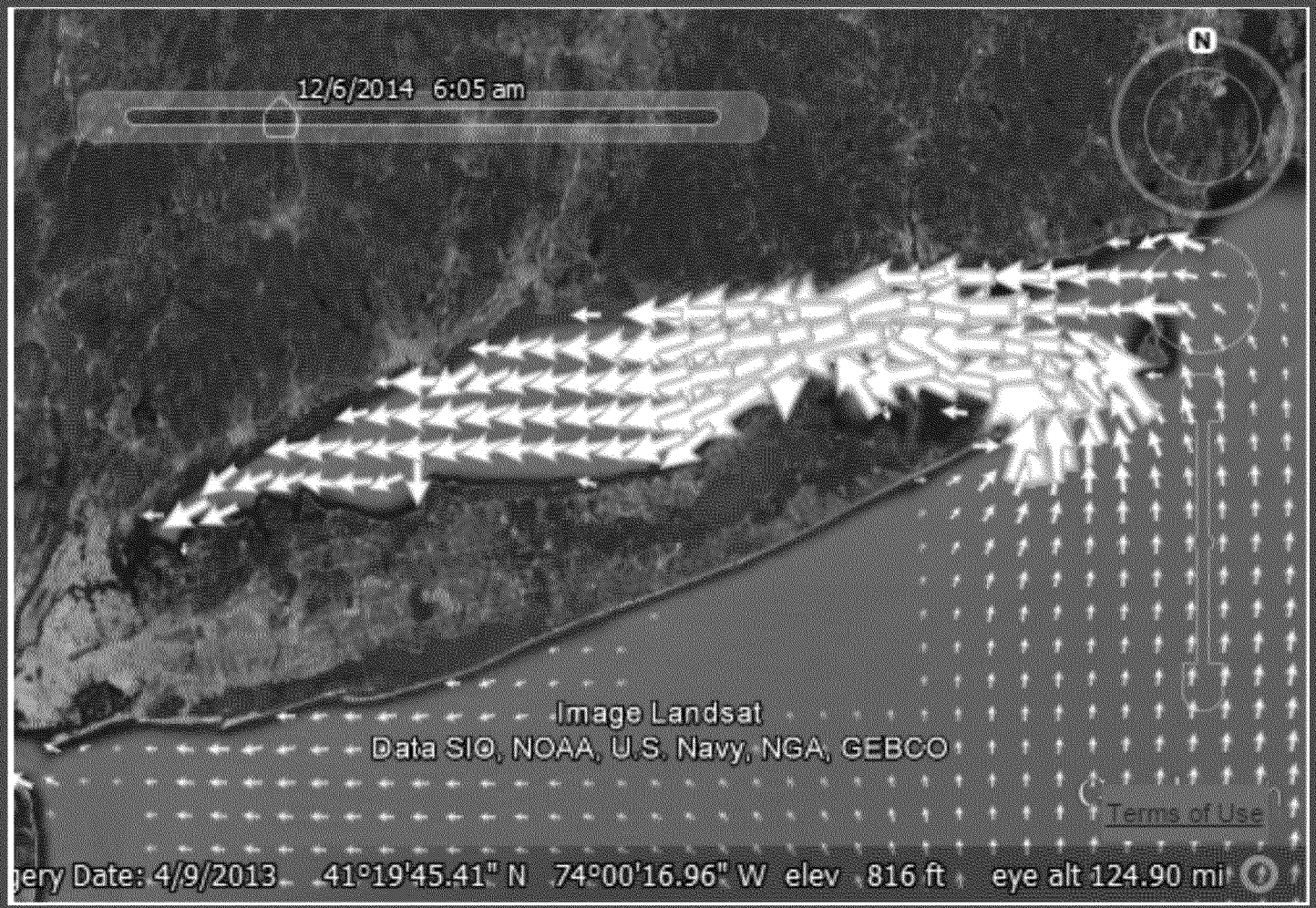


# Tidal Current Oscillations

- 03:00 AM

# Tidal Current Oscillations

- 06:00 AM

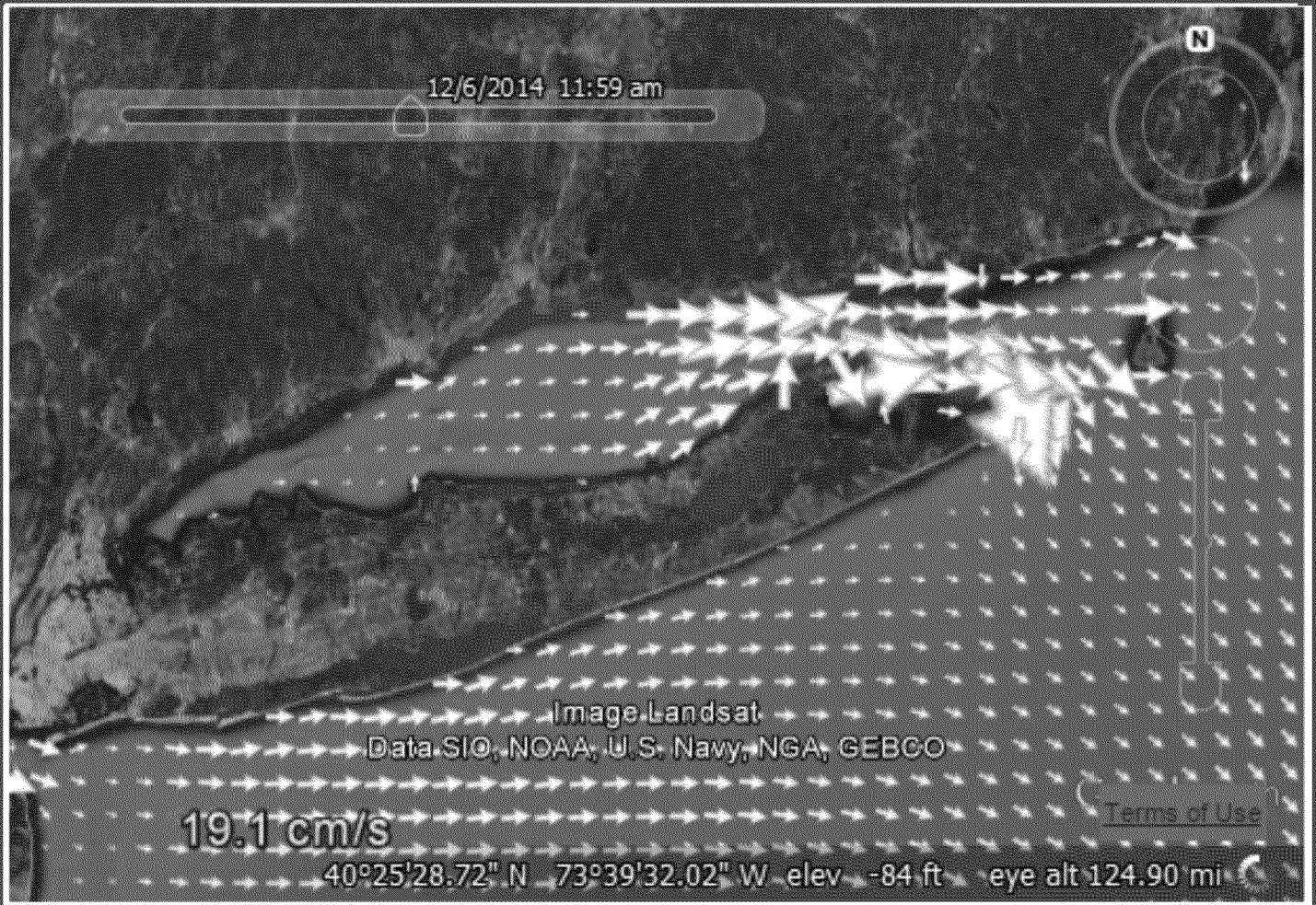


# Tidal Current Oscillations

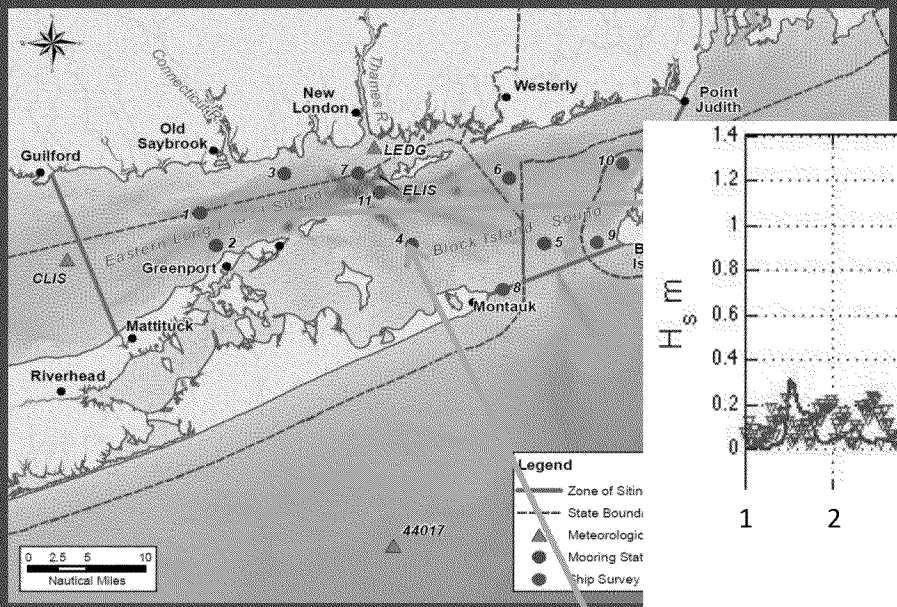
- 09:00 AM

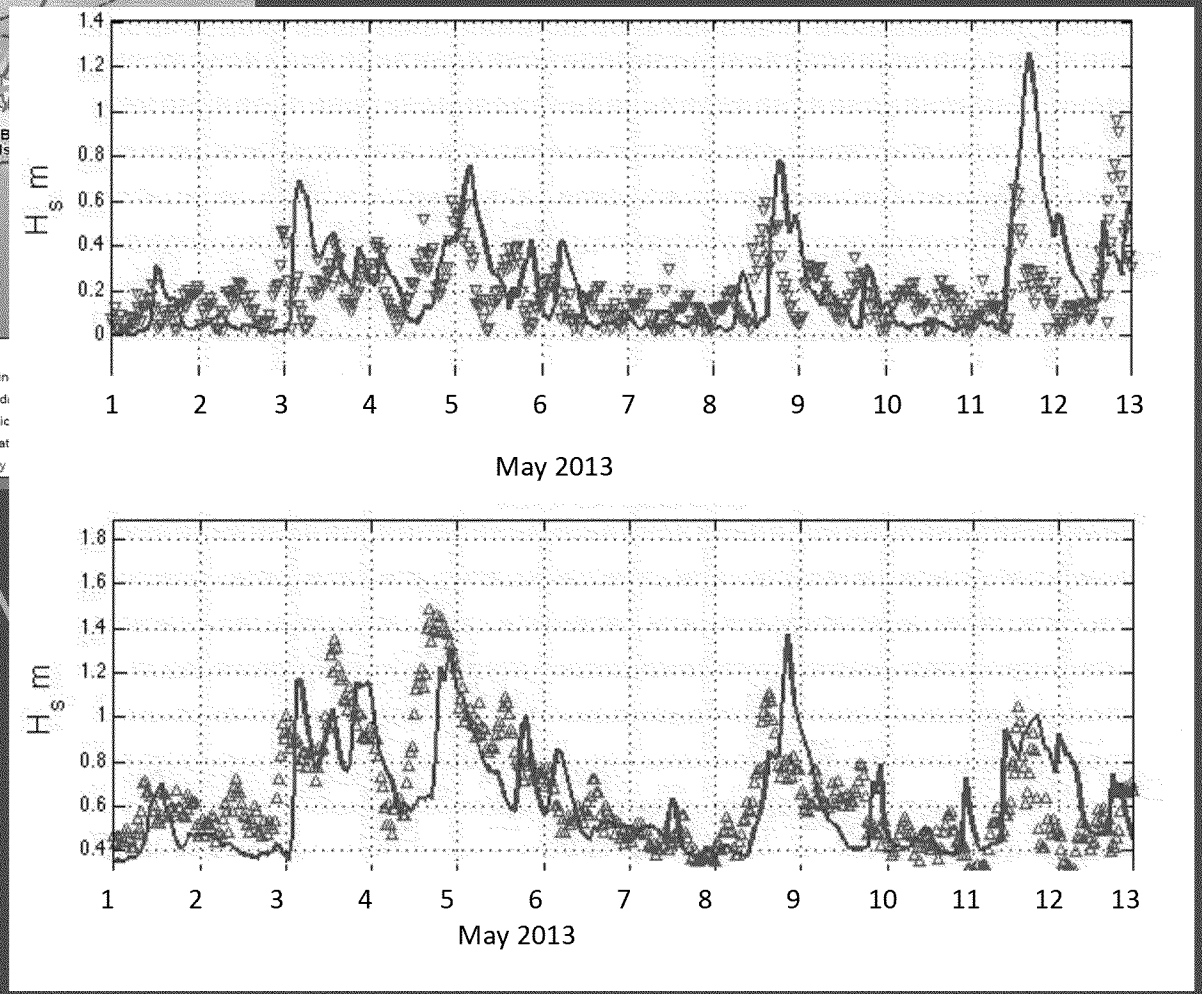
# Tidal Current Oscillations

- 12:00 AM



# Significant Wave Height Observations *(red)*




*Comparison of model and observed significant wave height at Stations DOT1 (upper panel) and DOT4 (lower panel) during May 2013.*

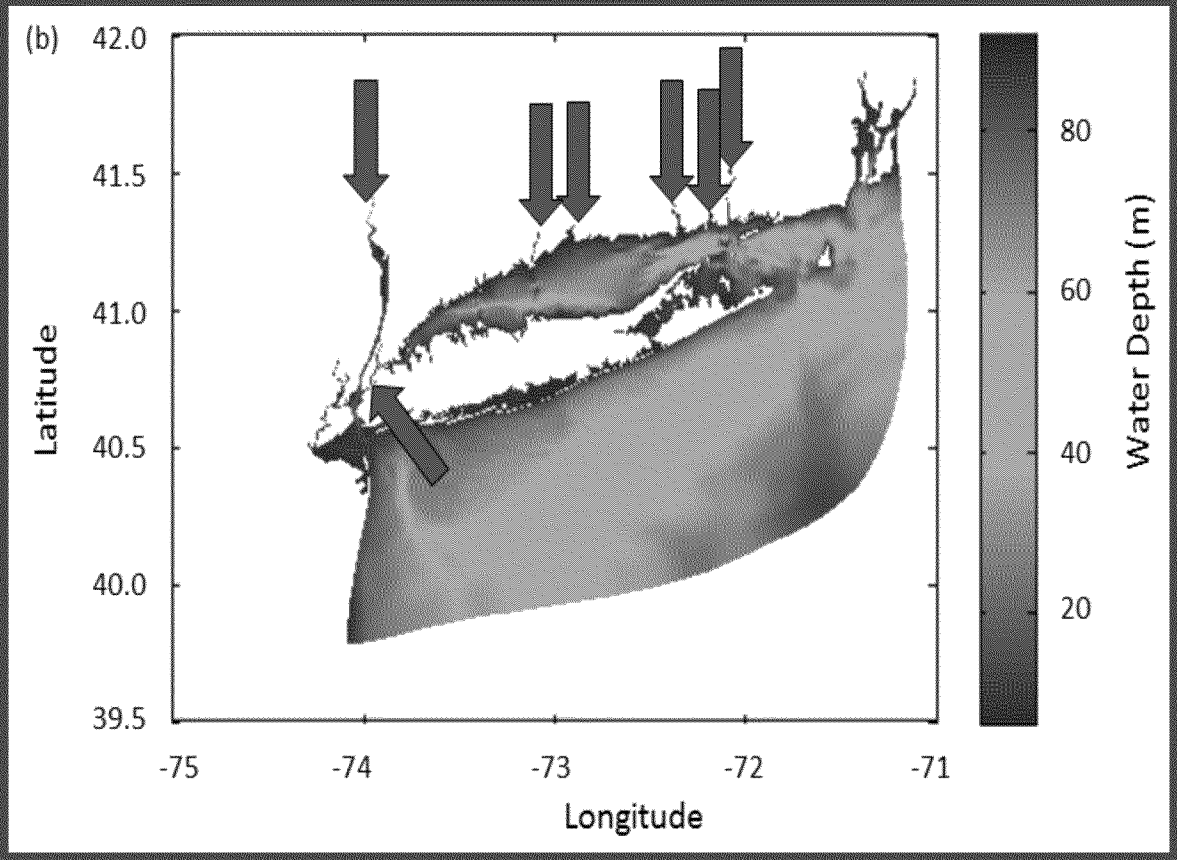
# 2. Model – Questions for Study

- What is the distribution and spatial variation in the bottom stress?
- Where are the regions in which the maximum stresses are smallest?
- Where does material in the water at potential sites go?

# 2. Model

## FVCOM - Finite Volume Community Ocean Model

- Developed by Prof. Chen, Univ. of Massachusetts, adapted for Long Island Sound
- Nested within NECOFS (Northeast Coastal Ocean Forecast System)
- Forced by:
  - Tides
  - Observed River flow and wind
  - Climatology for surface heat exchange
  - Climatology for initial conditions




*Bathymetry of the LIS model subdomain with the locations of freshwater sources (green arrows; from left to right: Hudson River, New York City wastewater treatment plants , Housatonic River, Quinnipiac River, Connecticut River, Niantic River, and Thames River).*

# 2. Model *(cont.)*

**An Unstructured Grid, Finite-Volume, Three-Dimensional, Primitive Equations Ocean Model: Application to Coastal Ocean and Estuaries**

CHANGSHENG CHEN AND HEDONG LIU

*School for Marine Science and Technology, University of Massachusetts–Dartmouth, New Bedford, Massachusetts*

ROBERT C. BEARDSLEY

*Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts*

The "Model" is based on Newton's laws.

It predicts the water velocity, level, temperature and salinity.

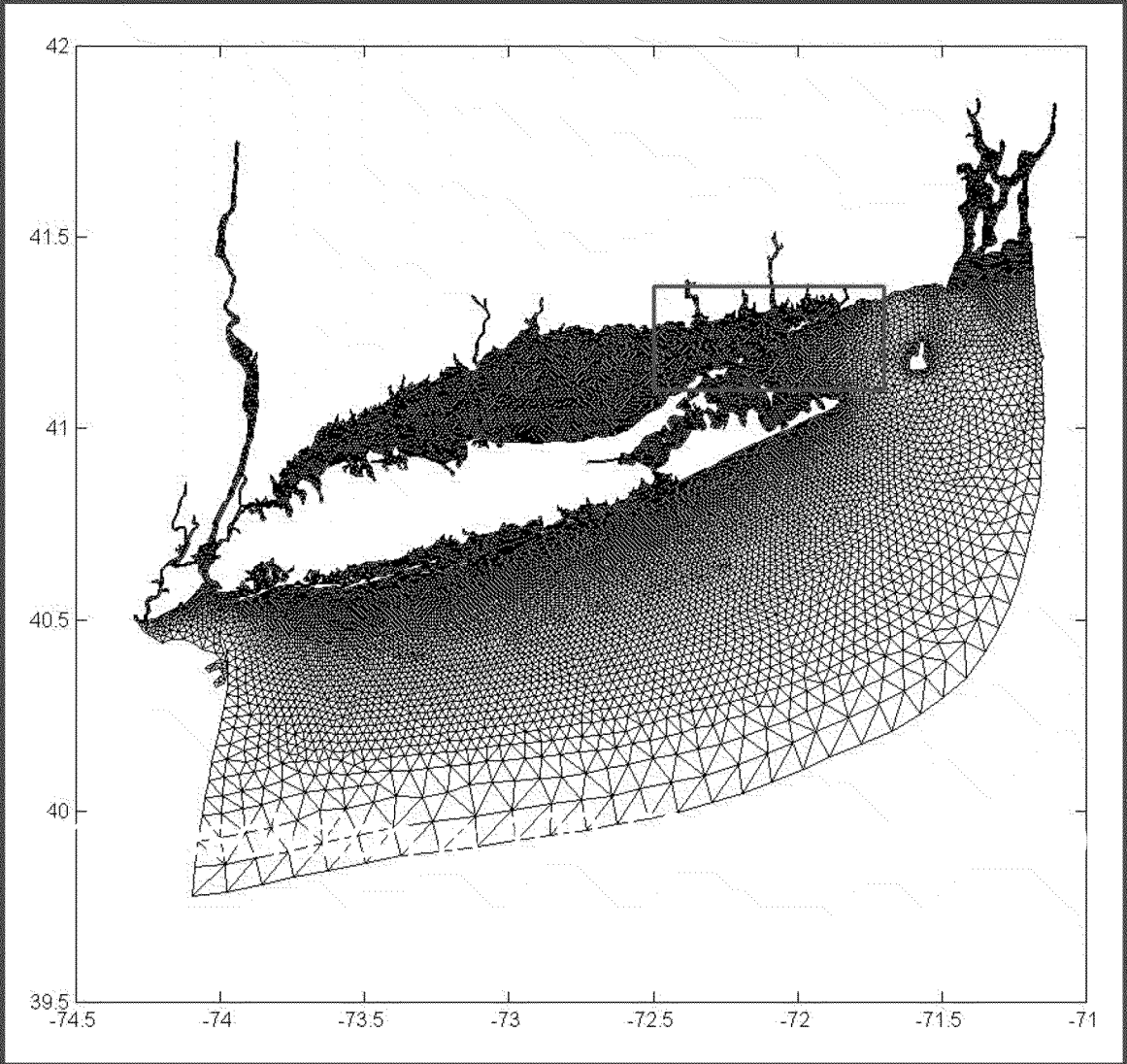
The bottom stress magnitude is computed from the formula

$$\tau = \rho C_D (u^2 + v^2)$$

Where the coefficient $C_D$, is called the DRAG COEFFICIENT.

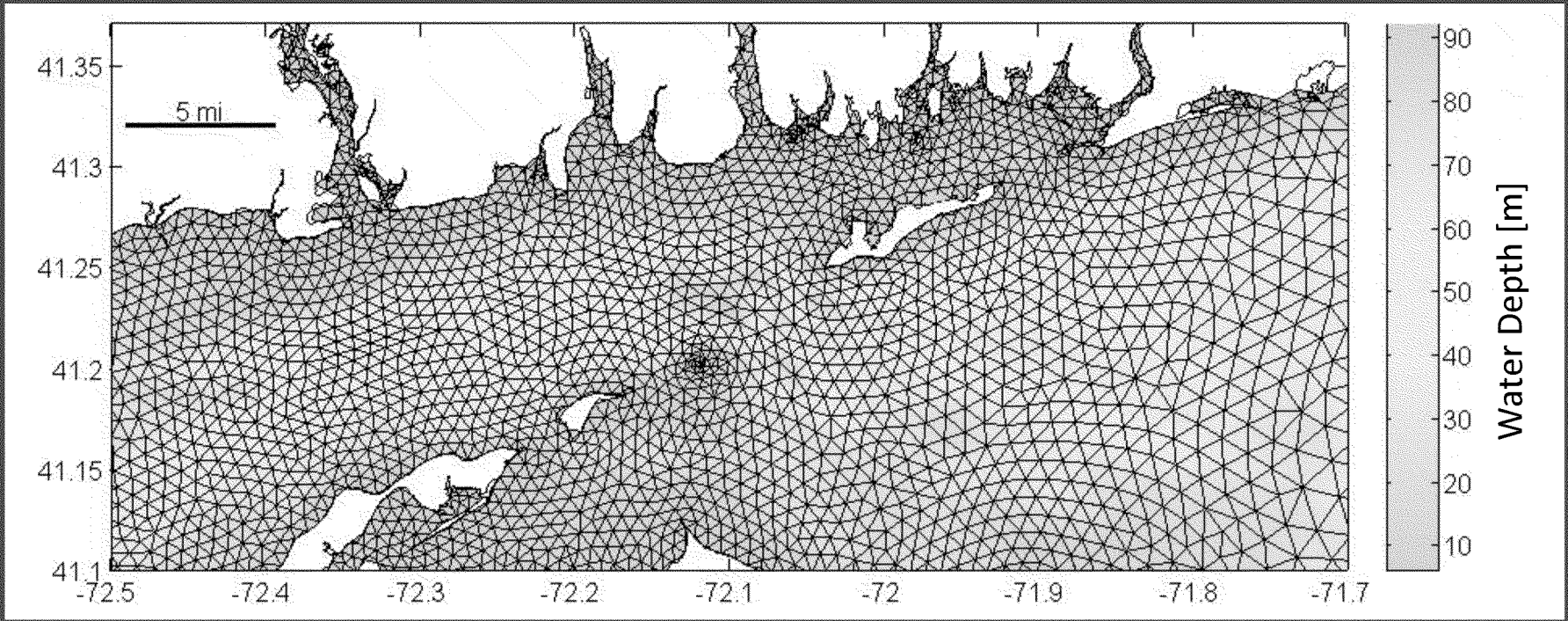
# 2. Model *(cont.)*

FVCOM runs on an unstructured triangular grid (mesh)



# 2. Model *(cont.)*

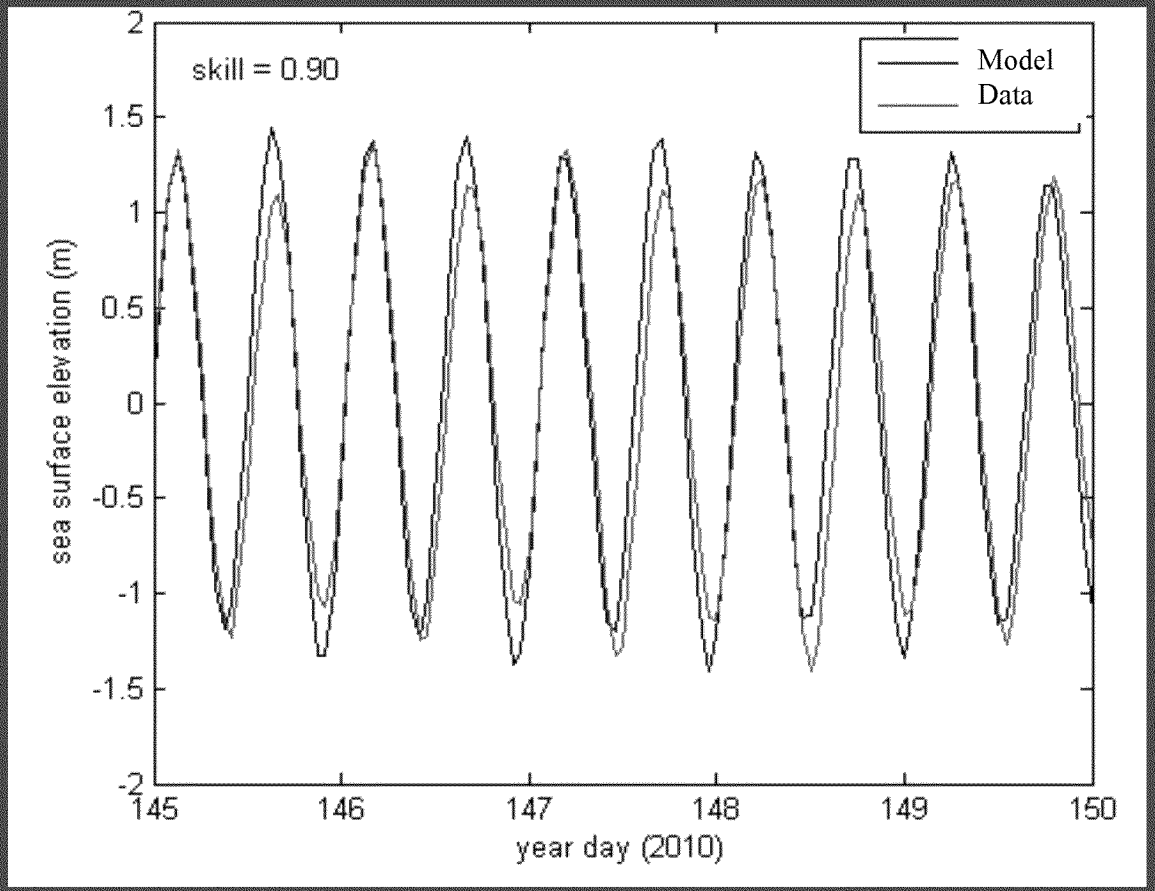
FVCOM runs on an unstructured triangular grid (mesh)




Grid resolution is 100-500 m (~ ¼ mile)

# 2. Model Calibration

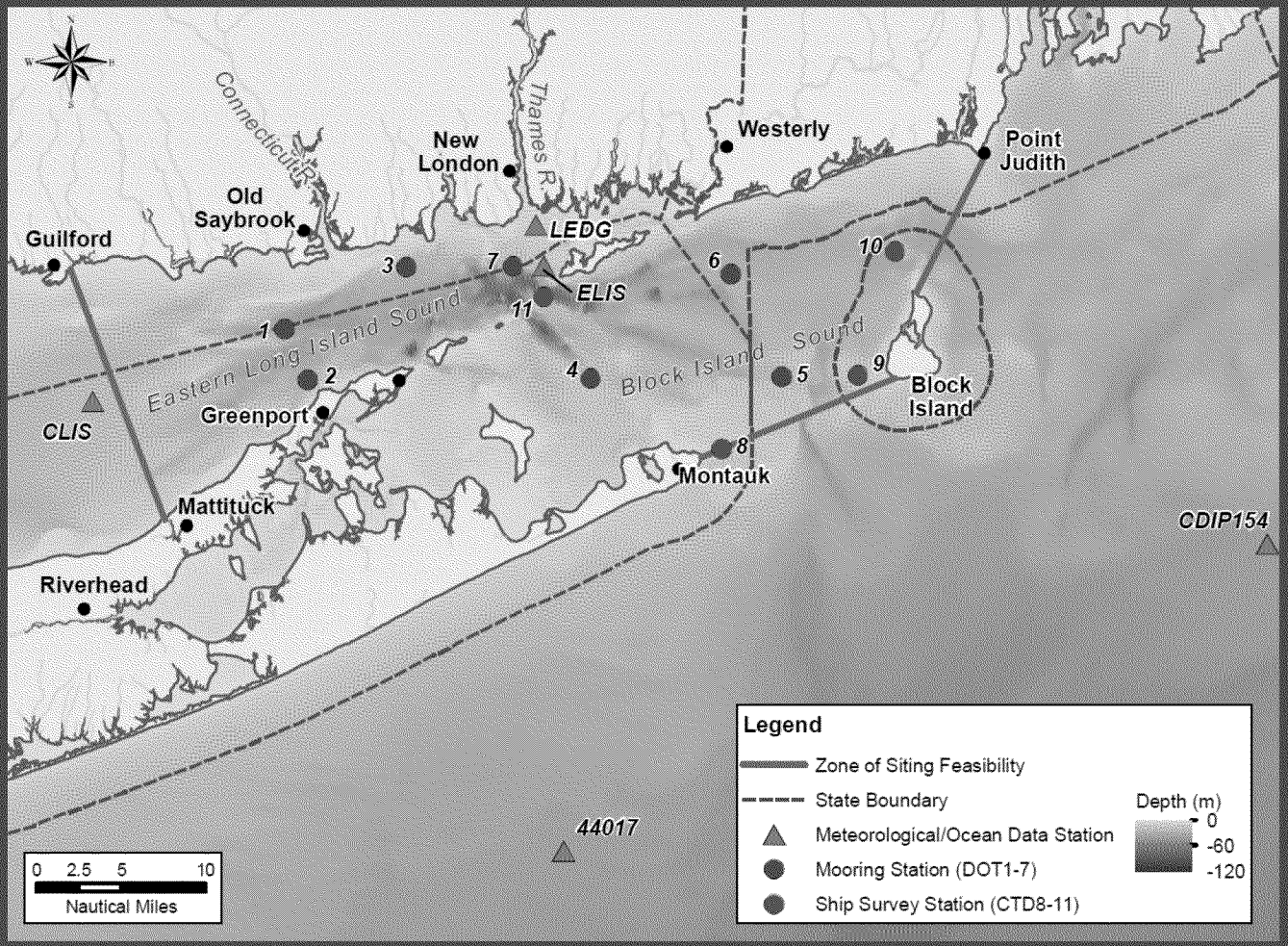
- Optimize the simulation of sea level, temperature, and salinity compared to observations
- Determine the Skill (variance in data explained/variance in data) to be 90%




*Comparison of tidal heights at the NOAA Bridgeport tidal height gauge (BDR, blue) compared to those predicted by the FVCOM model (black) after iteratively calibrating the model using the 2010 NOAA data . Note that year day 1 is January 1, 2010.*

# 3. Evaluation – Field Program

- Deploy instruments on 7 bottom tripods for 3 two-month observation campaigns to observe spring, fall winter conditions at locations having differing stresses etc
- Conduct 6 cruises with water column measurements at the 7 tripod stations and 4 additional stations




*Survey stations in the ZSF, as well as meteorological/ocean stations. The background represents water depth.*

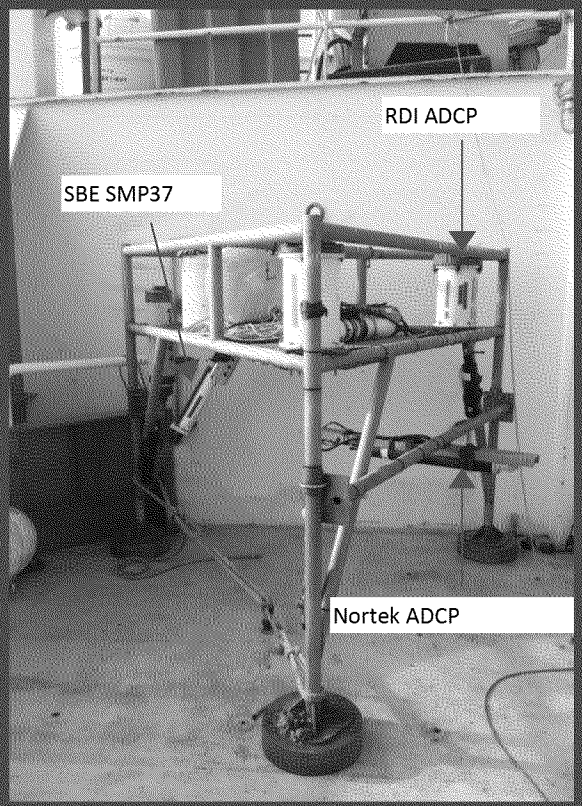
# Survey periods

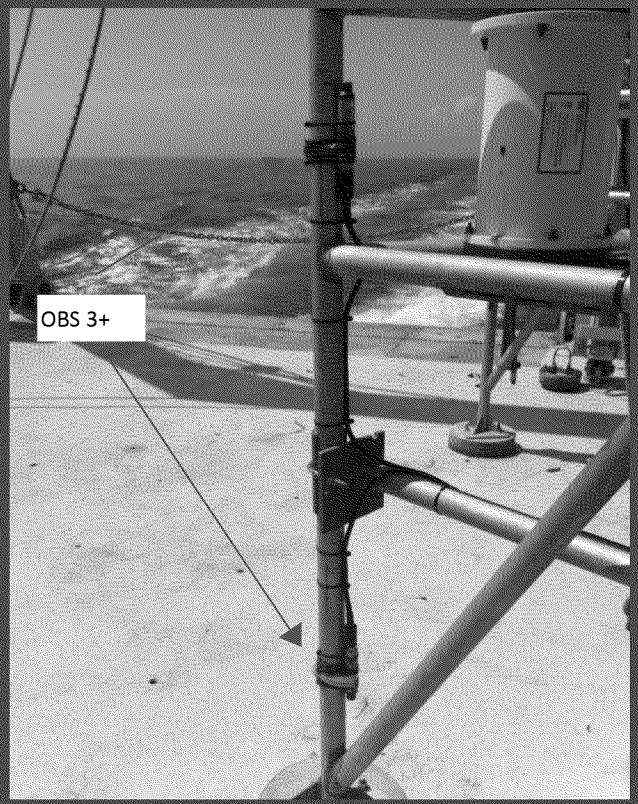
| Campaign | Period | Interval | Conditions |
|---|---|---|---|
| 1 | Spring | March 12 - May 17, 2013 *(66 days)* | High river flow High wind |
| 2 | Summer | June 11 – Aug. 8, 2013 *(58 days)* | Low river flow, Low wind |
| 3 | Winter | Nov. 20, 2013 – Jan. 16, 2014 *(57 days)* | Low river flow, High wind |

# Moored Instruments

## Sensors:

- Water column currents and waves
  *(upward looking RDI ADCP)*
- Currents near Seafloor - Stress
  *(downward looking Nortek ADCP)*
- Suspended sediment concentration
  *(2 optical backscatter OBS3+)*
- Salinity and temperature
  *(CTD SBE SMP37)*

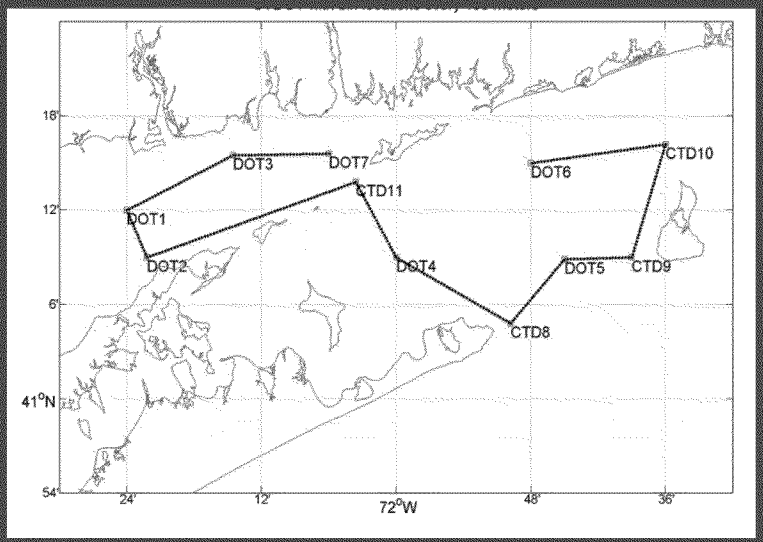


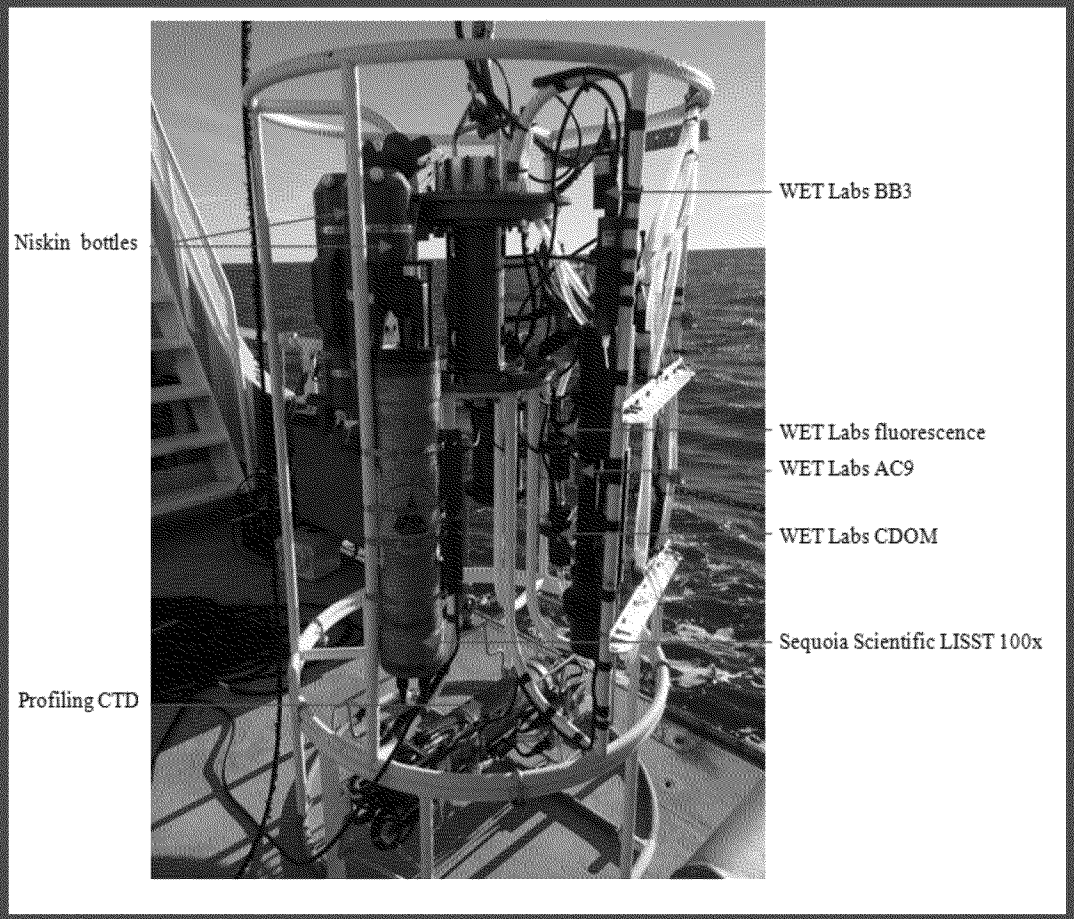




*Left: Location of instruments in moored tripod frame*
*Right: Close-up of the OBS3+ mounts*

# Ship Surveys

- Temperature and salinity
  *(Profiling CTD)*
- Suspended sediment
  *(WET Labs sensors)*
- Water sampling
- Sediment Sampling

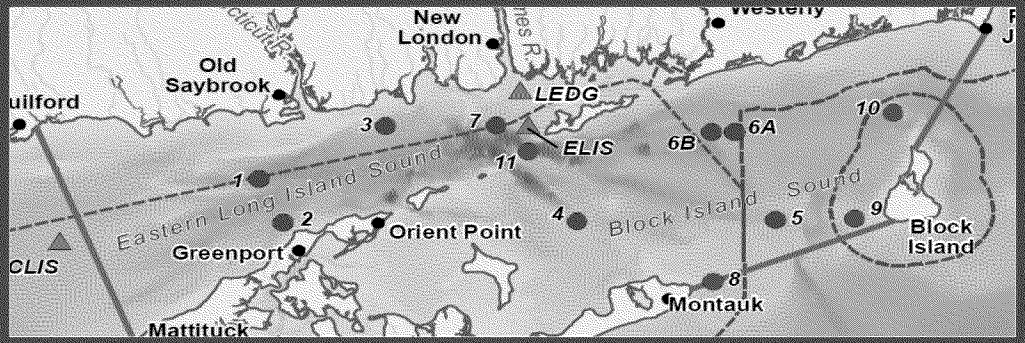



*Rosette sampler, equipped with a profiling CTD, Water samplers, and various optical sensors and particle analyzers.*

*Example of a cruise track for ship surveys. The track varied for each cruise due to weather conditions and sea state.*

# Data Recovery



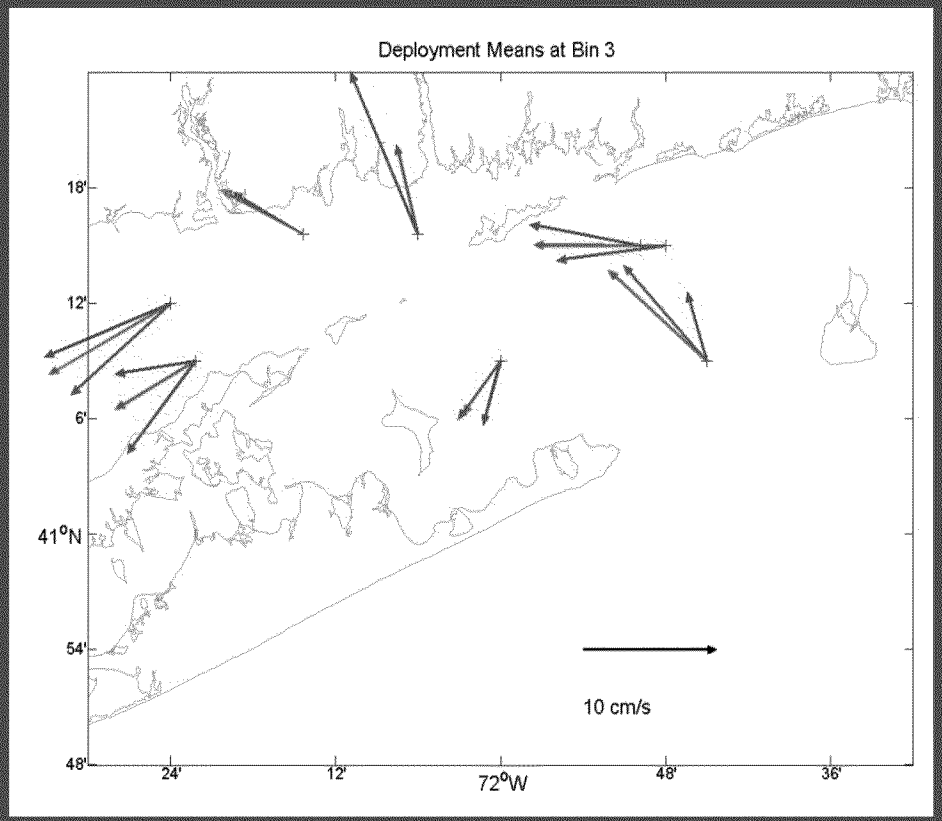

## For Moored Stations

| Para-meters | Temperature and Salinity near the Seafloor | | | | Currents and Suspended Sediment near the Seafloor | | | | Waves and Currents in the Water Column | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sensor* | *CTD (SBE SMP37)* | | | | *Nortek ADCP & OBS3+ sensor* | | | | *RDI ADCP* | | | |
| Mooring Stn | Campaign 1 | Campaign 2 | Campaign 3 | Total | Campaign 1 | Campaign 2 | Campaign 3 | Total | Campaign 1 | Campaign 2 | Campaign 3 | Total |
| | days | | | | days | | | | days | | | |
| DOT1 | 66 | 58 | 57 | 181 | 25 | 29 | 54 | 108 | 66 | 58 | 57 | 181 |
| DOT2 | 66 | 58 | 57 | 181 | 25 | 27 | 54 | 106 | 66 | 58 | 57 | 181 |
| DOT3 | 66 | 58 | 57 | 181 | 24 | 32 | 53 | 110 | 0 | 58 | 57 | 115 |
| DOT4 | 66 | 58 | 57 | 181 | 27 | 34 | 56 | 117 | 66 | 58 | 57 | 181 |
| DOT5 | 66 | 58 | 57 | 181 | 27 | 30 | 57 | 114 | 66 | 58 | 57 | 181 |
| DOT6 A/B | 66 | 58 | 43 | 167 | 25 | 16 | 44 | 86 | 28 | 16 | 43 | 87 |
| DOT7 | 49 | 58 | 57 | 164 | 28 | 34 | 27 | 89 | 0 | 58 | 57 | 115 |
| *Max Days* | *66* | *58* | *57* | *181* | *66* | *58* | *57* | *181* | *66* | *58* | *57* | *181* |

Full or near-full data (>90%)
About half or more data (45 - 90%)
About one quarter or more data (22.5 - 45%)
No data

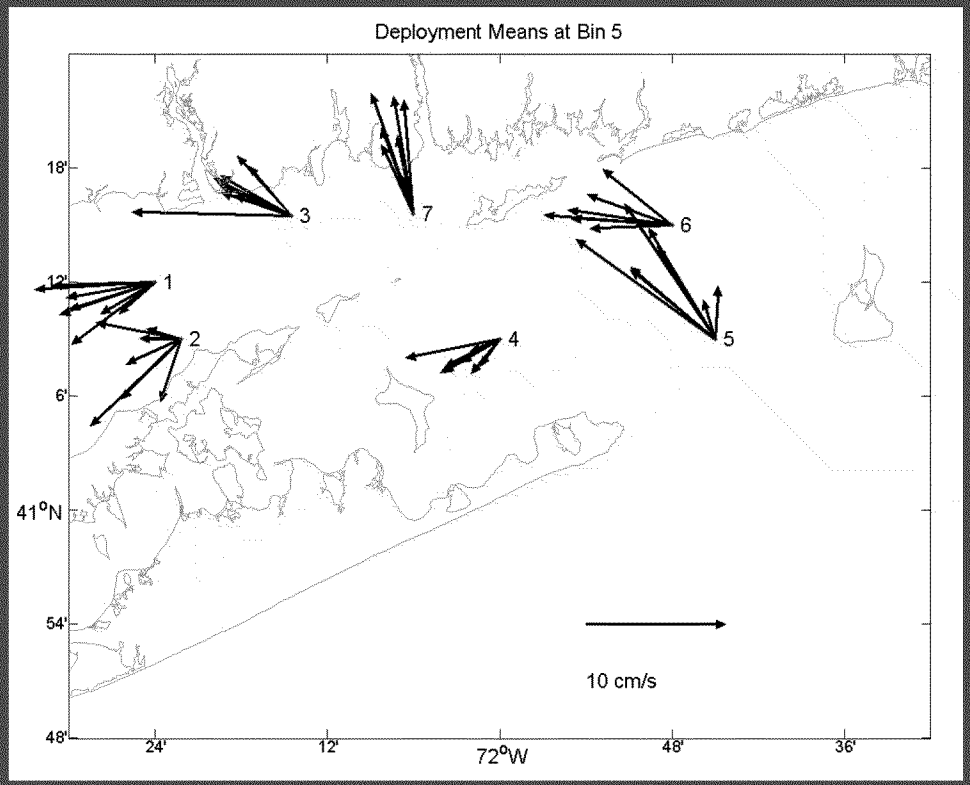
# Example of Observations – mean flow near the bottom

RDI ADCP means at ~3m from seafloor




*Mean currents at Bin 3 of the RDI ADCP measurements during Campaigns 1 (green), 2 (red), and 3 (blue).*

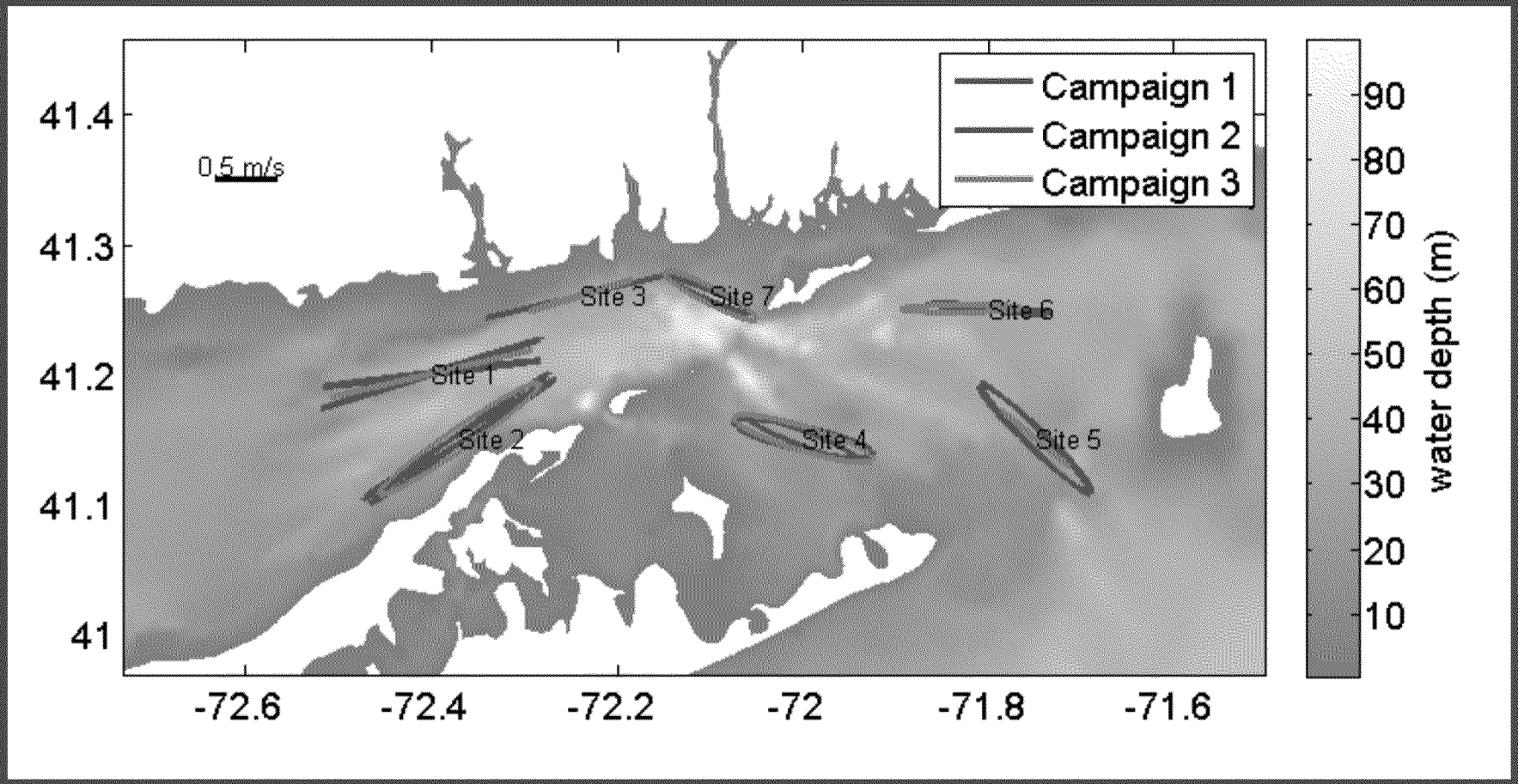
Nortek ADCP means at ~0.6m from seafloor




*Mean velocity vectors at each moored station from the Nortek ADCP near the seafloor. The velocity scale is shown on graphic.*

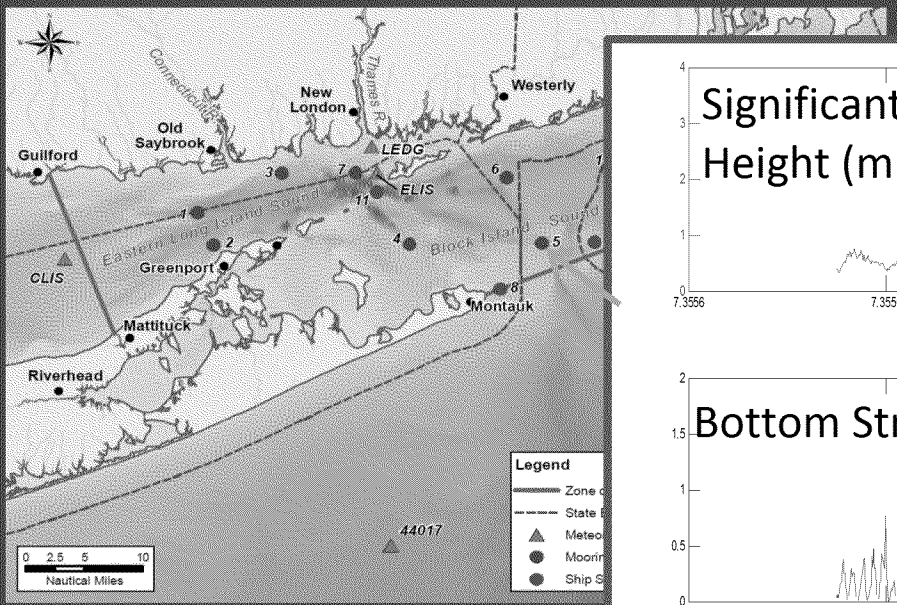
# Tidal Current (M2) Amplitudes

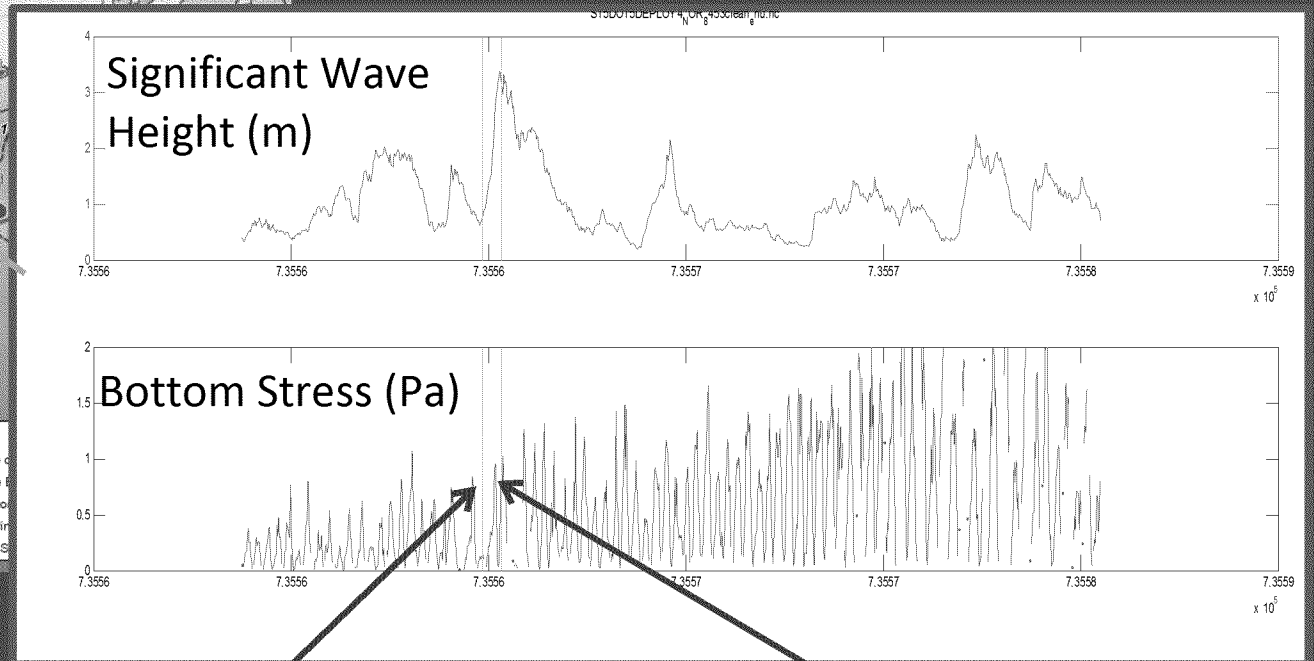
## M2 Tidal Constituents

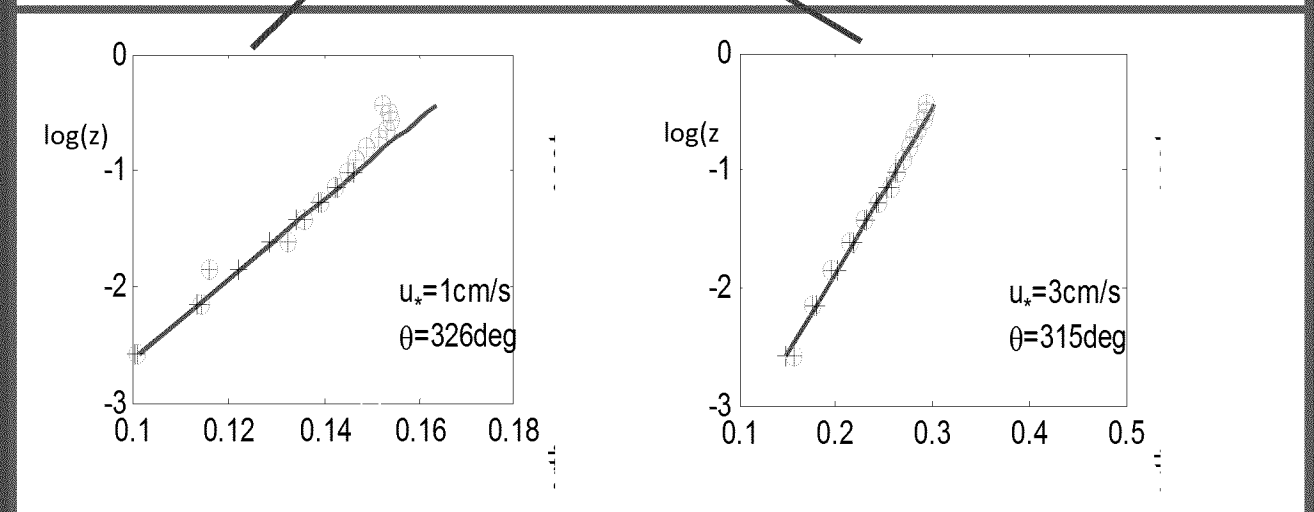



*M2 ellipses for depth-average velocities from RDI ADCP measurements from the three campaigns (colors) and for FVCOM model (black) at all seven DOT stations. The grey shading represents mean water depth.*

# Wave and Stress Measurements

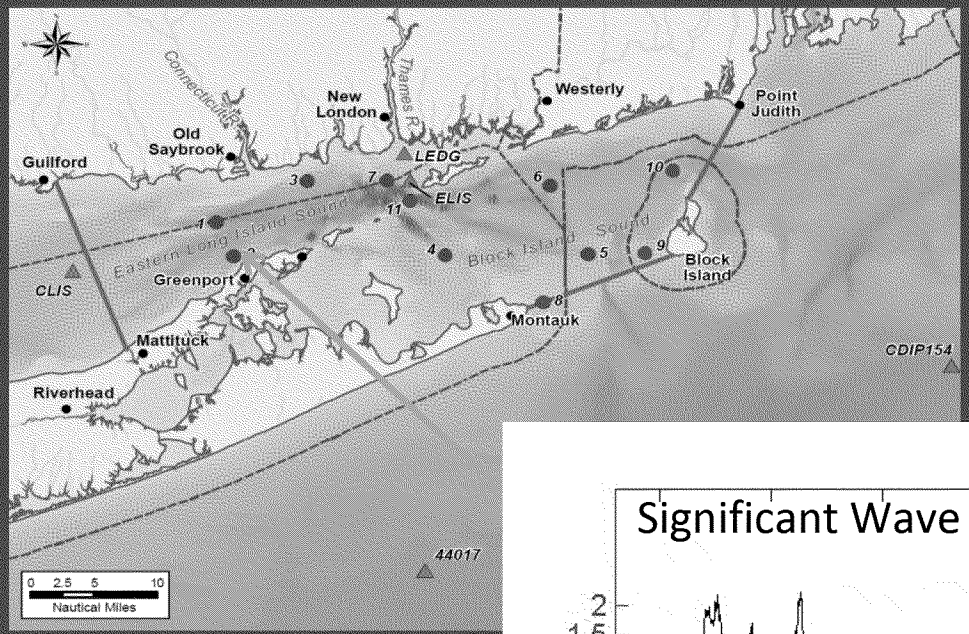


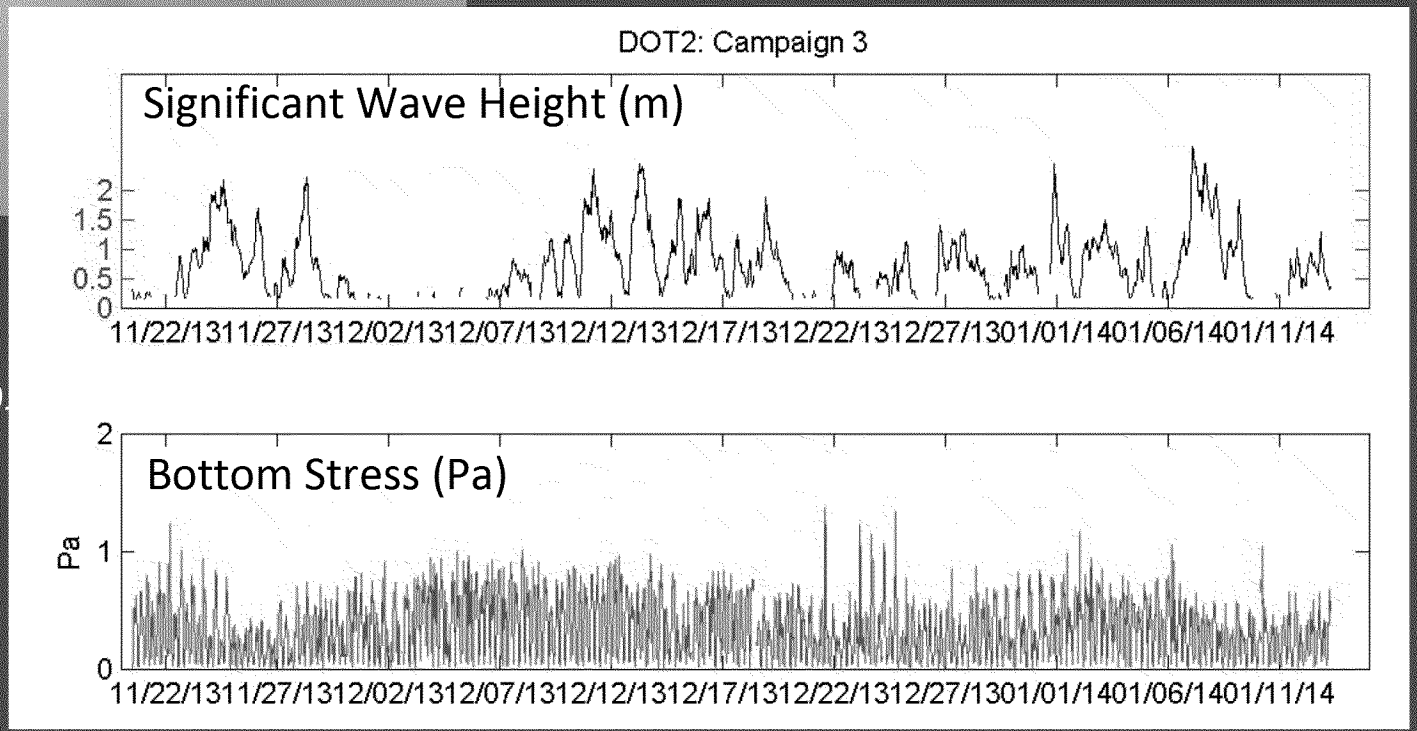




*The variation of u(z) with log(z) for ensembles 297 and 317*

# Wave and Stress Measurements

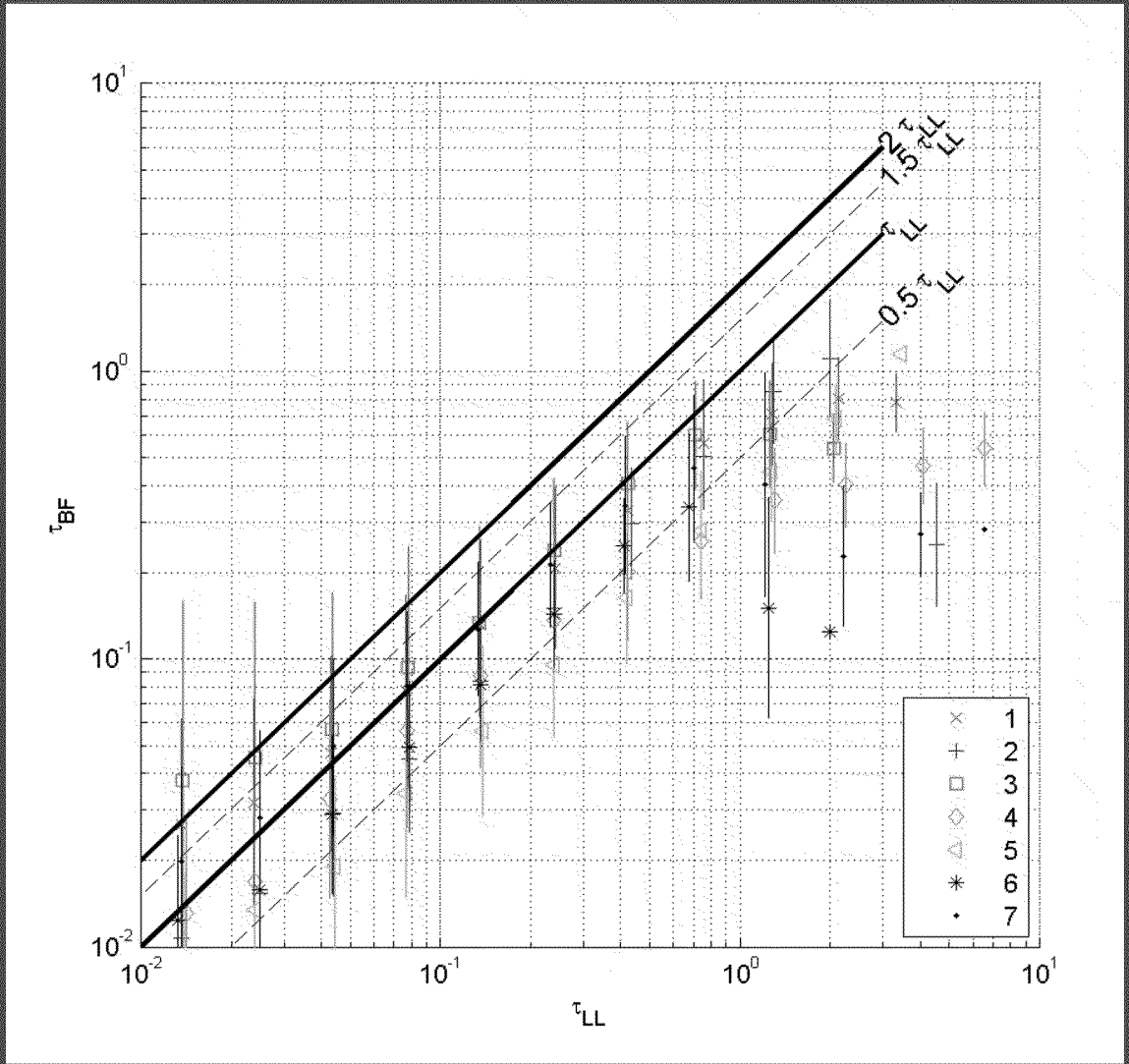



*Characteristics at Station DOT2 during Campaign 3:*
*Top: Significant wave height (in m).*
*Bottom Stress.*

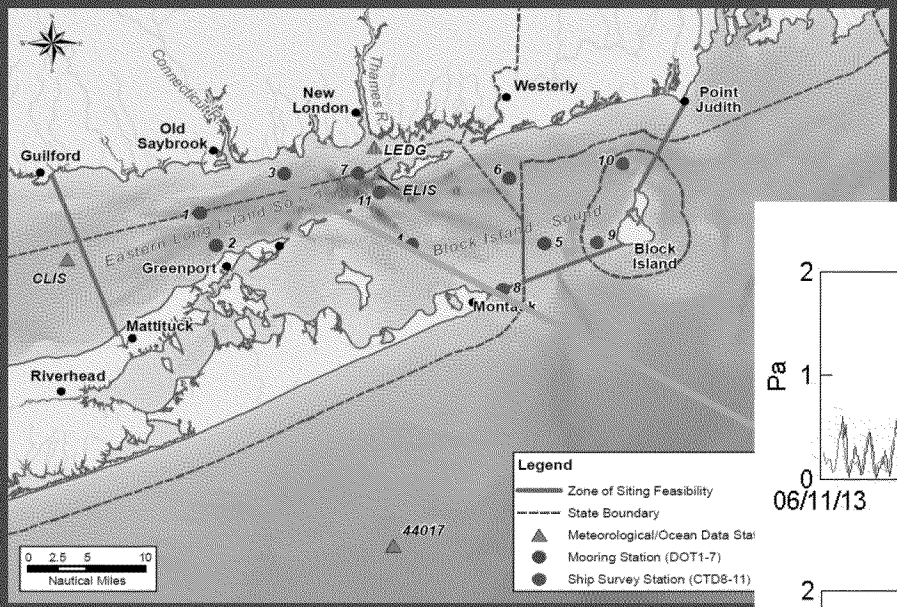
# Bottom Stress Drag Coefficient Evaluation

Measurements using the Log Law method (LL) support the use of Bulk Formula (BF) with $C_d$ =0.0025.

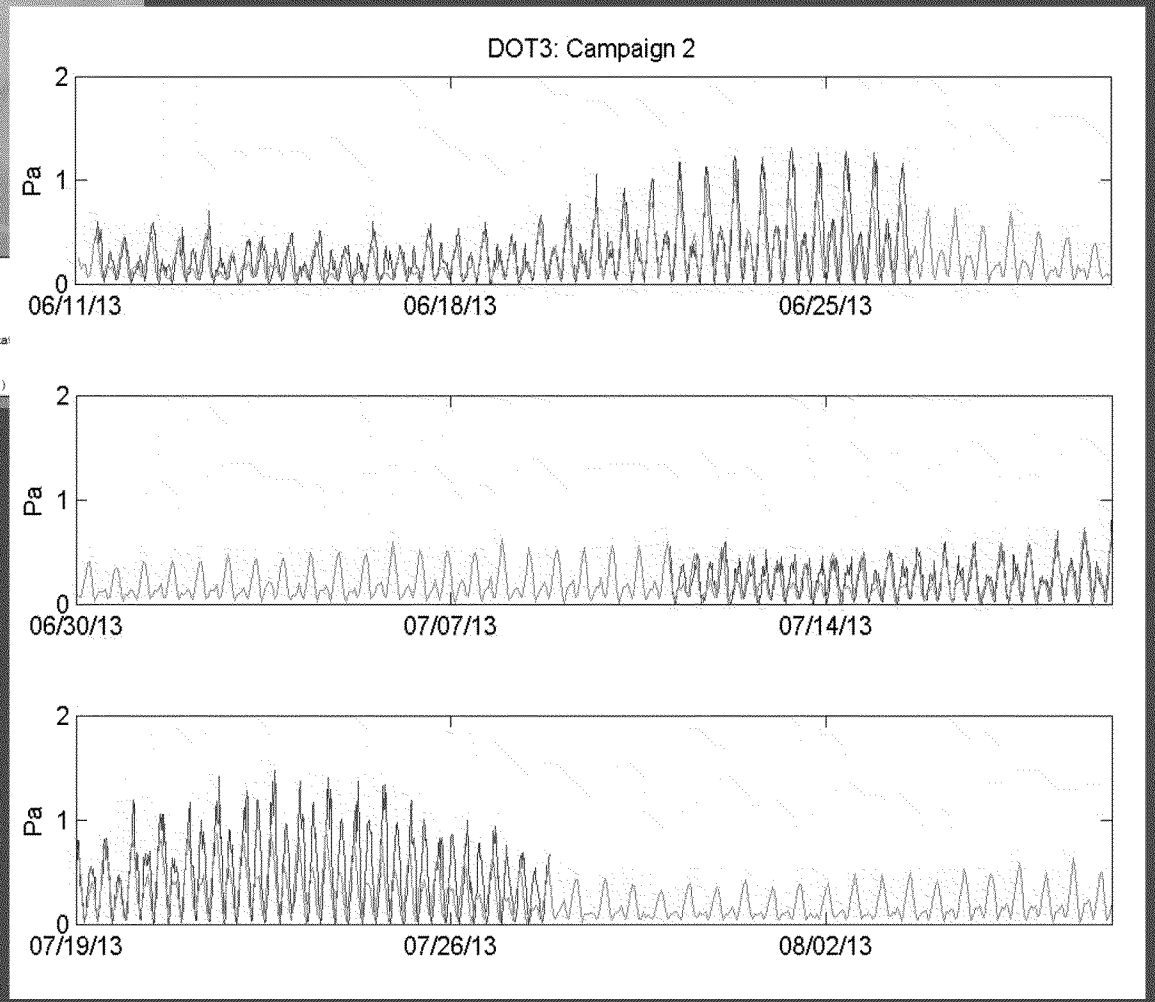



*Summary of stress magnitude measurements using the log law and the bulk formula with $C_d$=0.0025. To suppress the noise inherent in turbulent quantities, measurements were bin-averaged. The key shows the stations numbers.*

# 3. Evaluation of Bottom Stress in Model



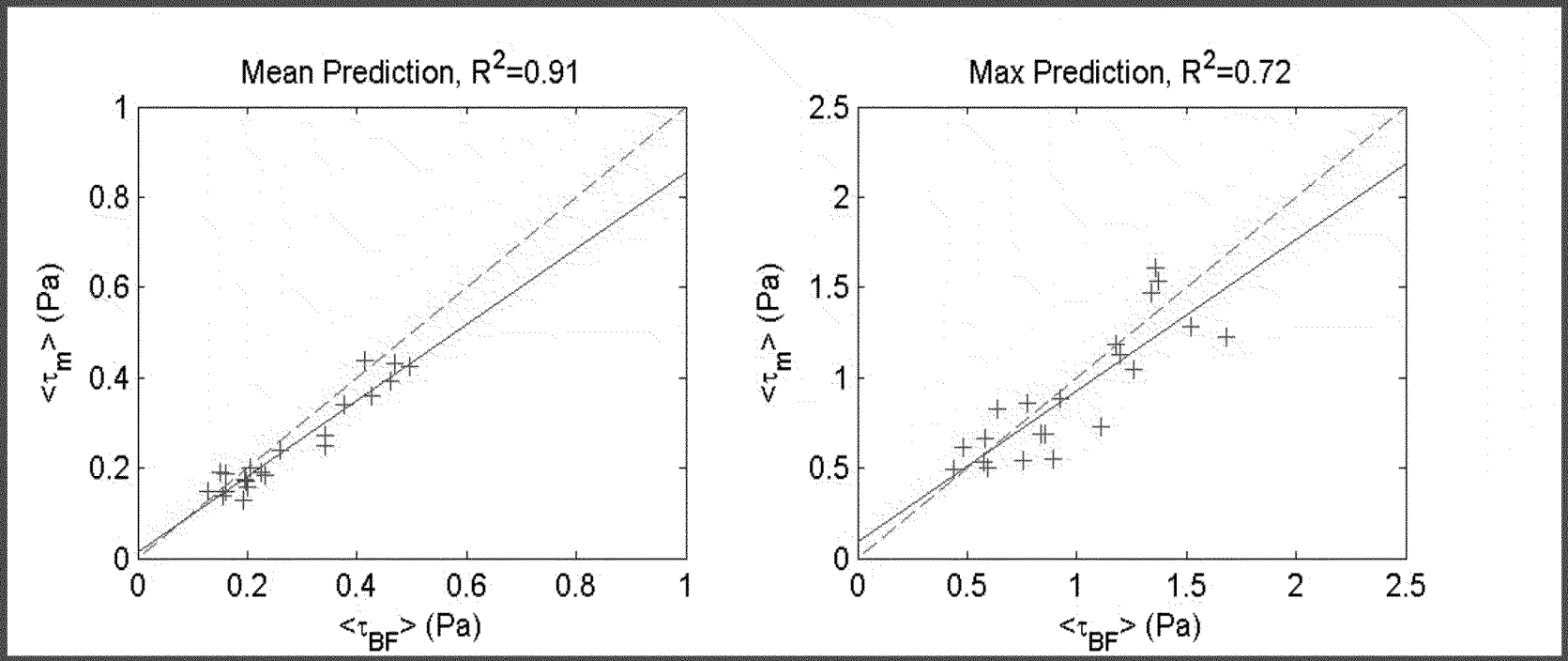

Model simulations reproduce tidal and the spring-neap variations on observed stress




*Model-predicted bottom stress at Station DOT3 during Campaign 2 in the summer of 2013 (magenta line). The blue line shows the measured stress using the bulk formula.*

# 3. Evaluation

- Model and observations agree on the campaign mean and maximum stress magnitudes.
- Model can effectively discriminate between places where the maximum measured stresses are large (>1 Pa) and those where they are smaller (<1Pa).



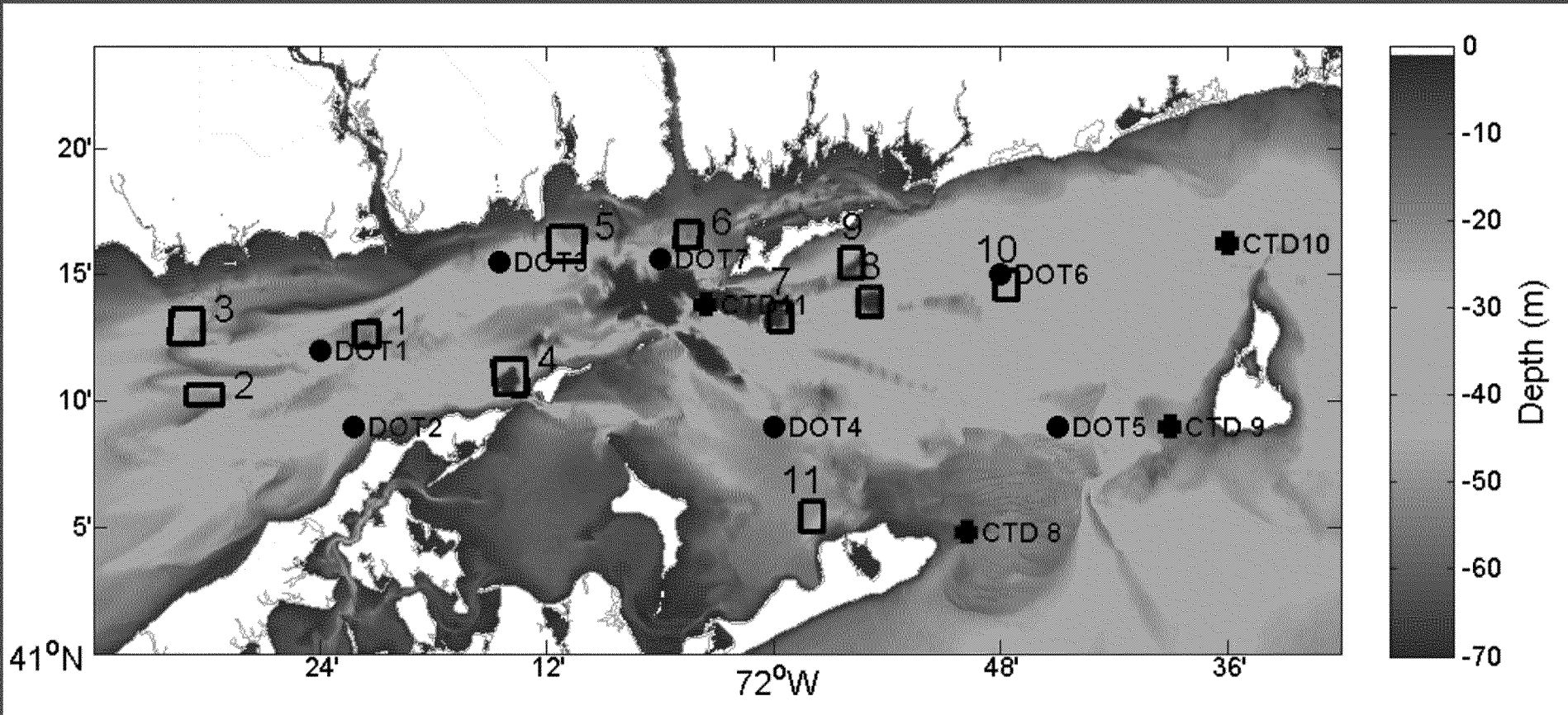

Left: Comparison of model predicted bottom stress magnitudes and mean bottom stress observed during the three campaigns. Points would all lie on the red dashed line if the model and data were in perfect agreement. The blue solid line shows the ordinary least-squares regression line which has a correlation coefficient of 0.91.
Right: Comparison of the predicted and observed maximum stress magnitudes. The correlation coefficient was 0.72.

# 4. Analysis

- Find maximum bottom stress magnitude at each point in the ZSF in the three Campaigns
- Compare values at sites identified in the screening process
- Simulate period of a severe storm (Superstorm Sandy) and compare maximum stress magnitudes

# 4. Analysis *(cont.)*

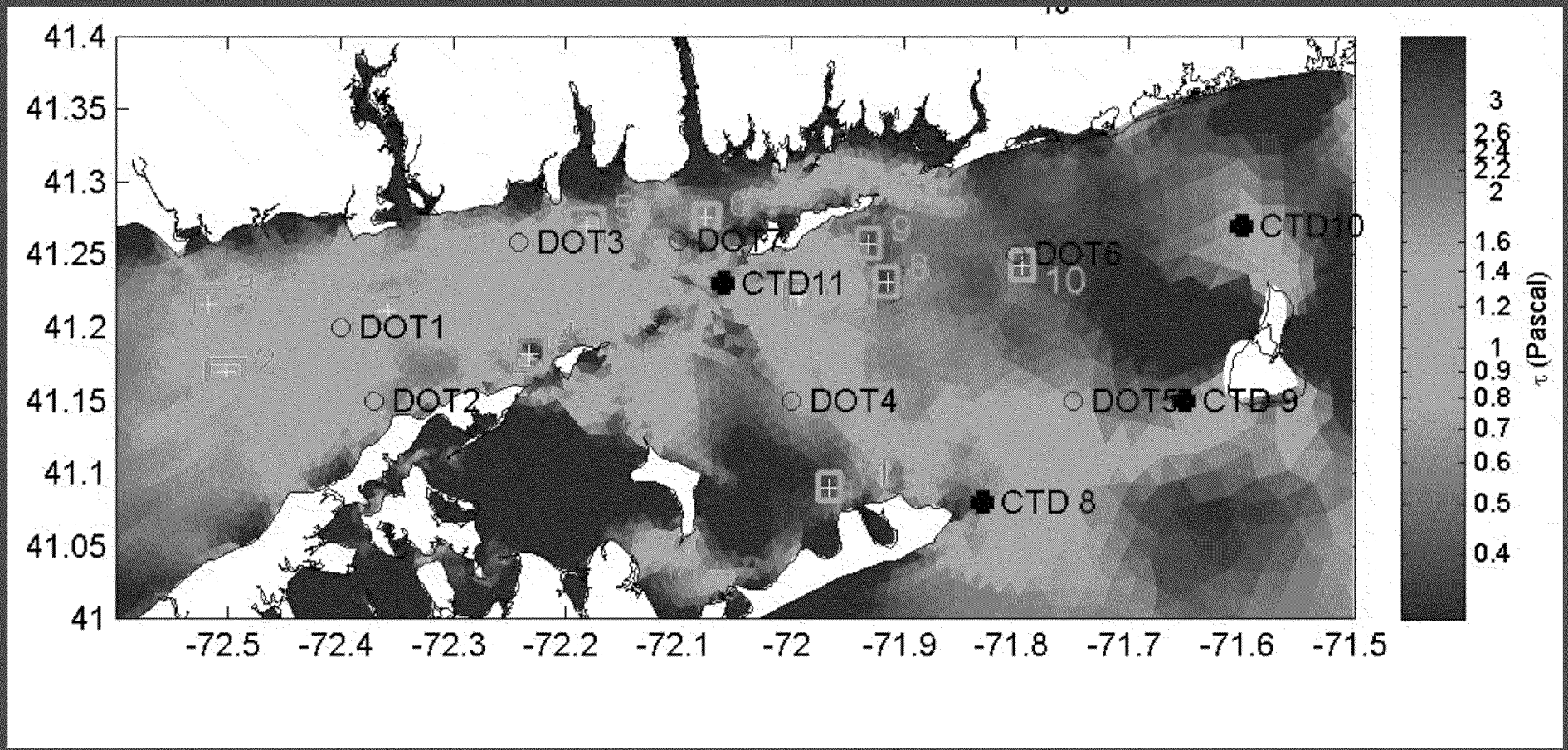
## Bathymetry and locations of potential sites




*Water depth and 11 potential dredged material disposal sites (open boxes) as identified during the initial screening process. Sites 1 and 6 are the active disposal sites (CSDS and NLDS, respectively). The seven mooring stations ('DOT') are identified by full circles; the four additional ship survey stations ('CTD') are identified by crosses.*

# 4. Analysis *(cont.)*

- Spatial differences are much larger than seasonal variations
- Stress is high in much of ZSF



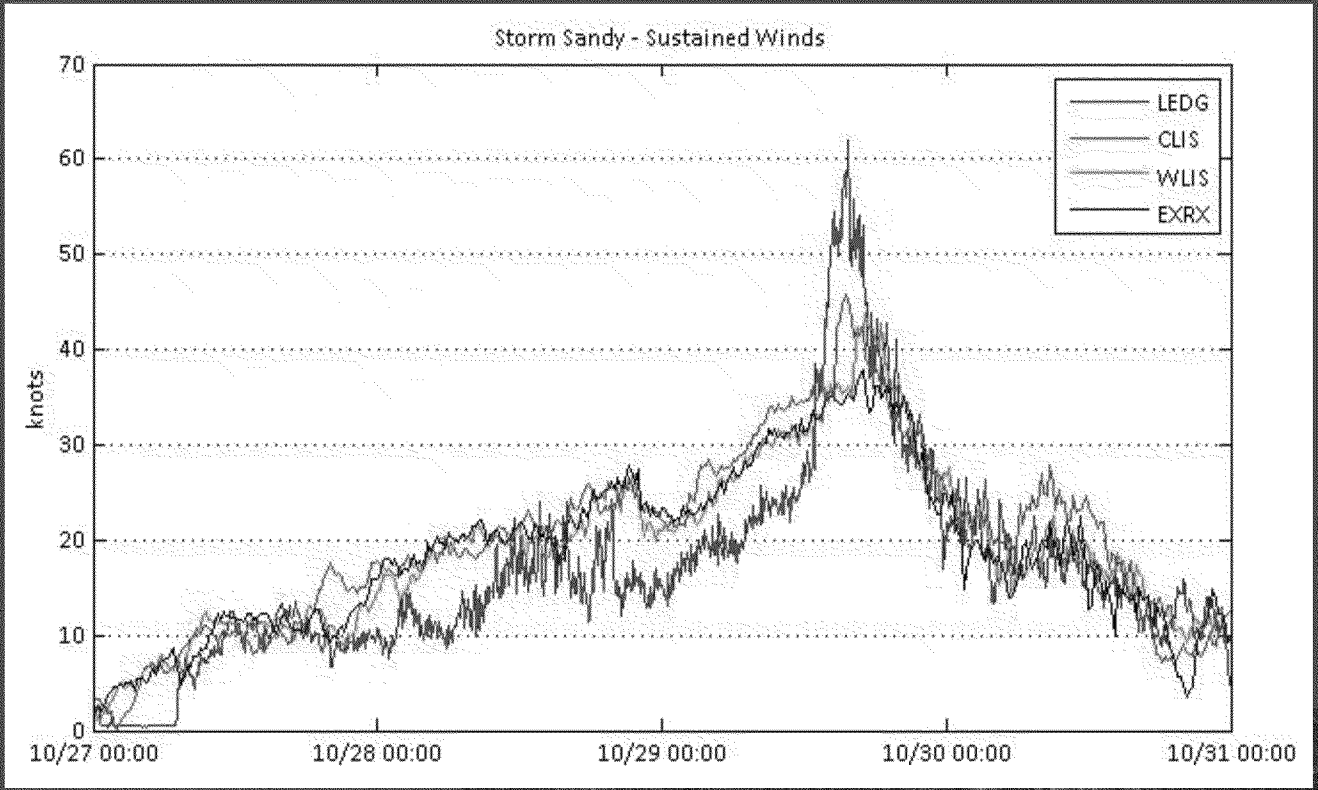

*Maximum bottom stress during Campaign 3 (November 20, 2013, to January 16, 2014) for storm conditions (i.e., due to the principal tidal current constituents and the seasonal mean flow, as well as wind).*

# 4. Analysis *(cont.)*

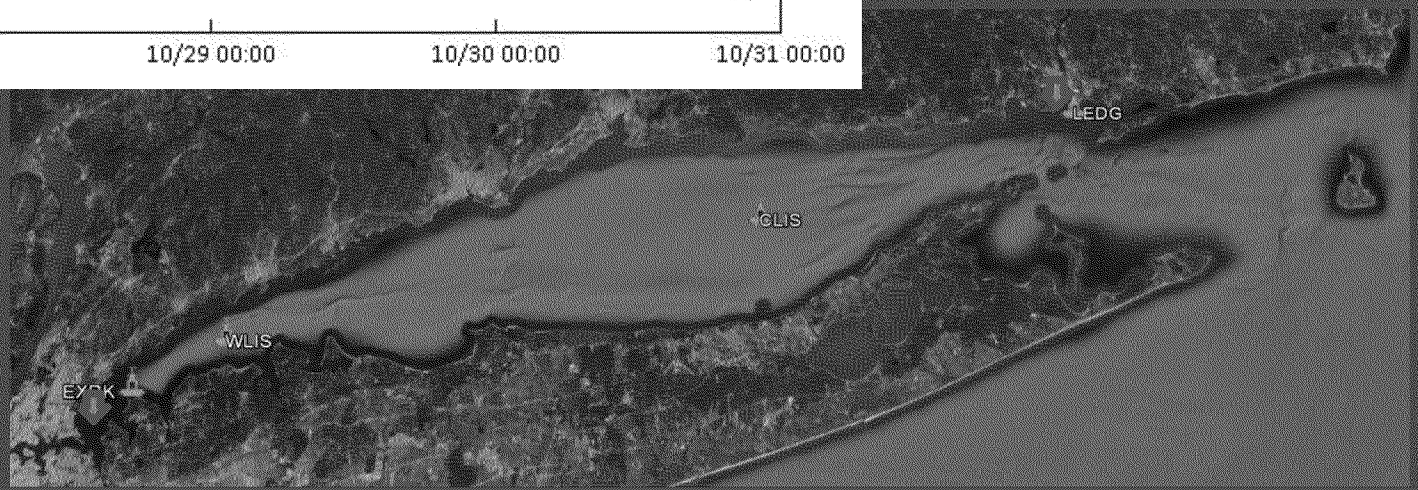
Maximum Bottom Stress (Pa) during Storm Conditions at Potential Dredged Material Disposal Sites

| **Potential Disposal Site** | | | **Maximum Bottom Stress** (Pa) | | |
|---|---|---|---|---|---|
| | | | **1. (spring)** | **2. (summer)** | **3. (winter)** |
| ELIS | 1 | Cornfield Shoals Disposal Site | 1.17 | 1.31 | 1.24 |
| | 2 | Six Mile Reef Disposal Site | 0.92 | 1.09 | 1.00 |
| | 3 | Clinton Harbor Disposal Site | 0.72 | 0.71 | 0.81 |
| | 4 | Orient Point Disposal Site | 0.52 | 0.61 | 0.48 |
| | 5 | Niantic Bay Disposal Site | 0.73 | 0.97 | 0.84 |
| | 6 | New London Disposal Site | 0.60 | 0.70 | 0.69 |
| BIS | 7 | Fishers Island-west | 0.79 | 0.91 | 0.86 |
| | 8 | Fishers Island-east | 0.49 | 0.51 | 0.39 |
| | 9 | Fishers Island-center | 0.39 | 0.50 | 0.38 |
| | 10 | Block Island Sound Disposal Site | 0.49 | 0.63 | 0.44 |
| | 11 | North of Montauk | 0.31 | 0.31 | 0.34 |

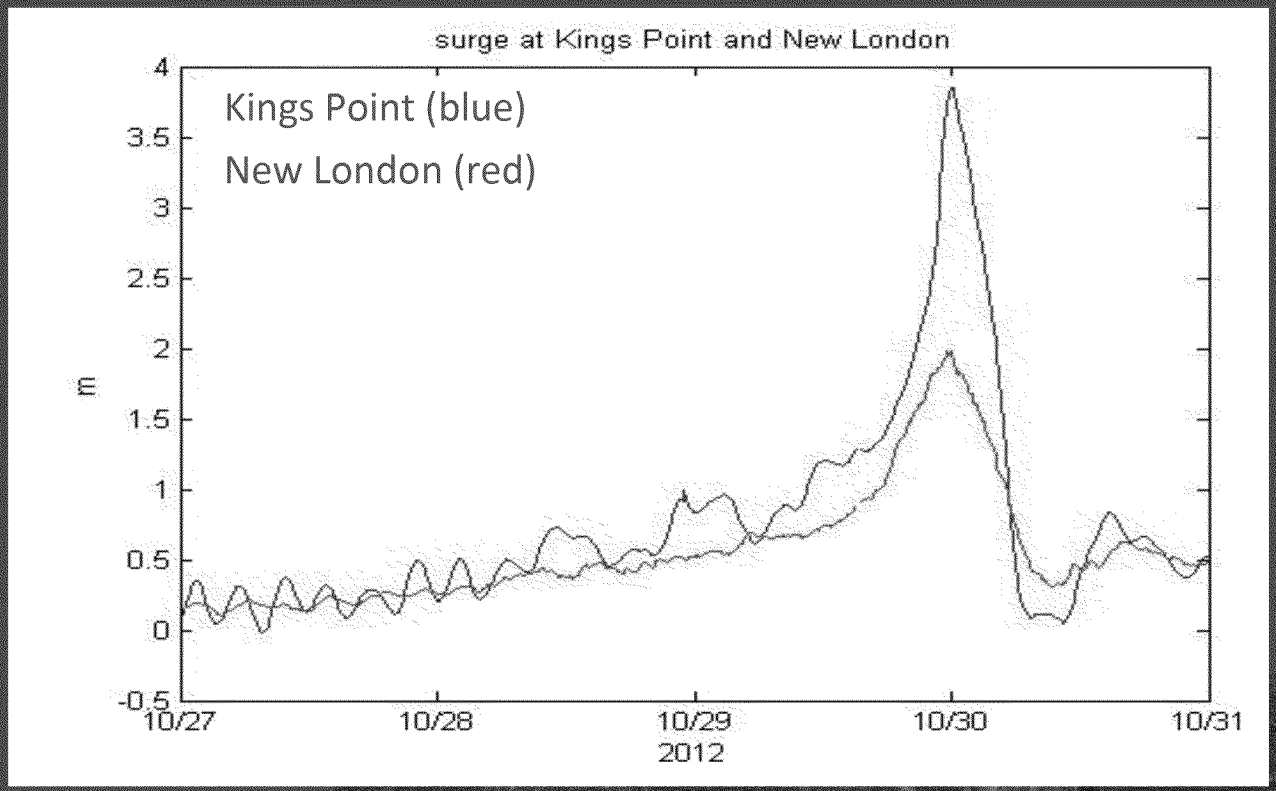
# 4. Analysis *(cont.)*



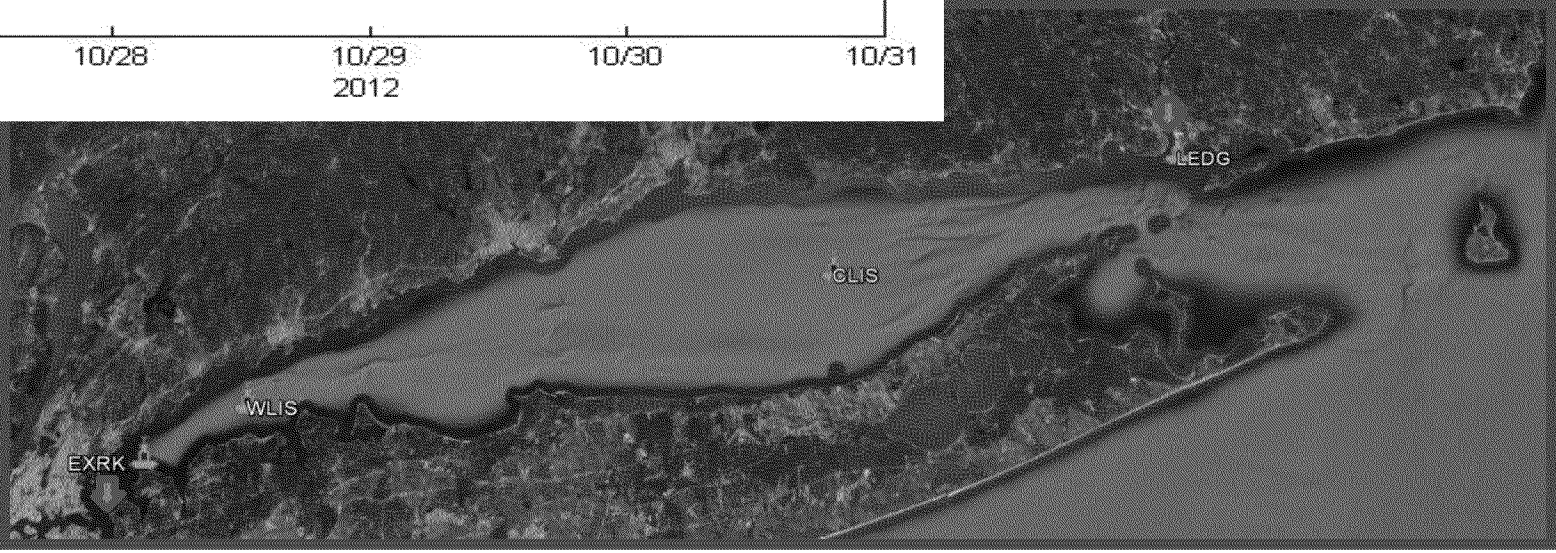

Superstorm Sandy: Sustained Winds



# 4. Analysis *(cont.)*

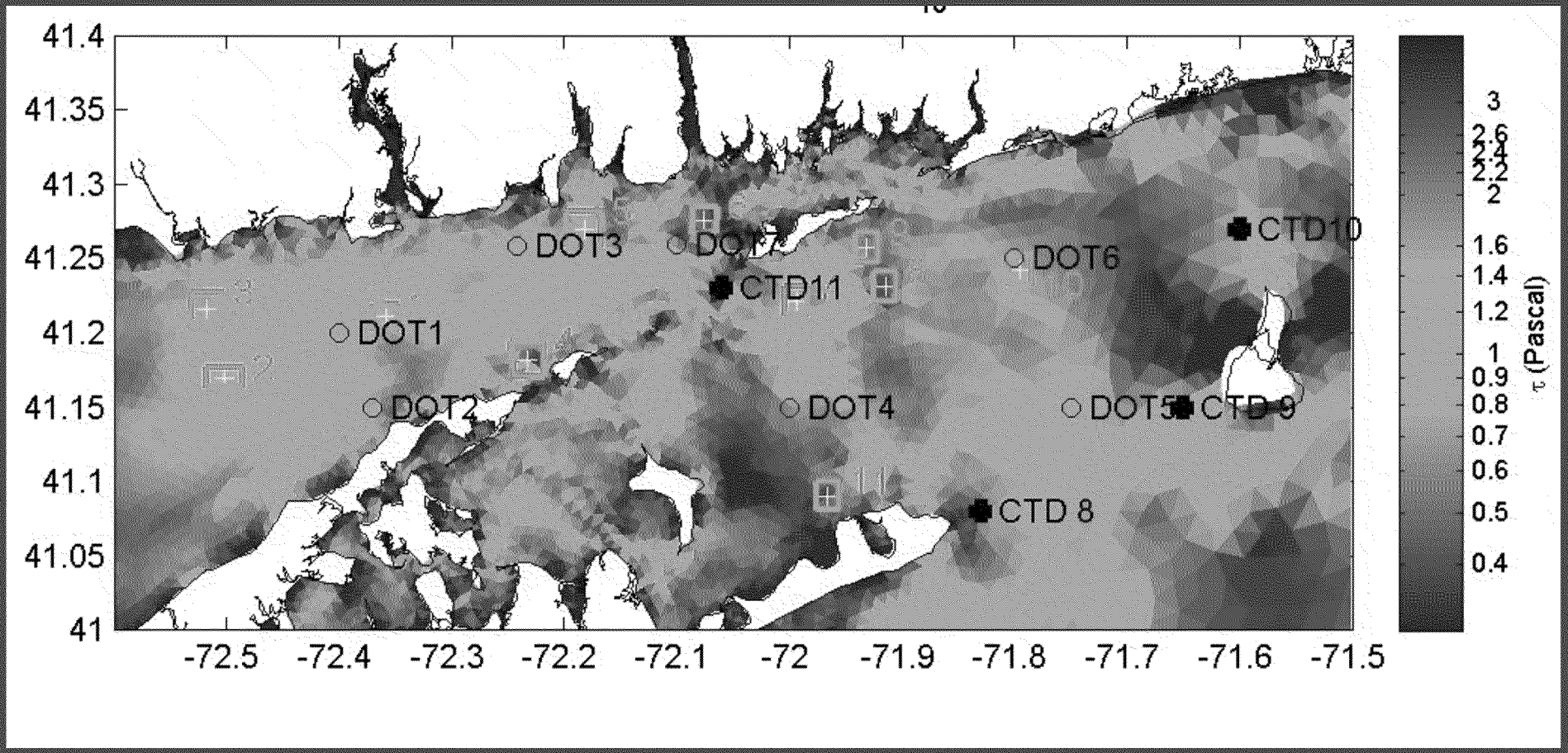



## Superstorm Sandy: Storm Surge



# 4. Analysis *(cont.)*

Superstorm Sandy created higher maximum bottom stresses in some areas




*Maximum bottom stress simulated for the period October 28 to 31, 2012 when Superstorm Sandy passed over New England.*

# 4. Analysis *(cont.)*

| Potential Disposal Site | | | Superstorm Sandy Conditions |
|---|---|---|---|
| | | | **Bottom Stress** (Pa) |
| ELIS | 1 | Cornfield Shoals Disposal Site | 1.16 |
| | 2 | Six Mile Reef Disposal Site | 1.26 |
| | 3 | Clinton Harbor Disposal Site | 0.87 |
| | 4 | Orient Point Disposal Site | 0.53 |
| | 5 | Niantic Bay Disposal Site | 0.99 |
| | 6 | New London Disposal Site | 0.48 |
| BIS | 7 | Fishers Island-west | 1.17 |
| | 8 | Fishers Island-east | 0.46 |
| | 9 | Fishers Island-center | 0.55 |
| | 10 | Block Island Sound Disposal Site | 0.73 |
| | 11 | North of Montauk | 0.39 |

# 4. Analysis *(cont.)*

## Stress Threshold for Erosion on Seafloor:

- Defined as the level of stress at which dredged material in a disposal area will be mobilized
- Depends upon sediment grain size, fraction of clay, volume fraction, level cohesiveness
- Based on a review of the literature, we choose 0.75 Pa as the design threshold

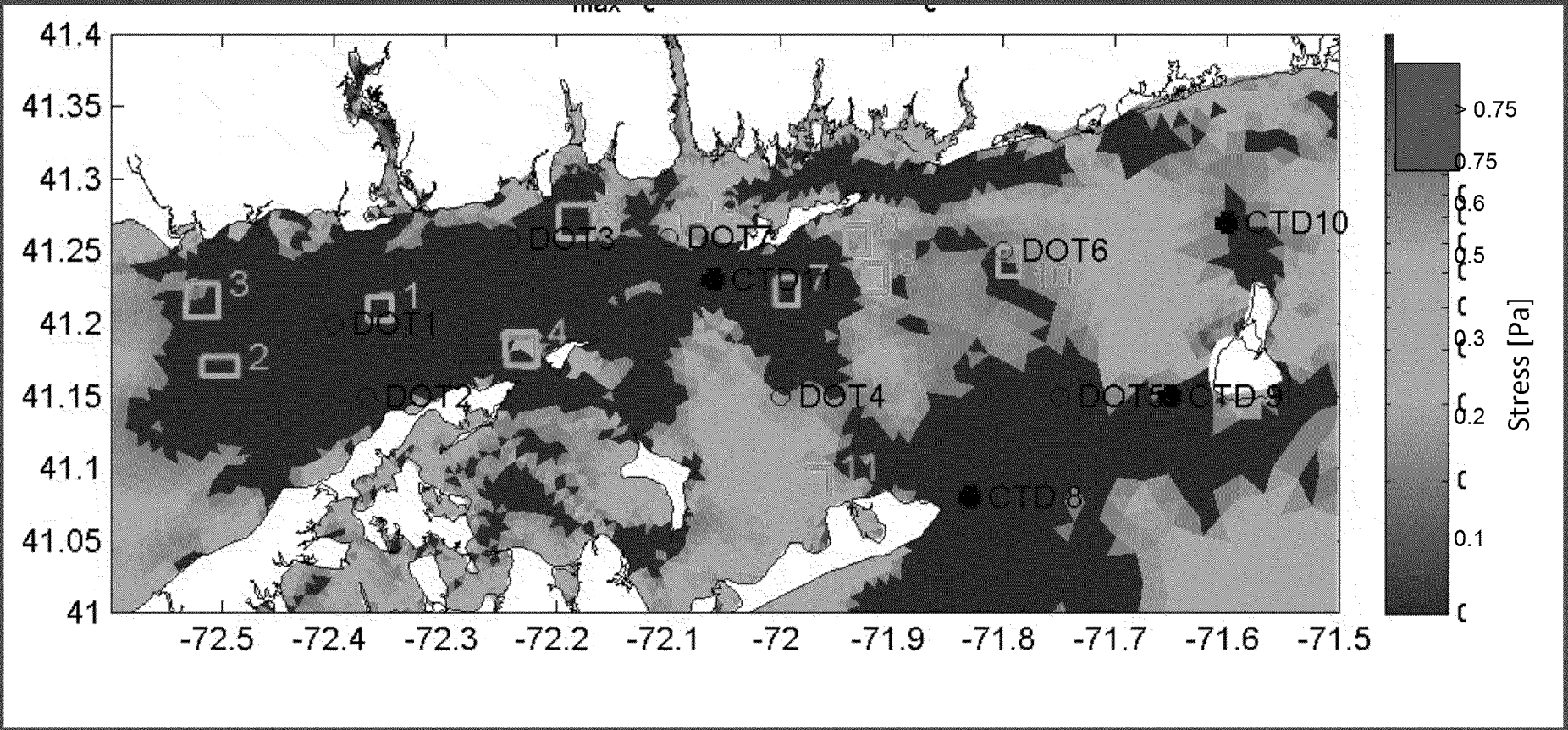
# 4. Analysis *(cont.)*

Comparison of Maximum Bottom Stress (Pa) for Potential Dredged Material Disposal Sites in the simulations of the three Observation Campaigns and Superstorm Sandy.

| Potential Disposal Site | | | | Maximum Stress in Simulations (Pa) | |
|---|---|---|---|---|---|
| ELIS | BIS | No. | Site Name | Group | Highest Value |
| ● | | 1 | Cornfield Shoals Disposal Site | >1 | 1.31 |
| ● | | 2 | Six Mile Reef Disposal Site | | 1.26 |
| | ● | 7 | Fishers Island-west Disposal Site | | 1.17 |
| ● | | 5 | Niantic Bay Disposal Site | 0.75-1.0 | 0.99 |
| ● | | 3 | Clinton Harbor Disposal Site | | 0.87 |
| | ● | 10 | Block Island Sound Disposal Site | <0.75 | 0.73 |
| ● | | 6 | New London Disposal Site | | 0.69 |
| | ● | 9 | Fishers Island-center | | 0.55 |
| ● | | 4 | Orient Point Disposal Site | | 0.53 |
| | ● | 8 | Fishers Island-east | | 0.46 |
| | ● | 11 | North of Montauk | | 0.39 |

# 5. Summary

*Areas with maximum bottom stress exceeding the 0.75 Pa threshold during the simulation of Superstorm Sandy (screened as a uniform brown layer). Areas with bottom stress below 0.75 Pa are scaled (see color key on the right).*



# 5. Summary (cont)

**Sites 1, 2, and 7**

**(Cornfield Shoals, Six Mile Reef, and Fishers Island - west)** have high maximum stresses.

**Sites 4 and 10**

**(Orient Point DS and Block Island Sound DS)** show maximum stress below the 0.75 Pa threshold at the center of the site, but have values in excess of 0.75 Pa within the boundary.

**Sites 5 and 3**

**(Niantic Bay and Clinton Harbor)** show maximum stresses exceeding 0.75 Pa but less than 1 Pa.

**Site 6**

**(New London DS)** is the only site in Eastern Long Island Sound with maximum bottom stress below the 0.75 Pa threshold.