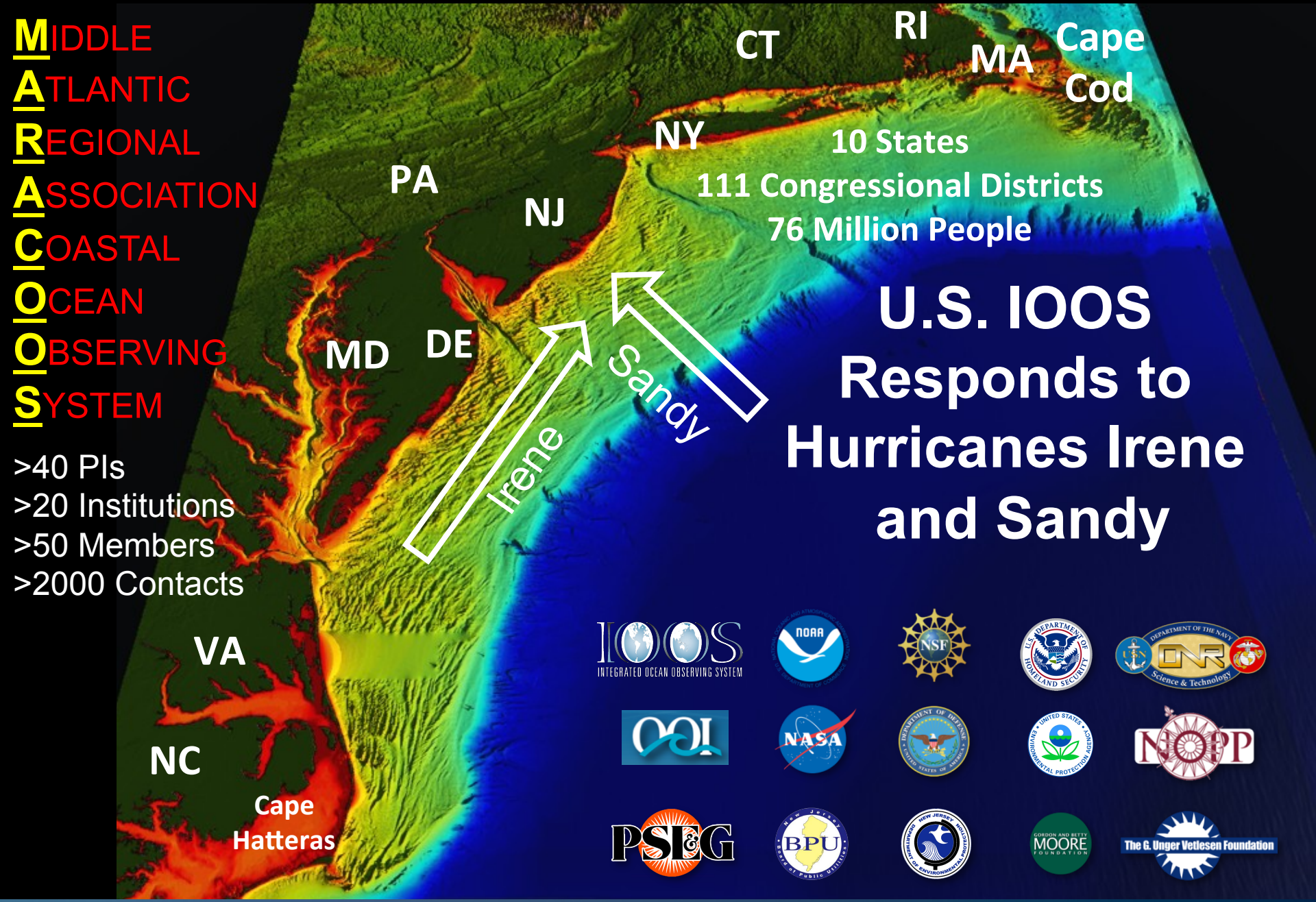
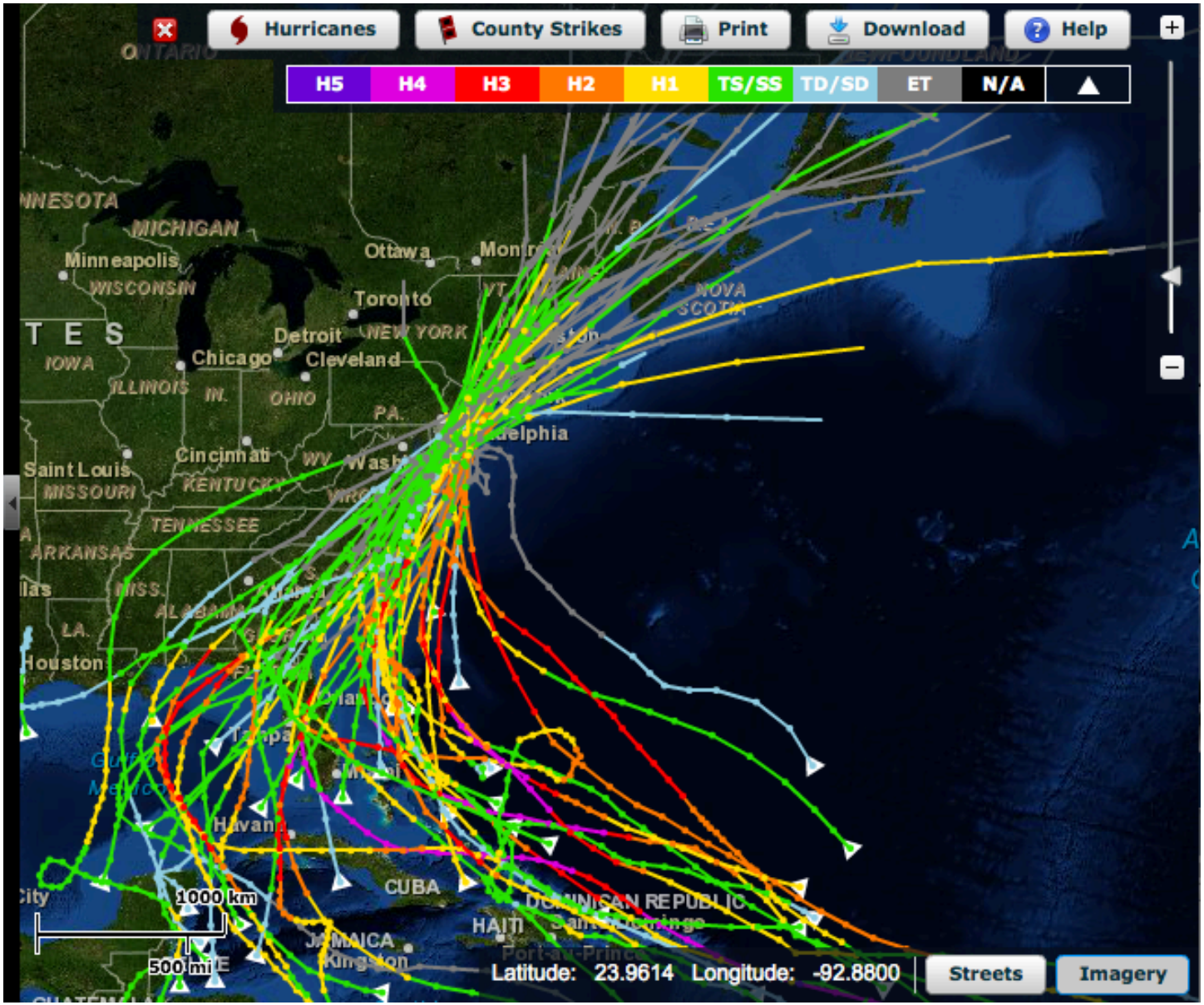
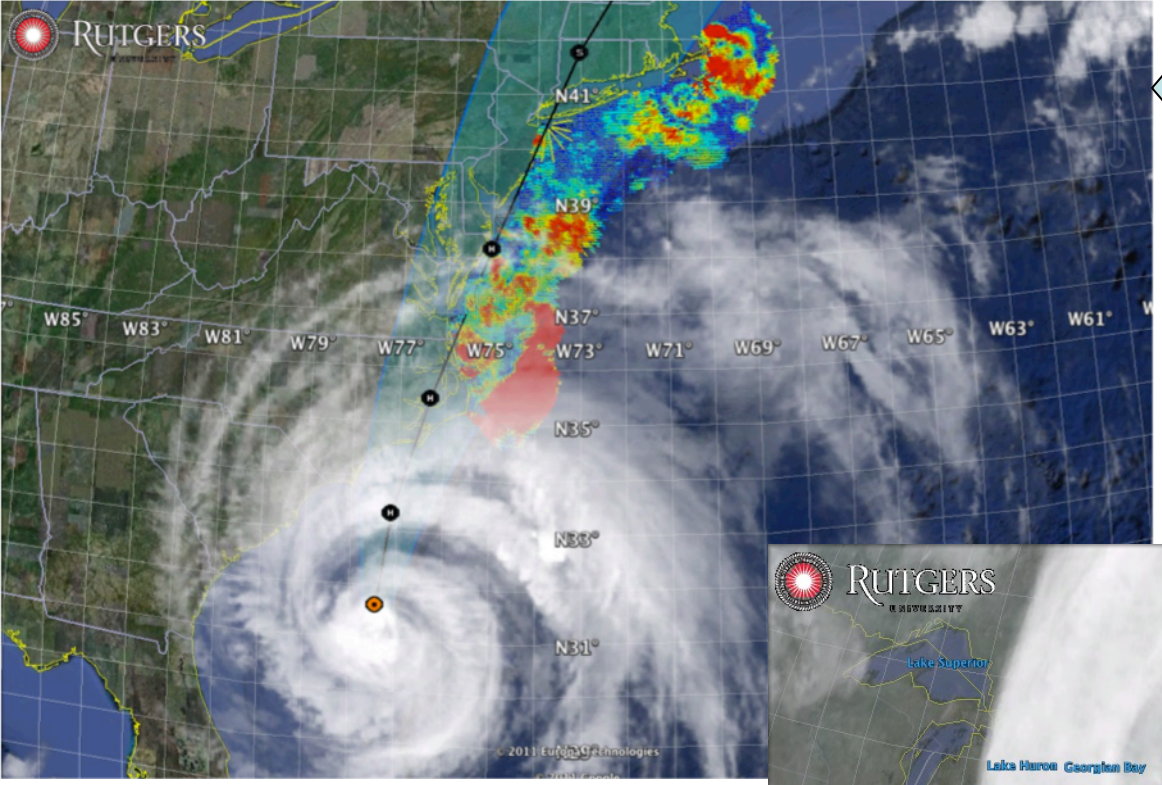

MIDDLE ATLANTIC REGIONAL ASSOCIATION COASTAL OCEAN OBSERVING SYSTEM
MARACOOS
>40 PIs
>20 Institutions
>50 Members
>2000 Contacts
CT
RI
MA
Cape Cod
NY
10 States
111 Congressional Districts
76 Million People
PA
NJ
MD
DE
VA
NC
Cape Hatteras
Irene
Sandy
U.S. IOOS Responds to Hurricanes Irene and Sandy
IOOS
INTEGRATED OCEAN OBSERVING SYSTEM
NOAA
NSF
U.S. DEPARTMENT OF HOMELAND SECURITY
DEPARTMENT OF THE NAVY
ONR
Science & Technology
OOI
NASA
DEPARTMENT OF DEFENSE
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NOPP
PSE&G
New Jersey
BPU
Board of Public Utilities
NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION
GORDON AND BETTY MOORE FOUNDATION
The G. Unger Vetlesen Foundation

Historical Hurricane Tracks within 65 nm of Atlantic City, NJ



Primary Approach: Alongshore from Southeast



Hurricane Irene
August 26, 2011

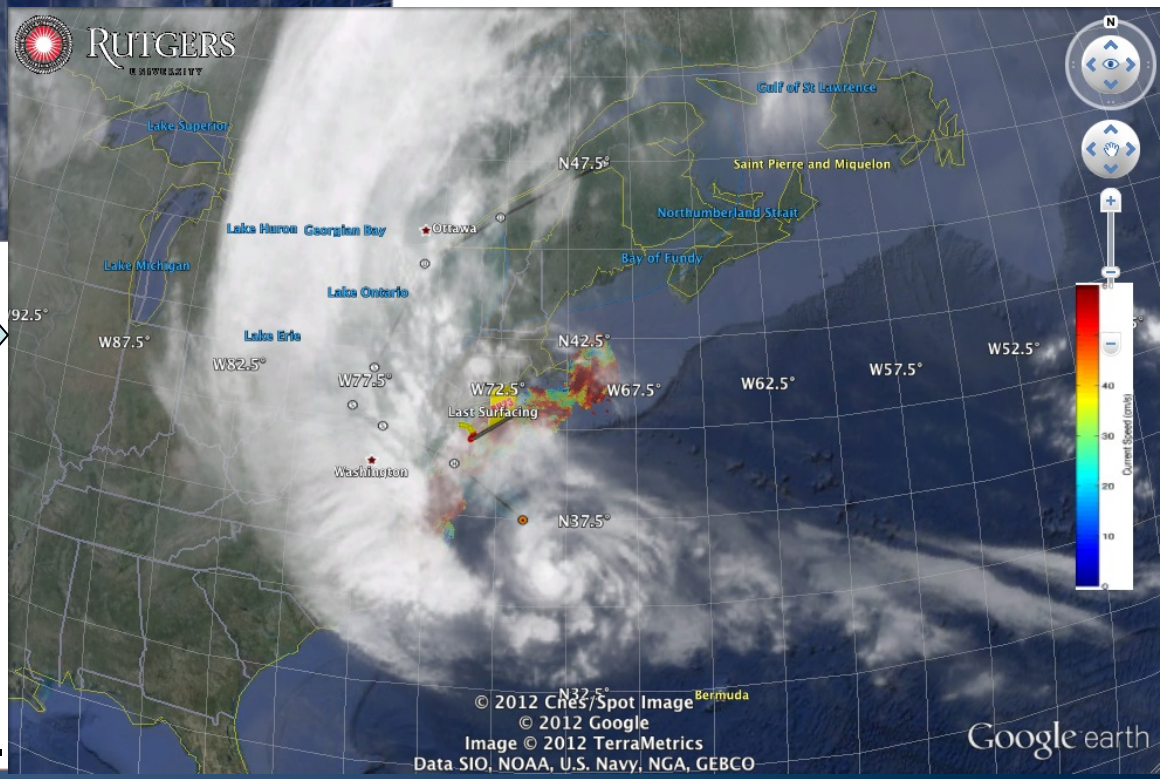
NOAA/NHC Damage:
#8 with >$15 Billion.

Track Accurate;
Intensity Over-predicted.

Hurricane Sandy
October 29, 2012

NOAA/NHC Damage:
#2 with >$60 Billion.

Track Accurate;
Intensity Under-predicted.



Hurricane Irene in the News:

- Track accurately forecast days in advance.
- Intensity was over-predicted.

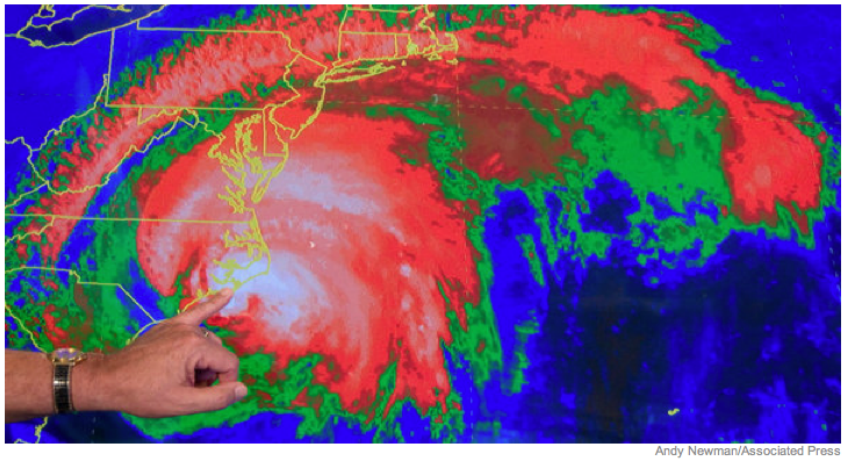
The New York Times

U.S.

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

POLITICS | EDUCATION | BAY AREA | CHICAGO | TEXAS

Challenges in Predicting the Intensity of Storms



Andy Newman/Associated Press

Scientists say that it is much easier to accurately predict what path a hurricane will take.

By HENRY FOUNTAIN
Published: August 27, 2011

The Miami Herald > Weather >

Hurricanes

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Posted on Friday, 09.02.11 A A Share 4

HURRICANE SEASON

Intensity remains a big gap in storm science

Like 1

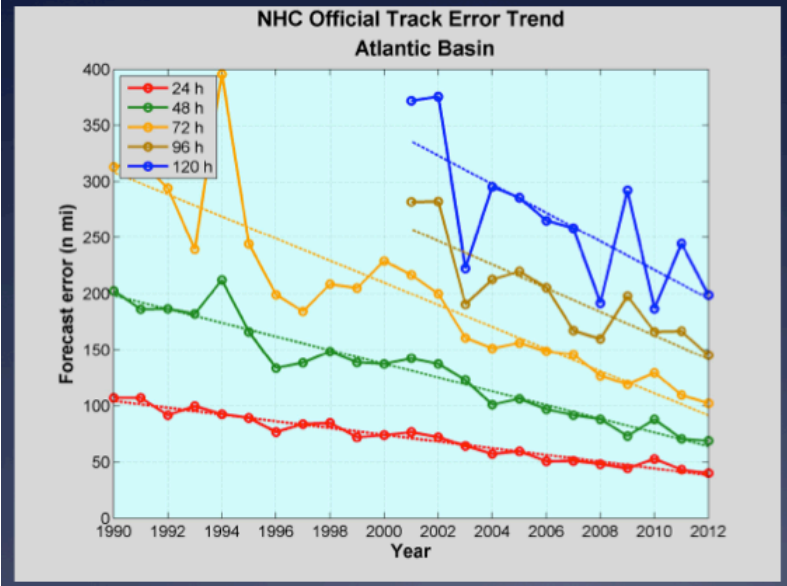
The _____ blew it on predictions of Irene's wind speed — and it wasn't the first time — but new research aims to bring intensity forecasting up to the increasing standards of track forecasts

BY CURTIS MORGAN
MORGAN@MIAMIHERALD.COM

IOOS®

Report from National Hurricane Center: **Track Error & Skill**

Atlantic Track Error Trends



Error Reduction since 1990

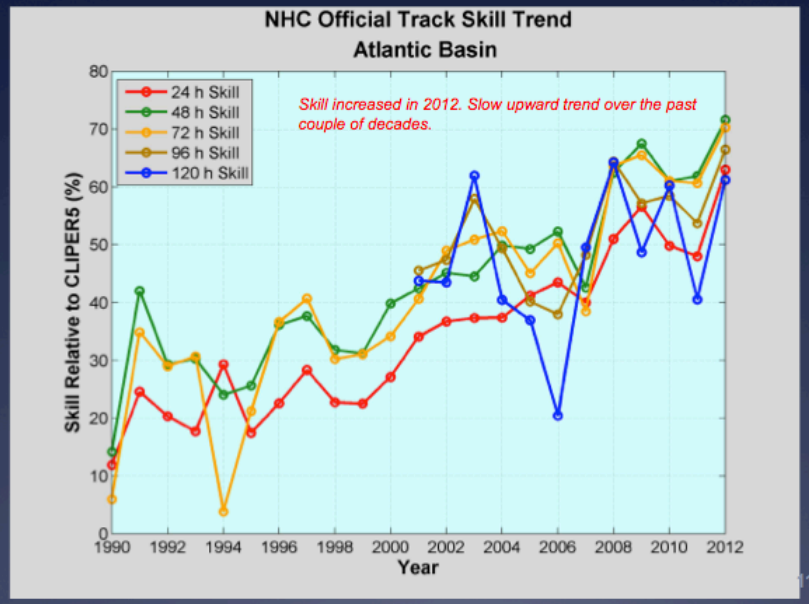
72 h: 67%

48 h: 63%

24 h: 58%

10

Atlantic Track Skill Trends



11

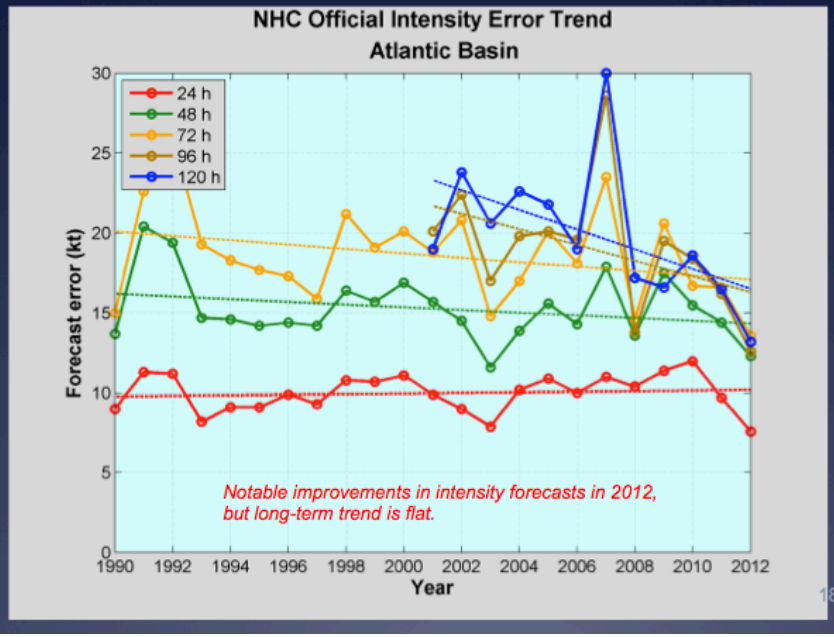
Reduction in forecast track error & Increase in forecast track skill over the last 2 decades.

Significant Drivers – Improvement in Global Forecast Models

- Super-Ensemble

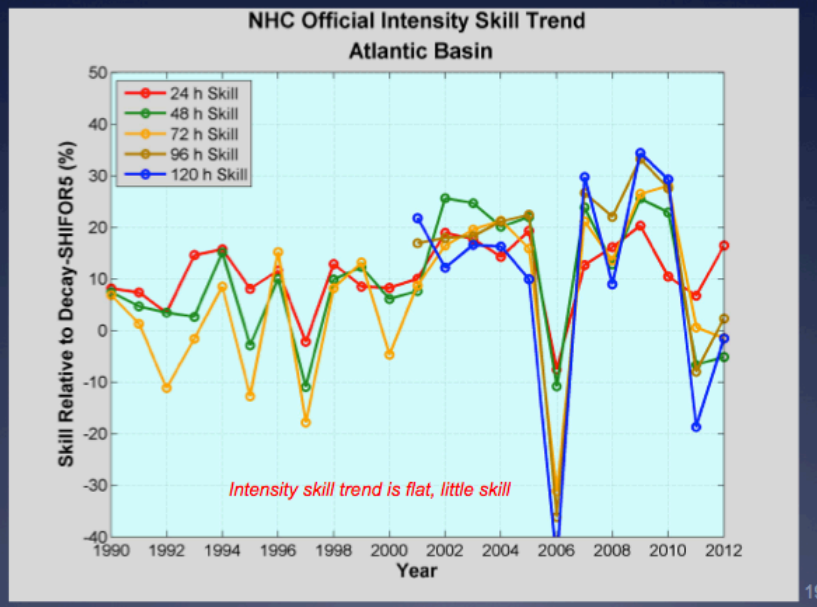
Report from National Hurricane Center: **Intensity Error & Skill**

Atlantic Intensity Error Trends



18

Atlantic Intensity Skill Trends



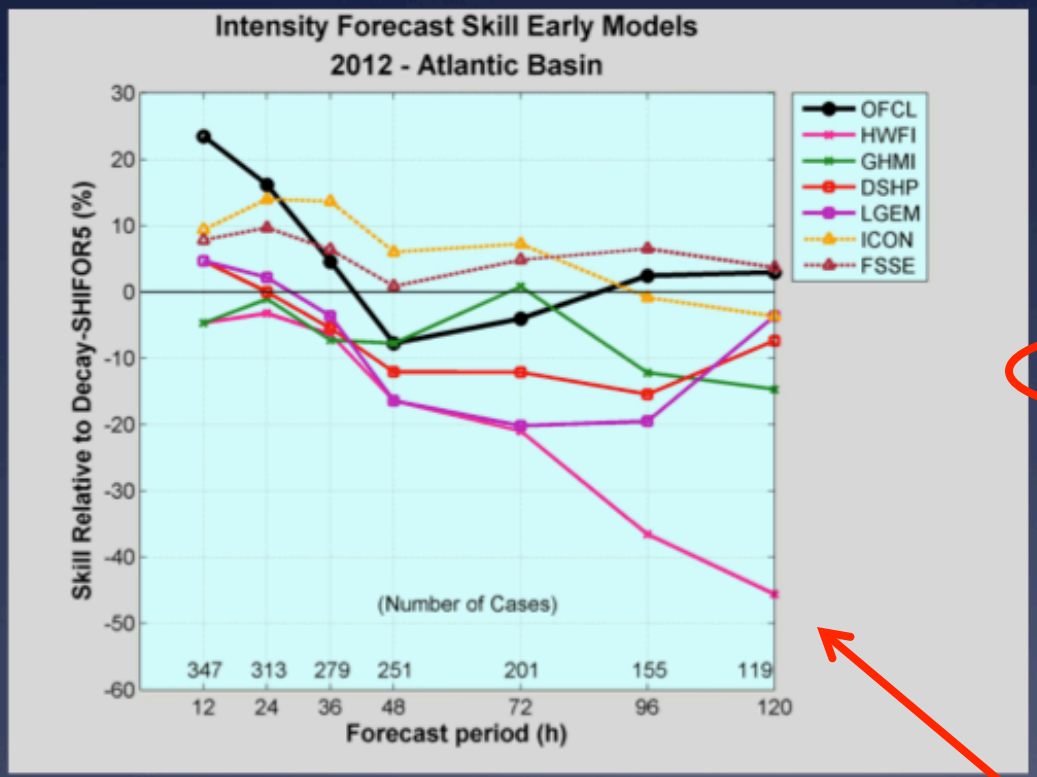
19

"Long-term trend is flat."

"Skill trend is flat, little skill."

Report from National Hurricane Center: **Intensity** Skill in 2012

2012 Intensity Guidance



Official forecasts had skill early, but little or no skill at 36 h and beyond.

FSSE and ICON were the best models.

DSHP and LGEM were not skillful in 2012.

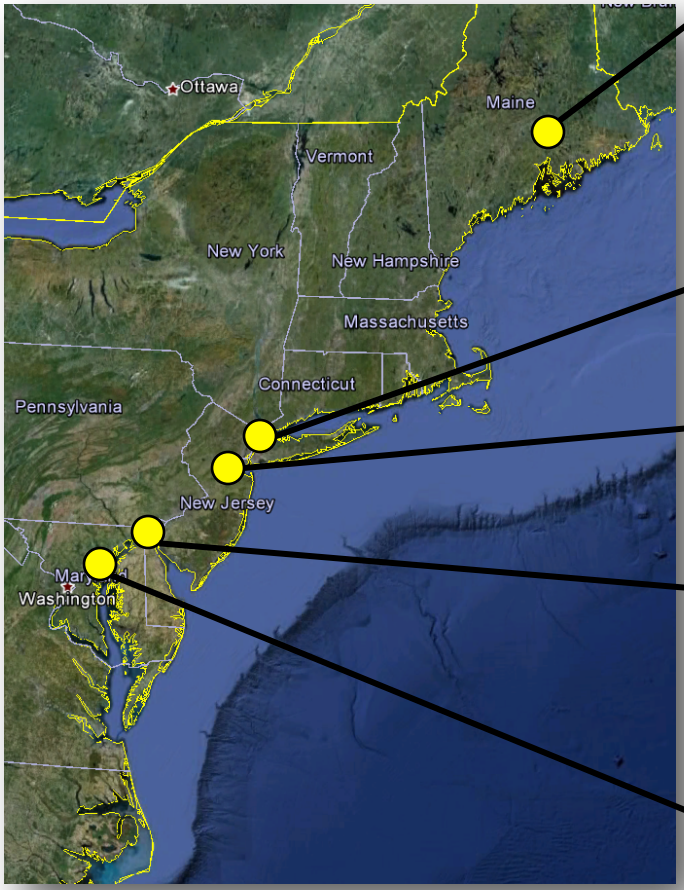
HWRF was the worst model.

20

Adding the ocean model reduced skill!

Real-Time Satellite Ground Stations in the Northeast U.S.

Satellites: NPP, Terra, Aqua, NOAA Polar Orbiters, Metop & GOES



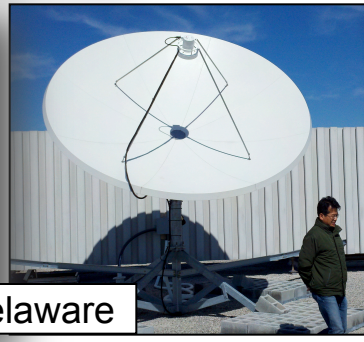

U. Maine


City College of N.Y.

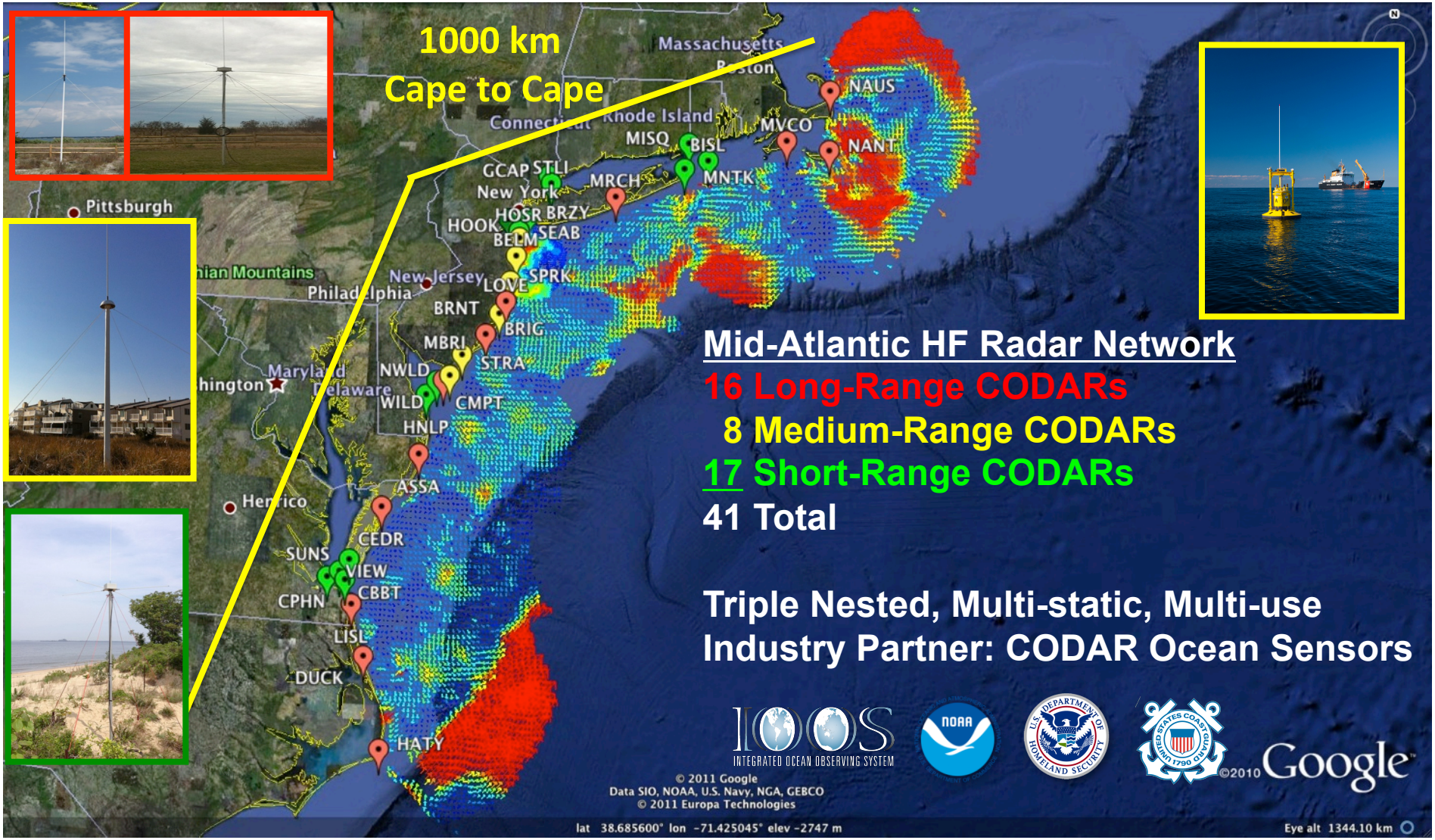


Rutgers

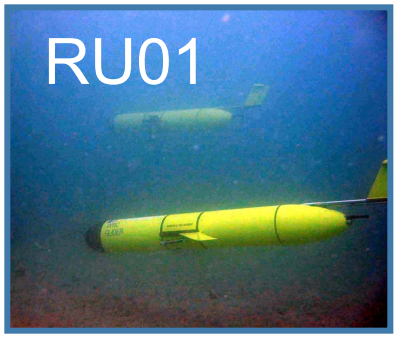

Johns Hopkins



U. Delaware

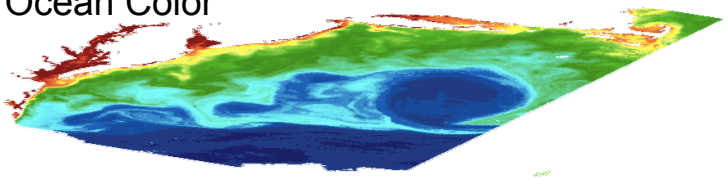
Mid-Atlantic Bight HF Radar Network



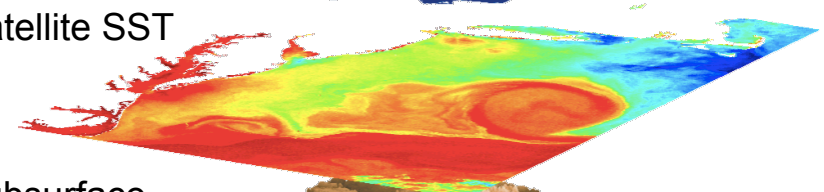
Rutgers Glider Network



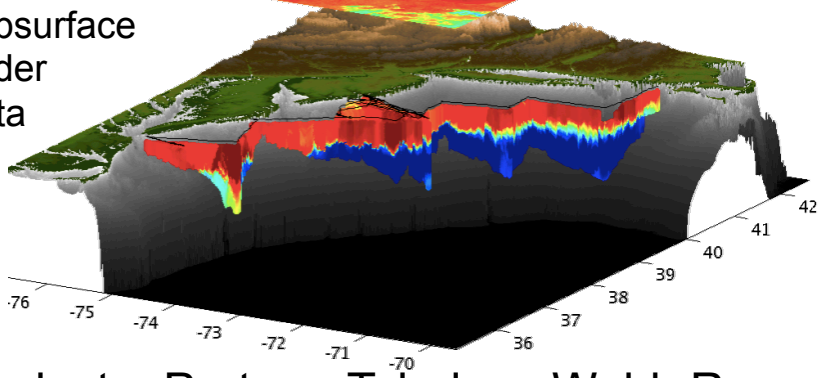
Satellite Ocean Color



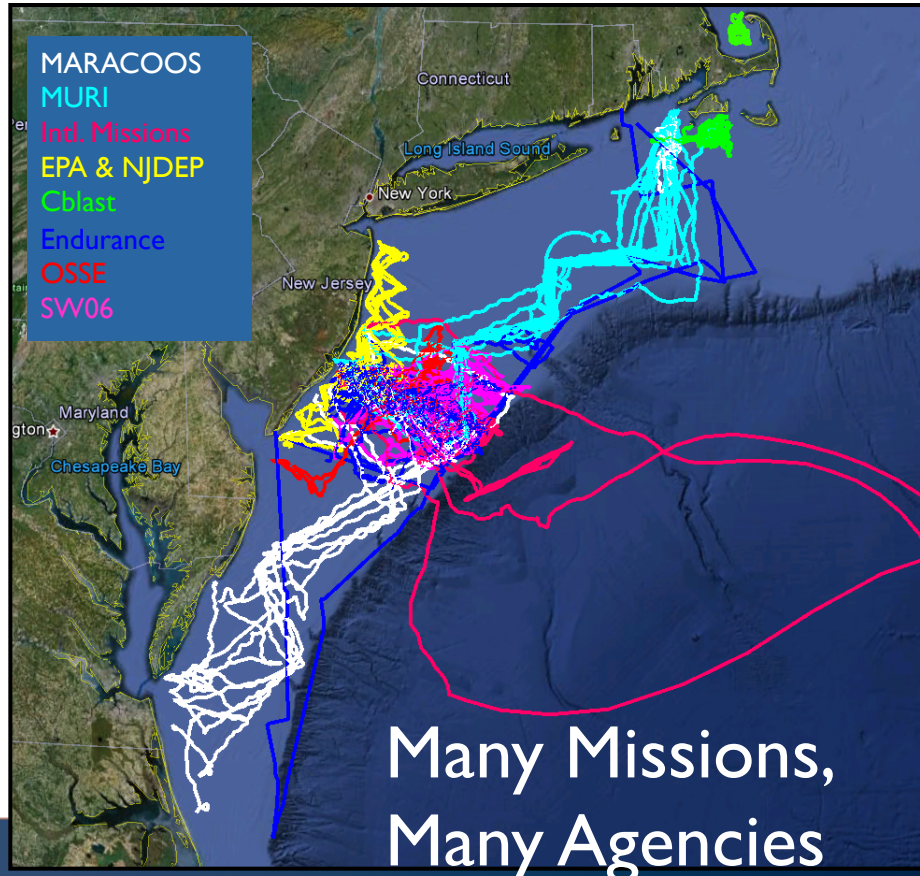
Satellite SST



Subsurface Glider Data



Industry Partner: Teledyne Webb Research



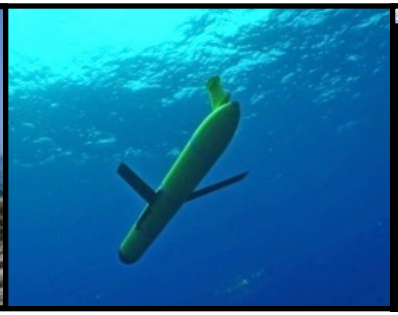
IOOS®

MARACOOS Operations Center

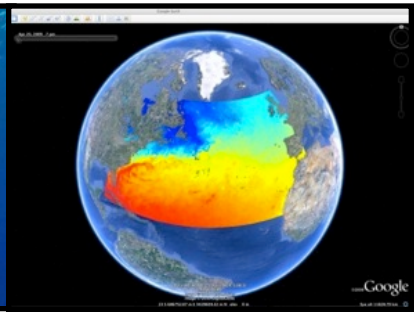
Rutgers University - Coastal Ocean Observation Lab

Satellite Data Acquisition Stations

CODAR Network



Glider Fleet



3-D Forecasts

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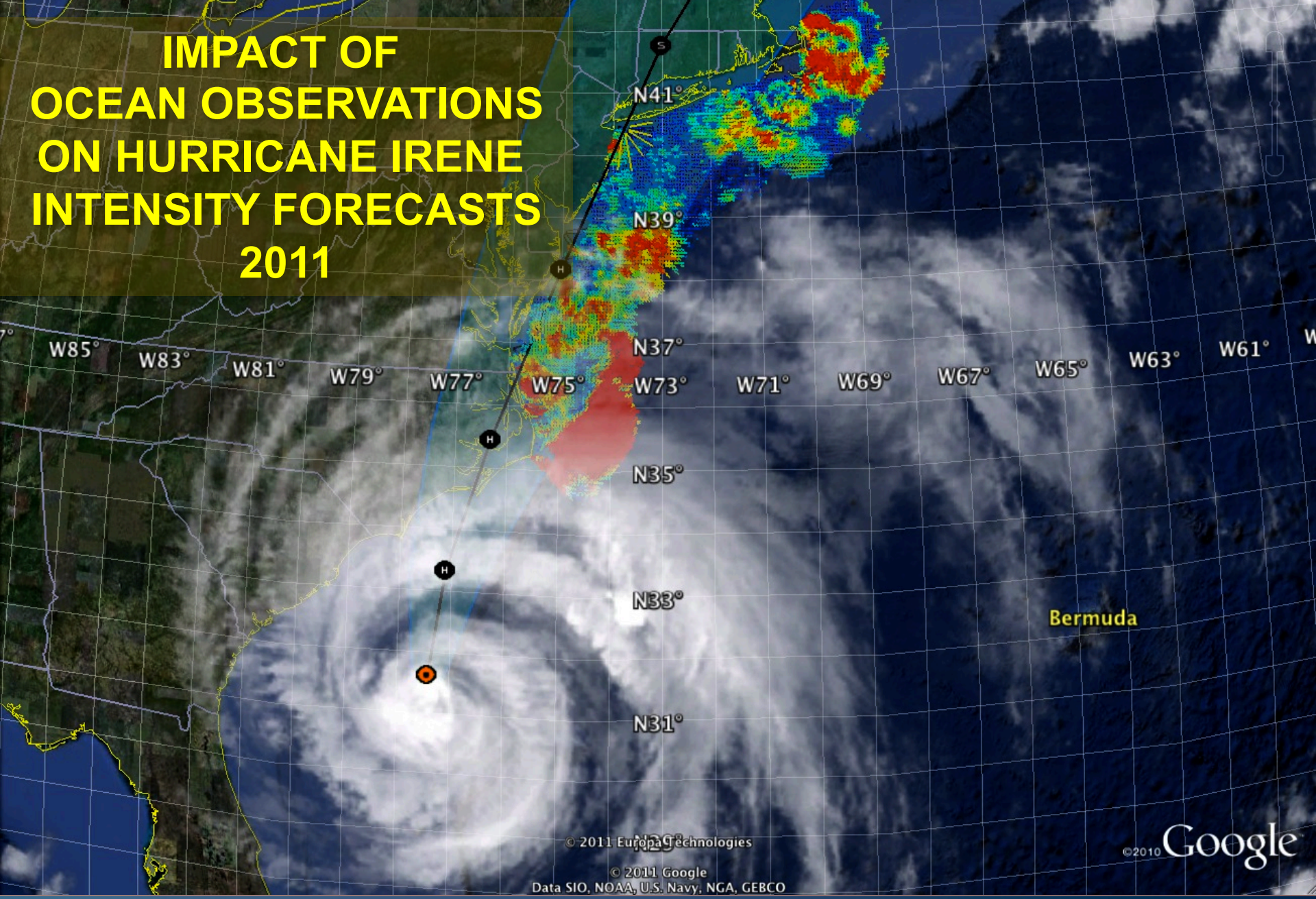
IMPACT OF
OCEAN OBSERVATIONS
ON HURRICANE IRENE
INTENSITY FORECASTS
2011
N41°
N39°
N37°
N35°
N33°
N31°
W85°
W83°
W81°
W79°
W77°
W75°
W73°
W71°
W69°
W67°
W65°
W63°
W61°
Bermuda
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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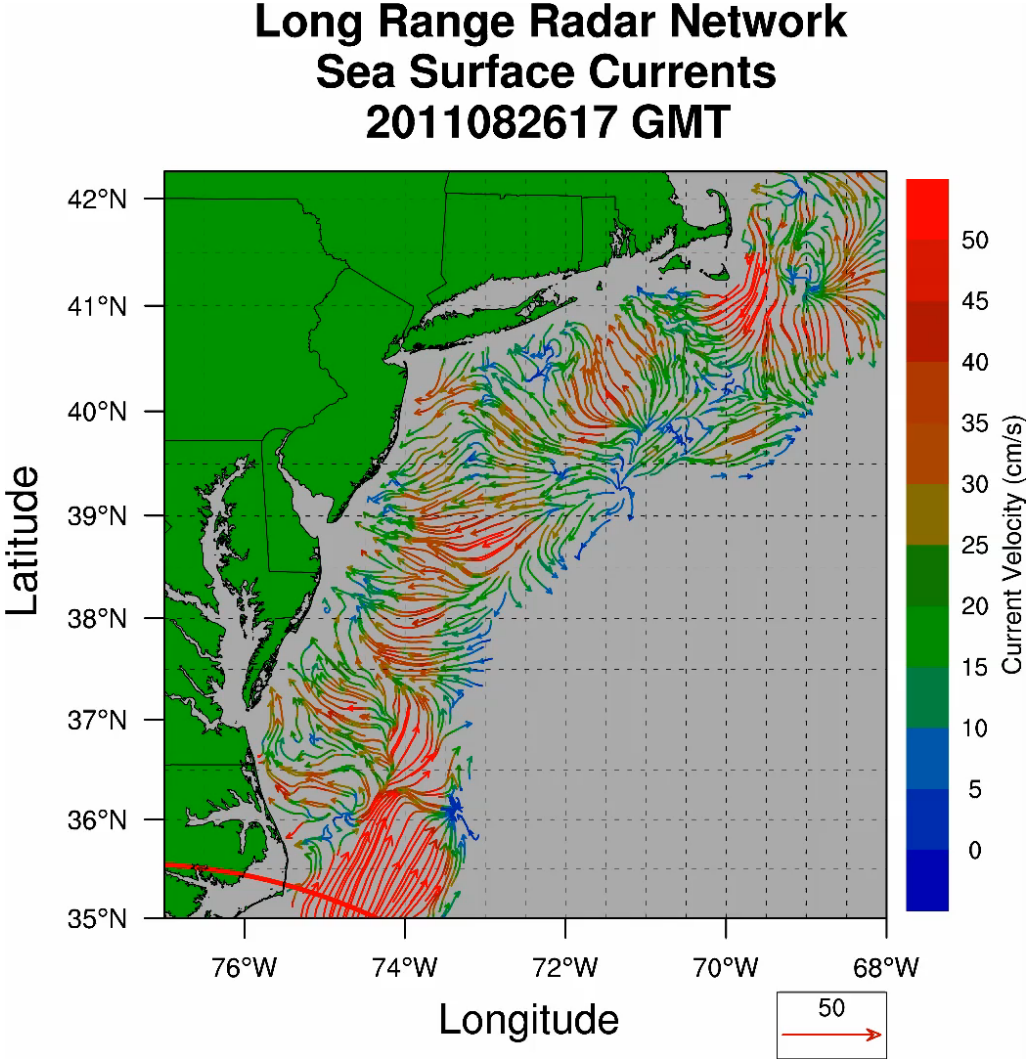
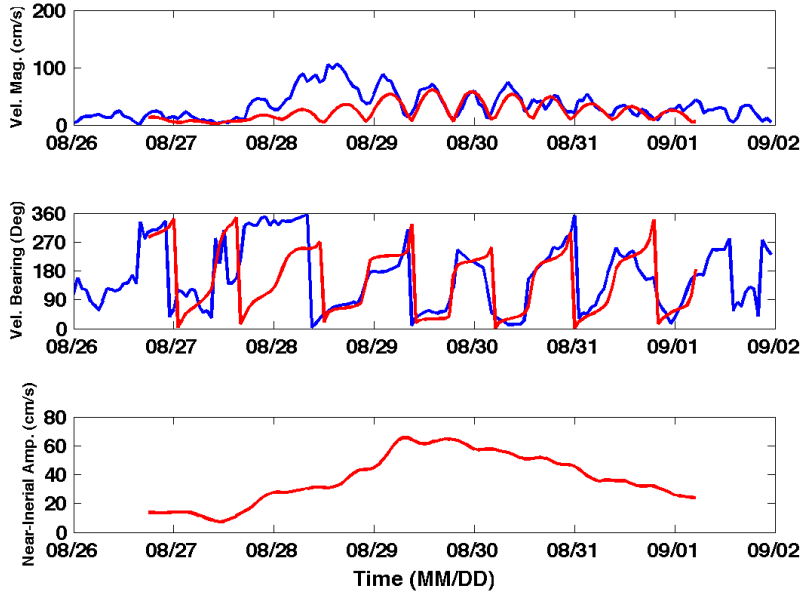
Hurricane Irene

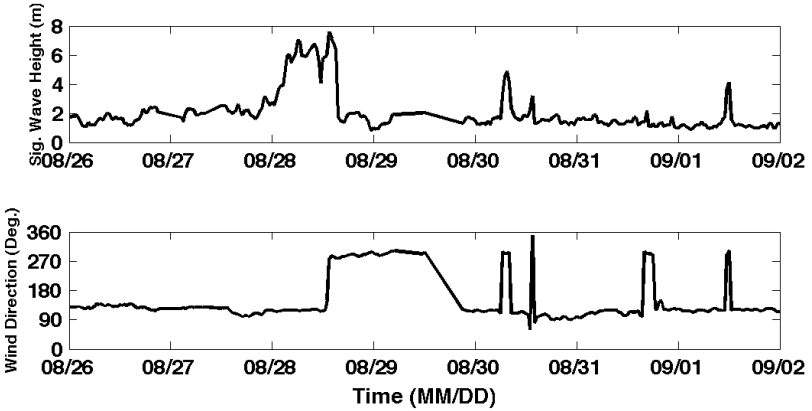


39.5N 73W Surface Current Time Series

Total Current Near-Inertial Current



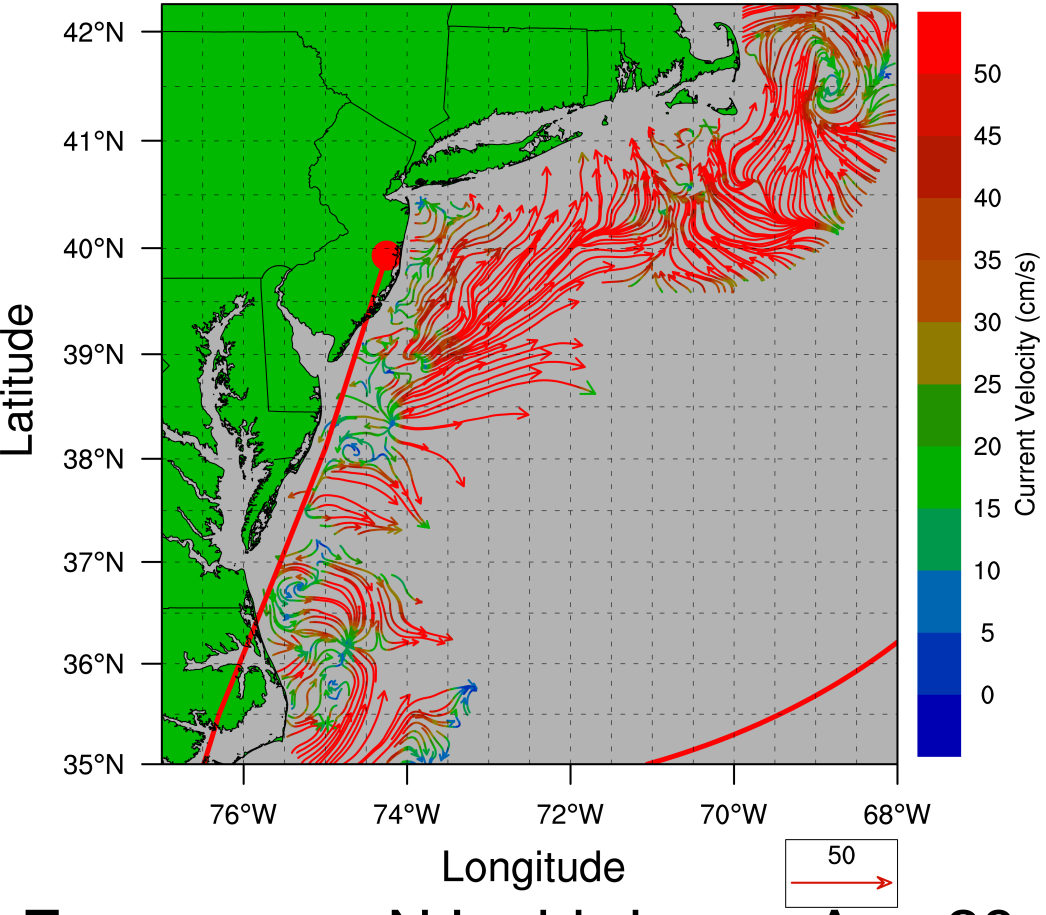
Wave & Wind Direction Time Series



Eye crosses NJ mid-day on Aug 28

Hurricane Irene

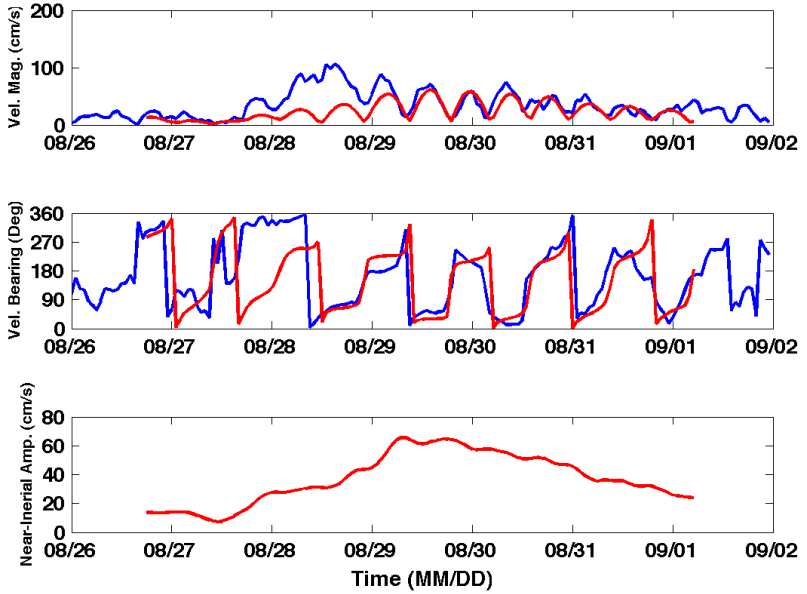
Long Range Radar Network
Sea Surface Currents
2011082812 GMT



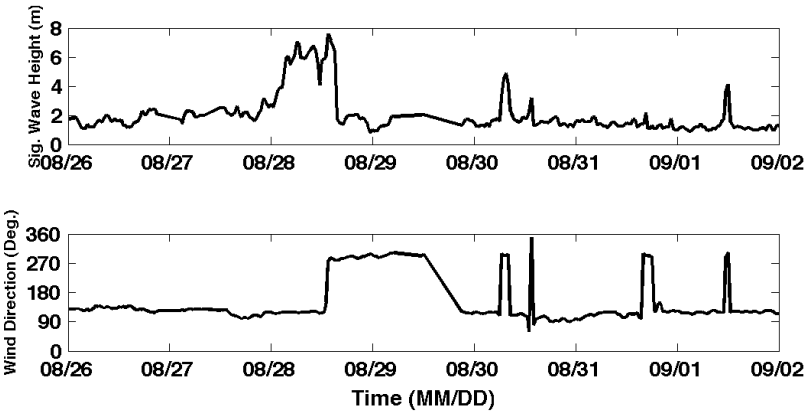
Eye crosses NJ mid-day on Aug 28

39.5N 73W Surface Current Time Series

Total Current Near-Inertial Current



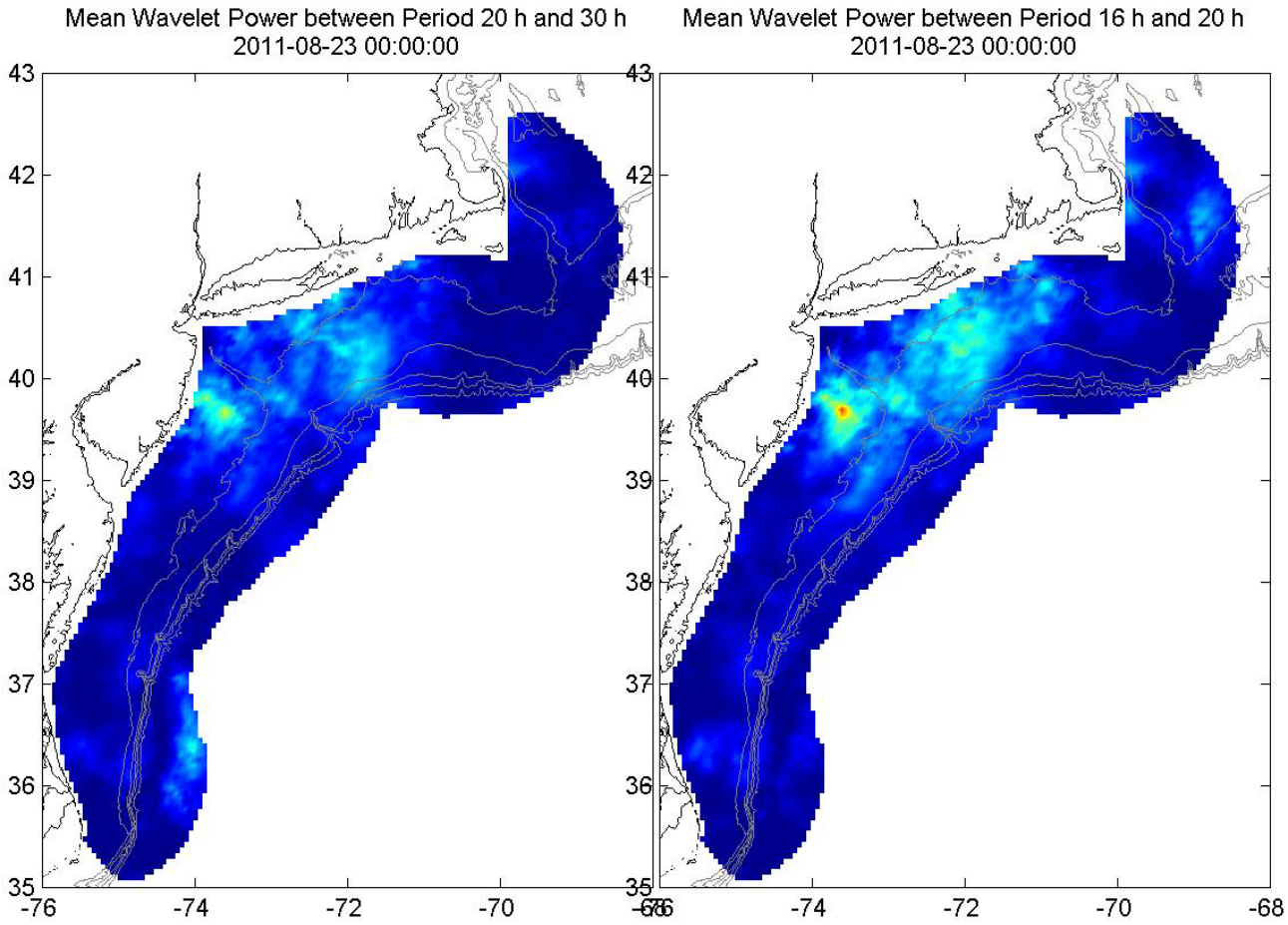
Wave & Wind Direction Time Series



Hurricane Irene Surface Current Wavelet Analysis

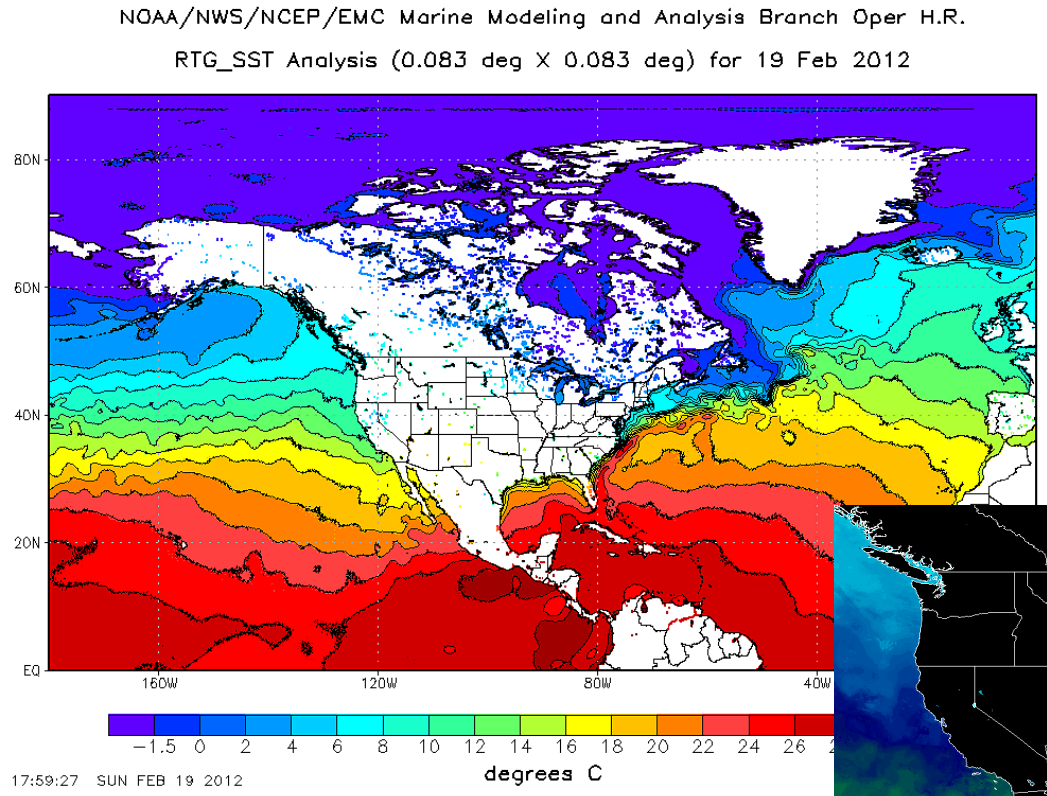
Direct Wind Forcing

Inertial Response

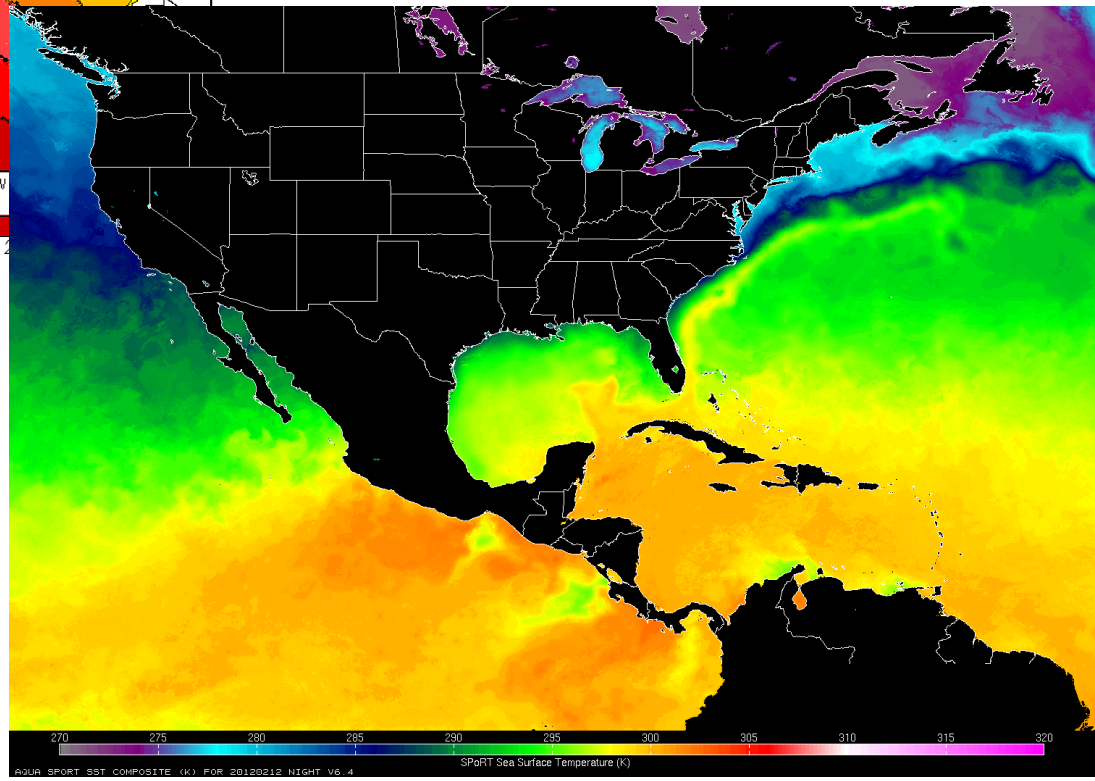


Aug 27	Aug 28	Aug 29	Aug 30	Aug 31	Sep 01
Frontside	Eye	Backside	Inertial	Inertial	Inertial

Operational Global SST Products

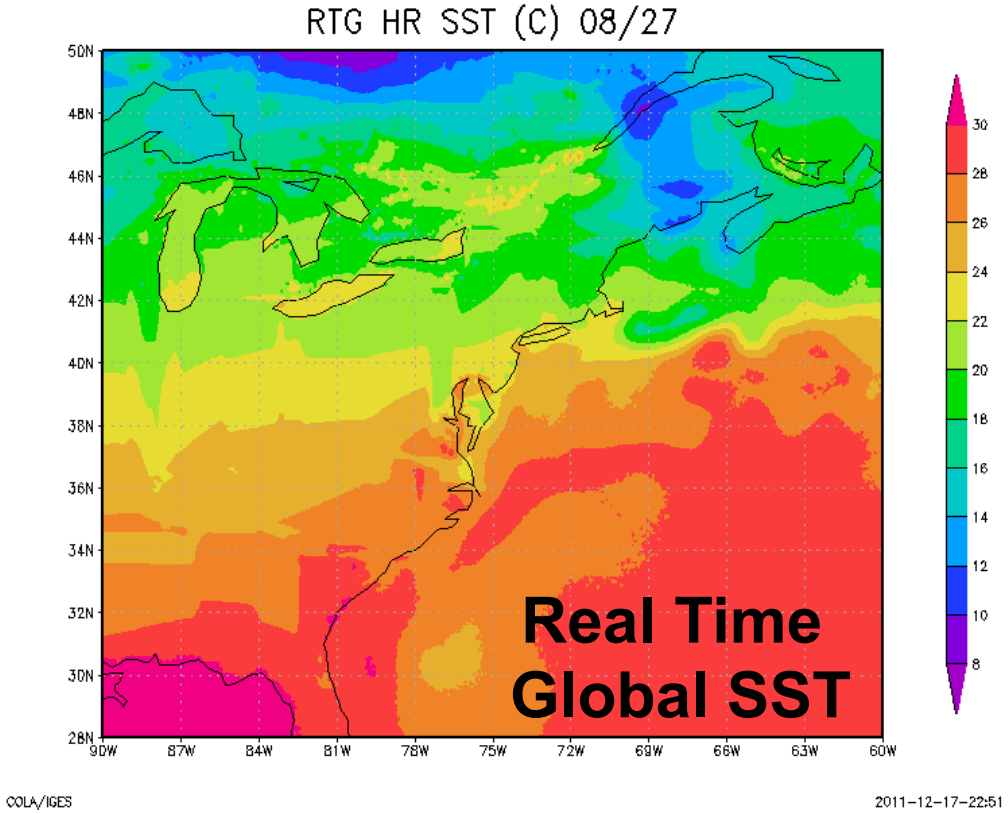


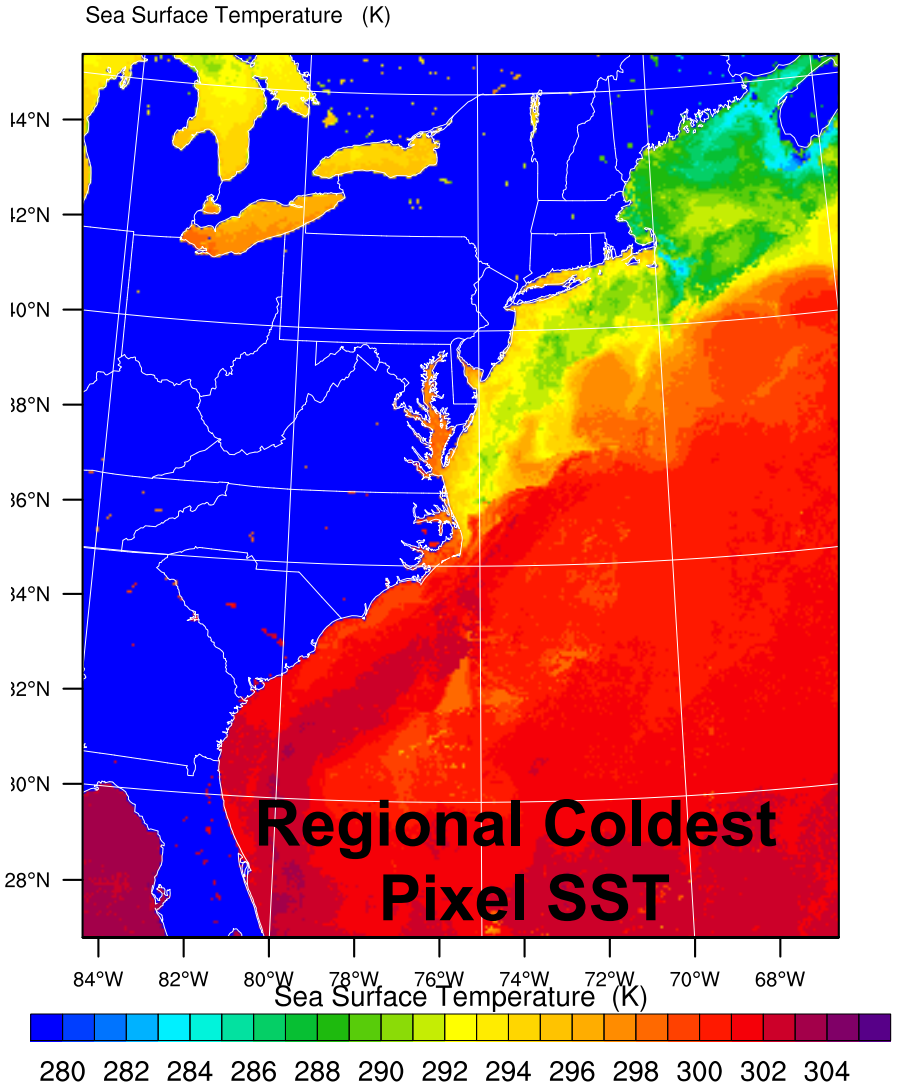
Real-Time Global (RTG)
Smooth Data in Space



Short Term Prediction Research & Transition Center (SPoRT)
Smooth Data in Time

MARACOOS SST Product for Offshore Wind

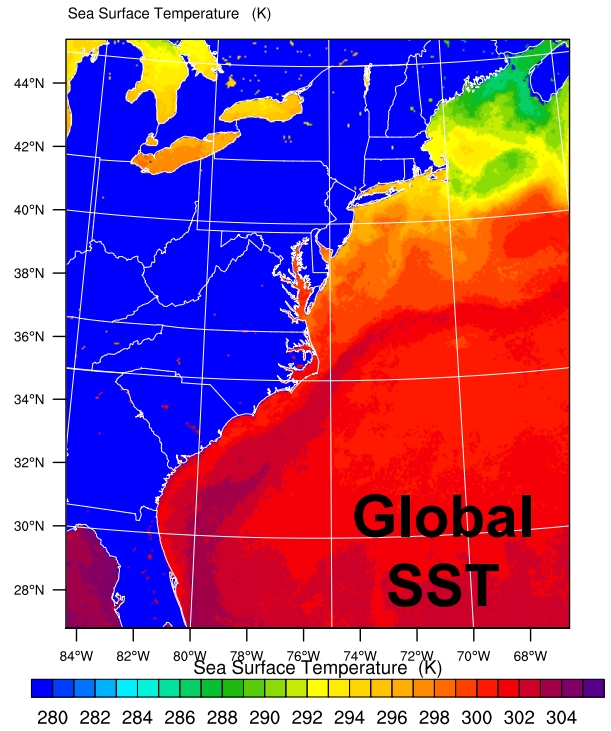


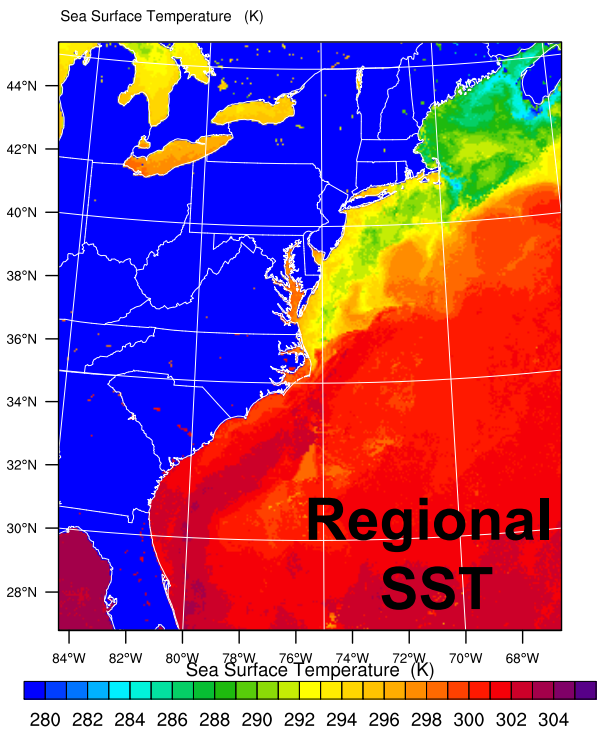


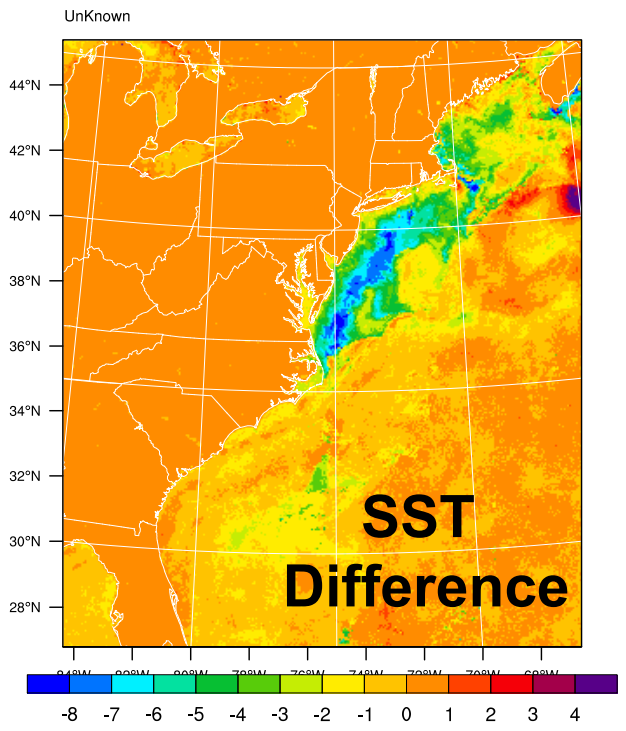
MARACOOSRegional SST

= Coldest Dark Pixel
Composite of Local AVHRR
+ SPoRT + RTG

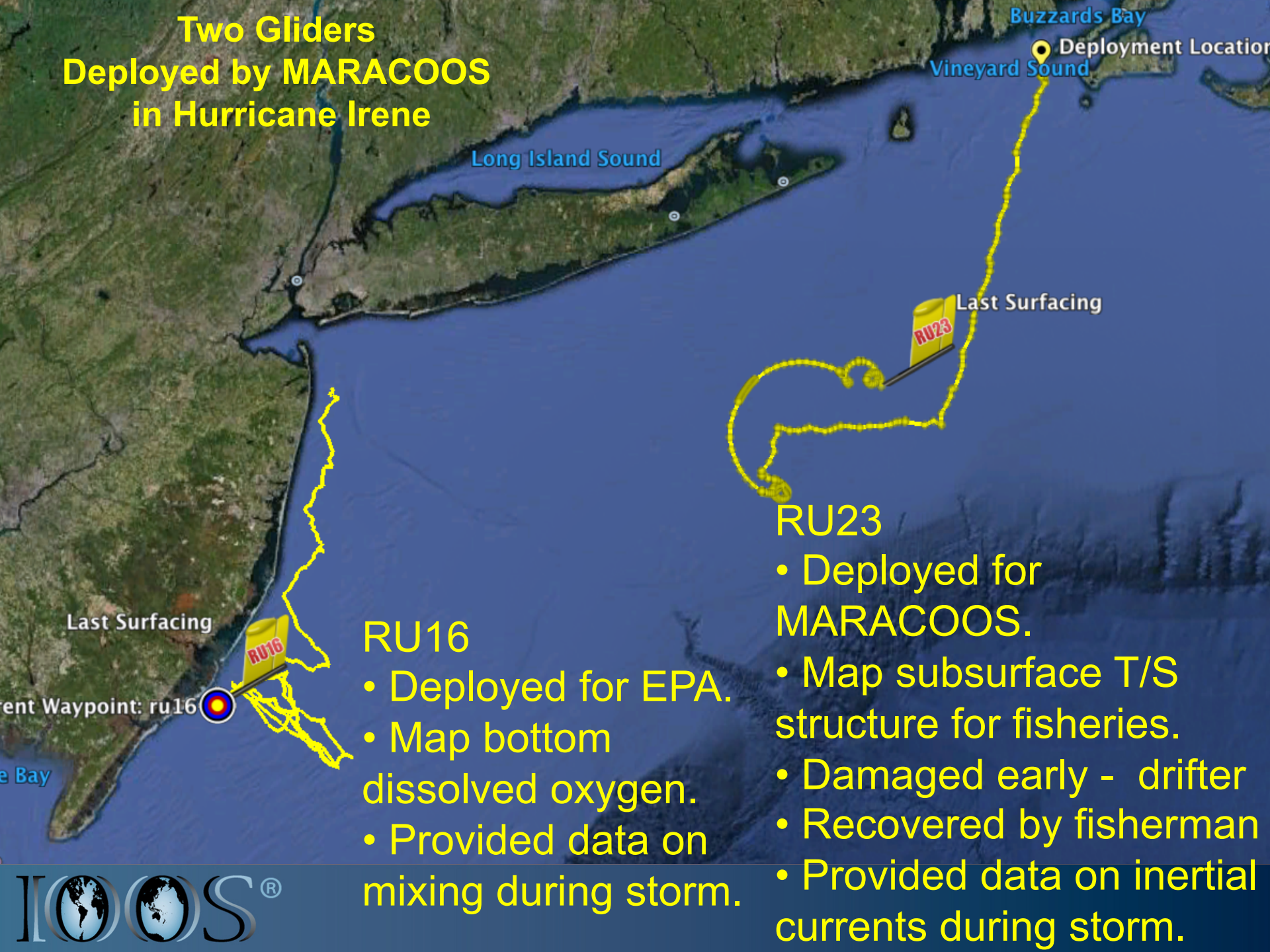
Post-Hurricane Irene Sea Surface Temperatures

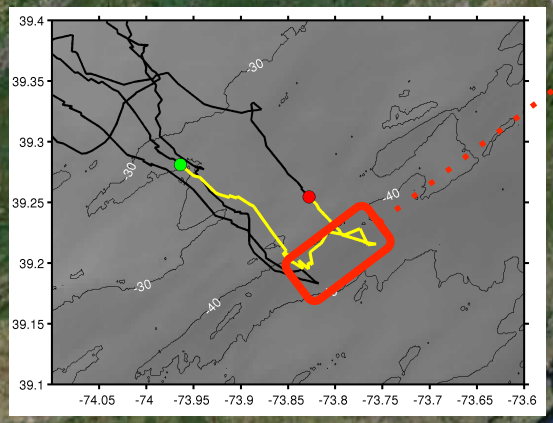






But when did the 6C - 10C Cooling occur?


Two Gliders
Deployed by MARACOOS
in Hurricane Irene
Buzzards Bay
Deployment Location
Vineyard Sound
Long Island Sound
Last Surfacing
RU23
Last Surfacing
RU16
ent Waypoint: ru16
e Bay
RU16
• Deployed for EPA.
• Map bottom dissolved oxygen.
• Provided data on mixing during storm.
RU23
• Deployed for MARACOOS.
• Map subsurface T/S structure for fisheries.
• Damaged early - drifter
• Recovered by fisherman
• Provided data on inertial currents during storm.
IOOS®



Hurricane Irene

Buzzards Bay

Vineyard Sound

Long Island S

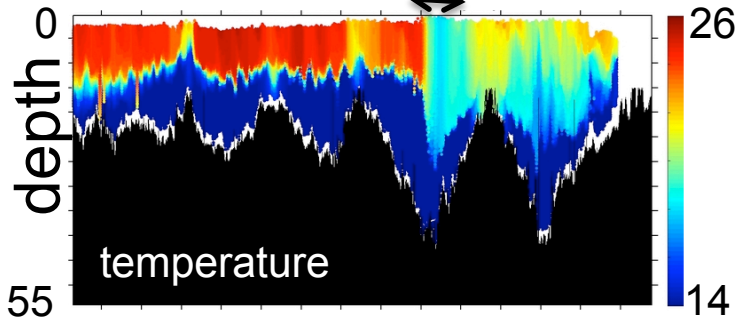
Last Surfacing

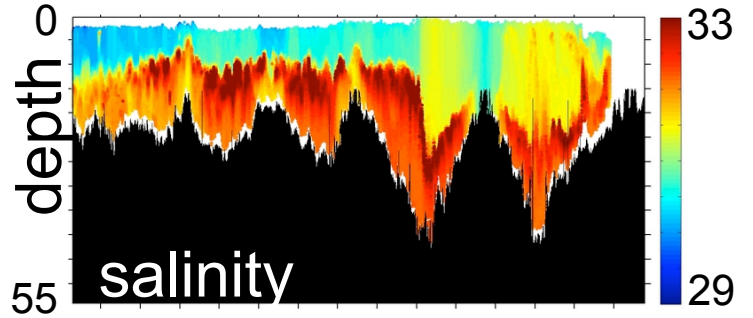
RU16

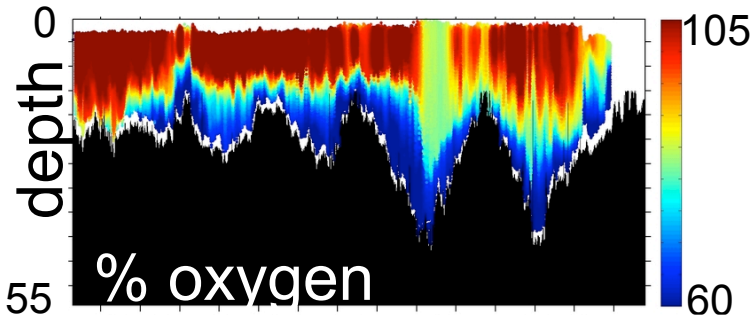
Current Waypoint: ru16

Delaware Bay

Hurricane Irene

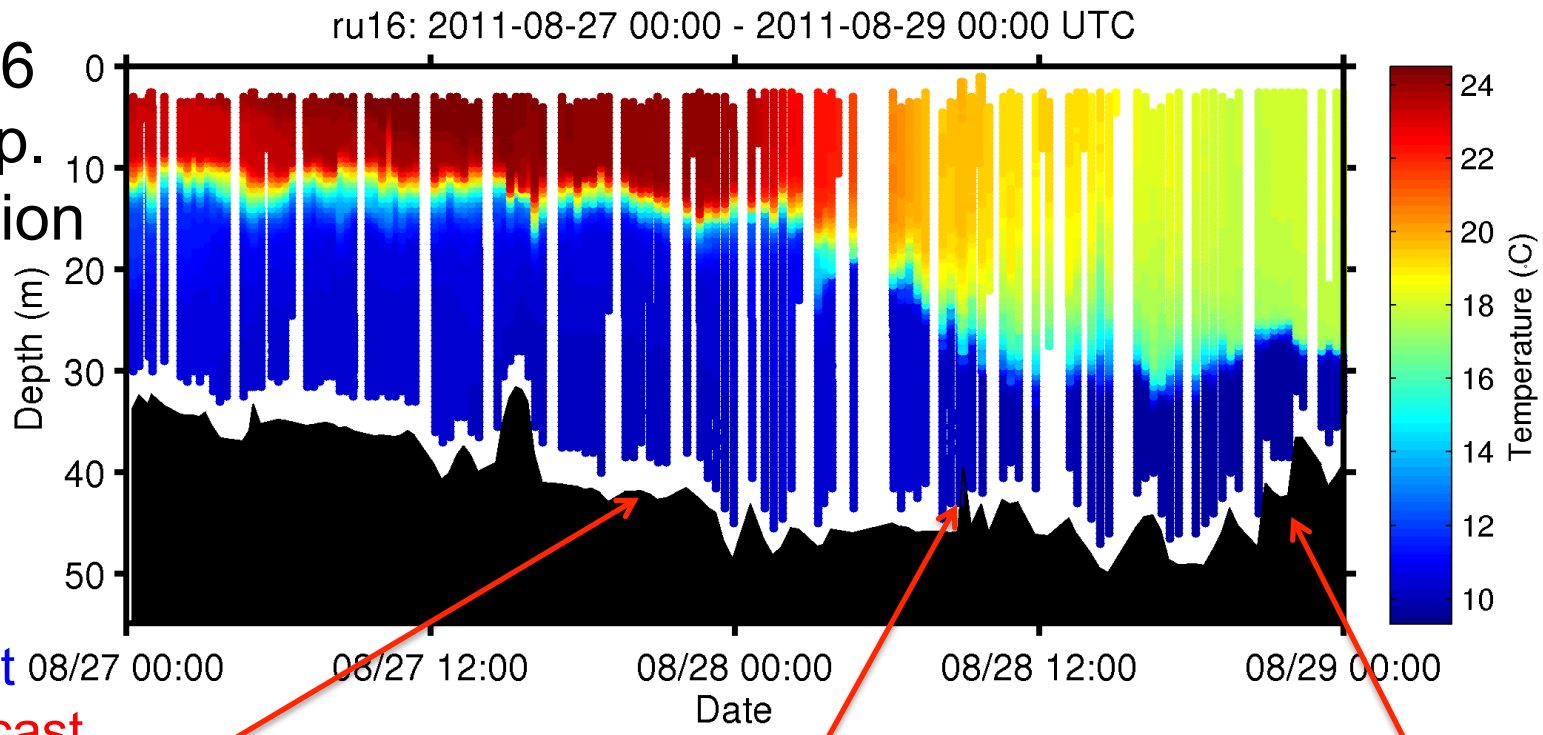






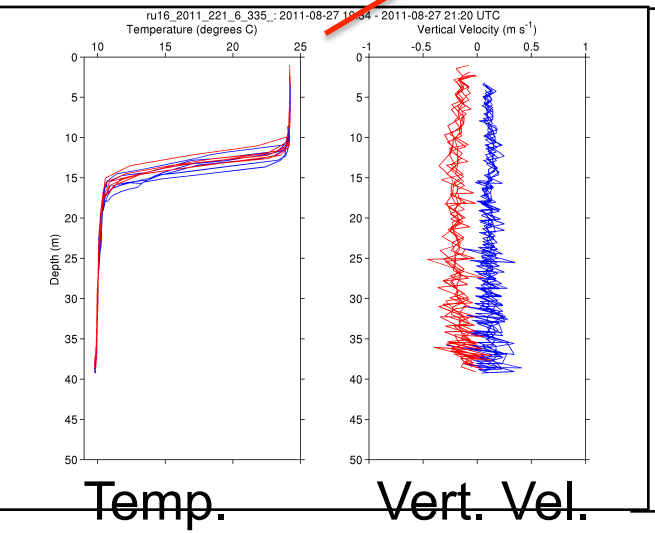
8/12 date 9/07

RU16 Temp. Section

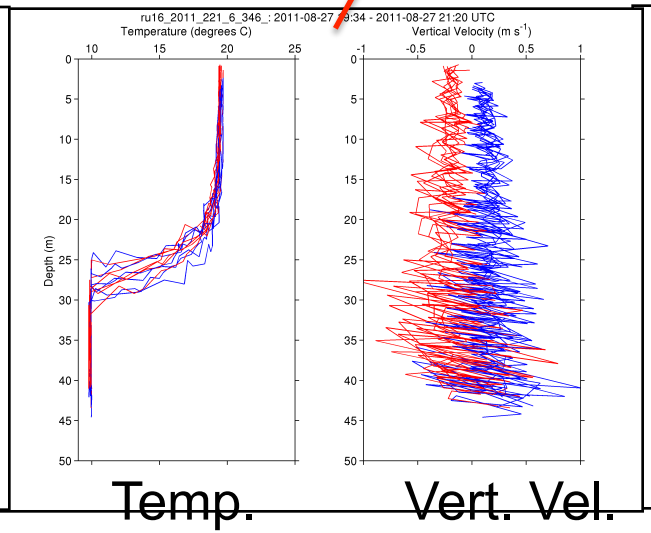


Upcast

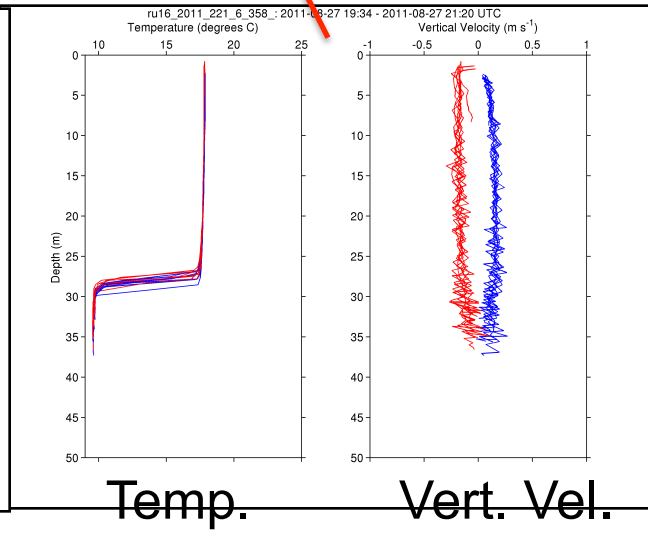
Downcast



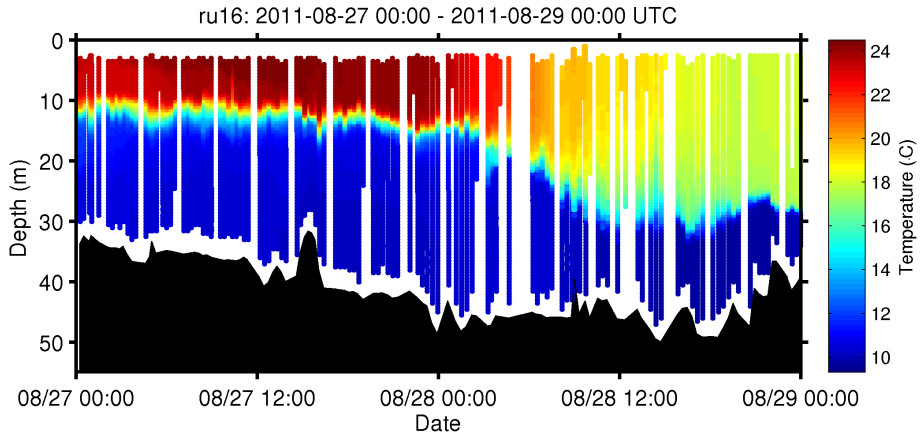
Temp. Vert. Vel.



Temp. Vert. Vel.



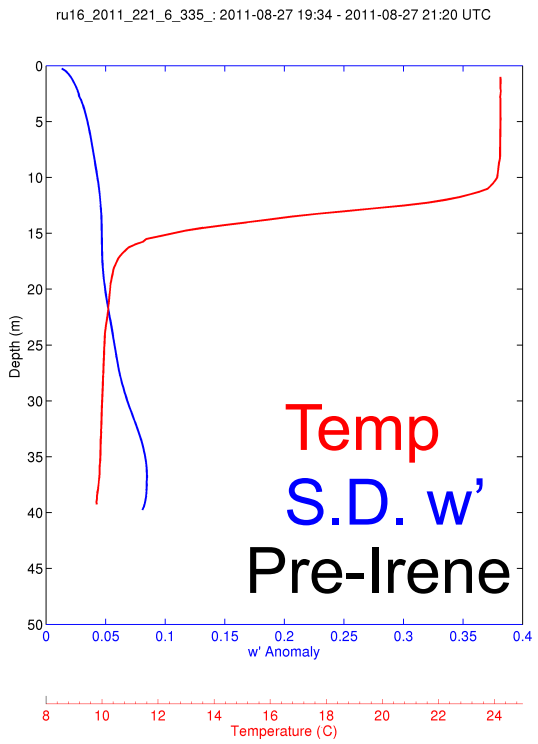
Temp. Vert. Vel.

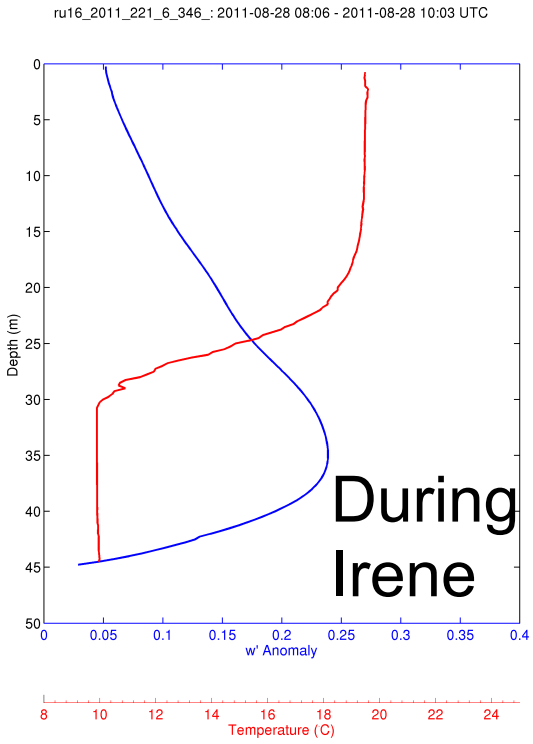


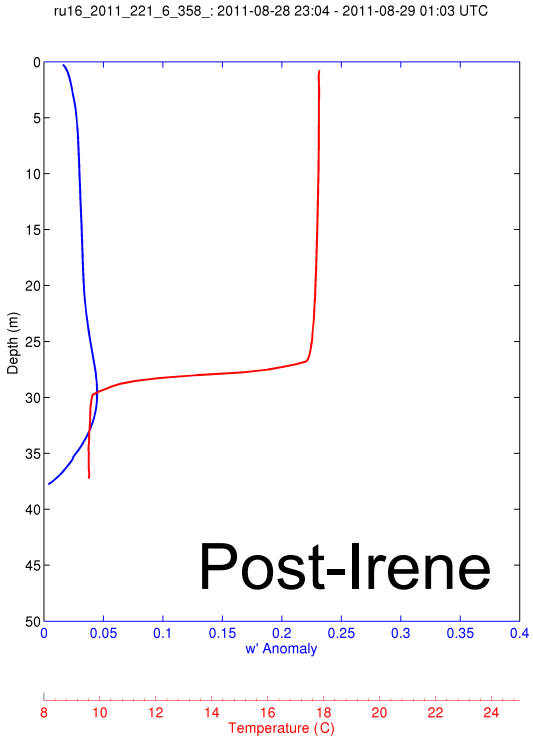
For Each 2-hour Segment:

1) Calculate the Average Temperature Profile

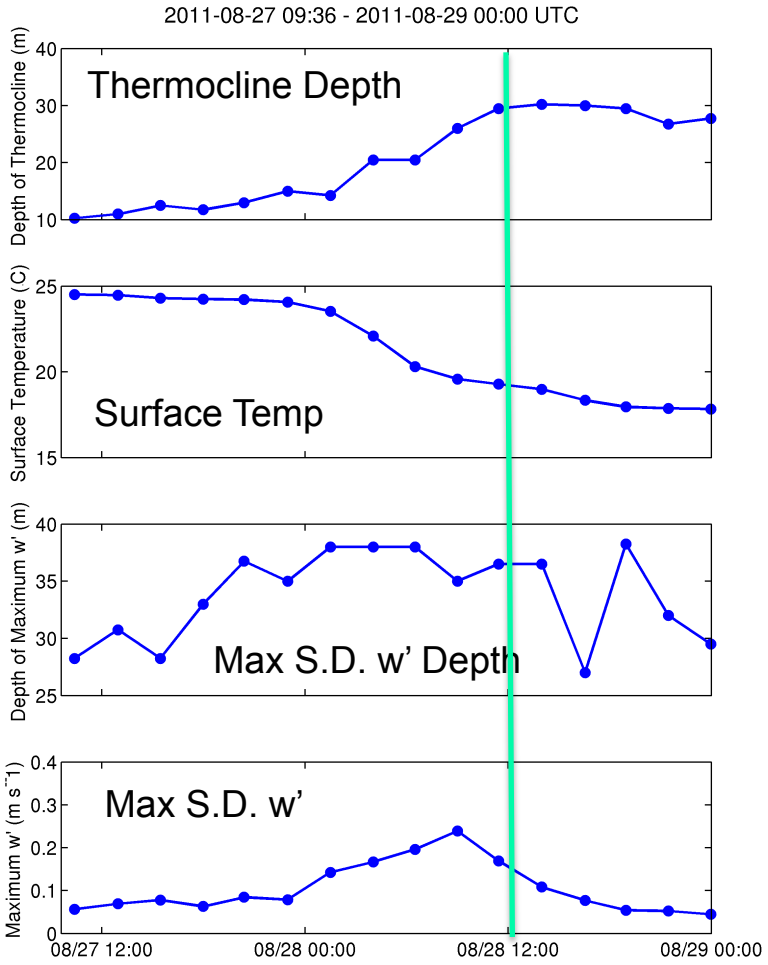
2) Calculate the Vertical Velocity Standard Deviation Profile and Smooth Vertically.



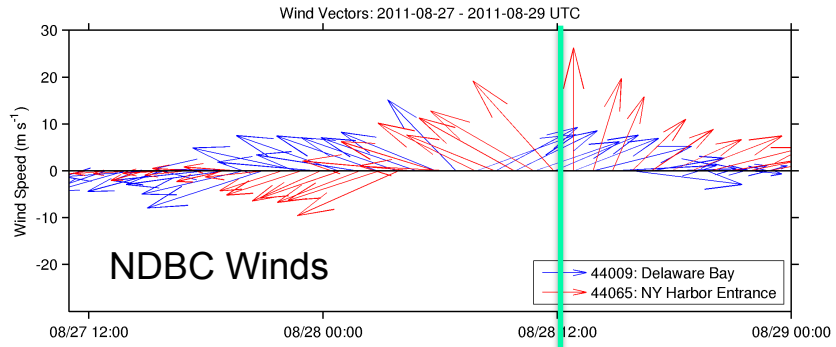


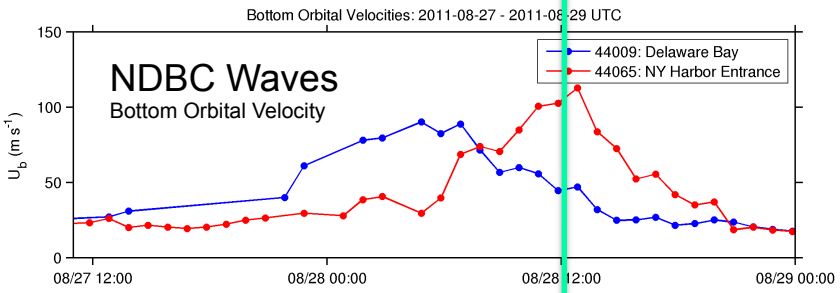


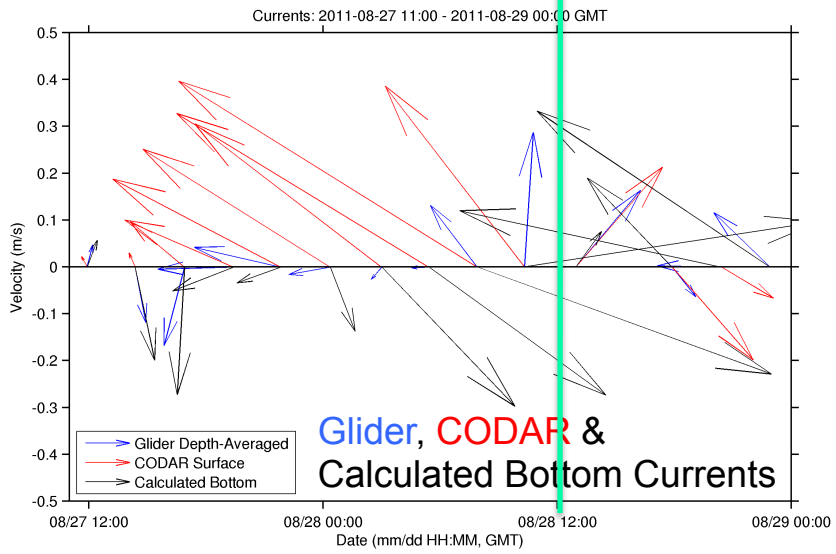
MARACOOS Network Observations:
Hurricane Irene



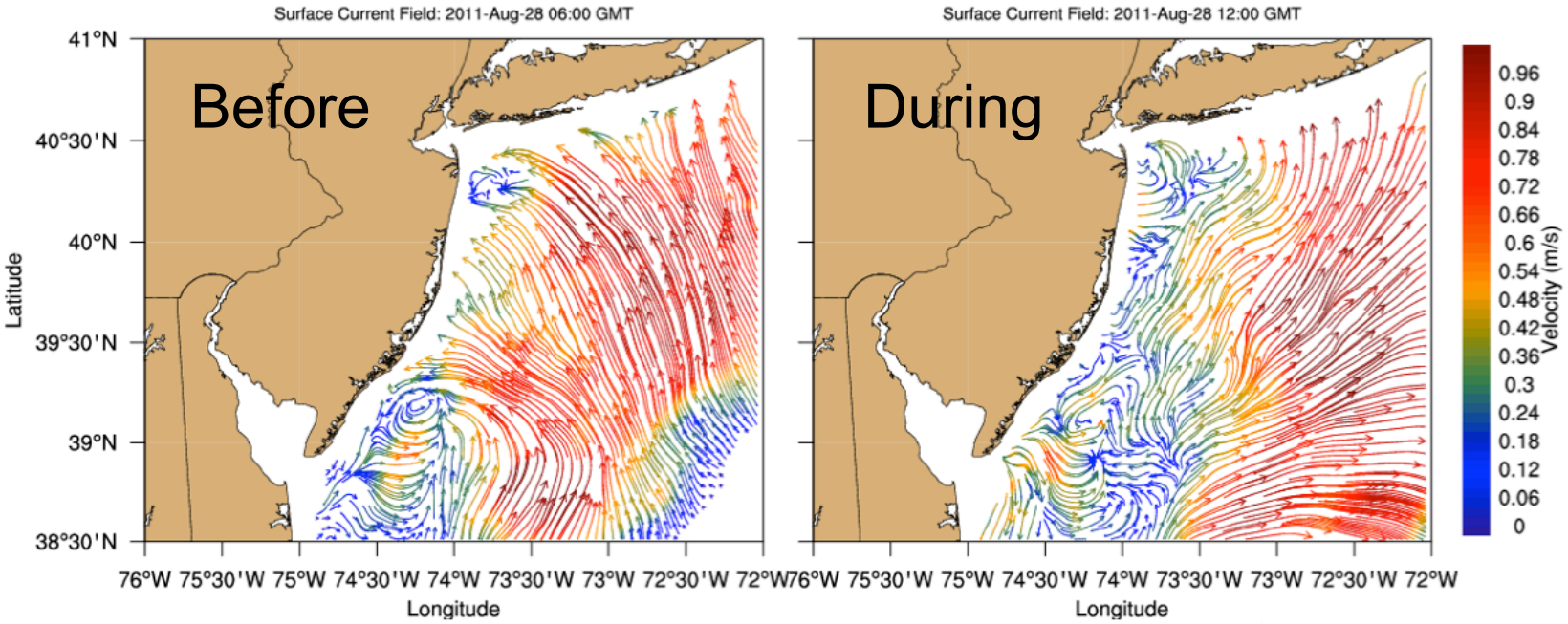
Glider RU16

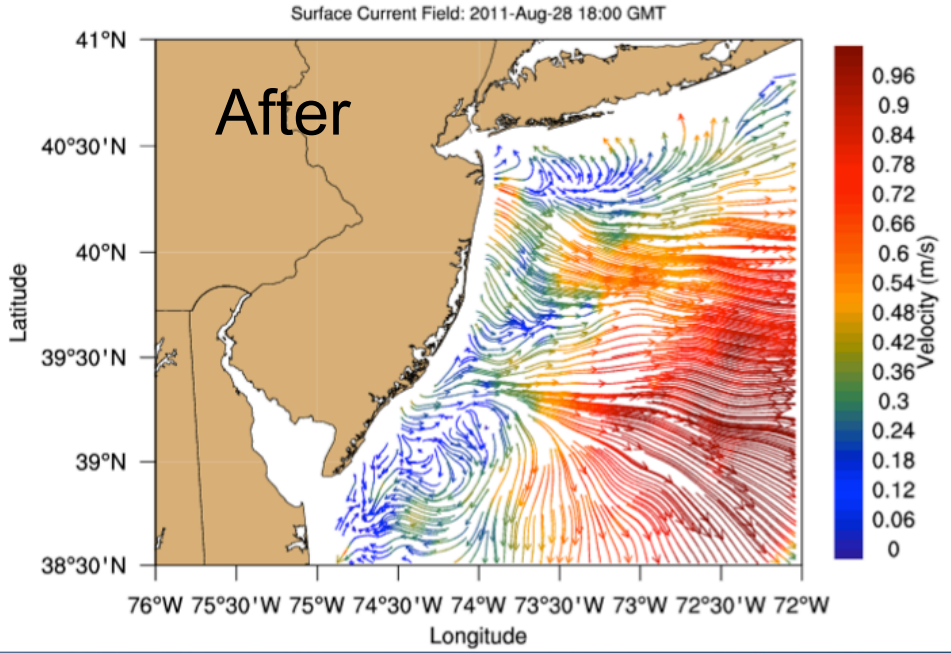




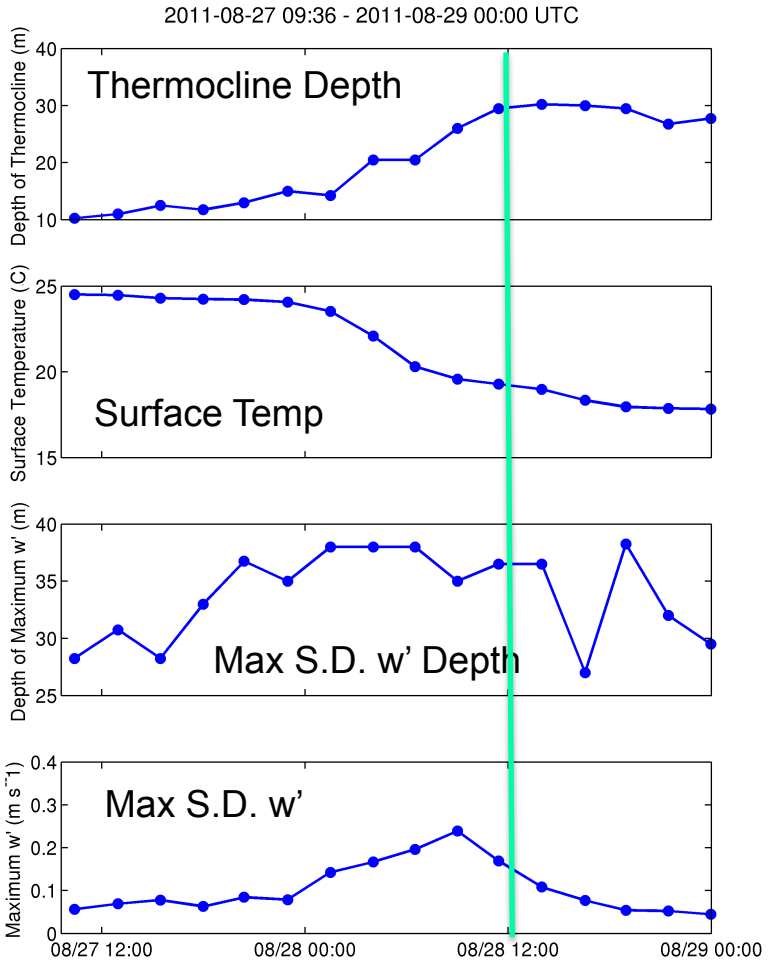


CODAR Surface Currents Near the Eye of Irene

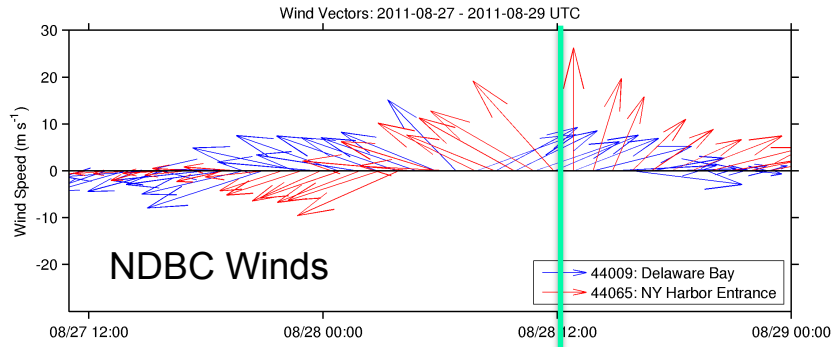


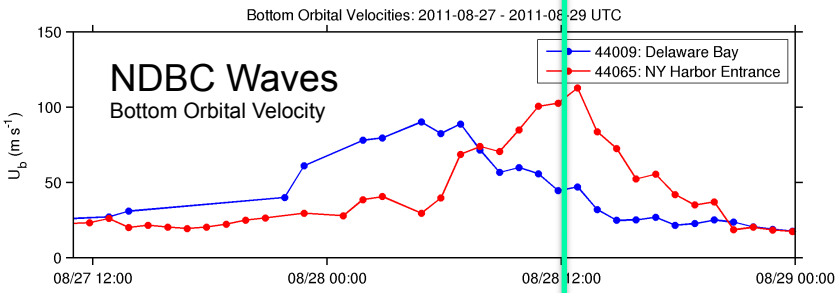


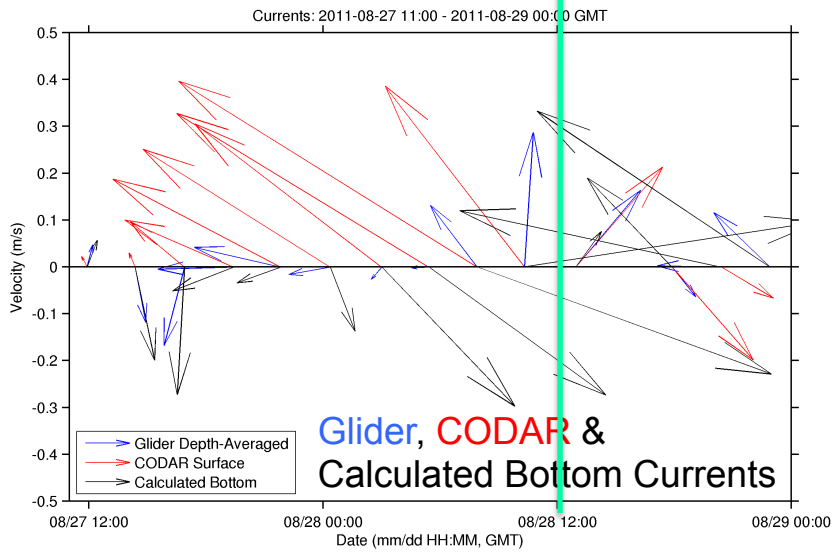
MARACOOS Network Observations:
Hurricane Irene



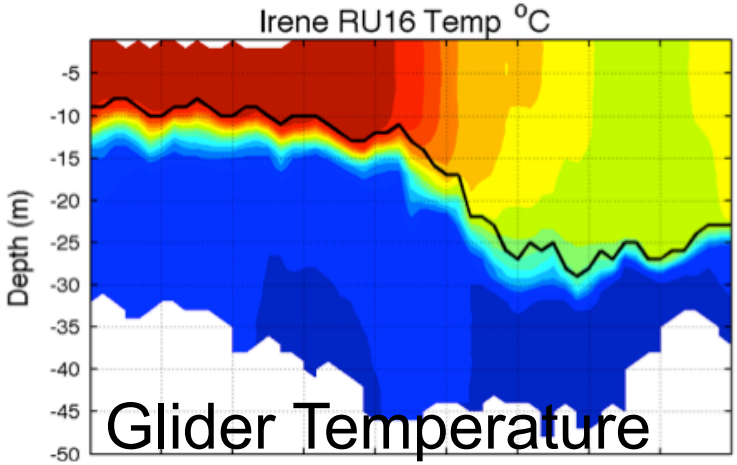
Glider RU16

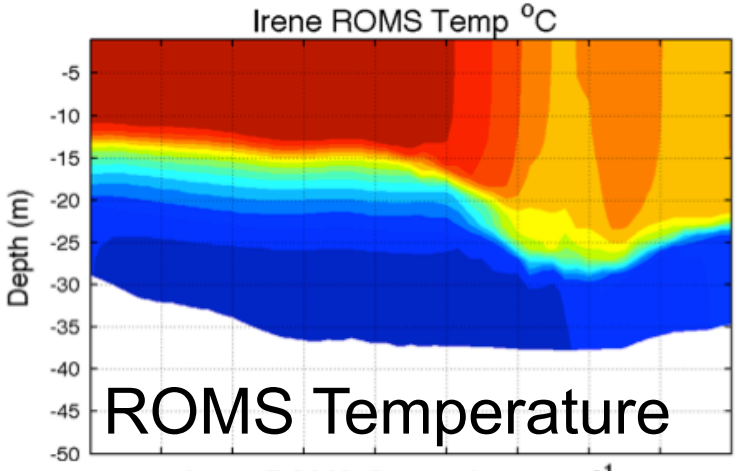


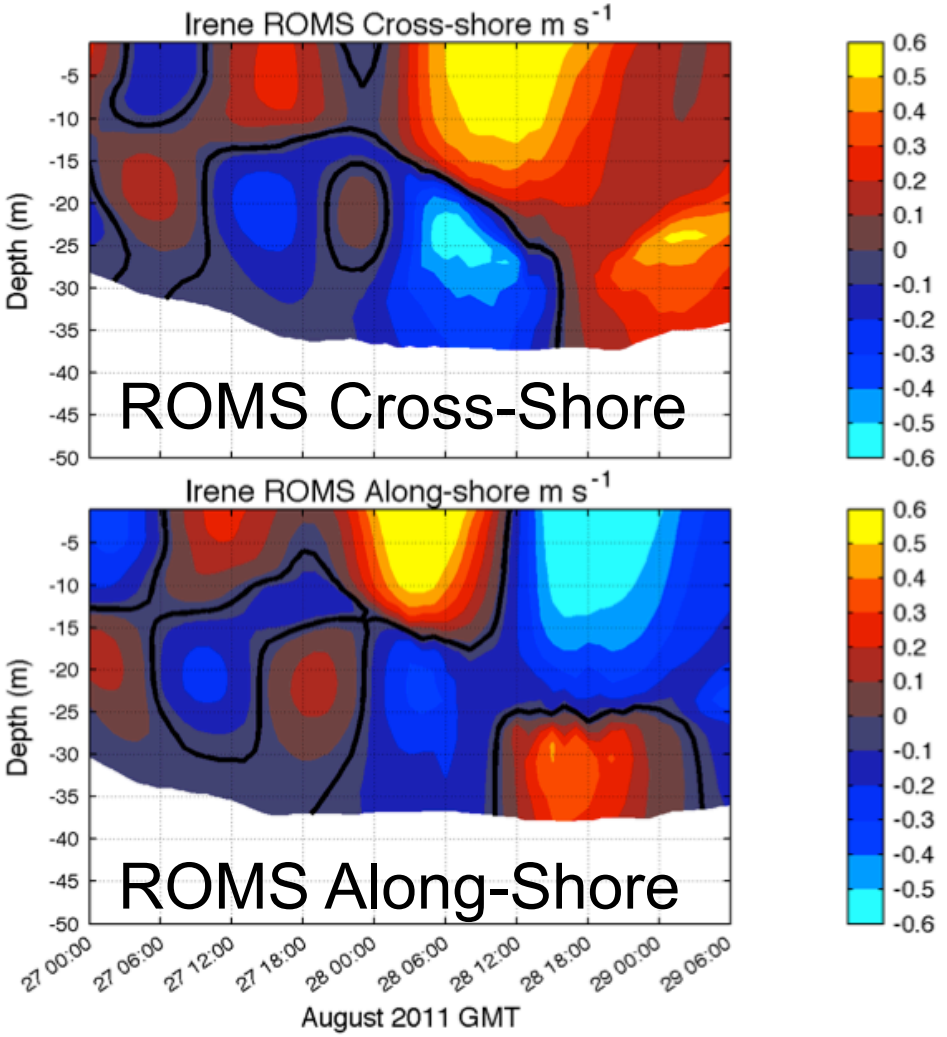




ROMS Model results for Hurricane Irene



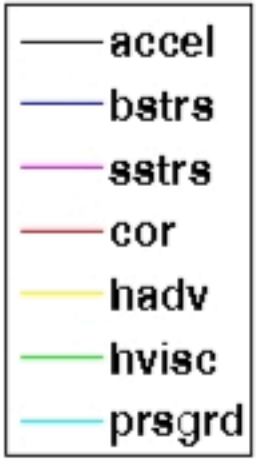


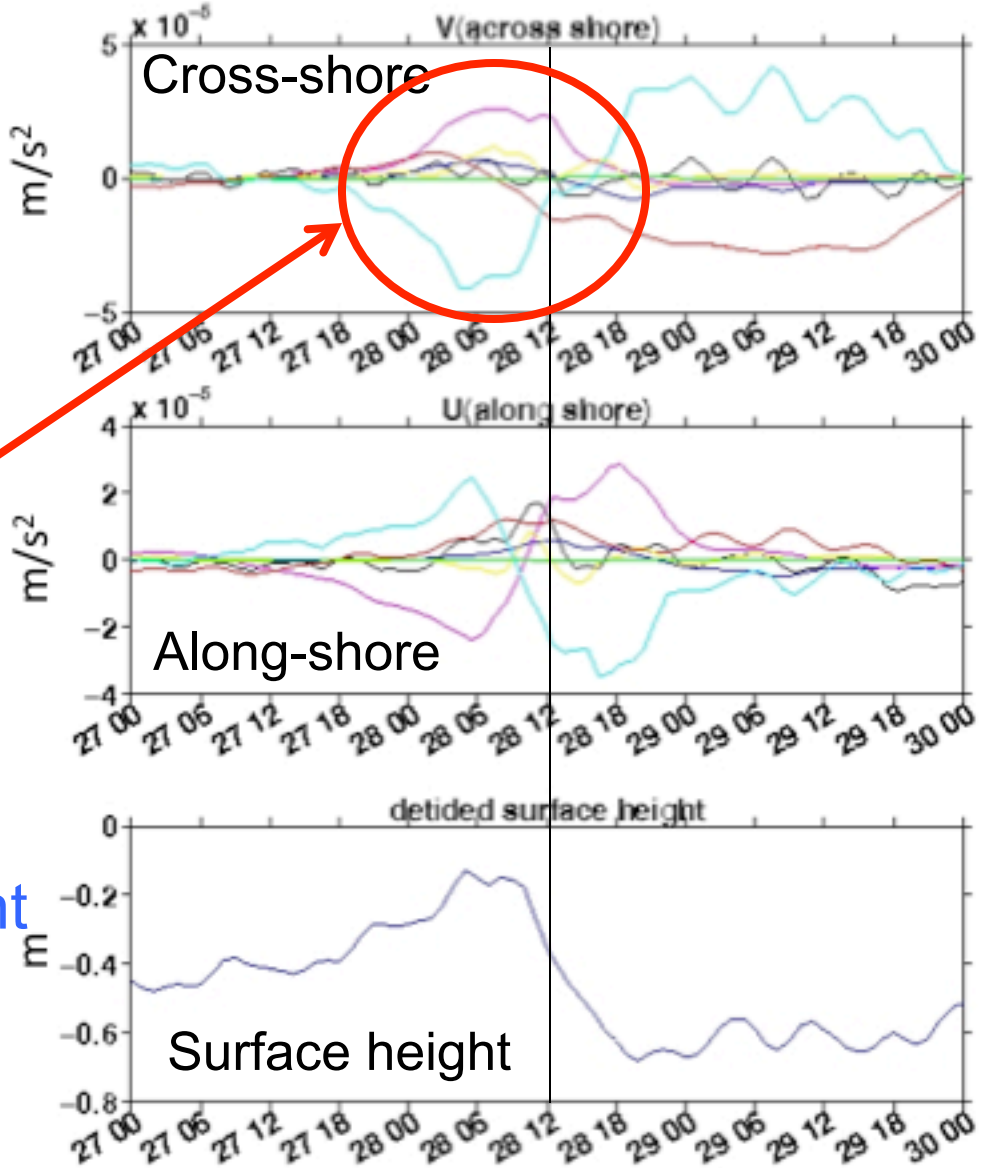


+ onshore, +north

ROMS Momentum Balance in Hurricane Irene

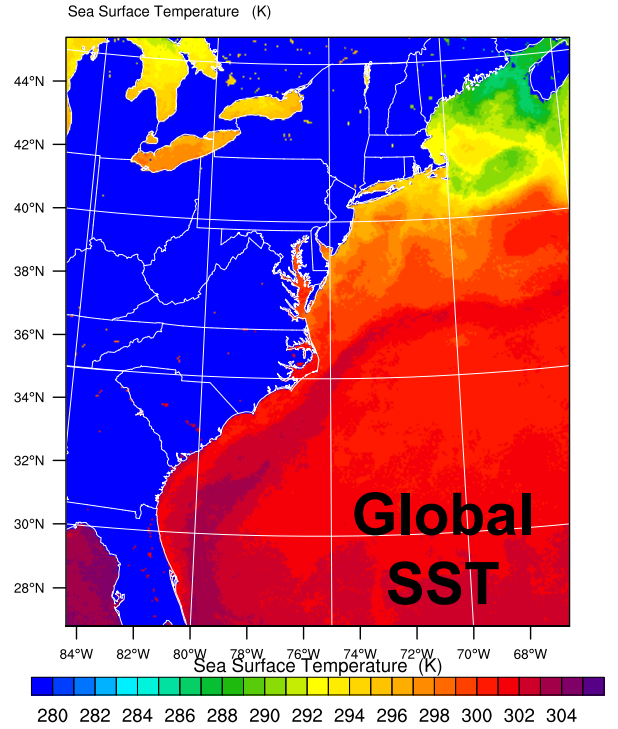
+ onshore, +north

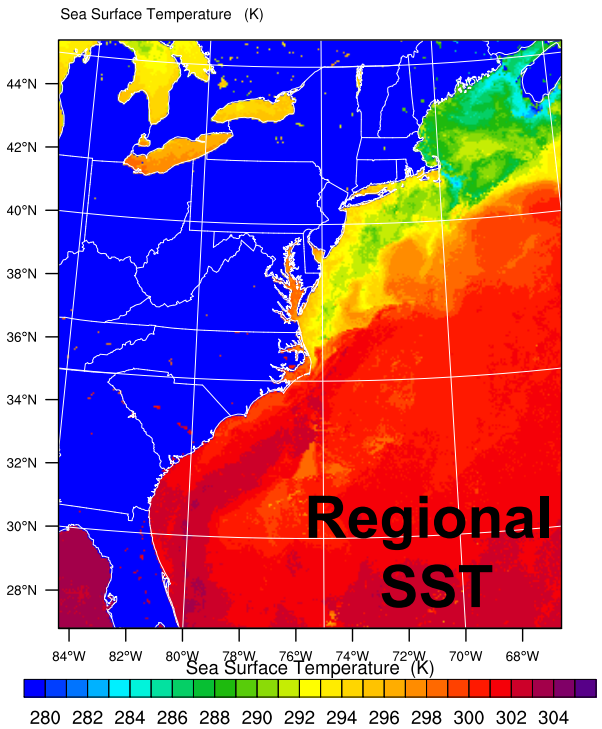


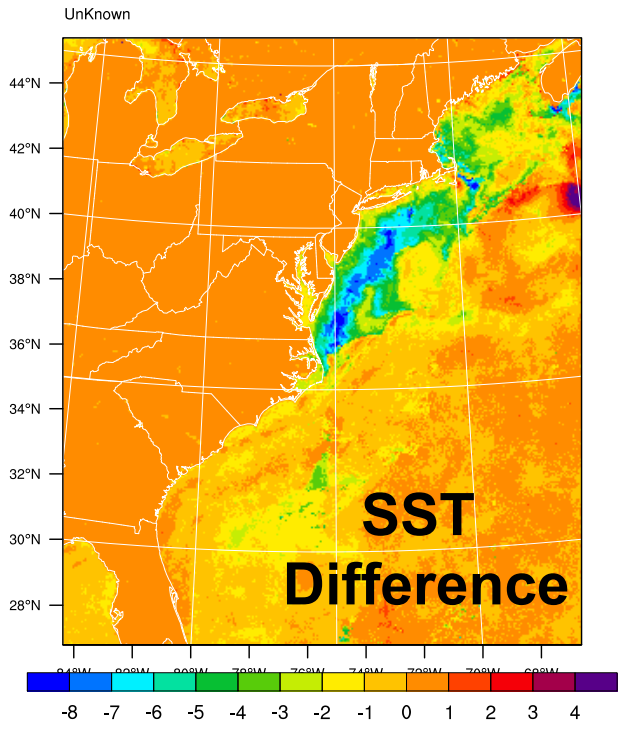


On-Shore Wind Stress
Persists longer than the
Off-shore Pressure Gradient

Post-Hurricane Irene Sea Surface Temperatures



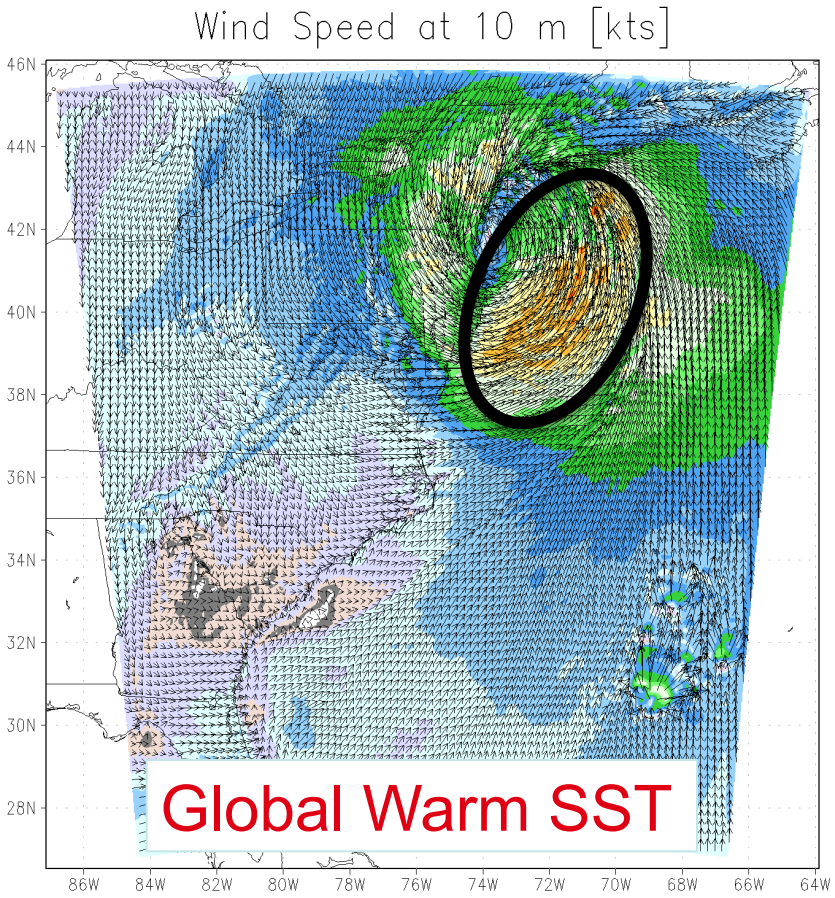


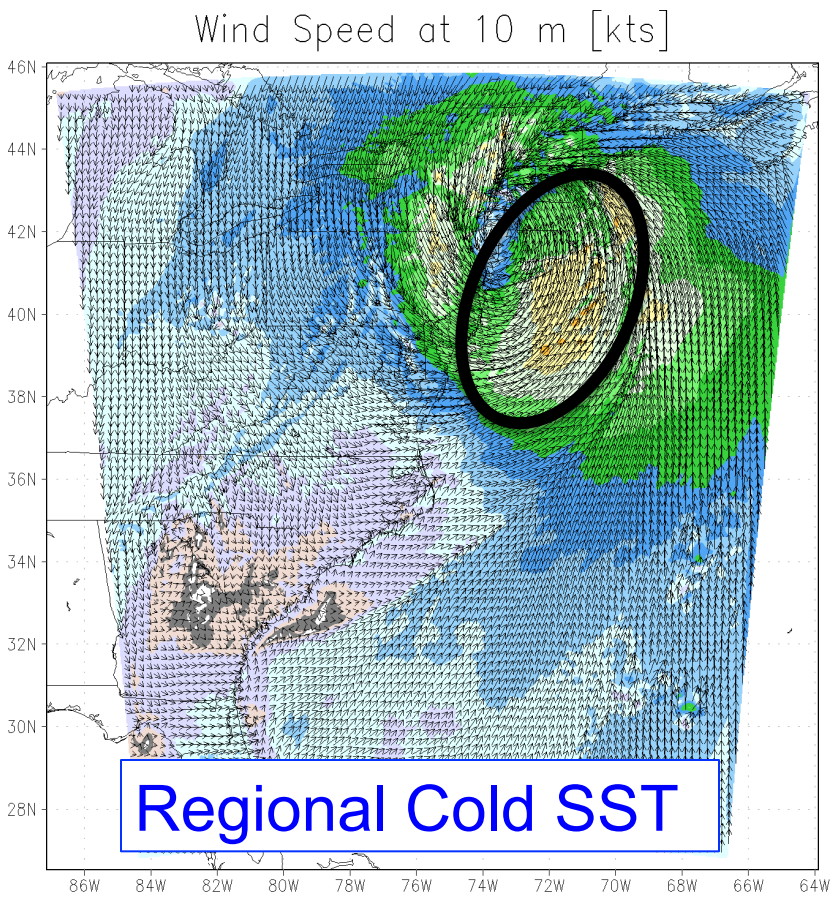


The 6C -10C Cooling occurred:

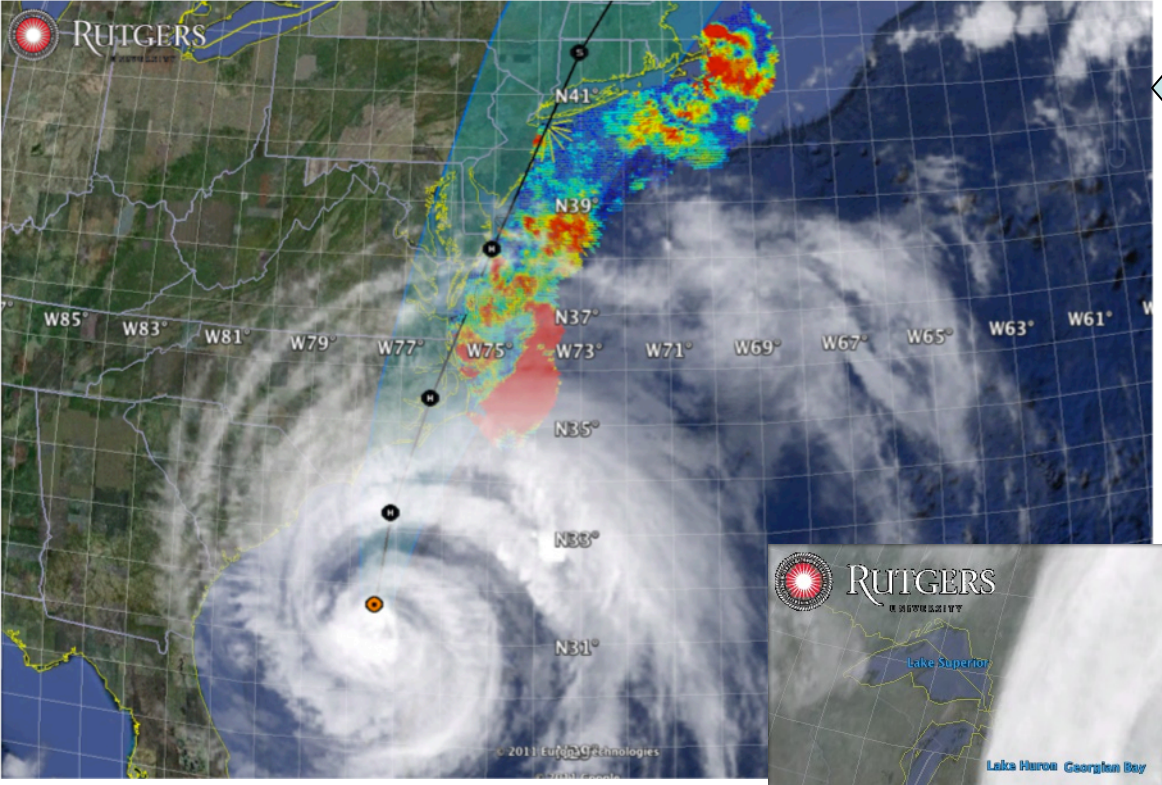
- With the outer wind bands
- Before the eye passed over

Hurricane Irene SST Sensitivity Hindcast





Maximum Wind Speed Skill Score	*Official Forecast*	*Warm SST Hindcast*	*Warm SST + OML Model Hindcast*	*Cold SST Hindcast*
RMS Error (knots)	9.43	7.13	7.09	3.61



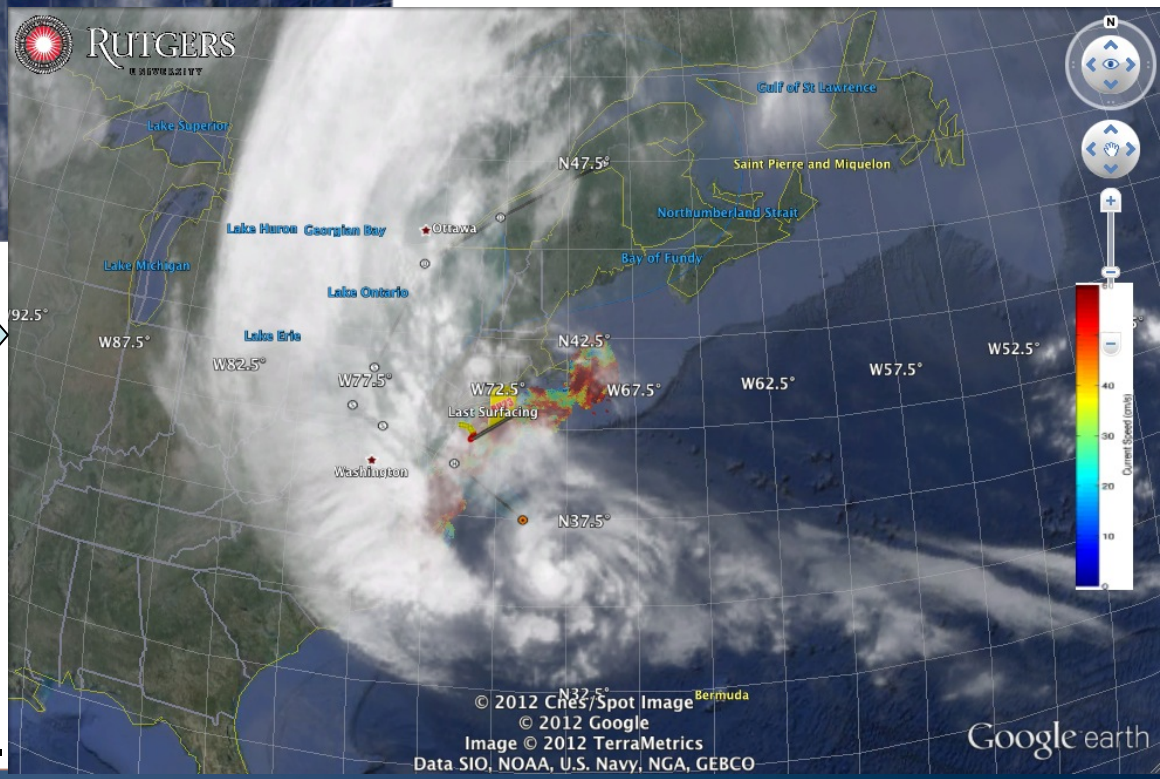
Hurricane Irene
August 26, 2011

- Strong Stratification
- Limited storm surge
- Mixing cooled surface
- Limited intensity

Hurricane Sandy
October 29, 2012

NOAA/NHC Damage:
#2 with >$60 Billion.

Track Accurate;
Intensity Under-predicted.



First Warning for Hurricane Sandy: Monday, Oct 22, 1-week prior to landfall

-------- Original Message --------
Subject: Re: [hfip-telecon] Telecon this week
Date: Mon, 22 Oct 2012 15:18:18 -0400
From: Louis Bowers <bowers@marine.rutgers.edu>
To: Scott Glenn <glenn@marine.rutgers.edu>
CC:

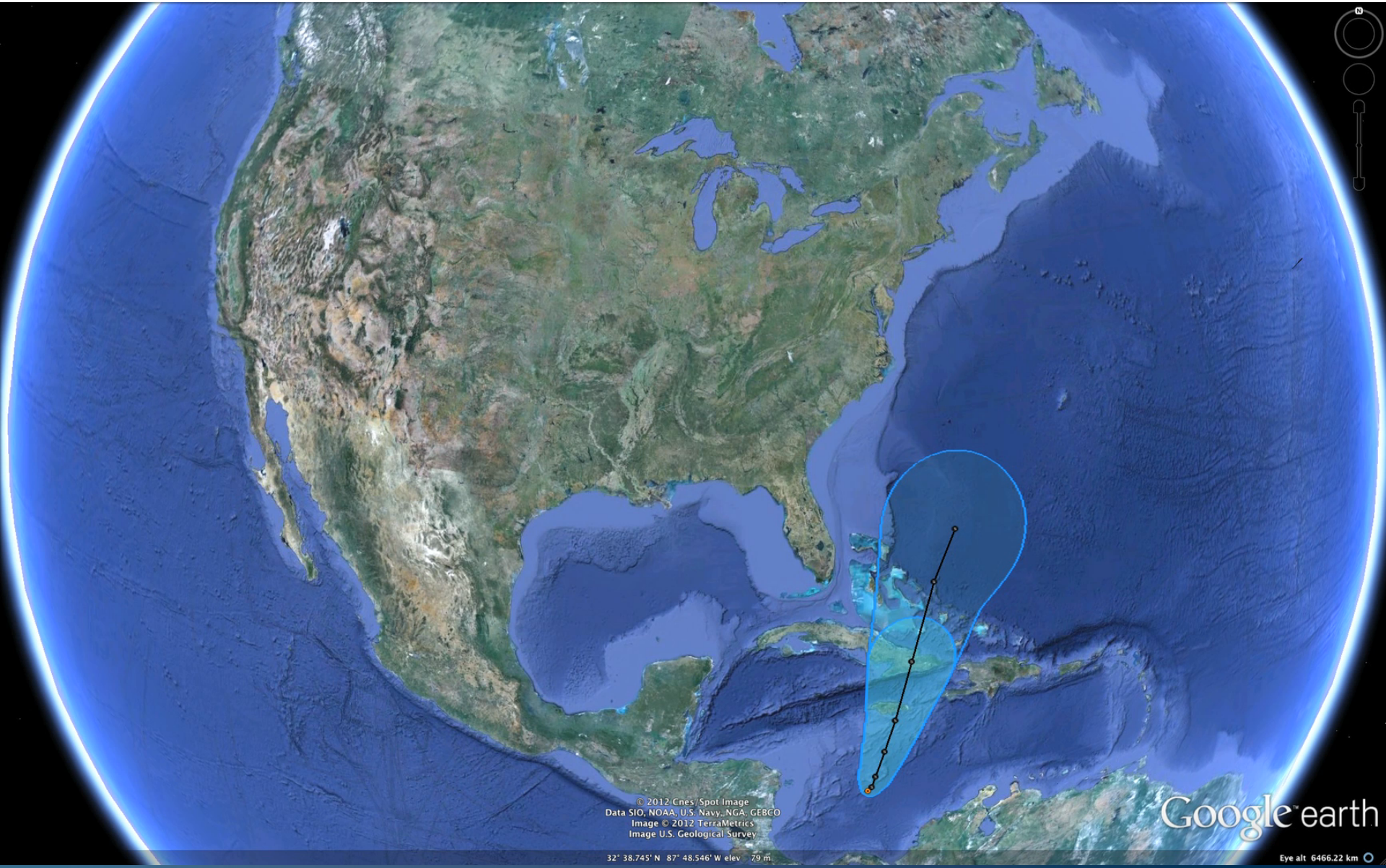
If you take the medium range models at face value, 30th thru 1st, historic storm, starting from to-be Sandy. Winds hurricane force, 6" + of rain, extreme coastal flooding. Or, it could miss completely.

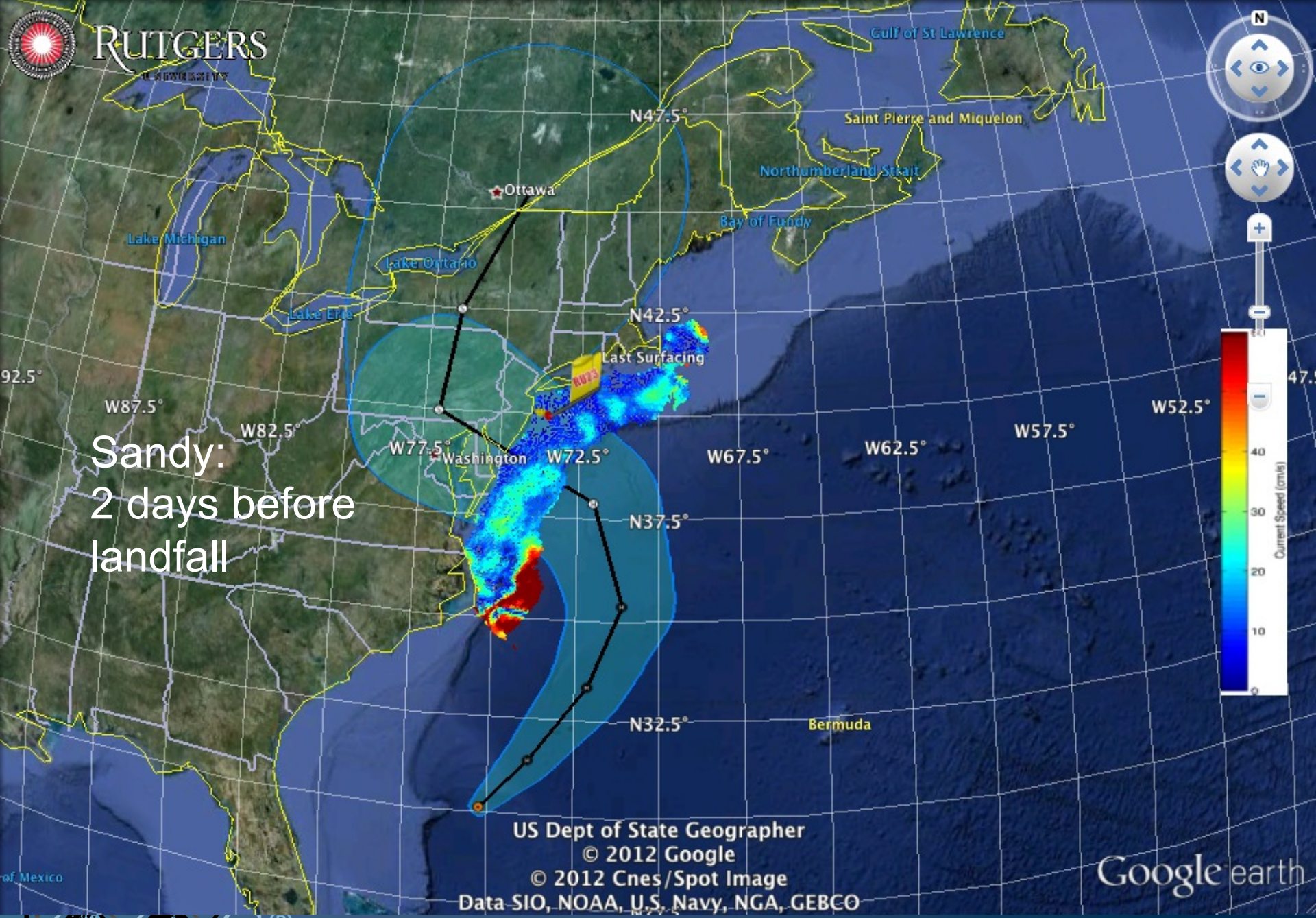
Louis Bowers
Sent from my iPhone

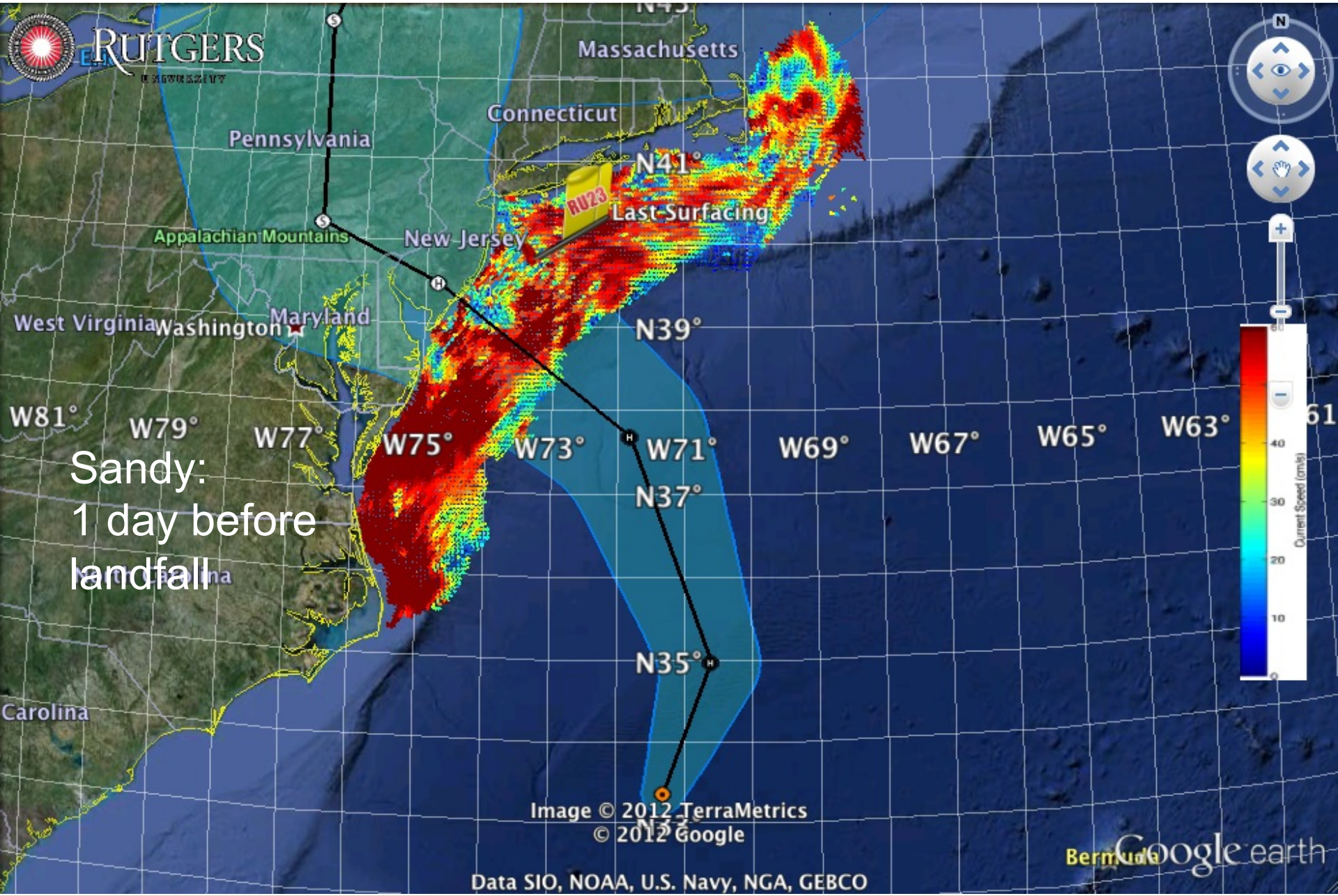
On Oct 22, 2012, at 3:11 PM, Scott Glenn <glenn@marine.rutgers.edu> wrote:

> Big storm coming.
> Sent from my iPhone
>
> On Oct 22, 2012, at 2:59 PM, Louis Bowers <bowers@marine.rutgers.edu> wrote:
>
> > Might get a chance to test out our forecasting early next week, could be a whopper of a coastal storm.
> >
> > Louis Bowers
> > Sent from my iPhone

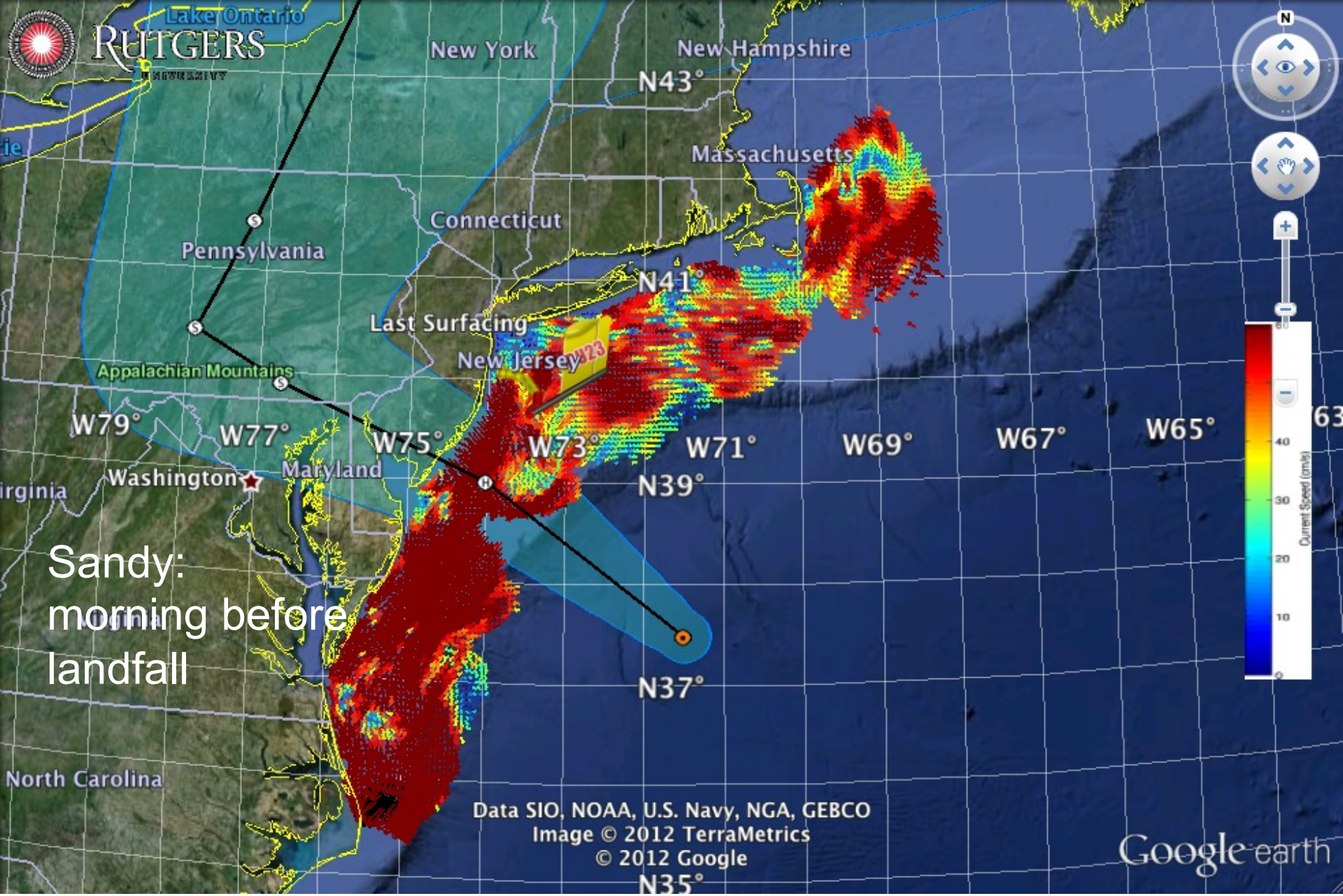
Hurricane Sandy: 5 Day Track Uncertainty Cone

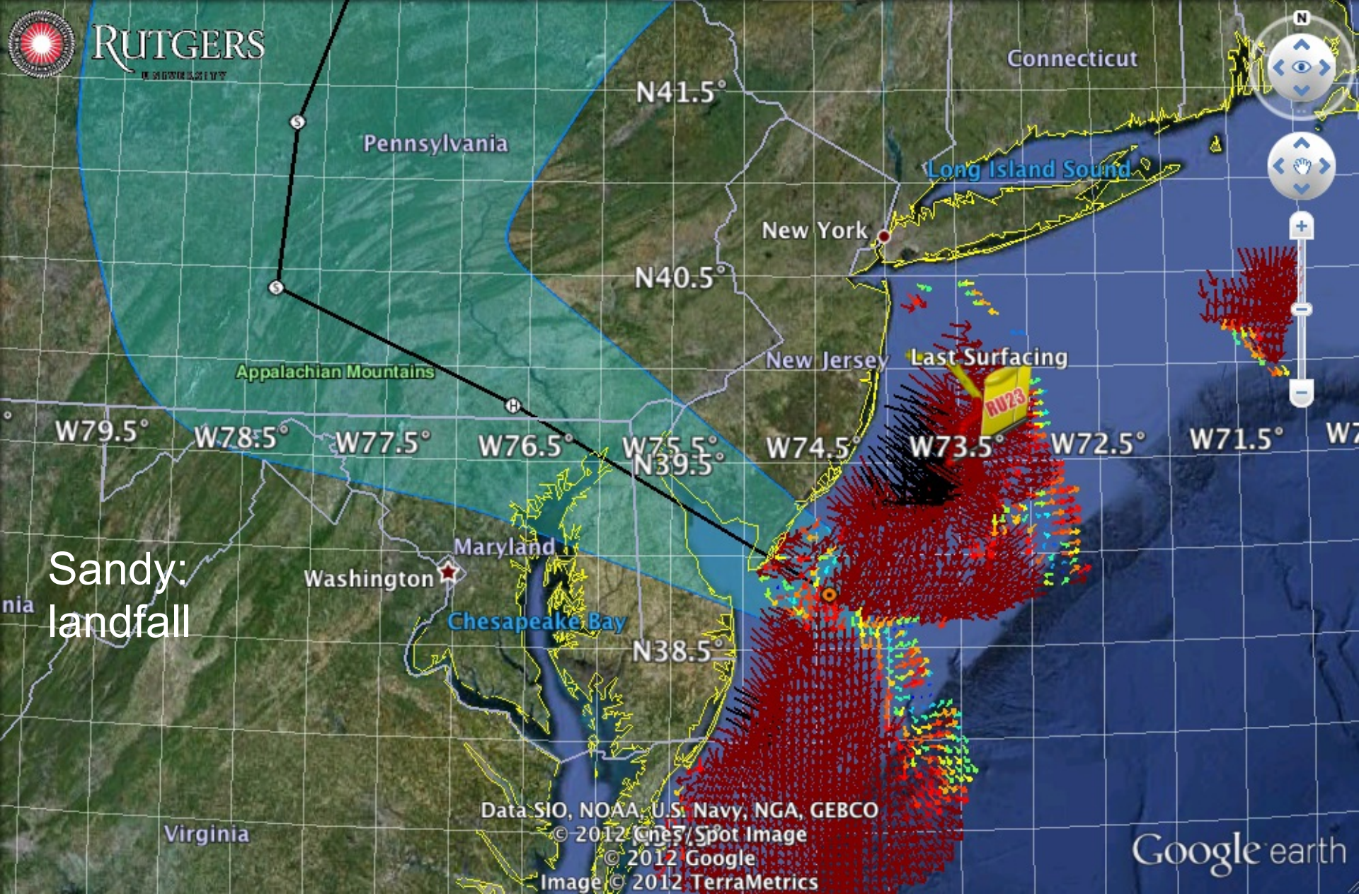



RUTGERS
Gulf of St Lawrence
Saint Pierre and Miquelon
Northumberland Strait
Bay of Fundy
Ottawa
Lake Michigan
Lake Ontario
Lake Erie
N47.5°
N42.5°
N37.5°
N32.5°
W87.5°
W82.5°
W77.5°
W72.5°
W67.5°
W62.5°
W57.5°
W52.5°
Washington
Last Surfacing
Bermuda
Sandy:
2 days before
landfall
Current Speed (cm/s)
40
30
20
10
0
US Dept of State Geographer
© 2012 Google
© 2012 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth


RUTGERS
UNIVERSITY
Massachusetts
Connecticut
Pennsylvania
N41°
RU23
Last Surfacing
Appalachian Mountains
New Jersey
West Virginia
Washington
Maryland
N39°
W81°
W79°
W77°
W75°
W73°
W71°
W69°
W67°
W65°
W63°
N37°
Sandy:
1 day before
landfall
N35°
Carolina
Image © 2012 TerraMetrics
© 2012 Google
Bermuda
Google earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Current Speed (m/s)
60
40
30
20
10
0

IOOS®


RUTGERS
Lake Ontario
New York
New Hampshire
N43°
Massachusetts
Connecticut
Pennsylvania
N41°
Last Surfacing
New Jersey
Appalachian Mountains
W79°
W77°
W75°
W73°
W71°
W69°
W67°
W65°
Washington
Maryland
N39°
Sandy:
morning before
landfall
N37°
North Carolina
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 TerraMetrics
© 2012 Google
N35°
Google earth
Current Speed (m/s)
0
10
20
30
40
50



Sandy: landfall

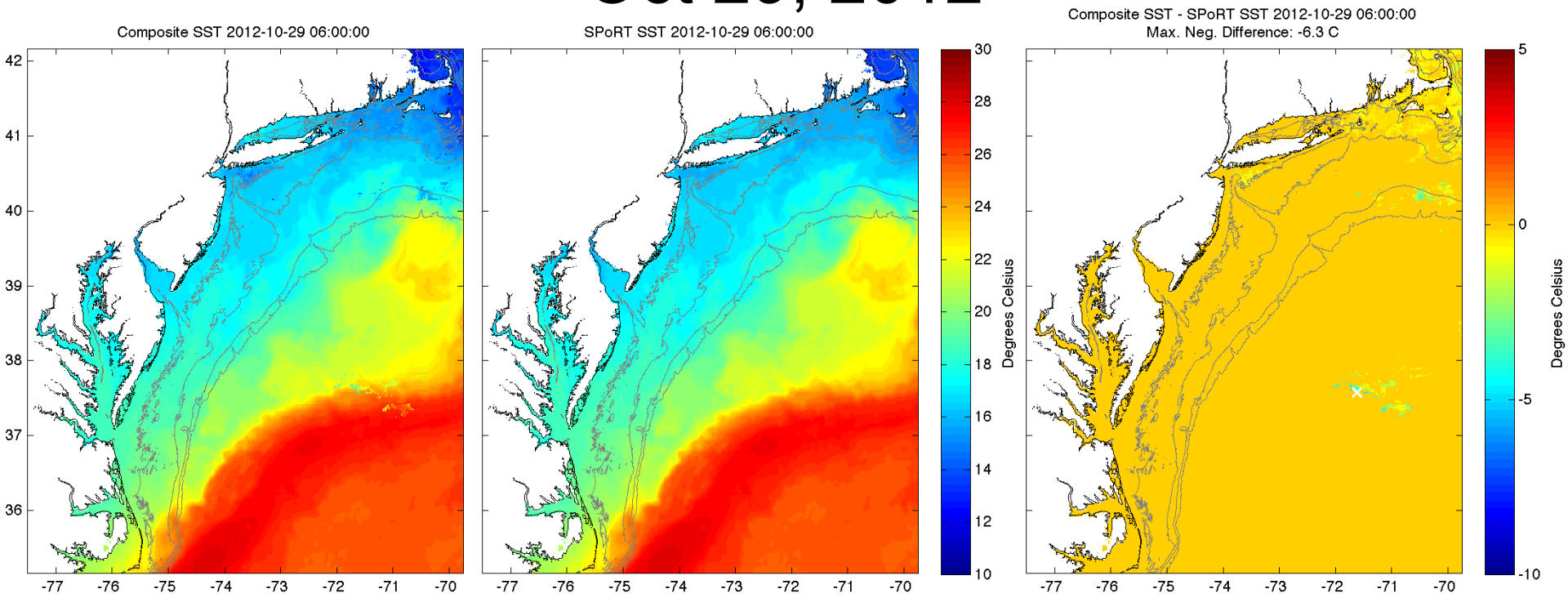
IOOS®

HF Radar Storm Damage

HF Radar Shed floats 0.85 km across barrier island & river

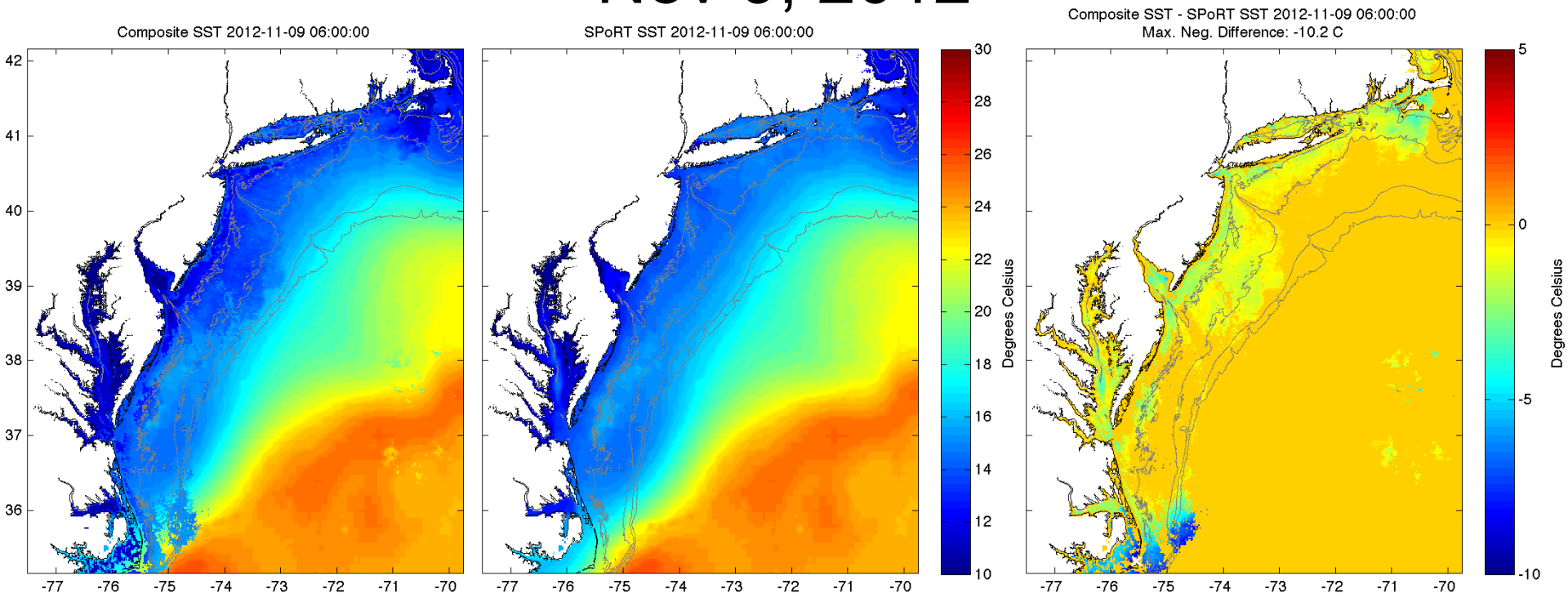
IOOS®

Sea Surface Temperature Products used for Atmospheric Forecasts Oct 29, 2012

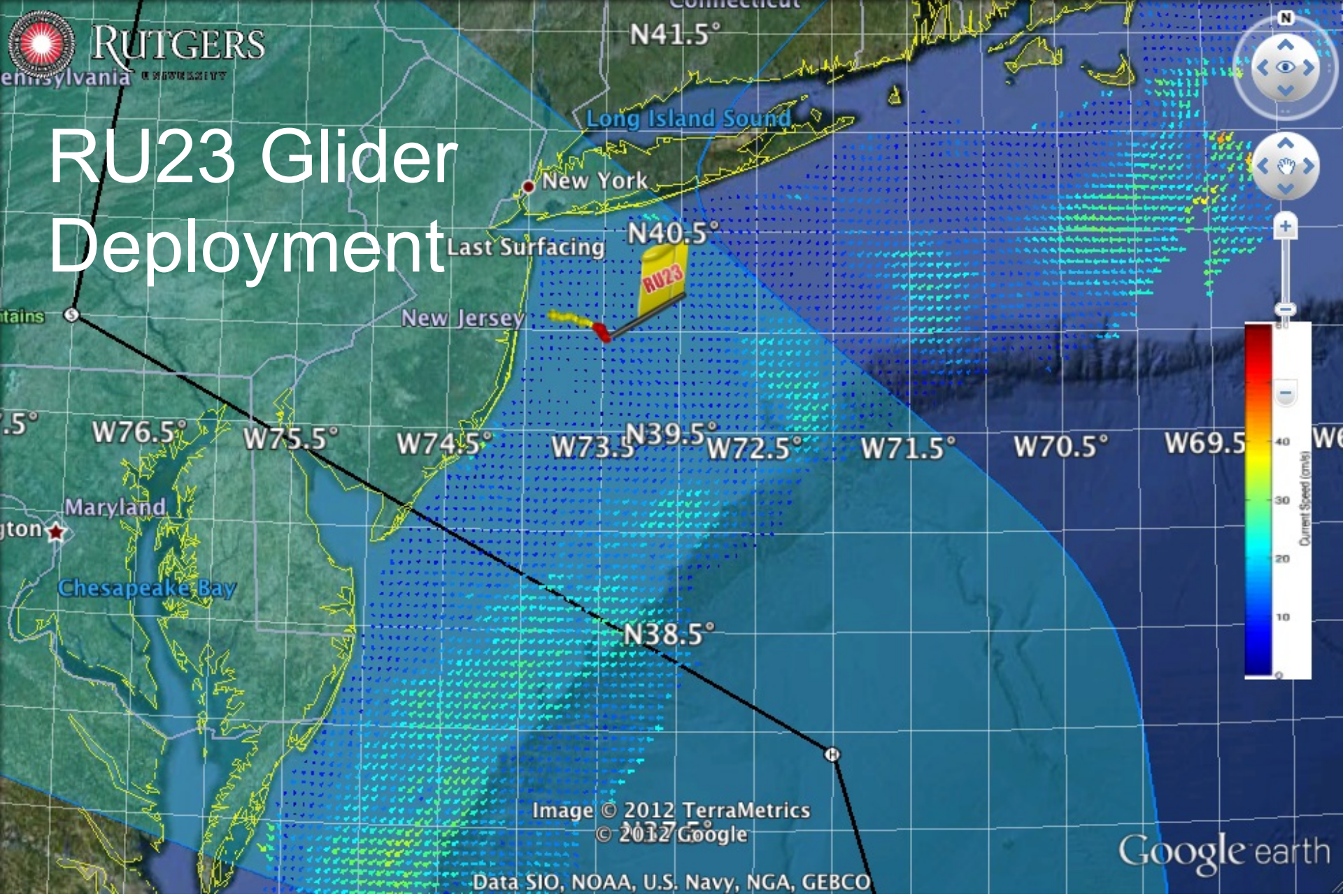


Regional Global Difference

Sea Surface Temperature Products used for Atmospheric Forecasts Nov 9, 2012

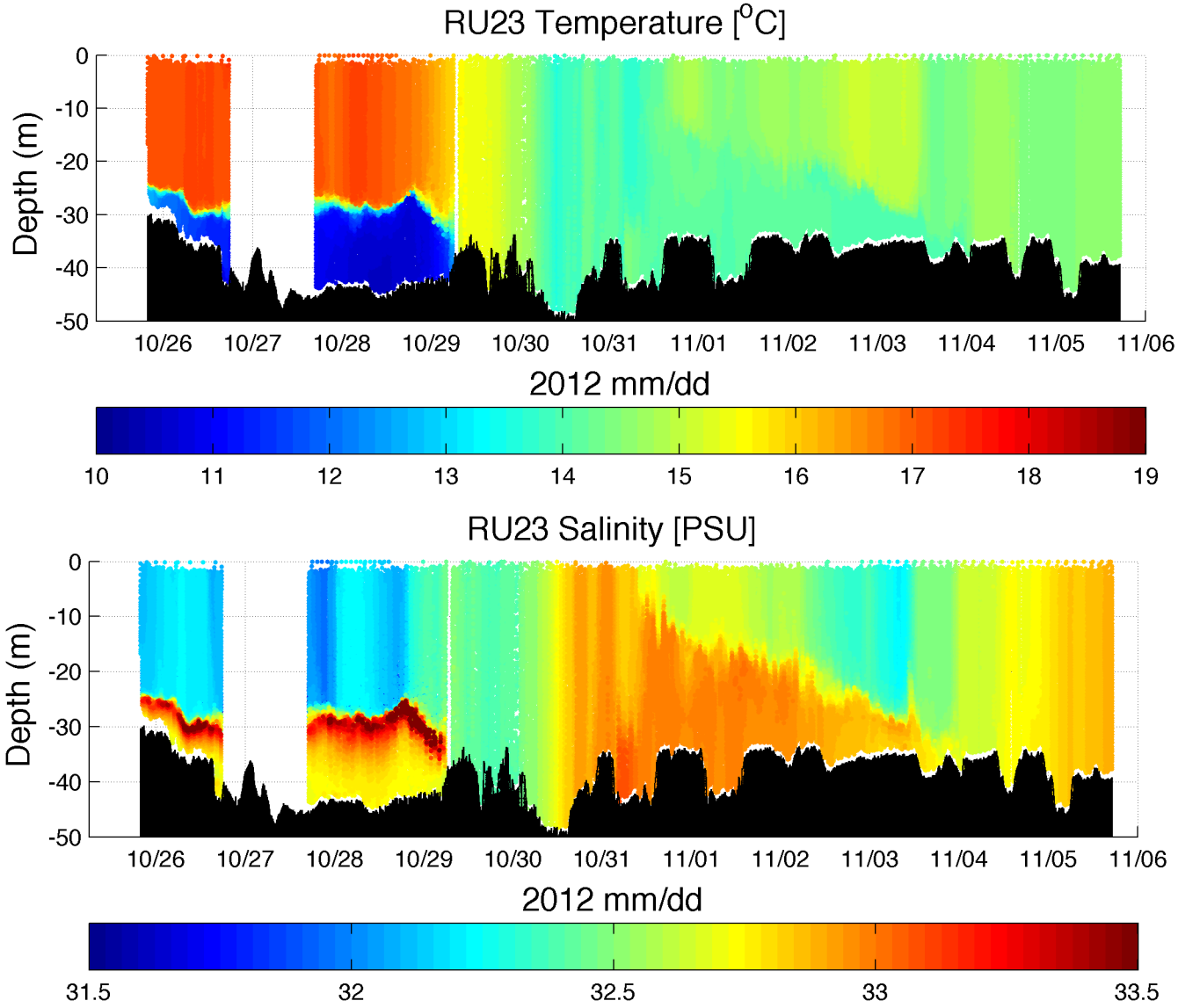


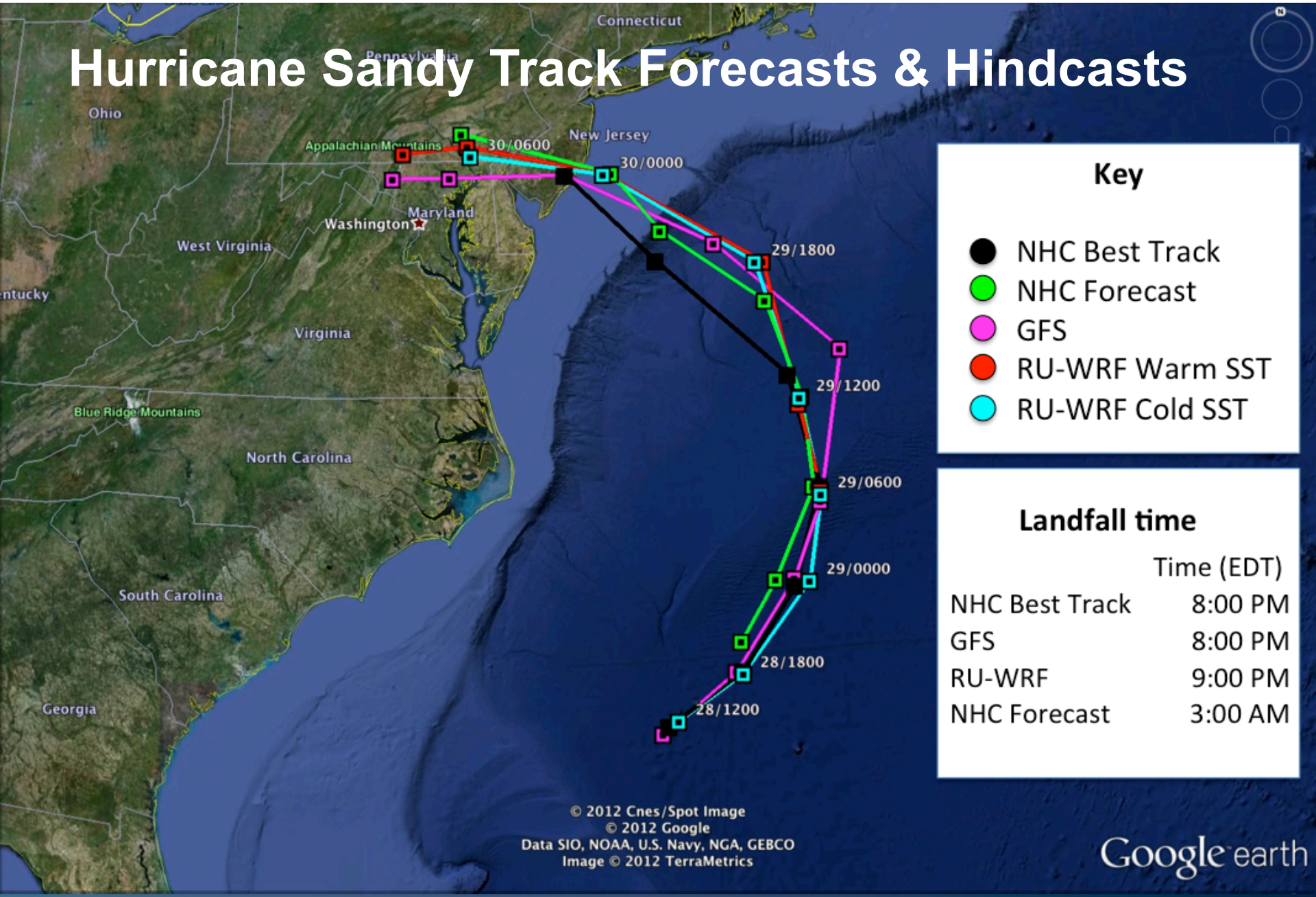
Regional Global Difference


RUTGERS
UNIVERSITY
RU23 Glider Deployment
N41.5°
Long Island Sound
New York
N40.5°
Last Surfacing
RU23
New Jersey
W76.5°
W75.5°
W74.5°
W73.5°
N39.5°
W72.5°
W71.5°
W70.5°
W69.5
Maryland
Chesapeake Bay
N38.5°
Current Speed (m/s)
Image © 2012 TerraMetrics
© 2012 Google
Google earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

IOOS®

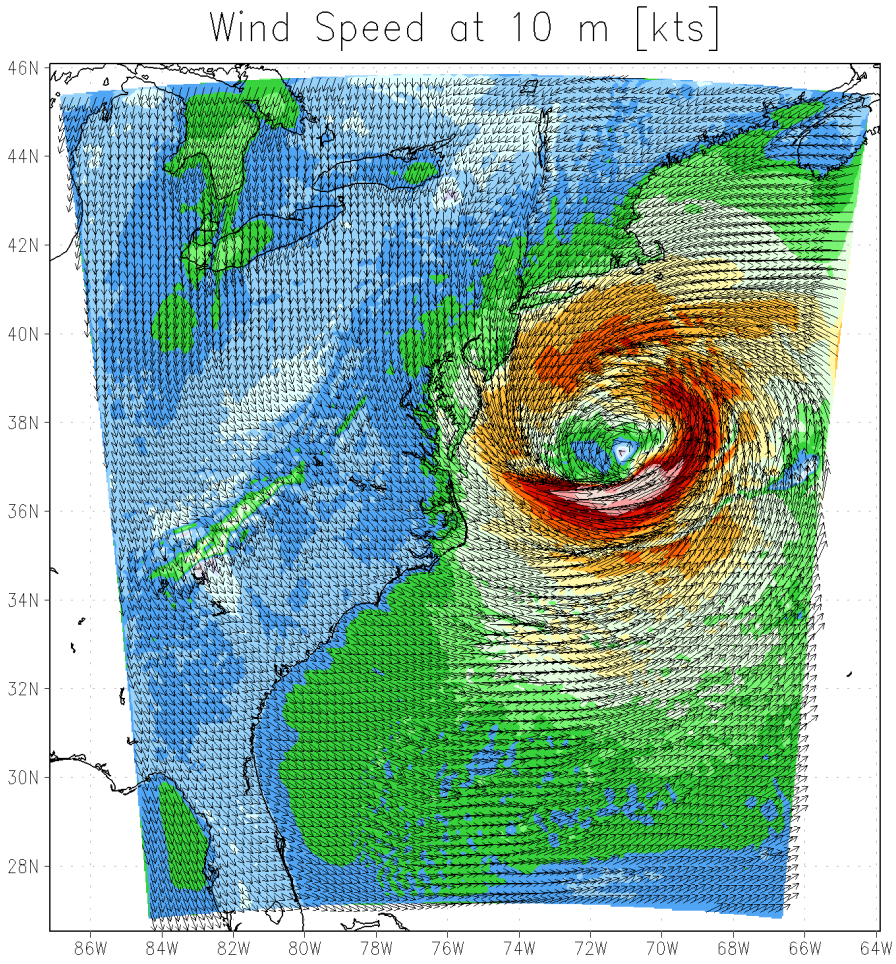
Glider RU23 Temperature and Salinity Section



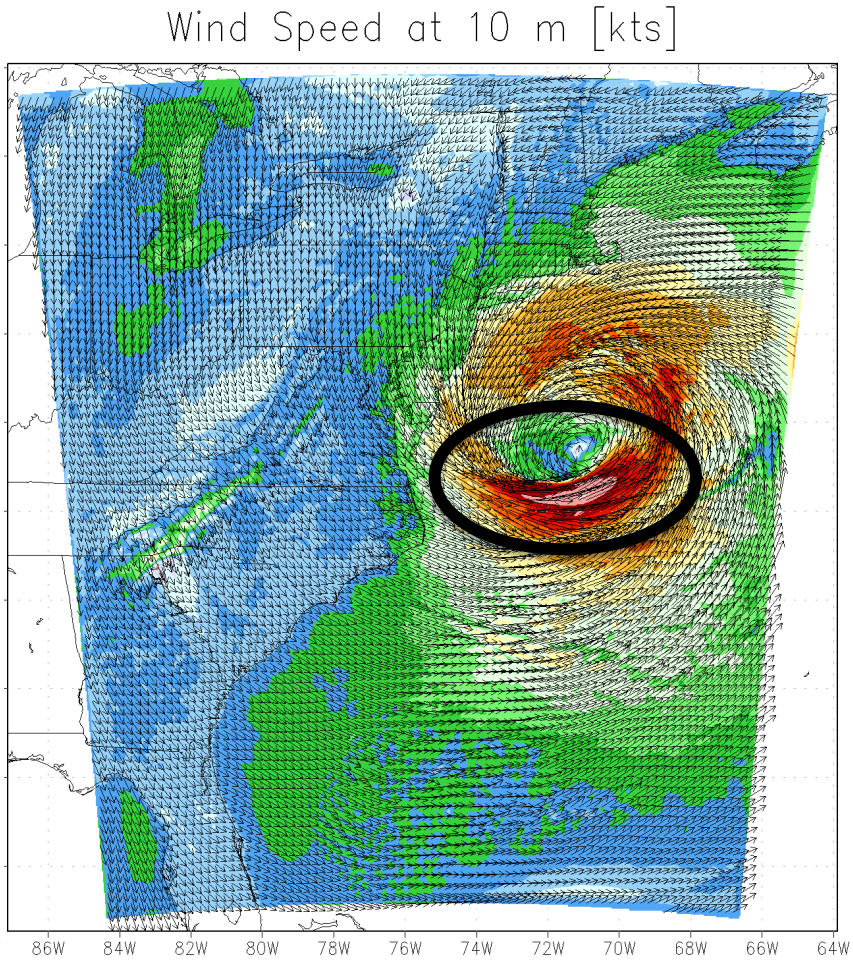

Hurricane Sandy Track Forecasts & Hindcasts
Connecticut
Ohio
New Jersey
Appalachian Mountains
30/0600
30/0000
Maryland
Washington
West Virginia
29/1800
Virginia
29/1200
Blue Ridge Mountains
North Carolina
29/0600
29/0000
South Carolina
28/1800
Georgia
28/1200
Key
NHC Best Track
NHC Forecast
GFS
RU-WRF Warm SST
RU-WRF Cold SST
Landfall time
Time (EDT)
NHC Best Track 8:00 PM
GFS 8:00 PM
RU-WRF 9:00 PM
NHC Forecast 3:00 AM
© 2012 Cnes/Spot Image
© 2012 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 TerraMetrics
Google earth

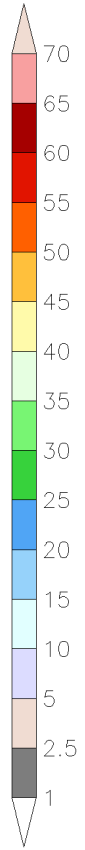
Hurricane Sandy Hindcast: SST Sensitivity

Warm SST

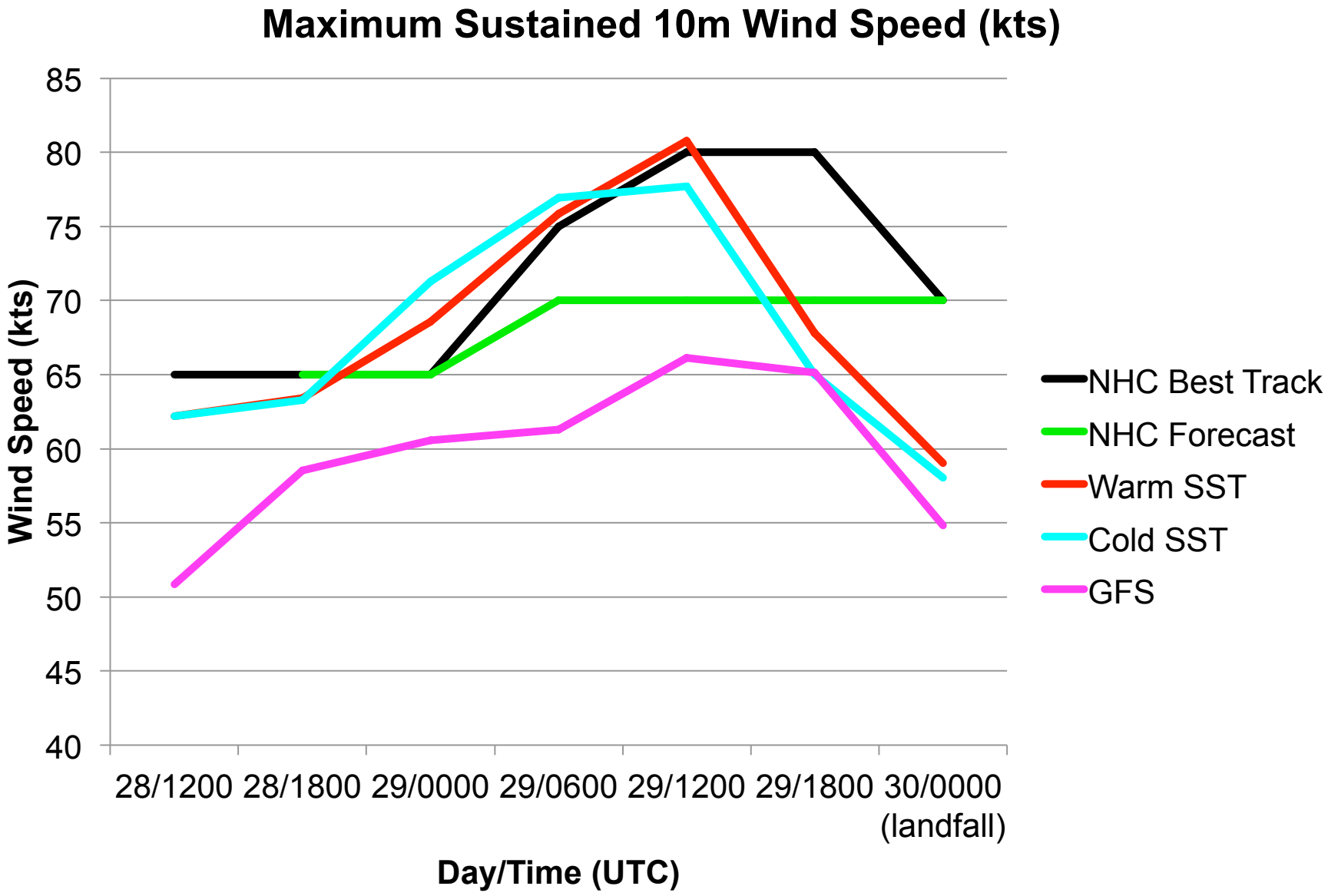


Cold SST

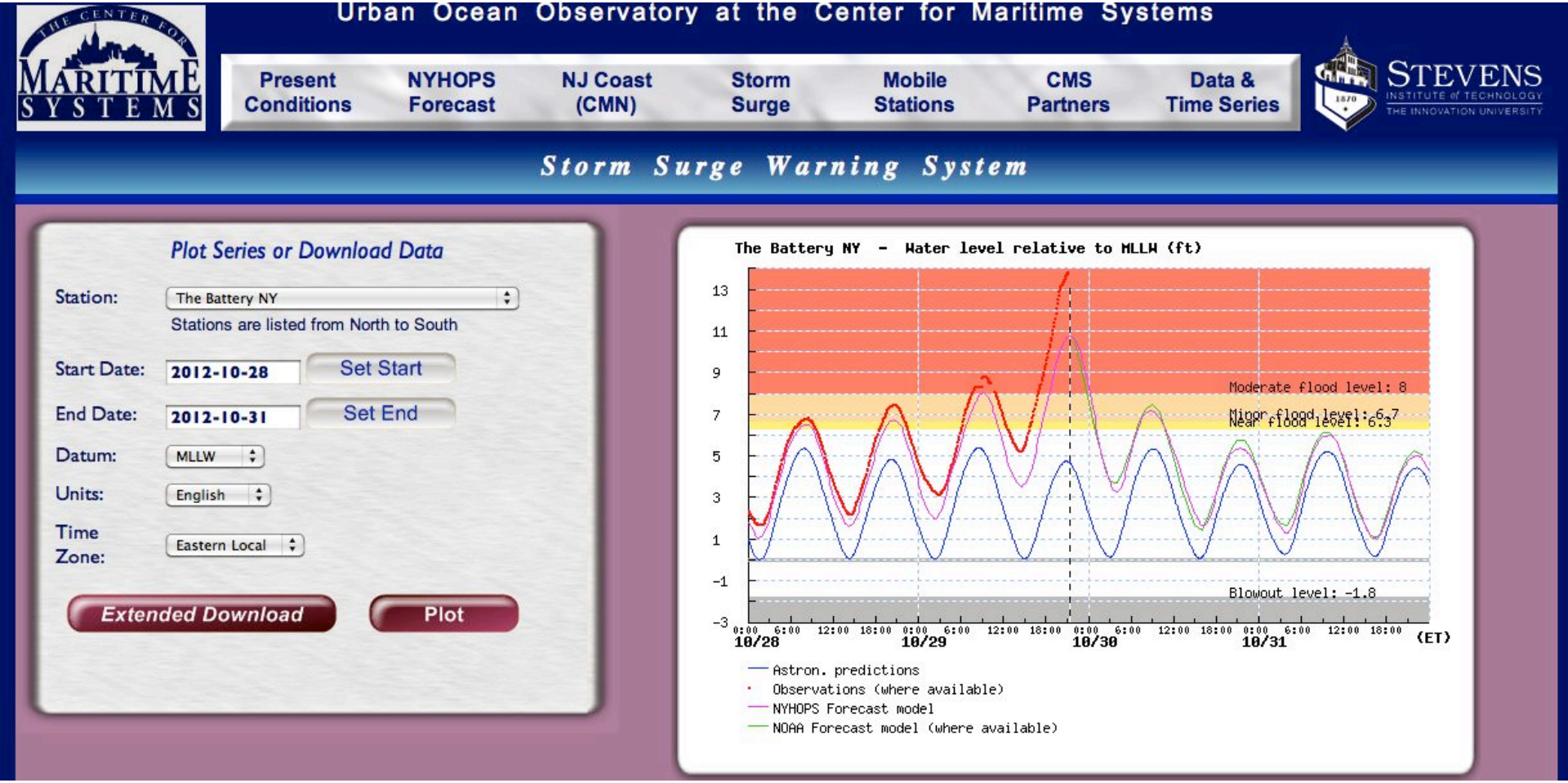


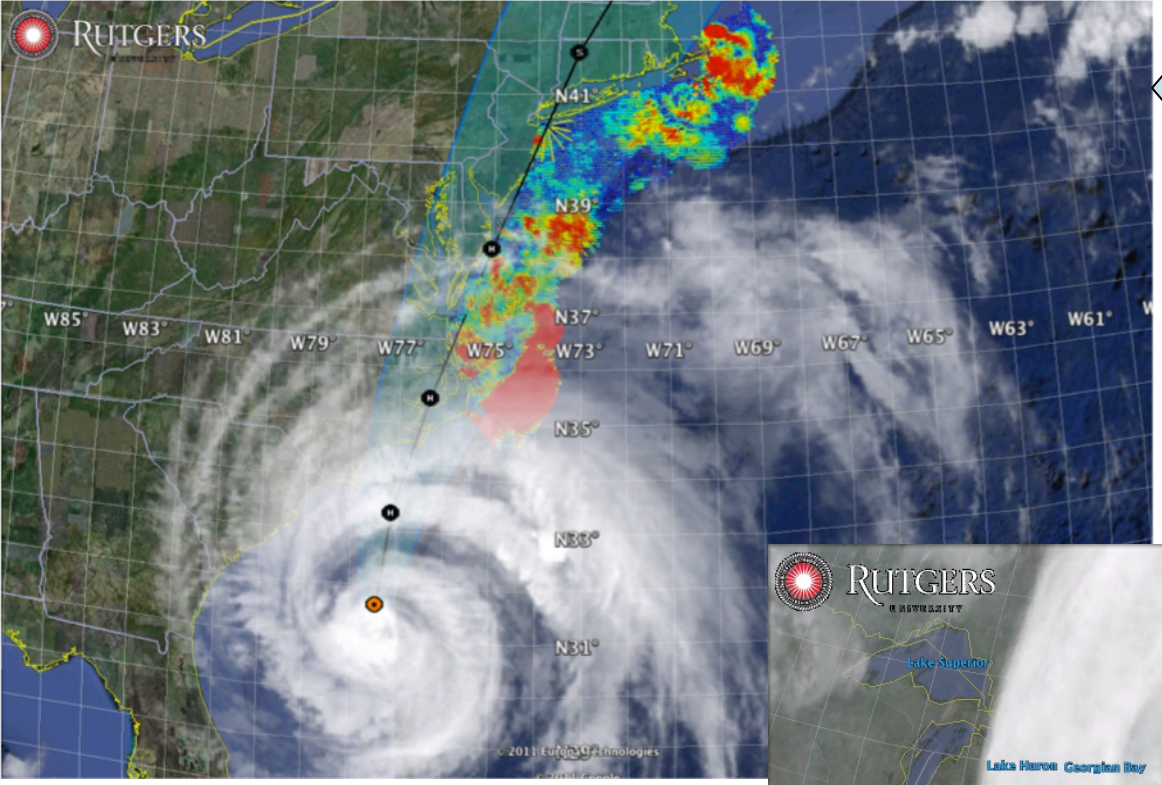


Hurricane Sandy Hindcast: Intensity



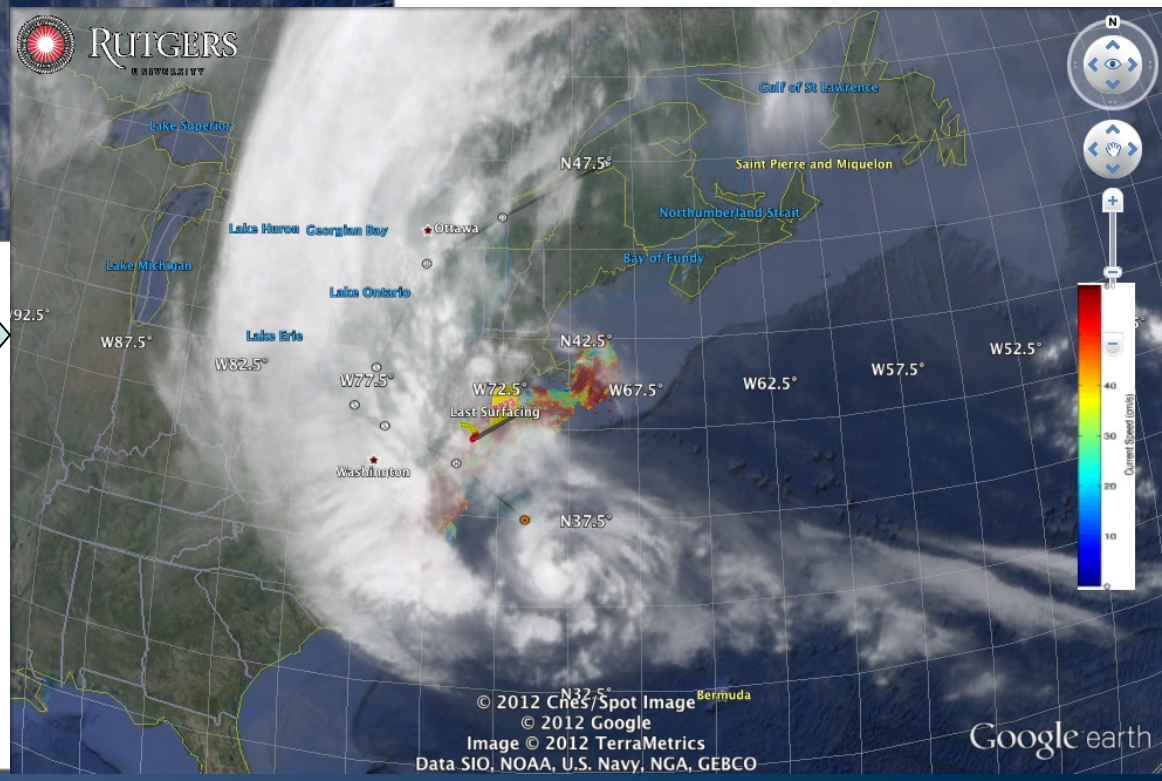
Storm Surge Forecast at Peak





Hurricane Irene
August 26, 2011

- Strong Stratification
- Limited storm surge
- Mixing cooled surface
- Limited intensity



Hurricane Sandy
October 29, 2012

- After fall transition
- Single layer ocean
- No mixing/cooling
- No escape for surge

Response Summary:

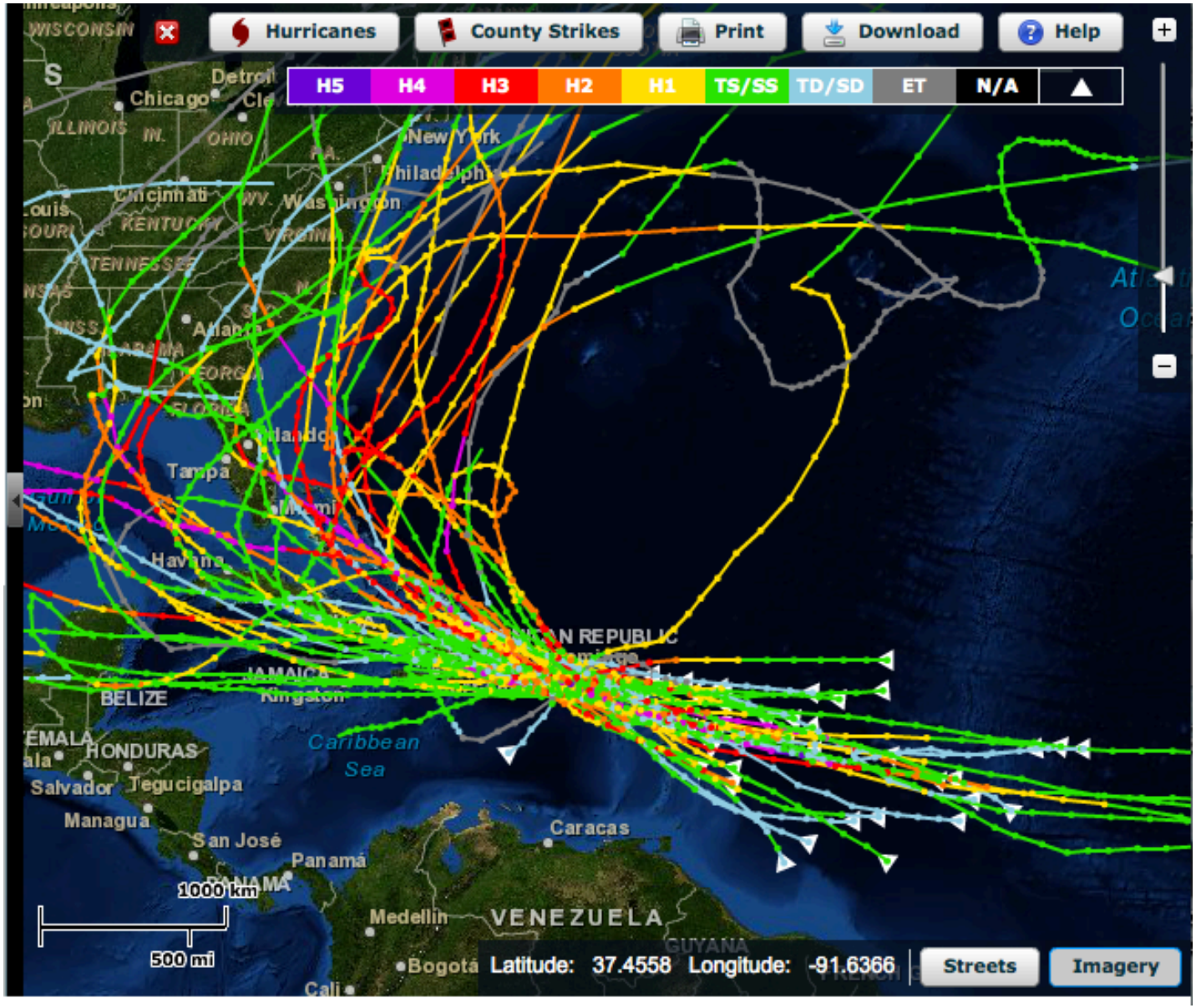
1) Sandy was a disruptive event.
2) IOOS was there before, during and after.
3) IOOS made a difference.

North Atlantic Storm Pathway:
Hurricane Intensity Forecast Improvement Initiative

5 regions: CARA, GCOOS, MARACOOS, NERACOOS, SECOORA

- *Filling gaps in operational hurricane monitoring, including the National Glider Network and Depth-Resolving Ocean Buoy Network*.
- *Upgrade coastal observing networks.*
- *The development of improved regional-scale ocean forecast models*.
- *A suite of complementary, coupled, real-time, ocean-atmosphere, forecast models.*

Historical Hurricane Tracks within 65 nm of Puerto Rico



Primary Approach: From East

U.S. Integrated Ocean Observing System
Caribbean Regional Association-CaRA

First CarICOOS Glider Deployment
Lajas, Puerto Rico - October 19, 2007

IOOS INTEGRATED OCEAN OBSERVING SYSTEM

CaRA Caribbean Regional Association

MACOORA Mid-Atlantic Coastal Ocean Observing Regional Association

U.S. DEPARTMENT OF ENERGY

PRM - Jorge Corredor & Julio Morell

Rutgers – Lee Kerkhof, Bob Chant, Hugh Roarty & Scott Glenn

MACOORA – Dave Chapman

HFR emplacements on the Mona Passage

CLUB DEPORTIVO DEL OESTE, INC

Estado Libre Asociado de Puerto Rico
Policía de Puerto Rico

Supported by CSR & CariCOOS

CARIBBEAN COASTAL OCEAN OBSERVING SYSTEM
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AND MORE...

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IOOS®

Mona Bistatic Experiment
November 7-9 2012

Field logistics, computational and communications support provided by CariCOOS, UPRM and RU COOL