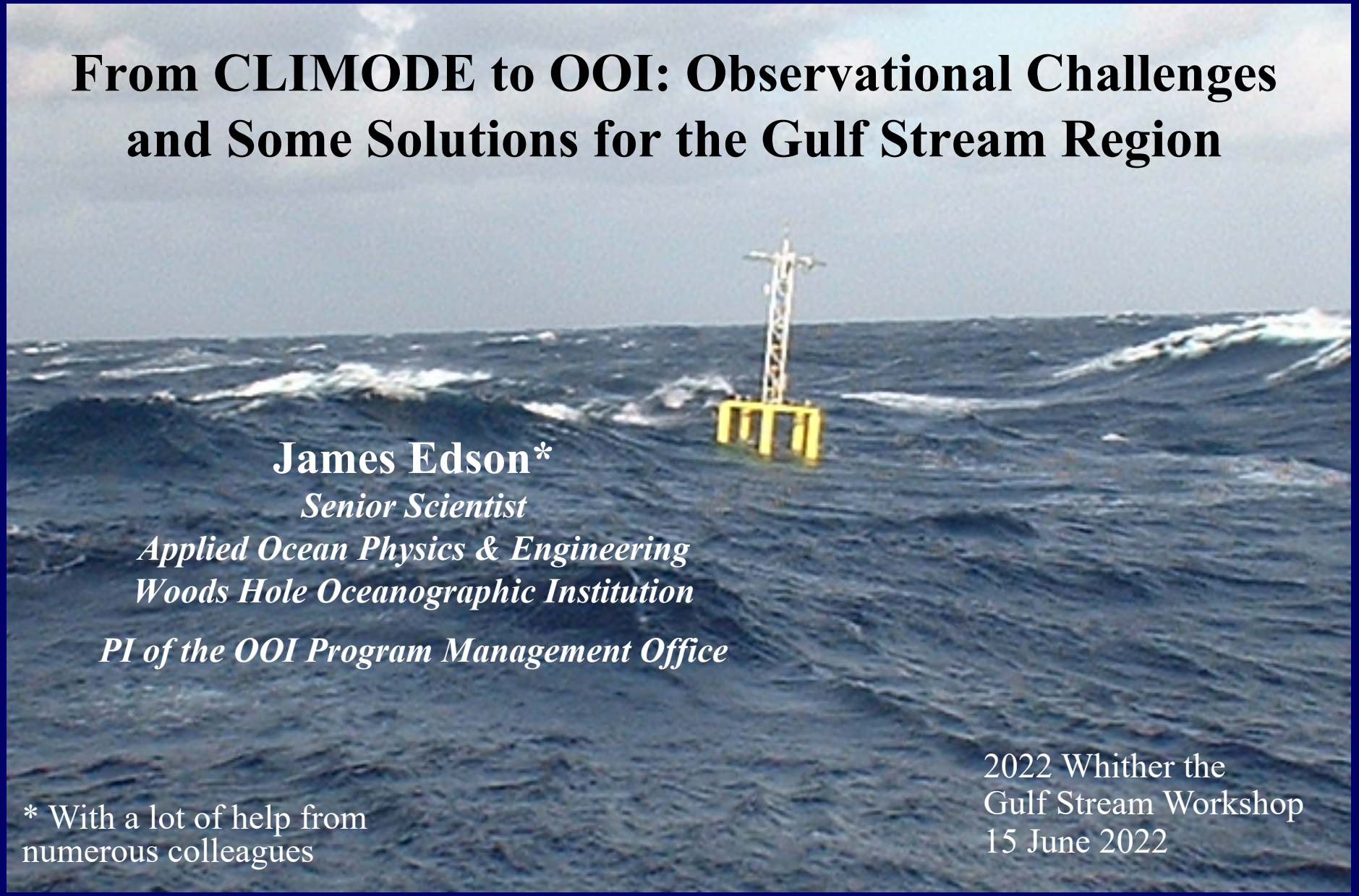
From CLIMODE to OOI: Observational Challenges and Some Solutions for the Gulf Stream Region



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Woods Hole Oceanographic Institution

PI of the OOI Program Management Office

2022 Whither the Gulf Stream Workshop
15 June 2022

* With a lot of help from numerous colleagues

Research supported by grants from the ONR, NSF, NOAA and NASA

Gulf Stream Research

- An amazing natural laboratory for air-sea interaction and coupled boundary layer research.
- Many of the research opportunities present observational challenges:
  - Strong currents and current shear
  - Strong winds from coastal storms (e.g., Nor'easterns)
  - Large though ultimately fetch limited waves
  - Air-mass advection (e.g., cold air outbreaks)
- We have met many of these observational challenges in recent field programs (e.g., CLIMODE, OOI, & PEACH)

Gulf Stream Research

CLIMODE: CLIVAR Mode Water Dynamic Experiment

Project to study the dynamics of 18º mode water formation at the Gulf Stream northern wall.

Marshall et al. 2009, BAMS

OOI-PA: Ocean Observatories Initiative - Pioneer Array

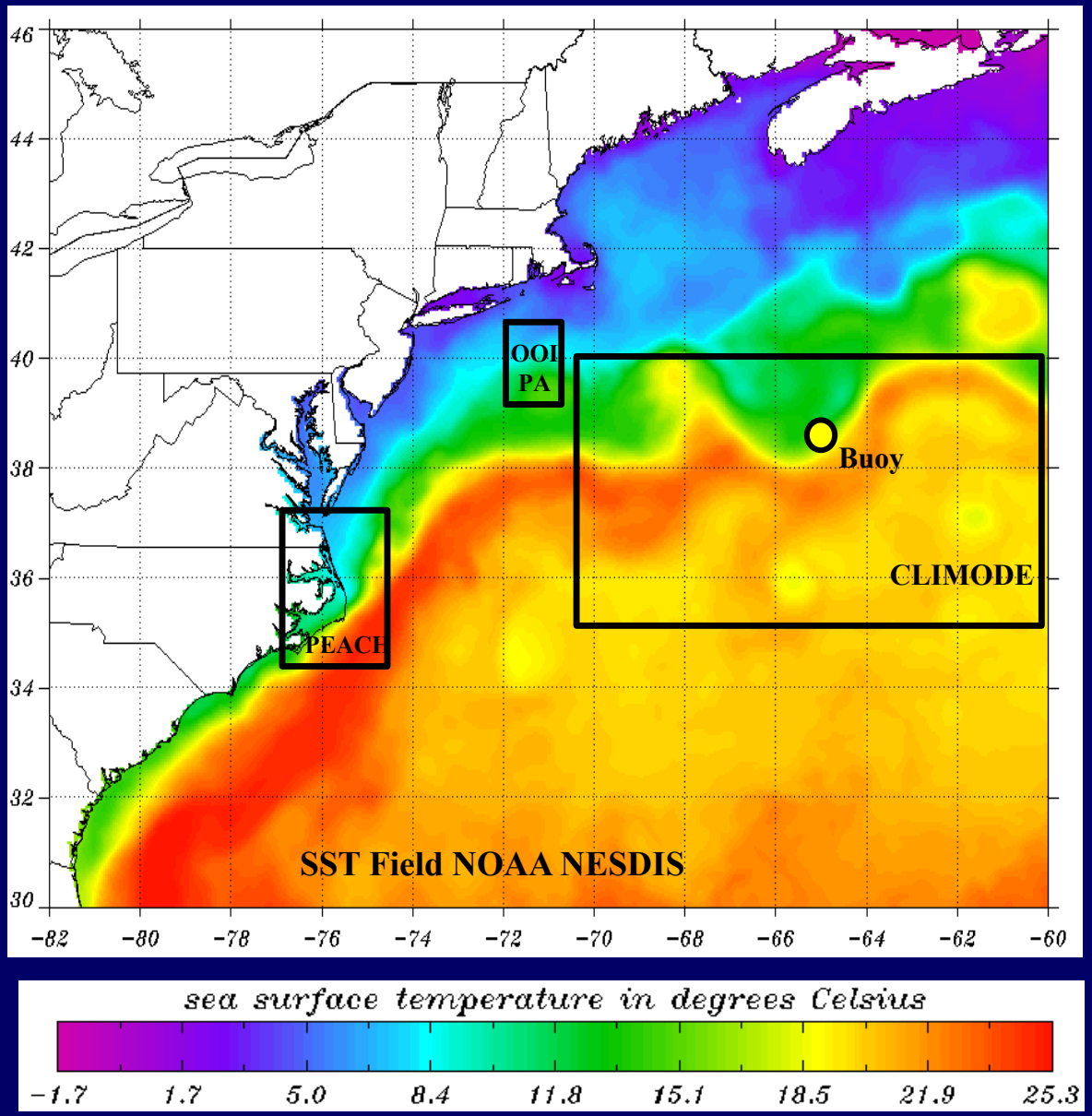
Array to investigate cross-shelf exchange nutrients, pollutants, and other properties are between the coastal shelf and the deep ocean.

Gawarkiewicz & Plueddemann, 2020, JPO

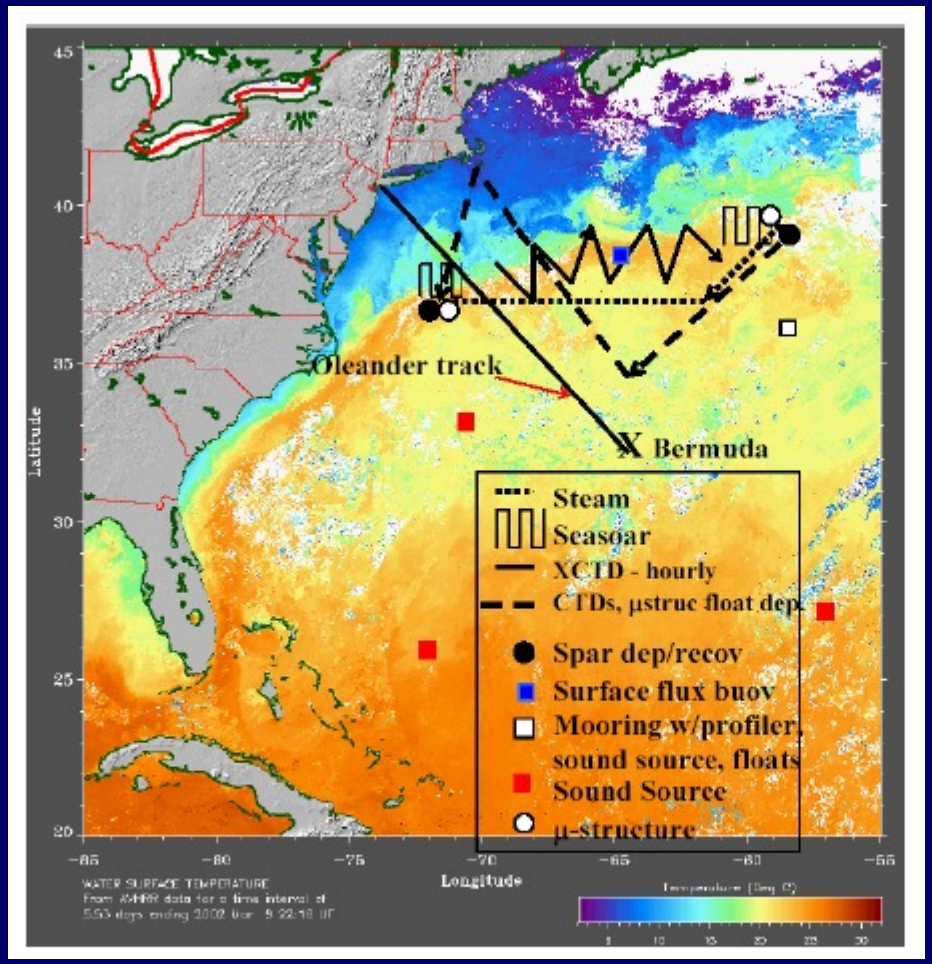
PEACH: Processes driving Exchange At Cape Hatteras

Better understanding of seawater exchanges over region where Gulf Stream transitions from boundary trapped to a free jet.

Seim et al. 2022, Oceanography



CLIMODE Deployments and Cruises



- November 2005: Mooring & Profiler Deployment Cruise
- January 18-30, 2006: Pilot Experiment, ASIS/FILIS Deployment
- October 2006: Mooring Turnaround Cruise
- February-March 2007: 6-week Main Experiment, ASIS/FILIS Deployments, Microstructure, Surveys.
- November 2007: Mooring Recovery Cruise

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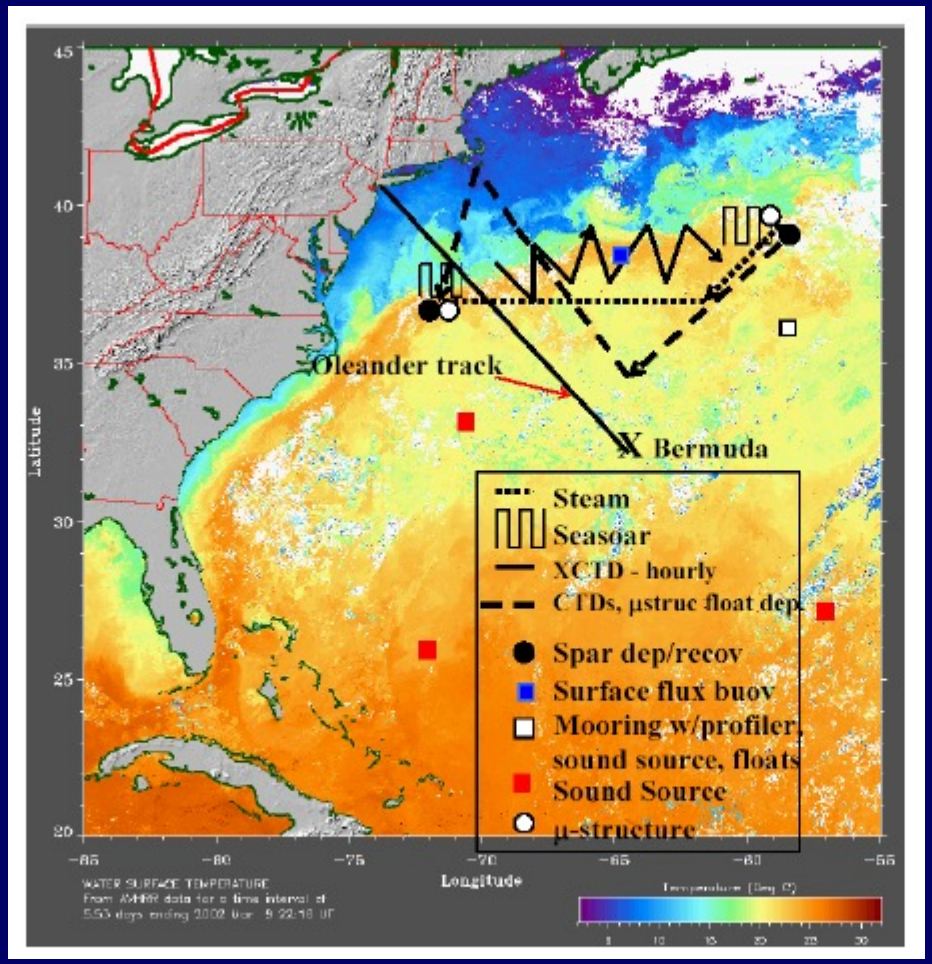

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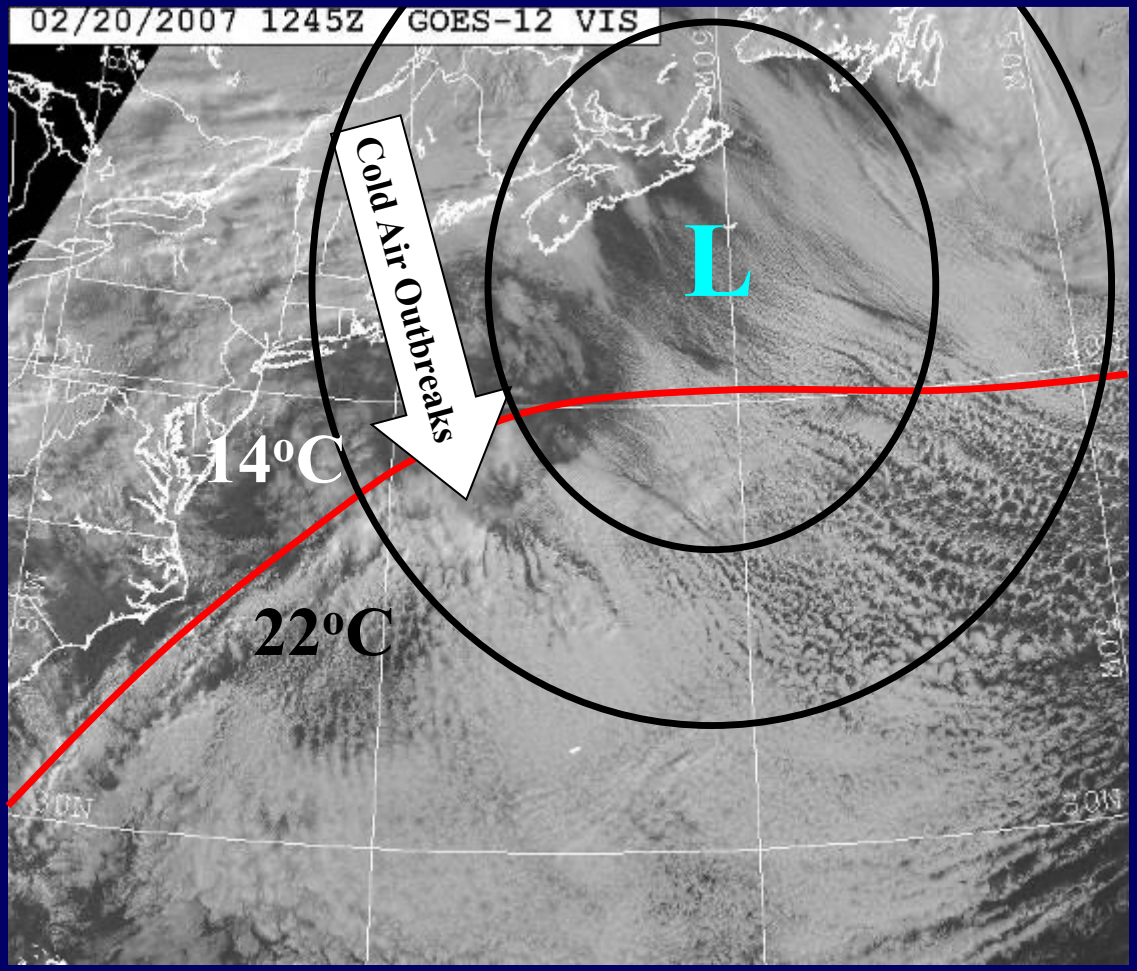
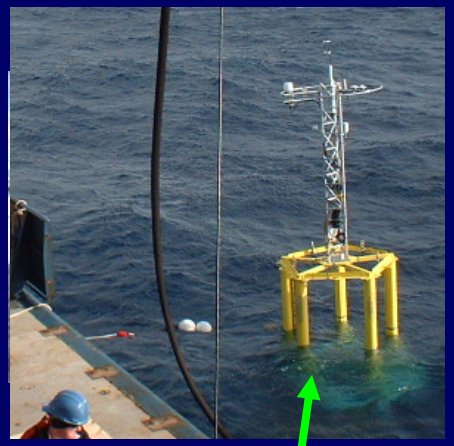
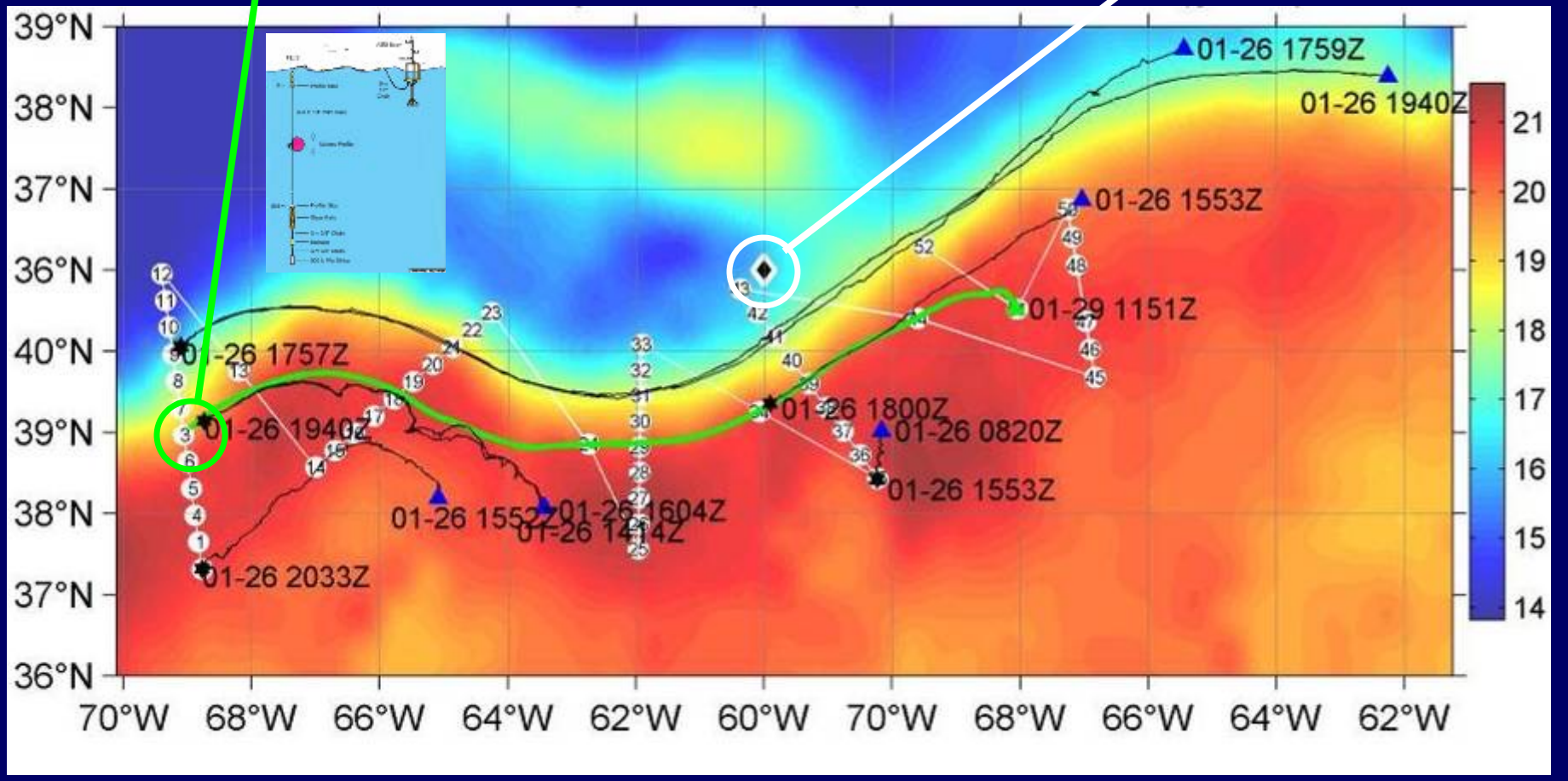
The Gulf Stream



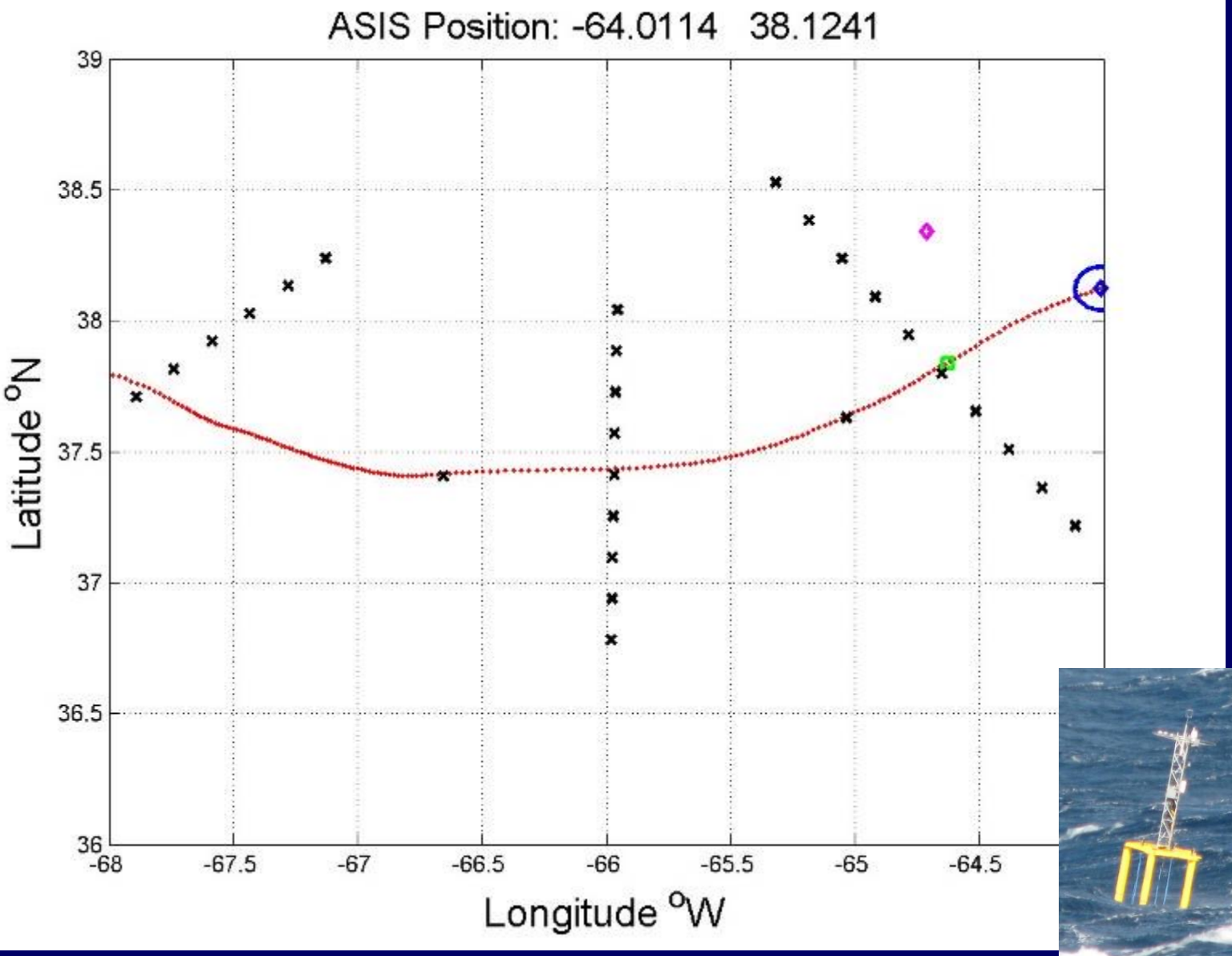
- Cold air outbreaks drive extremely active convection over the region.
- The net winter heat loss in this region is 400 W/m^2.

CLIMODE Platforms

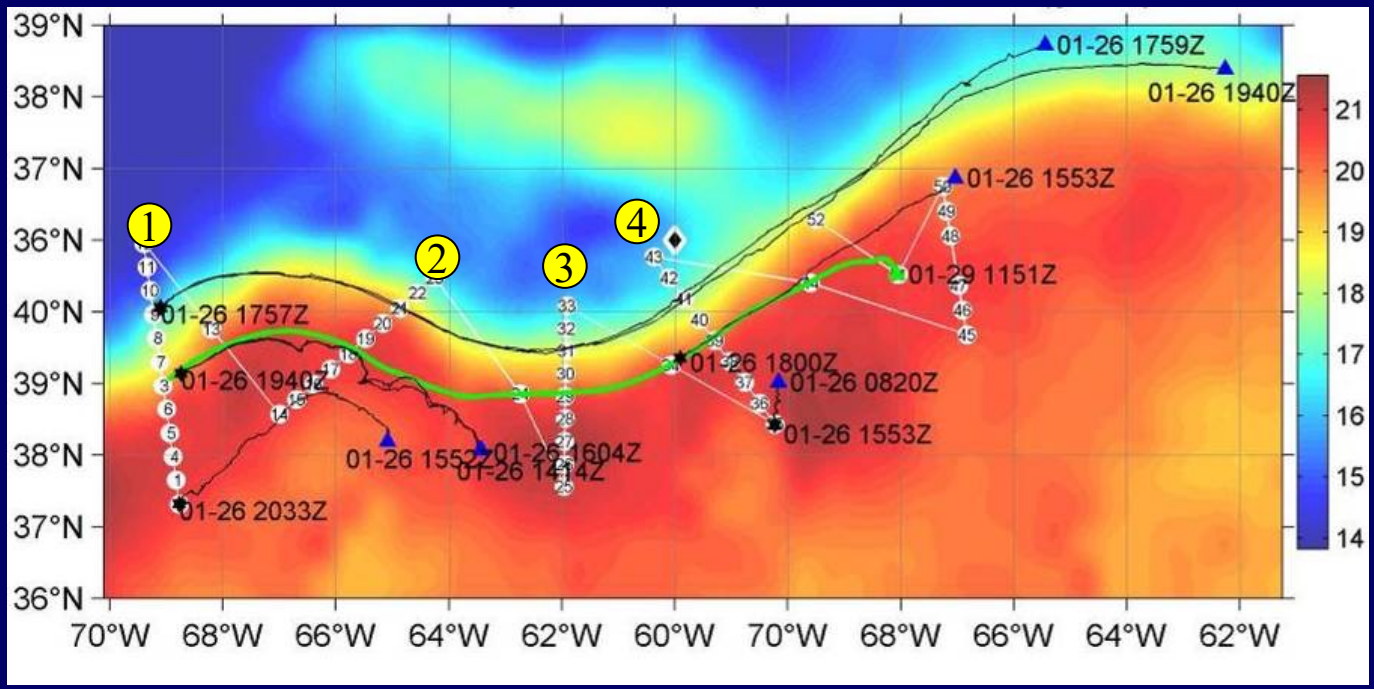


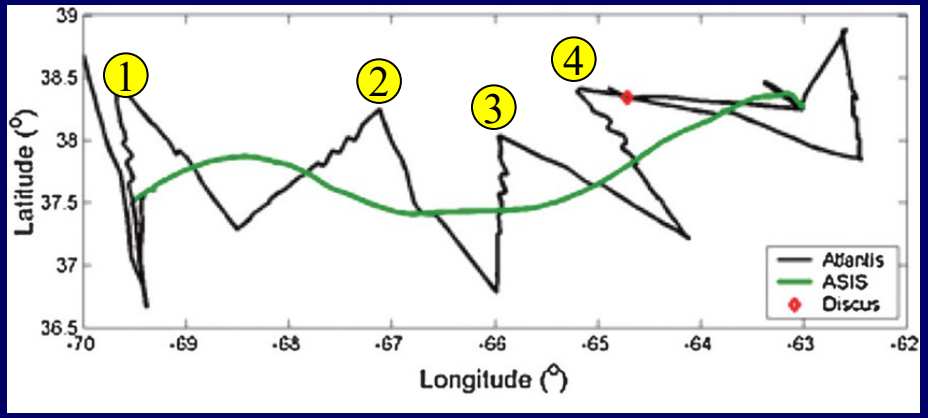


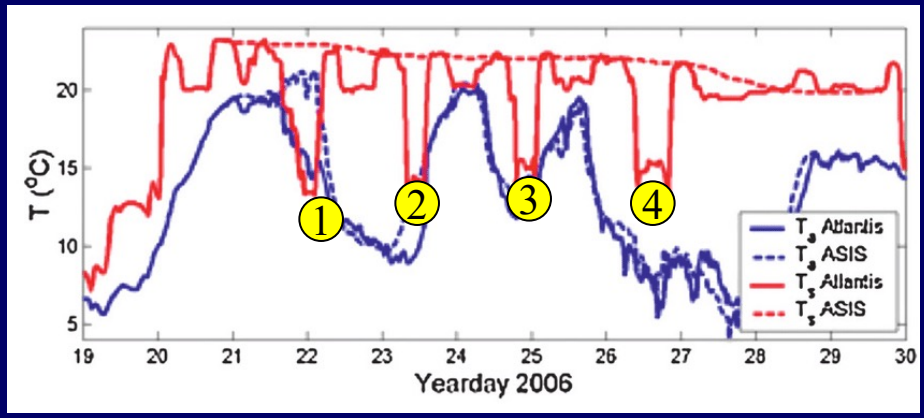
Lagrangian Assets



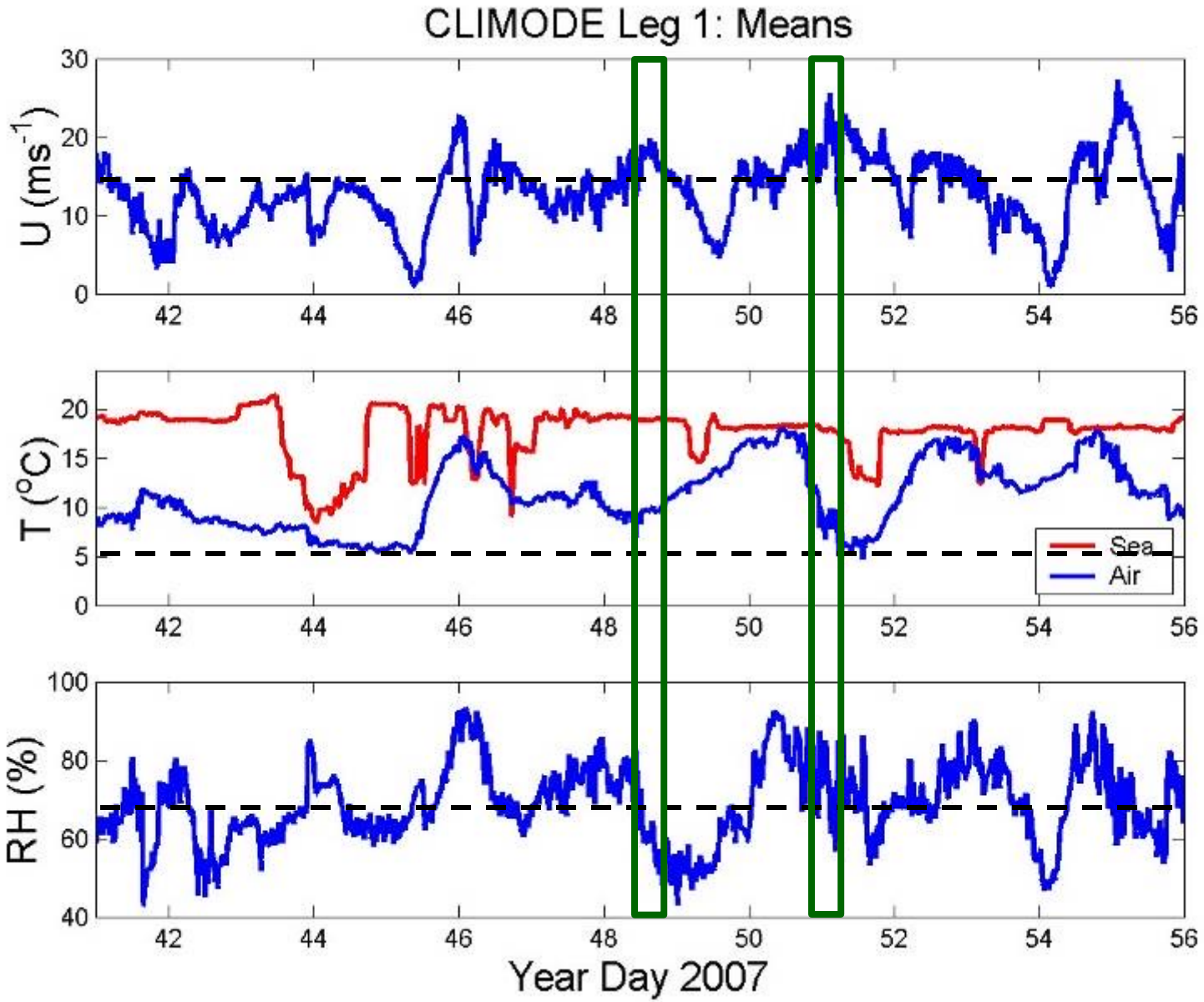
Gulf Stream Transects



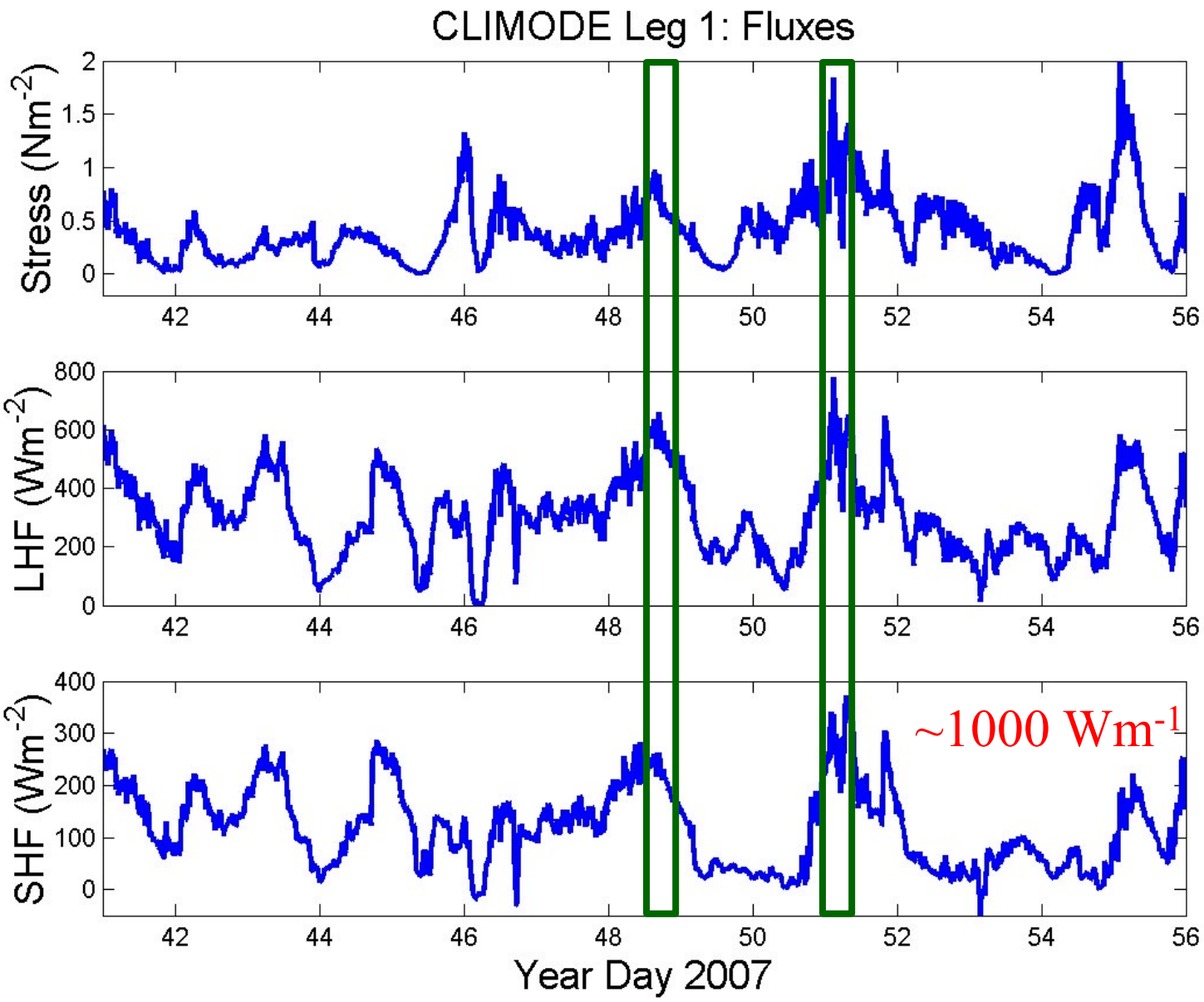




2007 Mean Meteorology

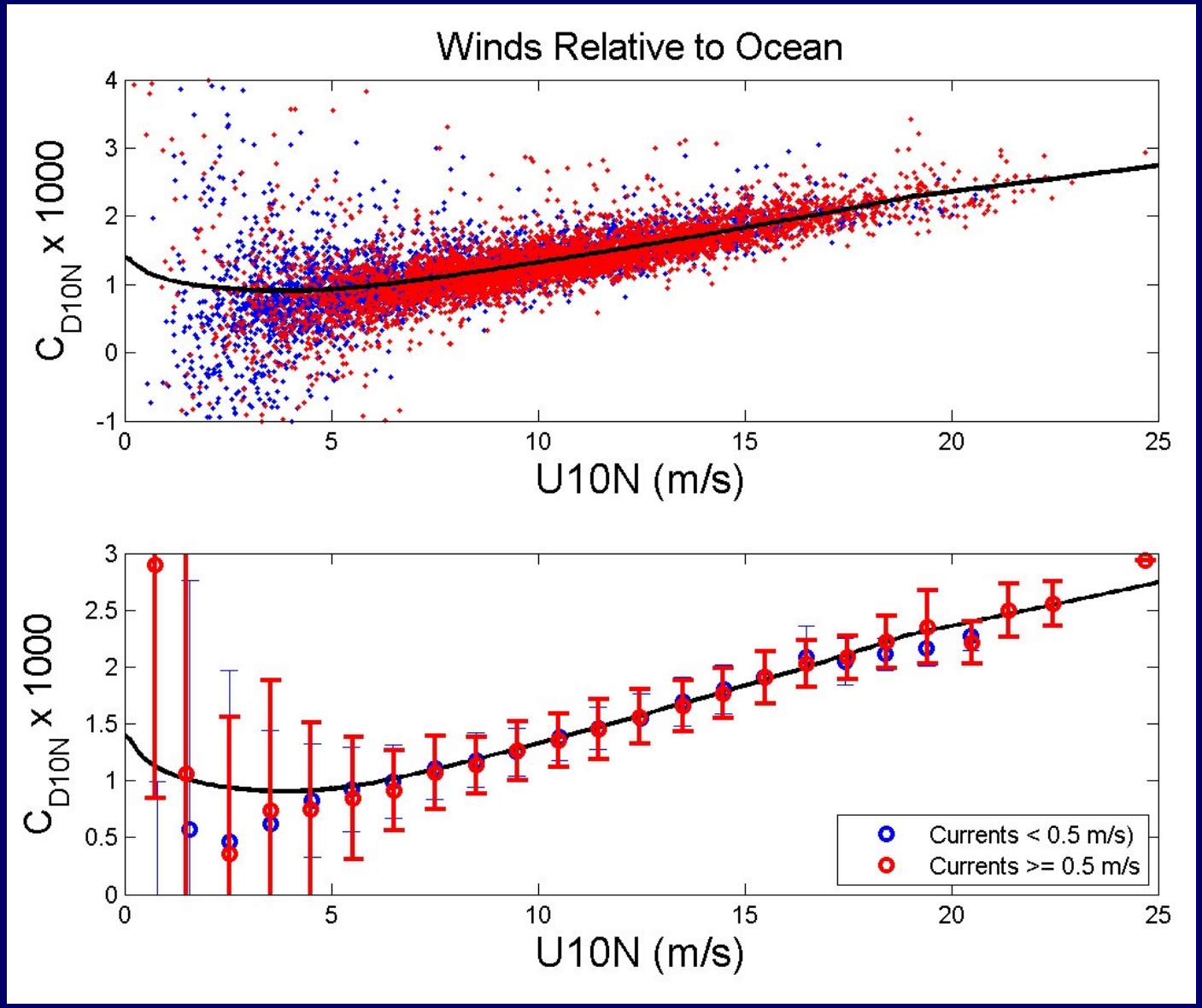


2007 Bulk Fluxes

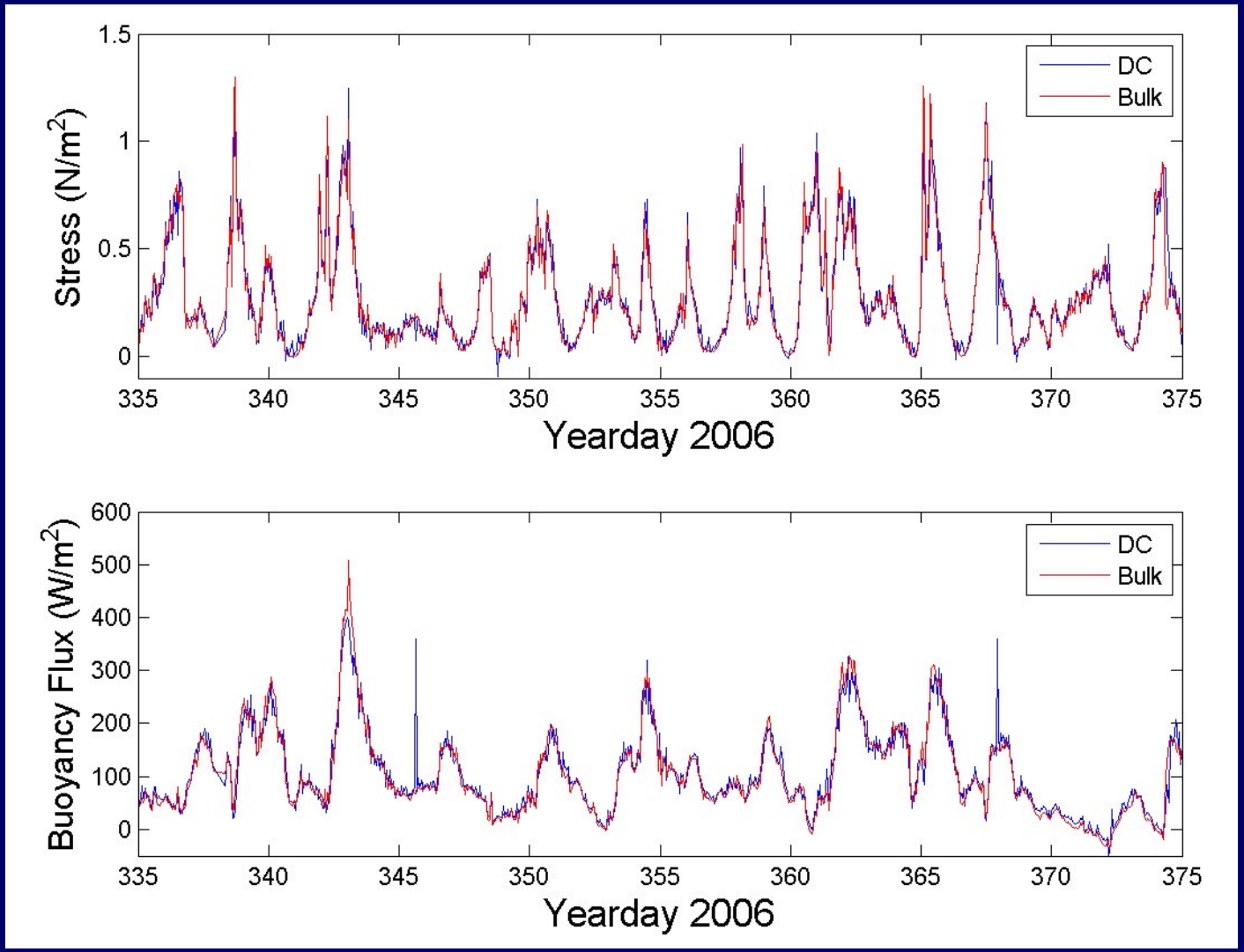


Relative Velocity

$$C_{DN}(z/z_o) = \frac{-\overline{uw}}{\Delta U_N G} = \left(\frac{\kappa}{\ln(z/z_o)}\right)^2$$



2005-2007 Buoy Flux Estimates



COARE 3.5

Edson, James B., and Coauthors, 2013: On the Exchange of Momentum over the Open Ocean. *J. Phys. Oceanogr.*, **43**, 1589–1610.

Wind Speed & Surface Stress Across SST Fronts

It is commonly observed that surface winds are enhanced over warmer water and suppressed over cooler water as air is advected over SST fronts. A number of different mechanisms have been suggested to explain these observations as summarized in Small et al. (2008):

- Surface layer adjustment (SLA) of shear because of changing atmospheric stratification explained by MOS.
- Changes in wind stress related to changes in the relative wind due to large surface currents often associated with fronts (e.g., the Gulf Stream).
- The enhancement of vertical mixing because of cool air advection over warmer water that mixes down larger momentum from aloft on the warm side of the front.
- The horizontal pressure and boundary layer height gradients set up by the adjustment of air temperature and humidity to the underlying SST.

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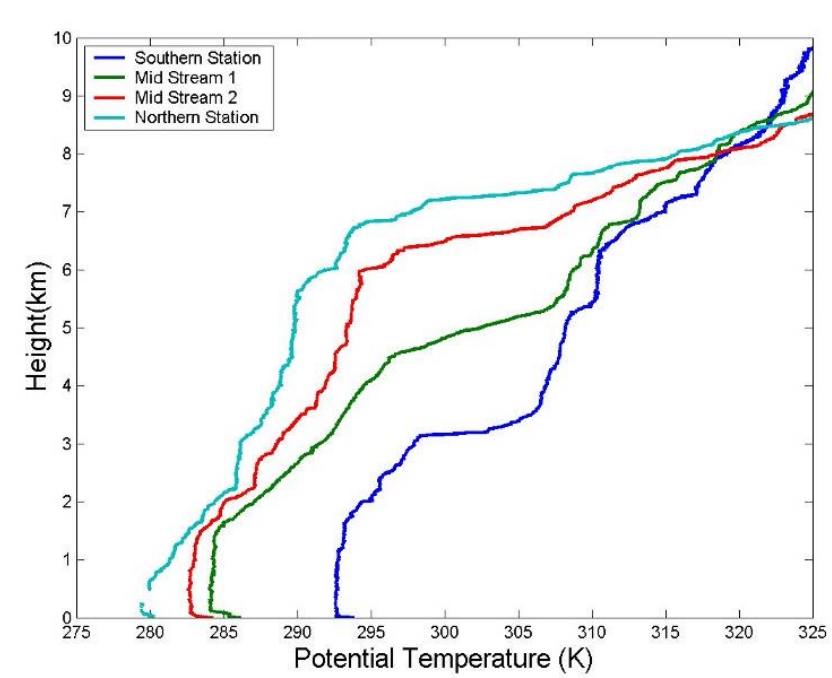
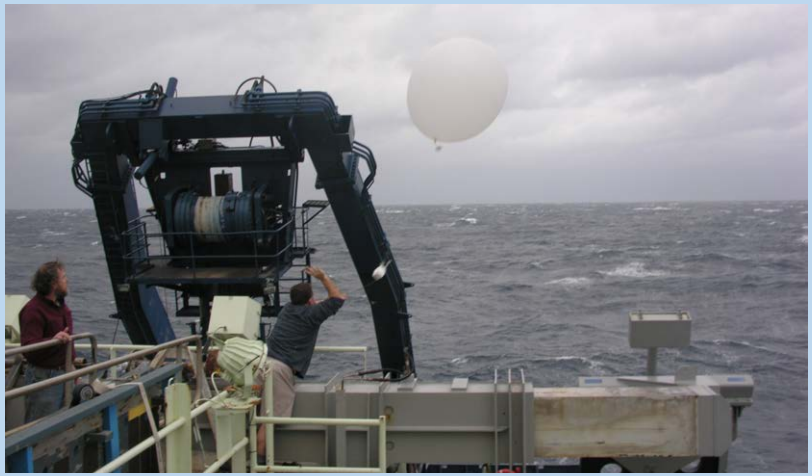
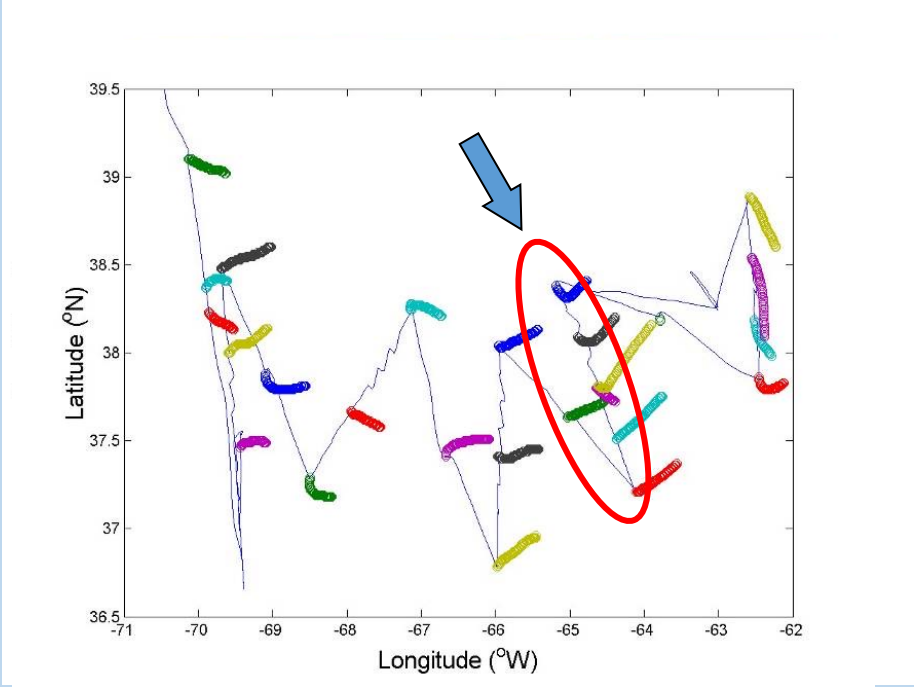
Gulf Stream Soundings– Pilot Experiment

Dissertation research of Hanyuan Liu

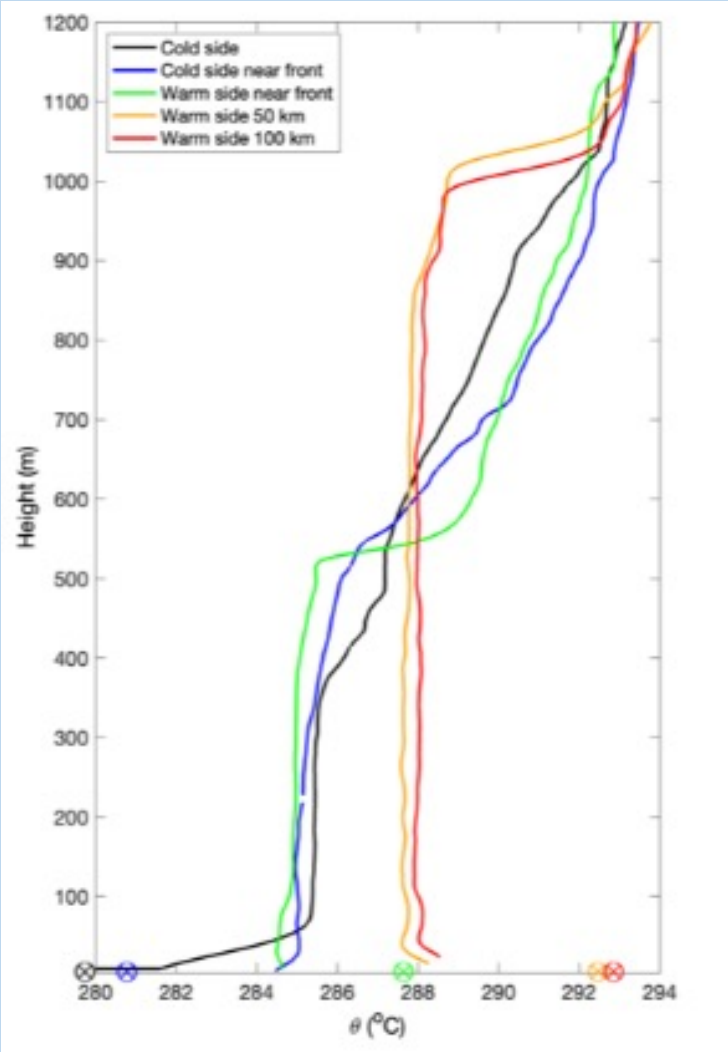


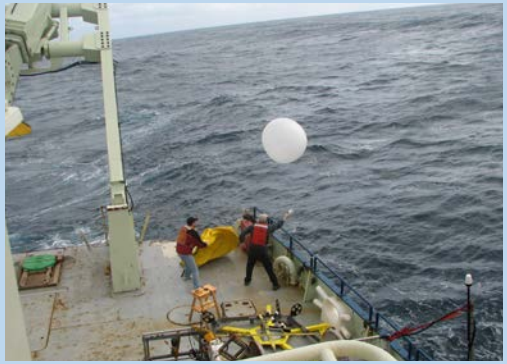


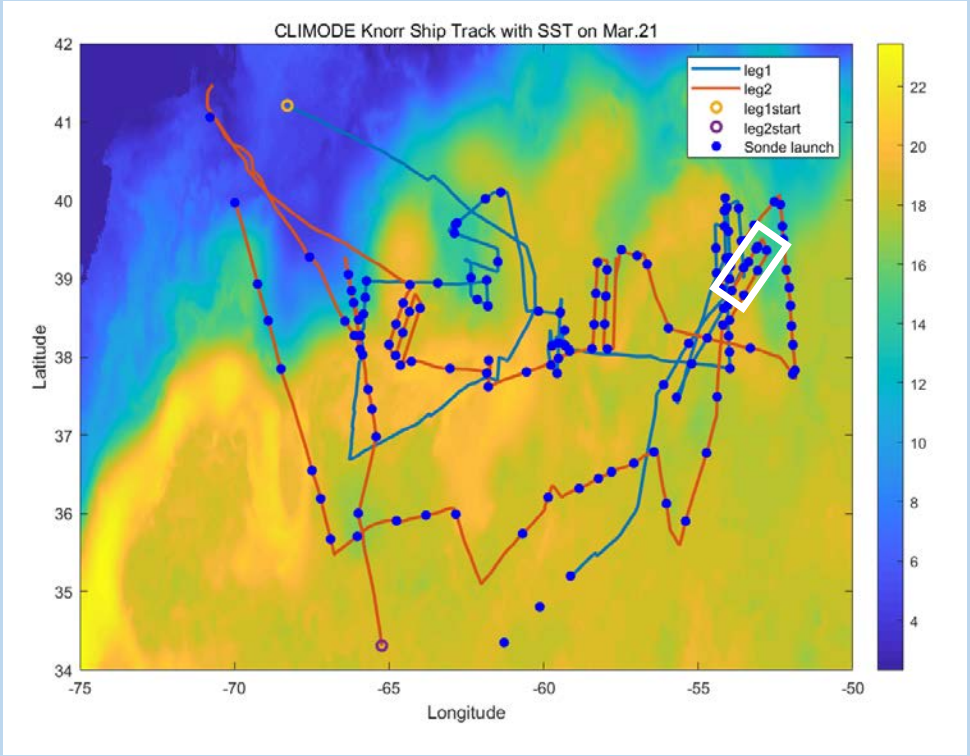


Gulf Stream Soundings– Main Experiment

Dissertation research of Hanyuan Liu

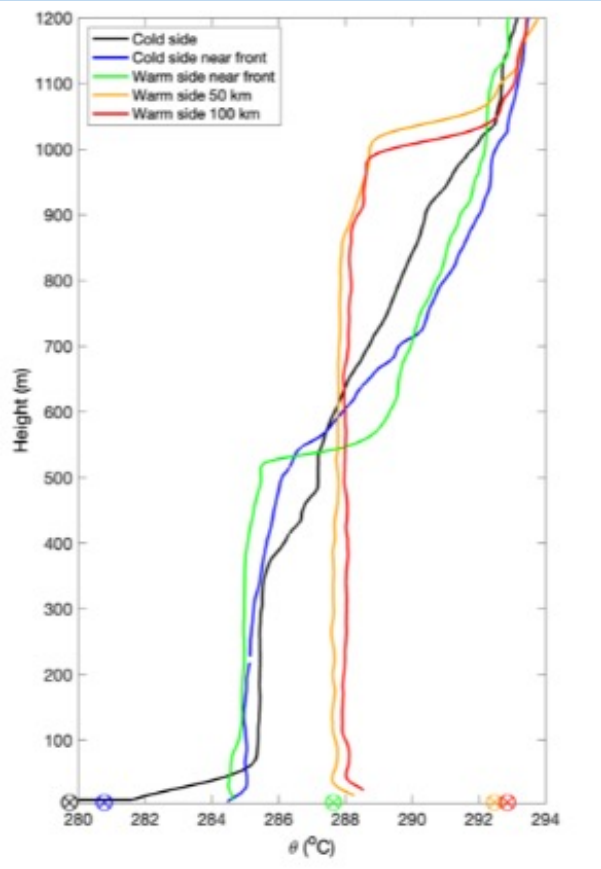


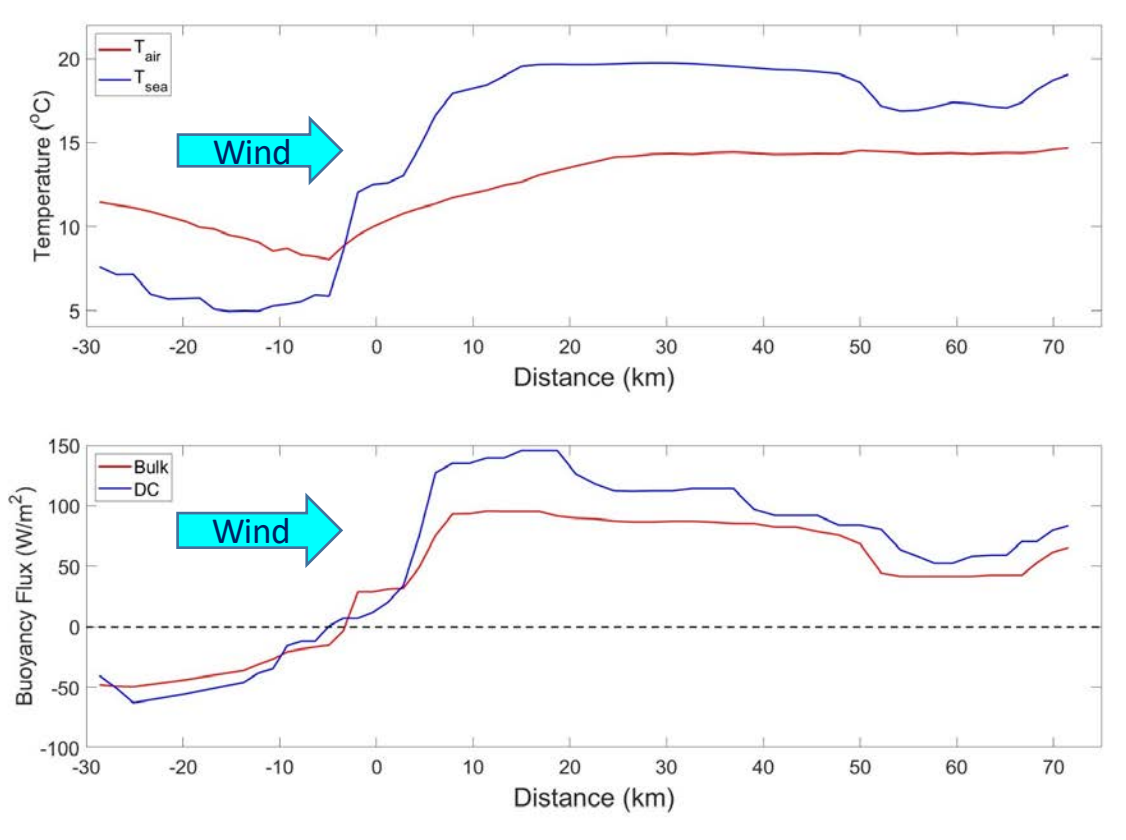




CLIMODE Soundings & Surface Layer Response

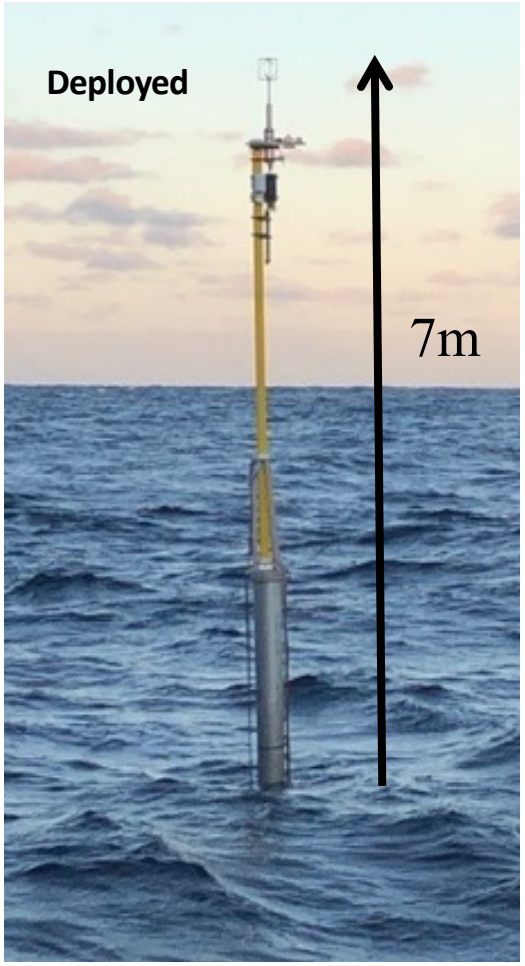
Dissertation research of Hanyuan Liu



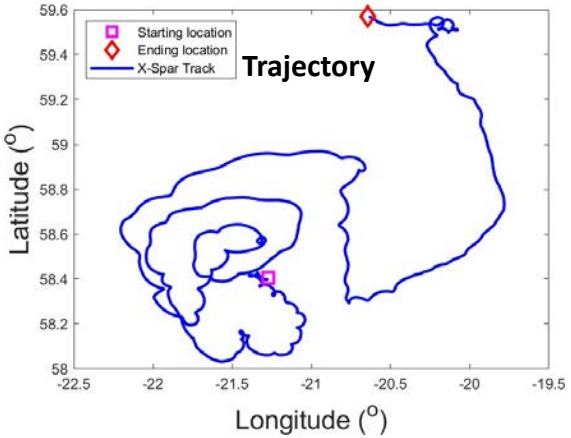


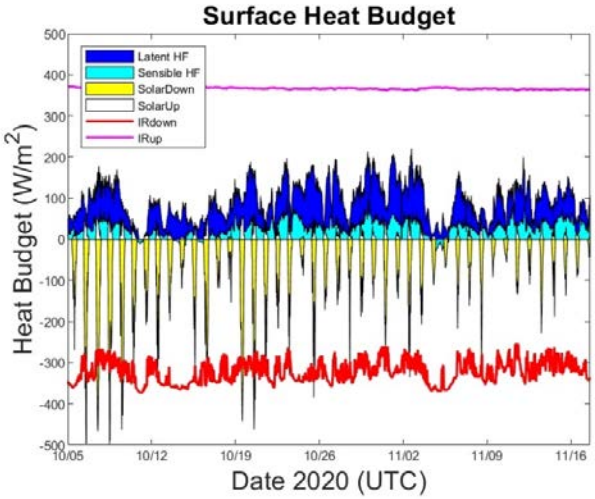
Other Observational Assets

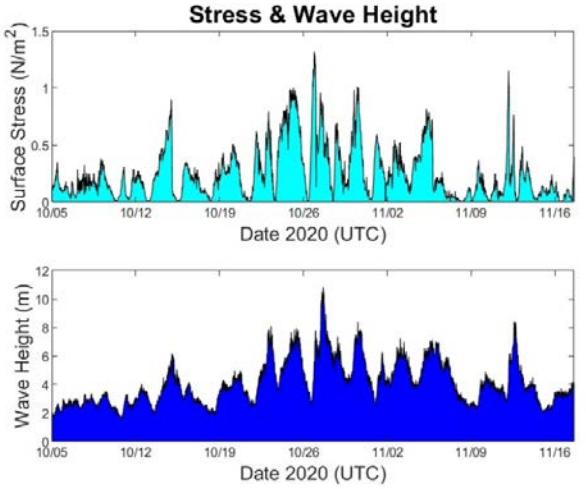
eXpendible Spar Buoy (X-Spar)



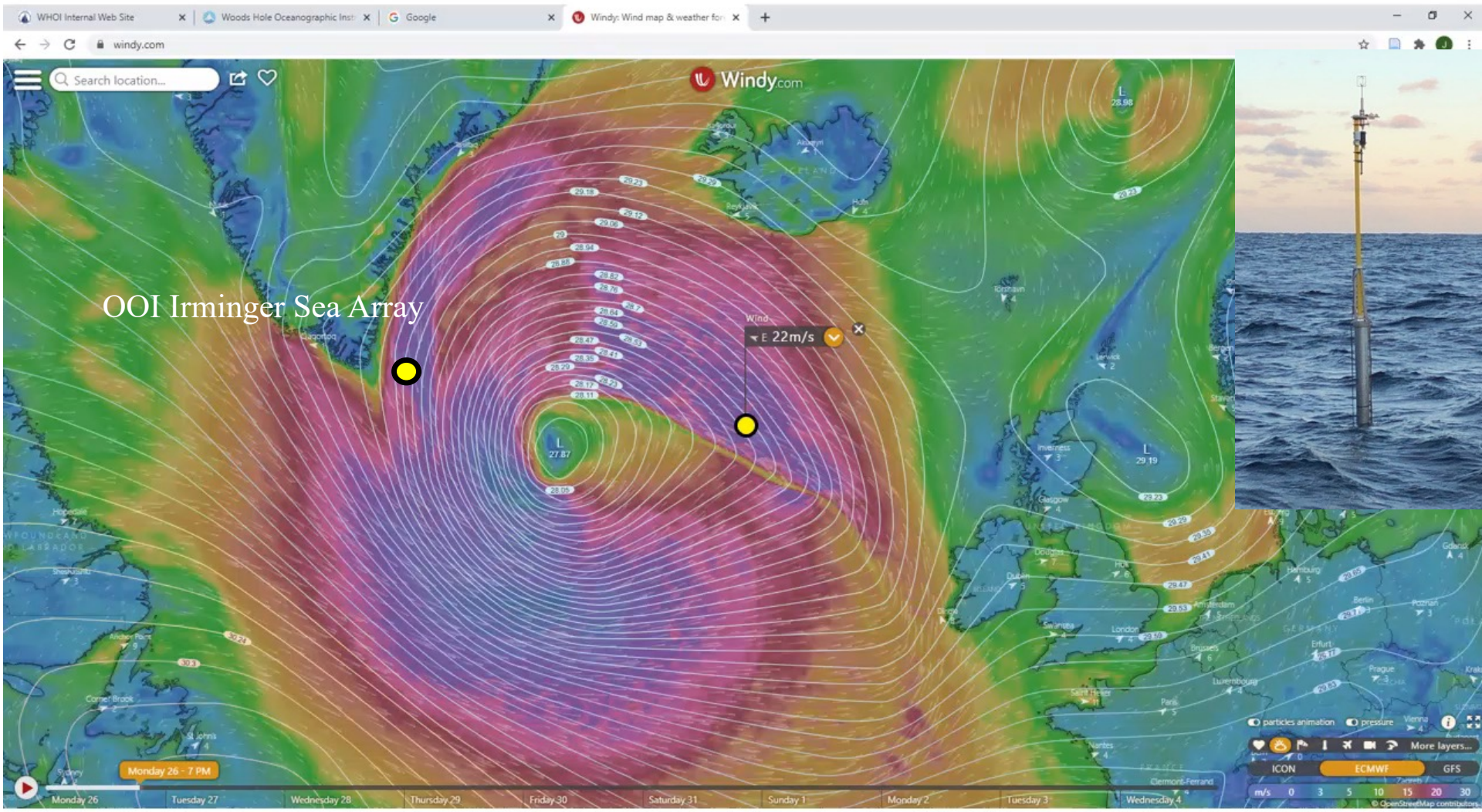
- Real-time direct covariance platform for stress and buoyancy fluxes.
- Battery pack could run DCFS for 14 months
- It could run a DCFS/IRGA for ~10 months to measure latent and sensible heat flux



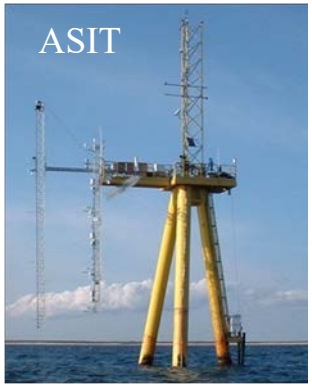


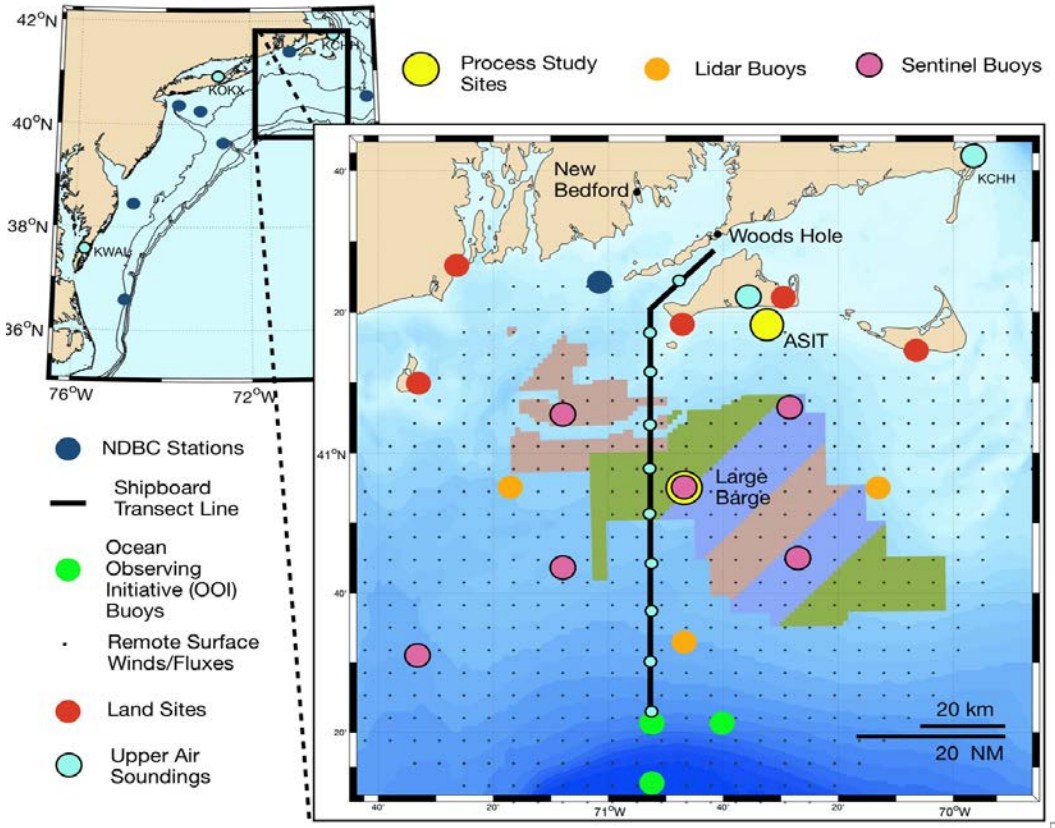


Through the Eye of Epsilon



An Ocean Test Bed



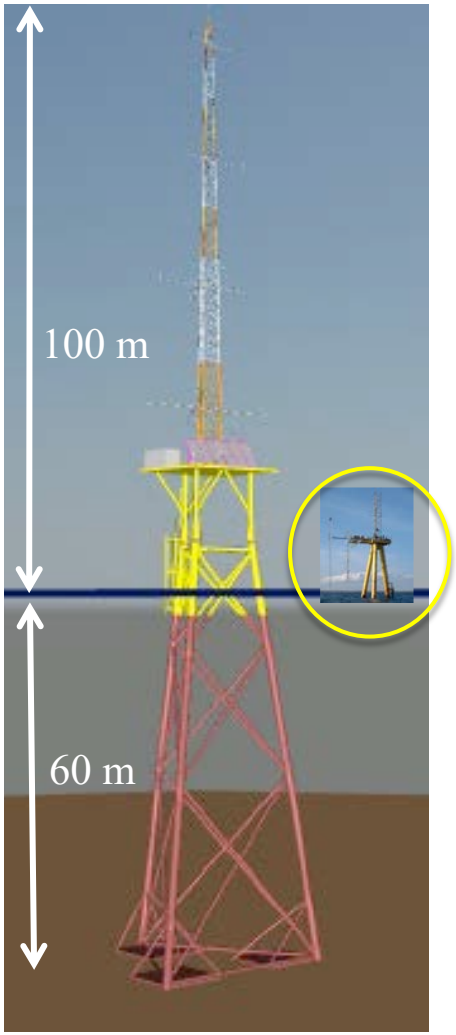


Large Barge

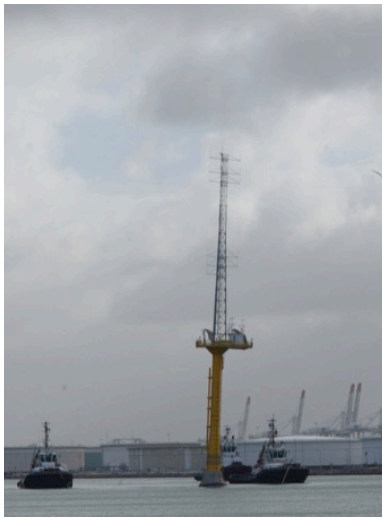
Woods Hole Oceanographic Institution

Vertical Structure: Three Viable Designs

Fixed Tower

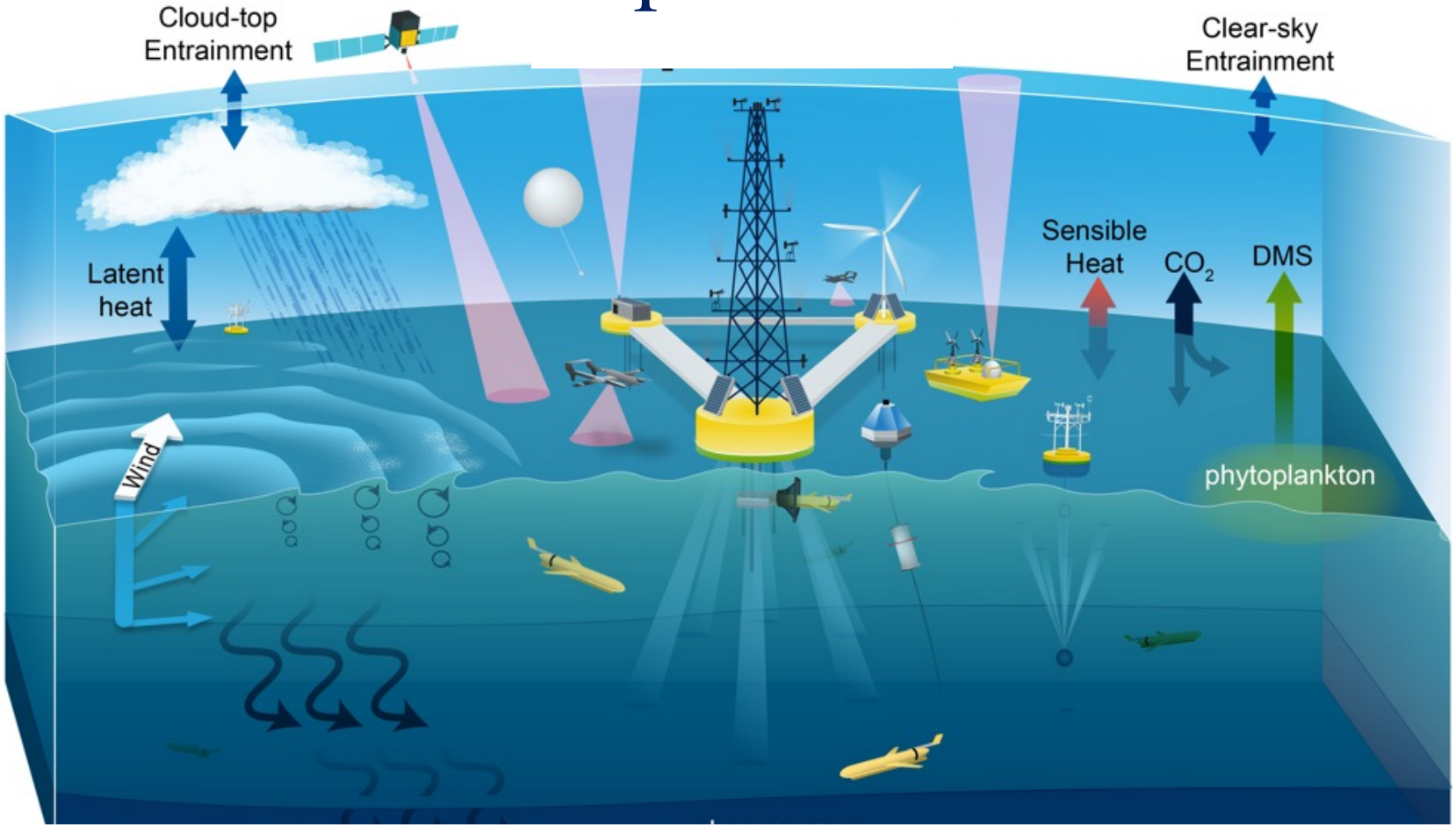


Concrete-base Tower



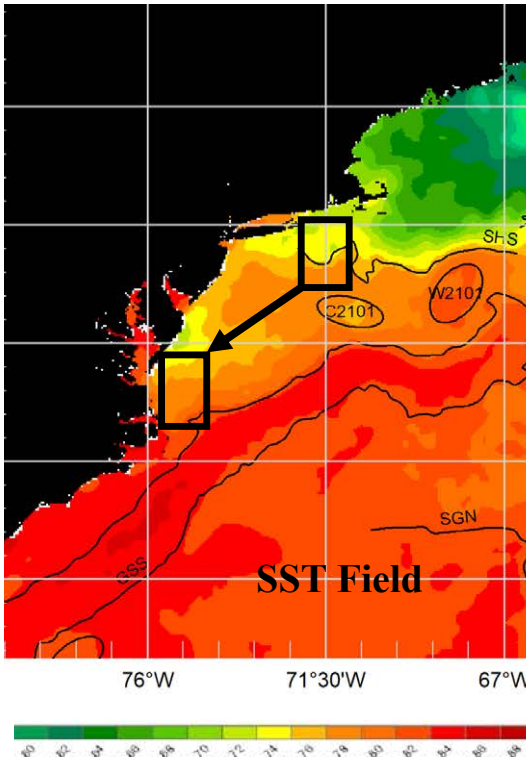
Jack-up Tower

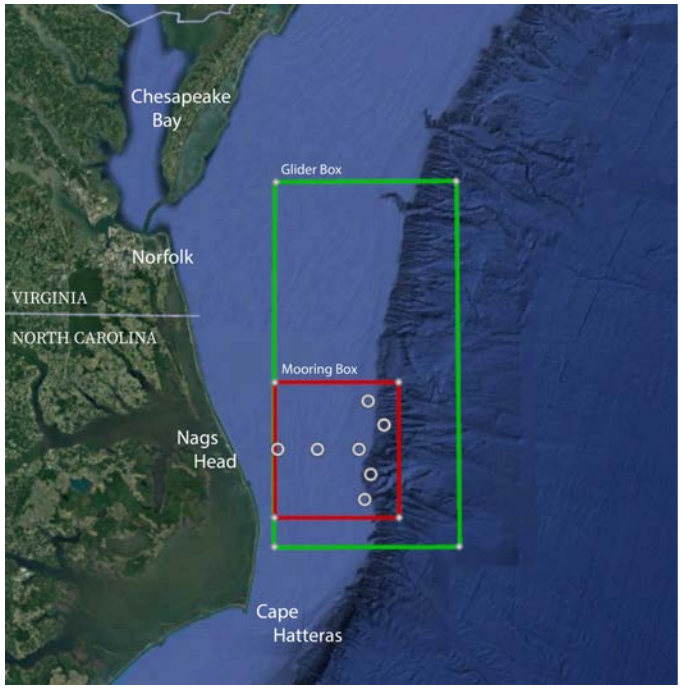
Super Sites

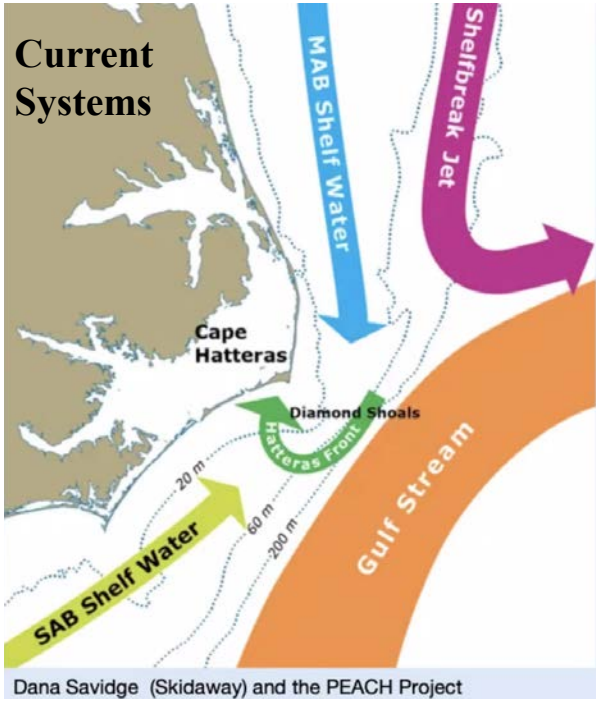


- An ocean laboratory to gather data essential for marine weather and climate forecasts.
- Super Sites have become feasible through technology developed by the offshore wind industry.

Coastal Pioneer Array – Southern Mid-Atlantic Bight





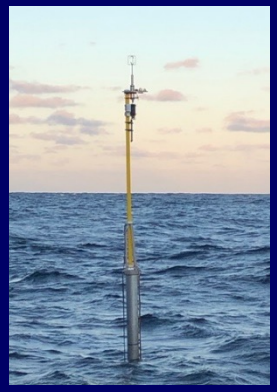


Recent Advances in Marine Platforms and Sensors for Air-Sea Interaction Studies

CLIMODE
Year long

OOI
Real-time Fluxes

SPURS
Latent Heat Flux



X-Spar
Long duration
Real-time Fluxes

Lidar Buoy
Long duration
Profiles

Gliders
Long duration
profiles

Remote Sensing
Continuous
Profiling

UAV
Profiling &
Missions

Saildrone
Long duration
Mobile

Wave Glider
Long duration
Mobile

Gulf Stream Research Questions?

- An amazing natural laboratory for air-sea interaction and coupled boundary layer research.
- Many of the research opportunities present observational challenges:
  - Strong currents and current shear
  - Strong winds from coastal storms (e.g., Nor'easterns)
  - Large though ultimately fetch limited waves
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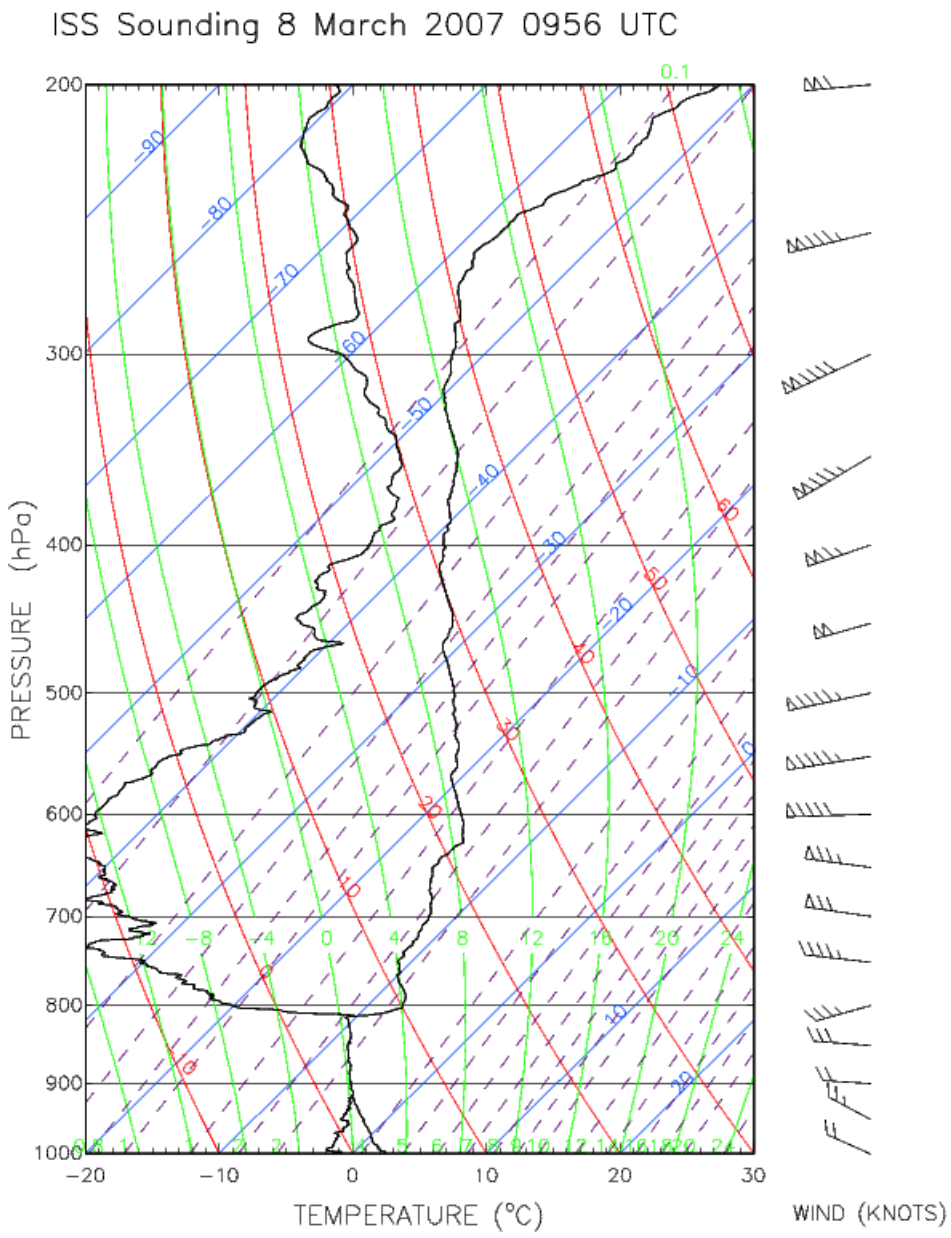
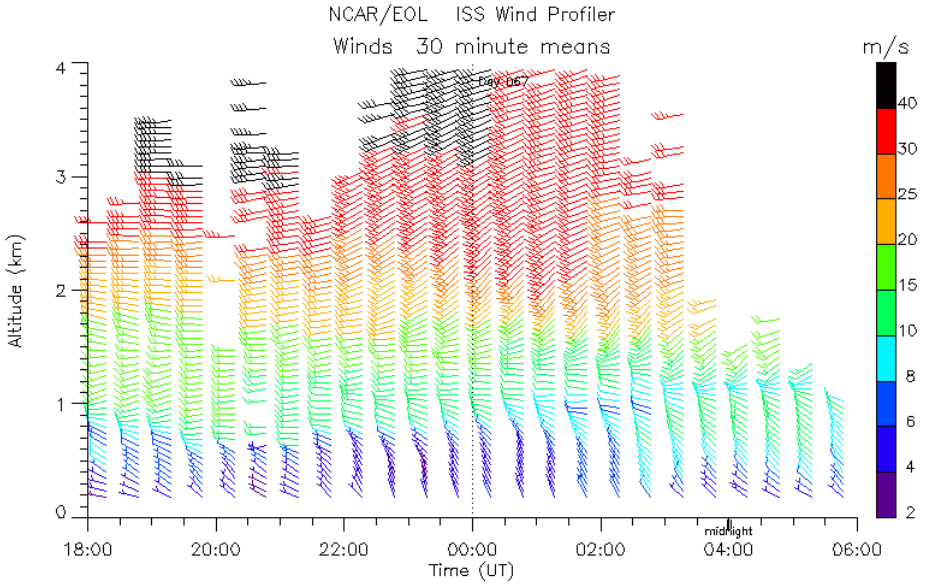
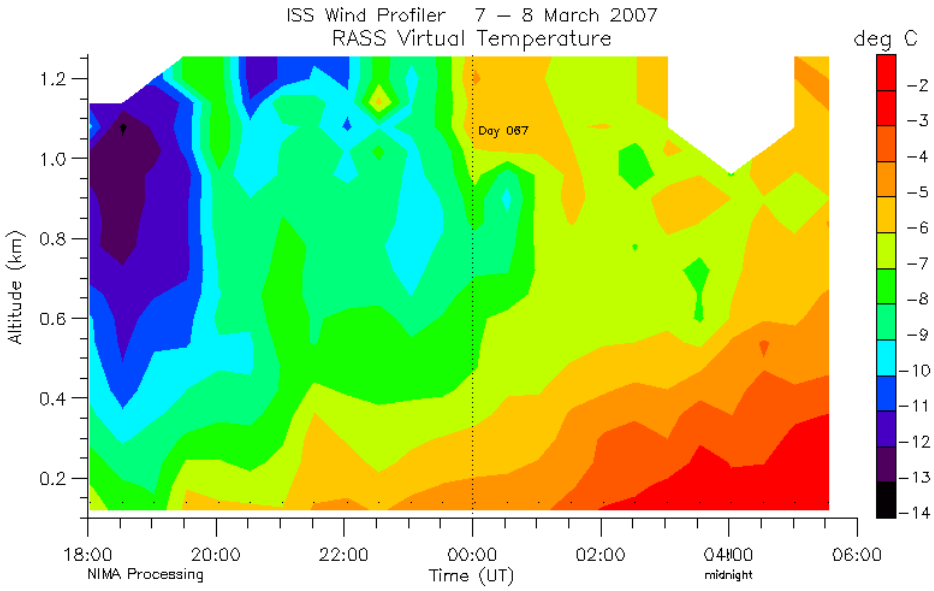
- We have met many of these observational challenges in recent field programs (e.g., CLIMODE, PEACH)

Remote Soundings– Main Experiment

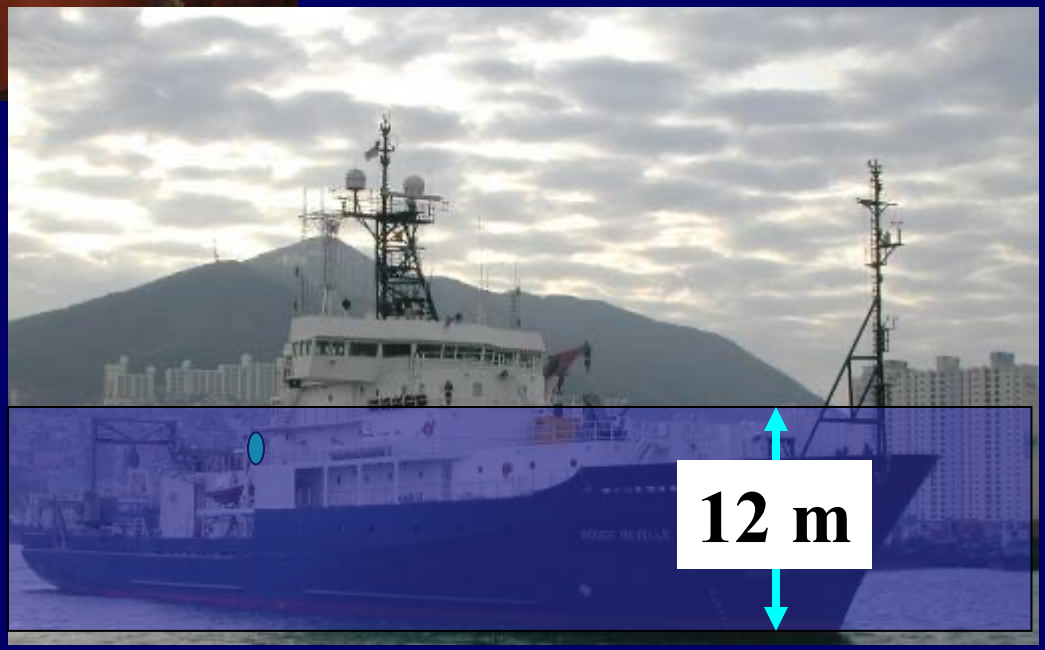


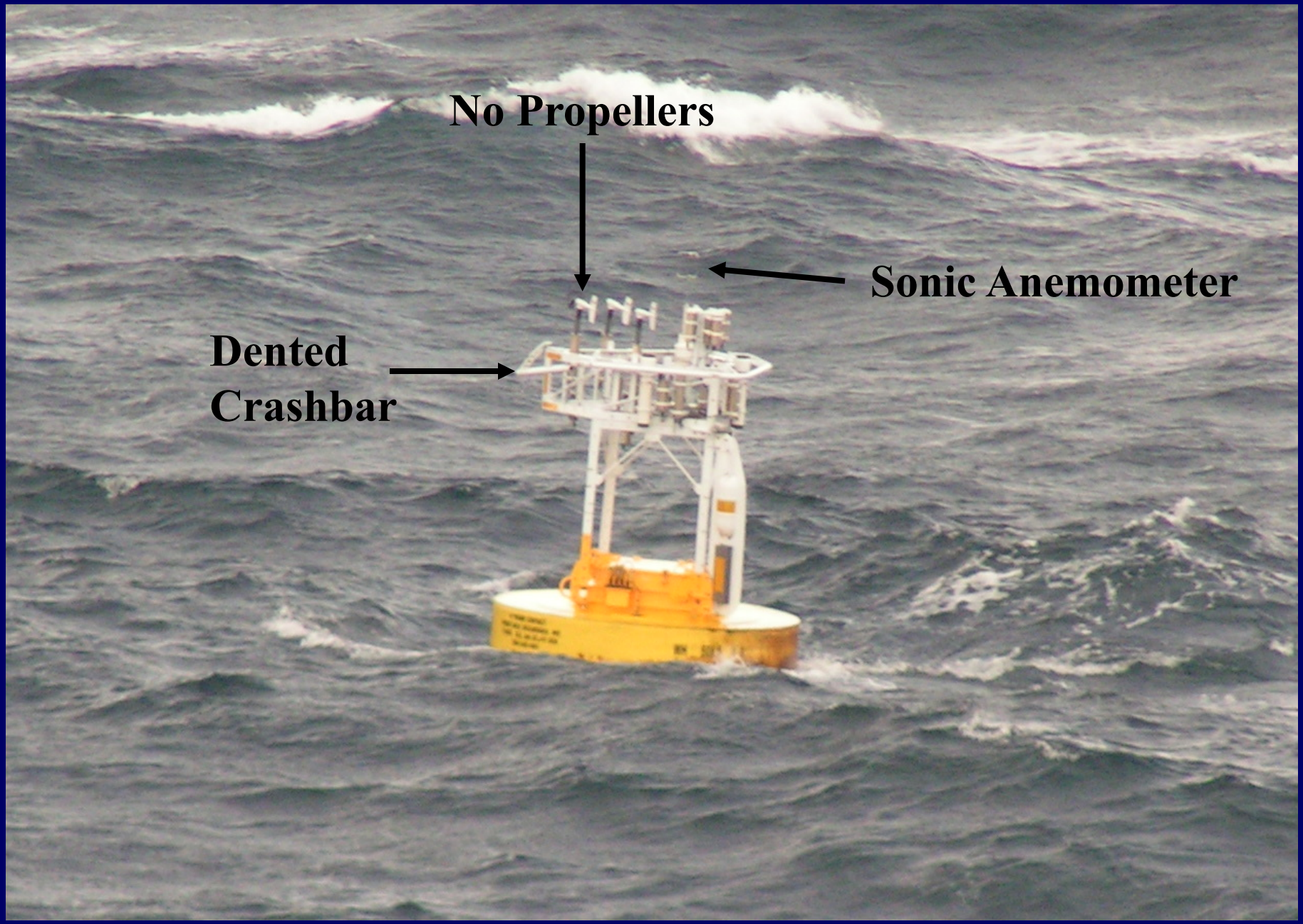




Extreme Conditions

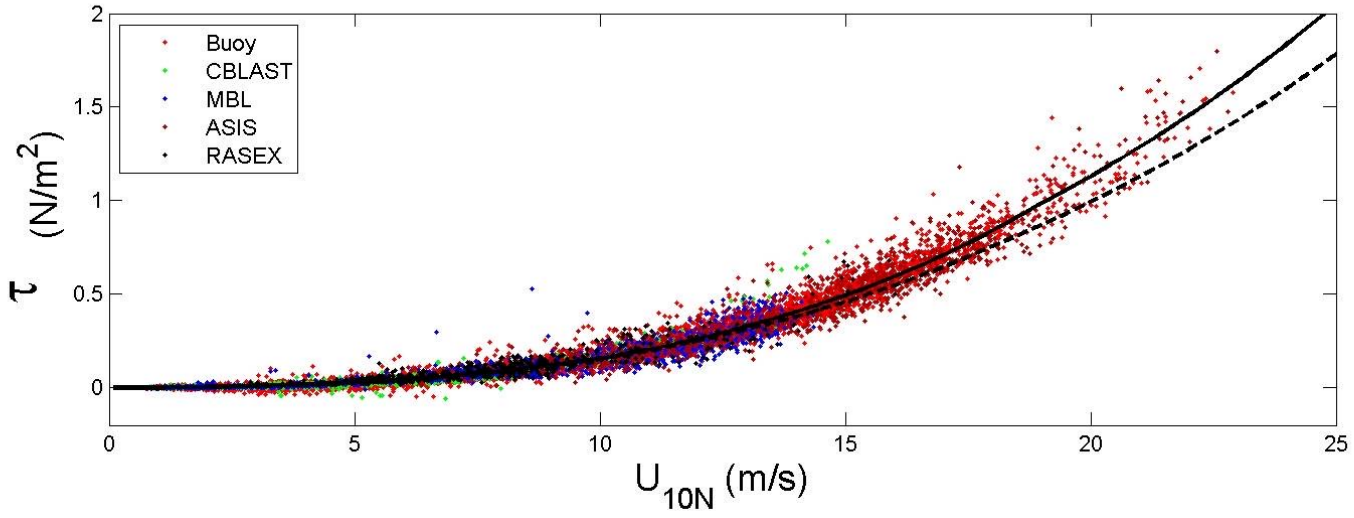
Maximum wind speeds exceeded 30 m/s in near hurricane conditions.

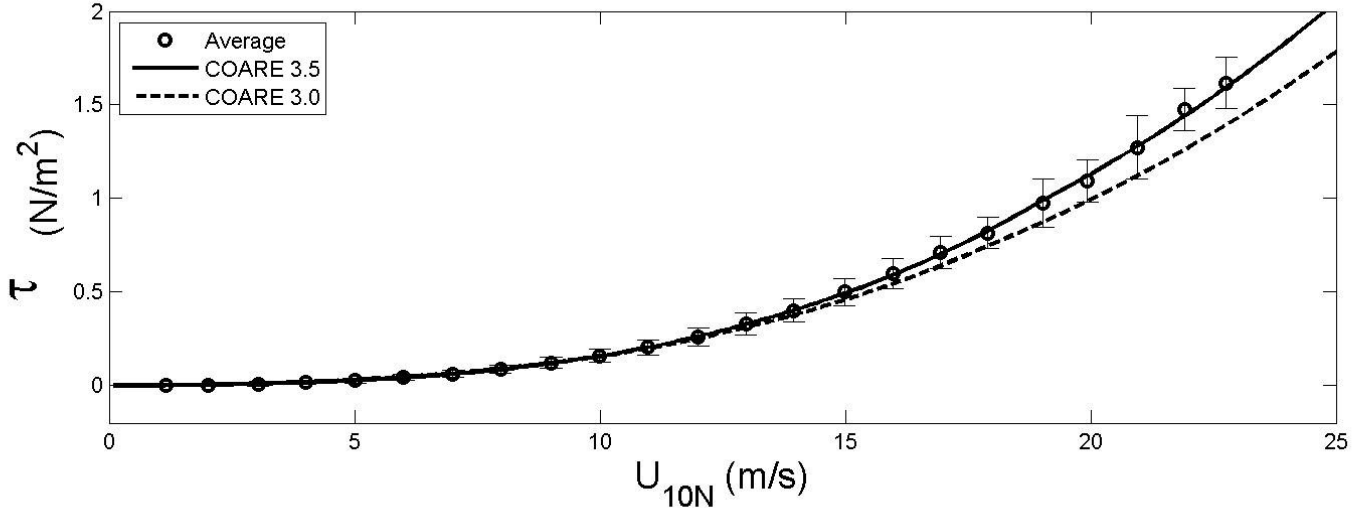



No Propellers
Sonic Anemometer
Dented
Crashbar

ASIS Destroyed by Rogue Wave

Stress vs Wind Speed





2007 ASIS Flux Estimates