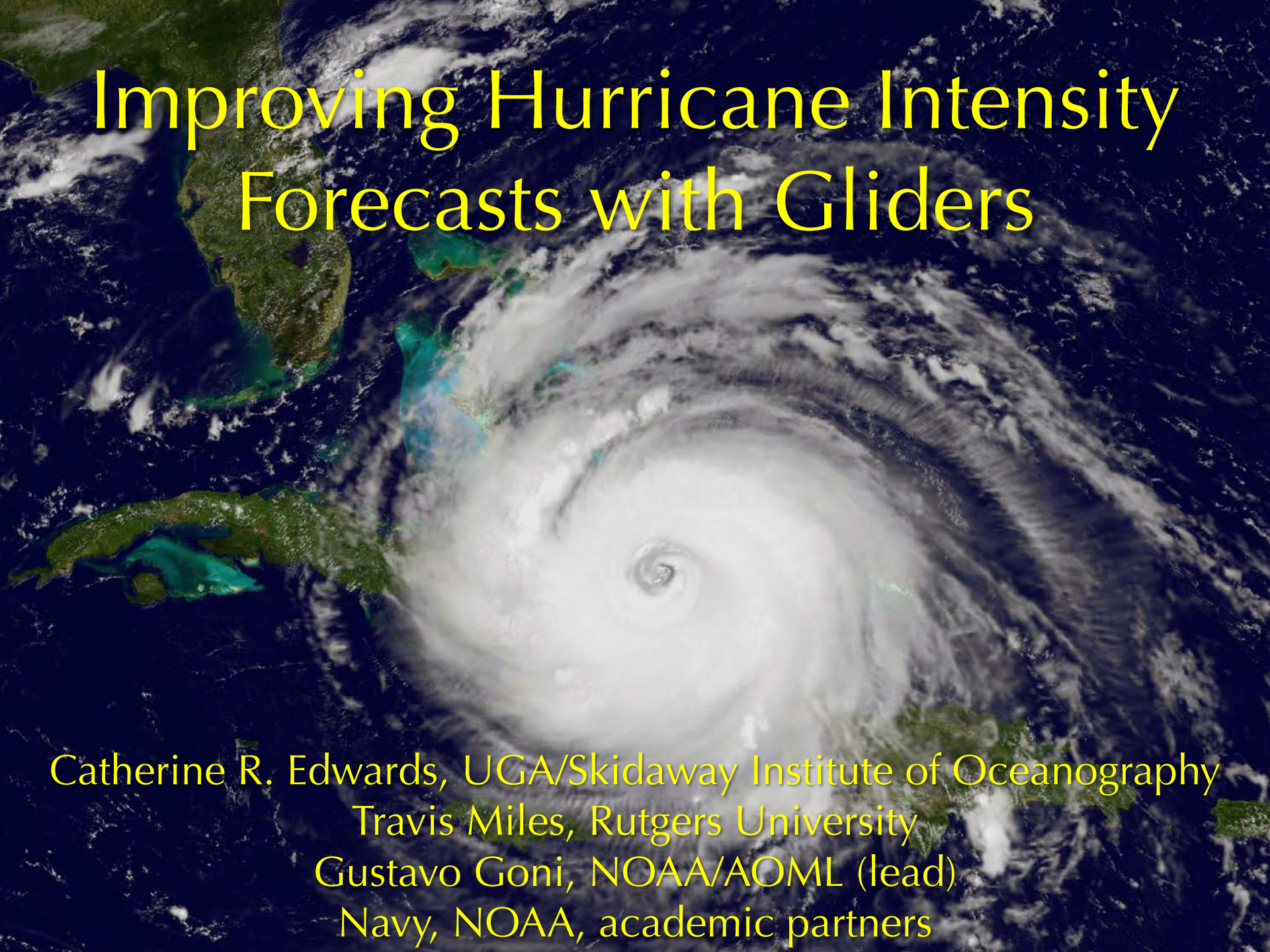
Improving Hurricane Intensity Forecasts with Gliders



Catherine R. Edwards, UGA/Skidaway Institute of Oceanography
Travis Miles, Rutgers University
Gustavo Goni, NOAA/AOML (lead)
Navy, NOAA, academic partners

Improving Hurricane Intensity Forecasts with Gliders

RESEARCH
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

IOOS | Integrated Ocean Observing System

Volunteer/leveraged partnerships

Hurricane Irma
Wednesday September 06, 2017
8 PM AST Intermediate Advisory 31A
NWS National Hurricane Center

Current information: ×
Center location 19.1 N 66.1 W
Maximum sustained wind 185 mph
Movement WNW at 16 mph

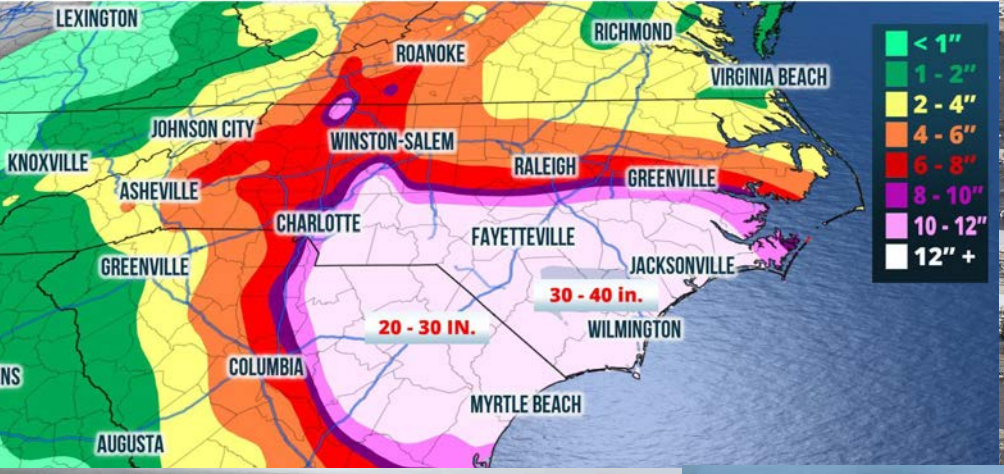
Forecast positions:
● Tropical Cyclone ○ Post/Potential TC
Sustained winds: D < 39 mph
S 39-73 mph H 74-110 mph M > 110 mph

Potential track area: Day 1-3, Day 4-5

Watches: Hurricane, Trop Stm

Warnings: Hurricane, Trop Stm

Current wind extent: Hurricane, Trop Stm



Images: AP, Getty Images, Savannah Morning News, SC Public Radio

NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

https://www.ncdc.noaa.gov/billions/

Billion-Dollar Weather and Climate Disasters: Summary Stats

Billion-dollar events to affect the U.S. from 1980 to 2019 (CPI-Adjusted) (40 years)

DISASTER TYPE	NUMBER OF EVENTS	PERCENT FREQUENCY	CPI-ADJUSTED LOSSES *(BILLIONS OF DOLLARS)*	PERCENT OF TOTAL LOSSES	AVERAGE EVENT COST *(BILLIONS OF DOLLARS)*	DEATHS	PERCENT OF TOTAL DEATHS
Drought	26	10.1%	$249.7 CI	14.2%	$9.6	2,993†	22.6%
Flooding	32	12.4%	$146.5§ CI	8.3%§	$4.6§	555	4.2%
Freeze	9	3.5%	$30.5 CI	1.7%	$3.4	162	1.2%
Severe Storm	113	43.8%	$247.8 CI	14.1%	$2.2	1,642	12.4%
Tropical Cyclone	44	17.1%	$945.9 CI	53.9%	$21.5	6,502	49.1%
Wildfire	17	6.6%	$84.9 CI	4.8%	$5.0	347	2.6%
Winter Storm	17	6.6%	$49.3 CI	2.8%	$2.9	1,048	7.9%
All Disasters	**258**	**100.0%**	**$1,754.6** CI	**100.0%**	**$6.8**	**13,249**	100.0%

Tropical Cyclone damages ($945.9 B) & deaths (6,502) are similar to All Other Weather Disasters Combined

Road map

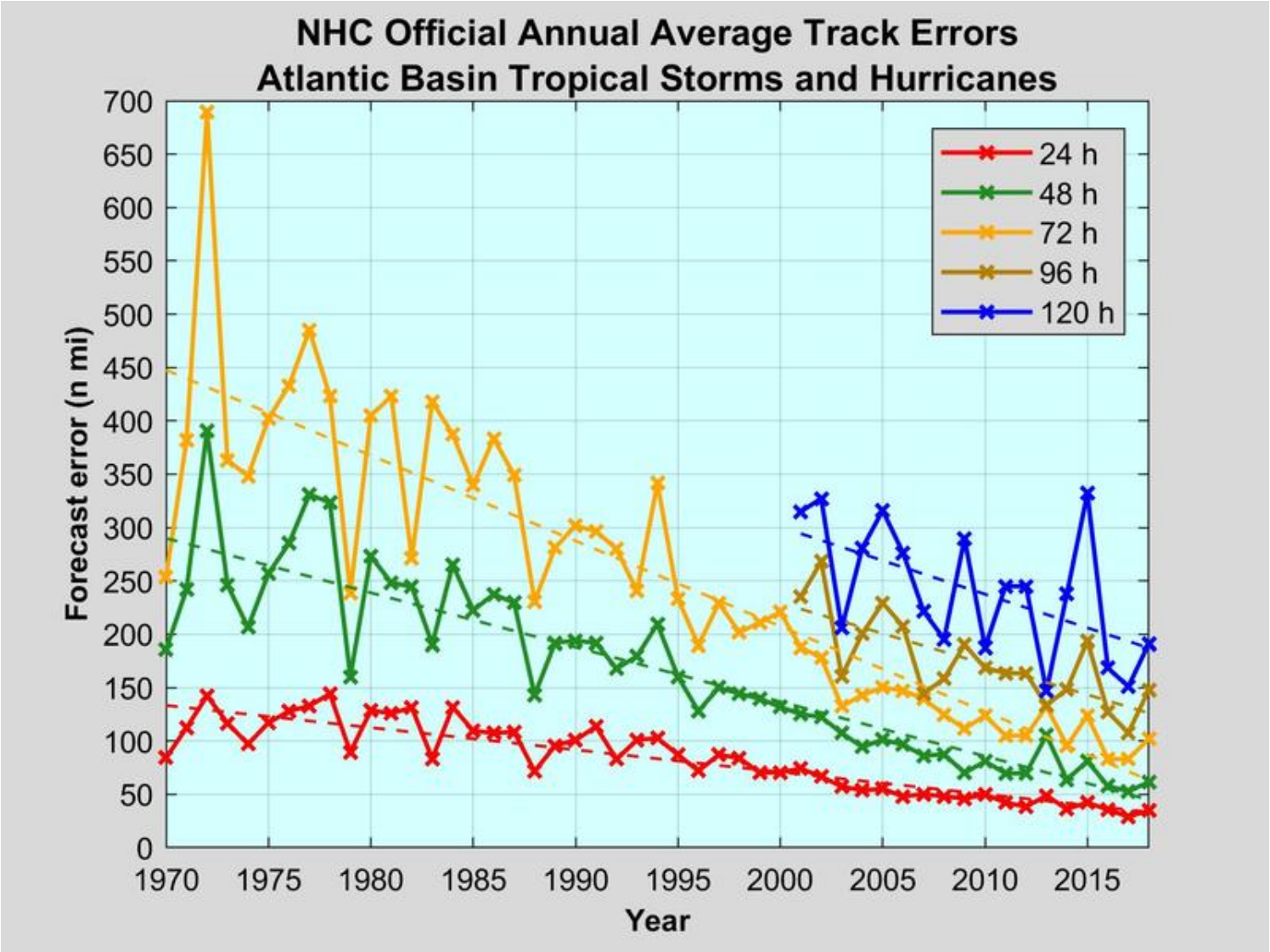
The intensity problem

Hurricane Irene: 2011

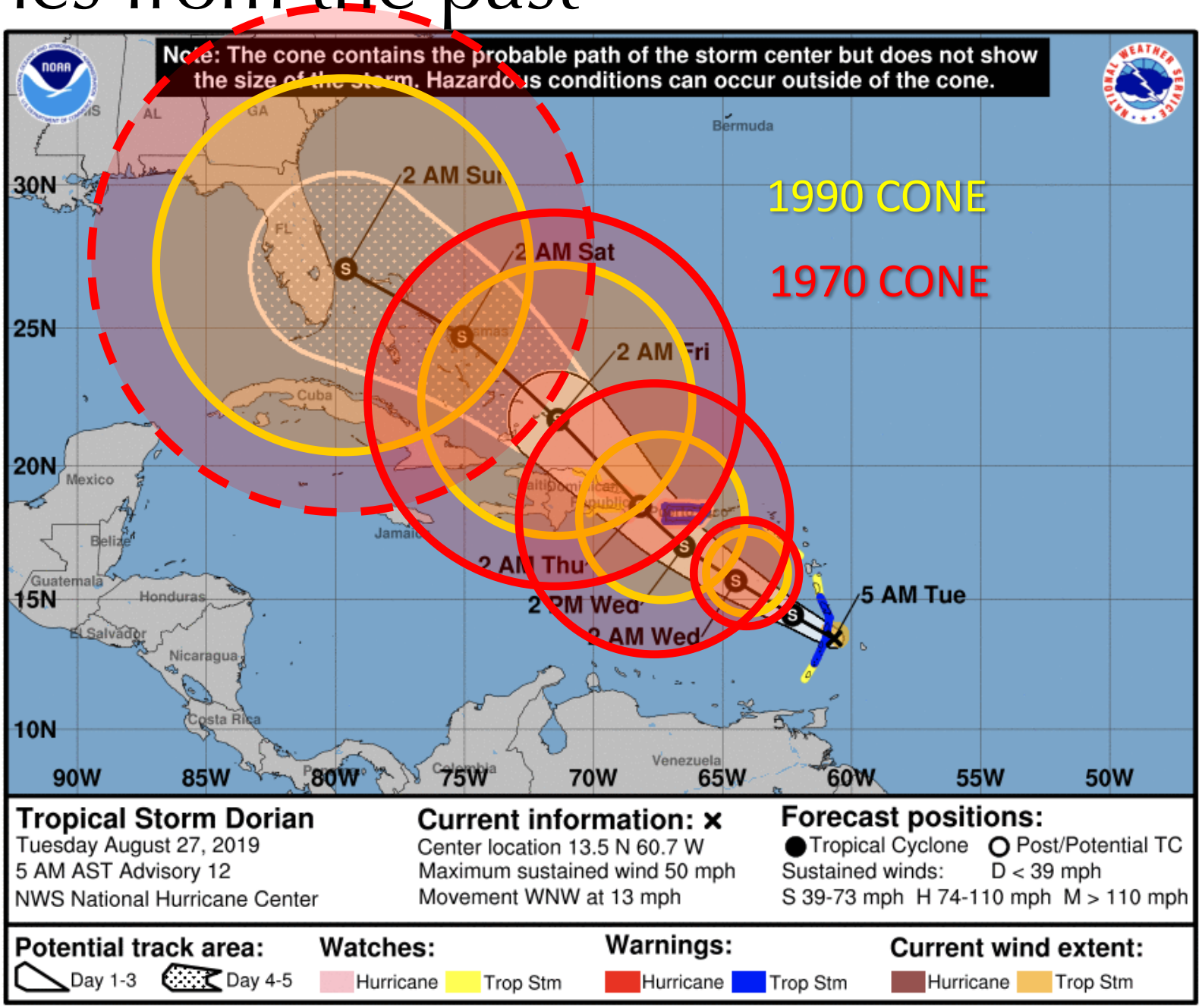
Hurricane Florence: 2018

Next steps

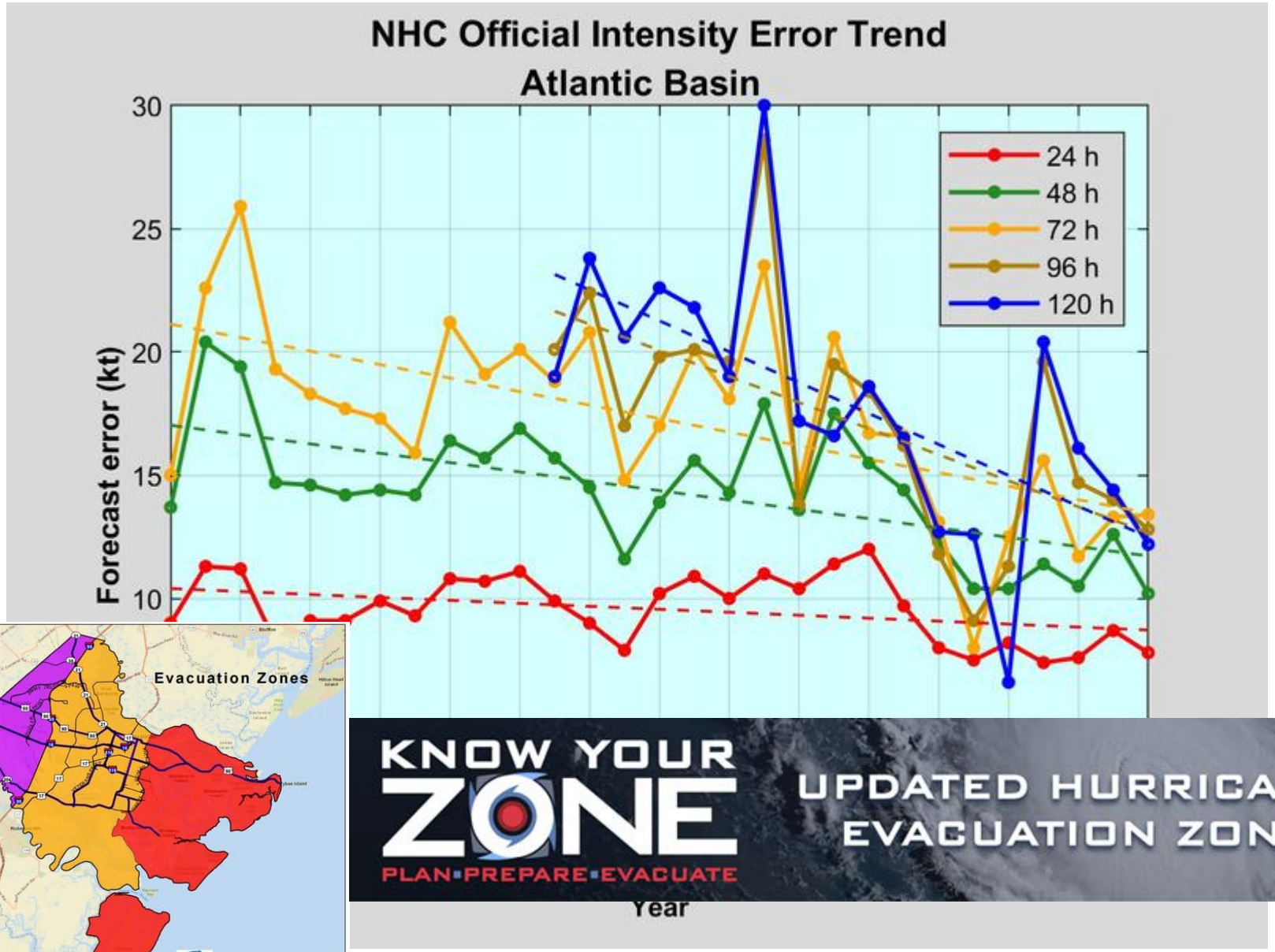
Reduction in hurricane track errors

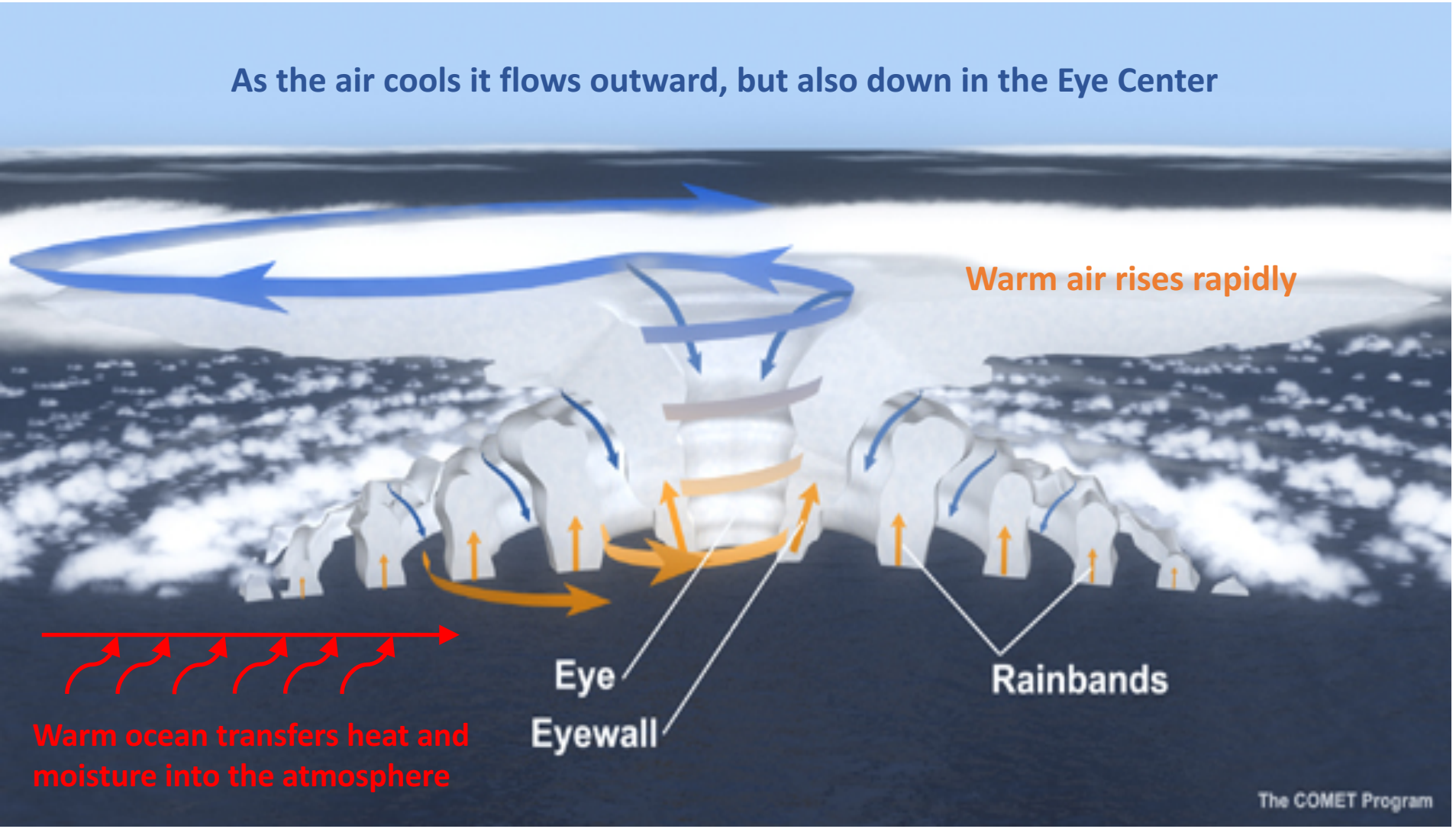


Cones from the past

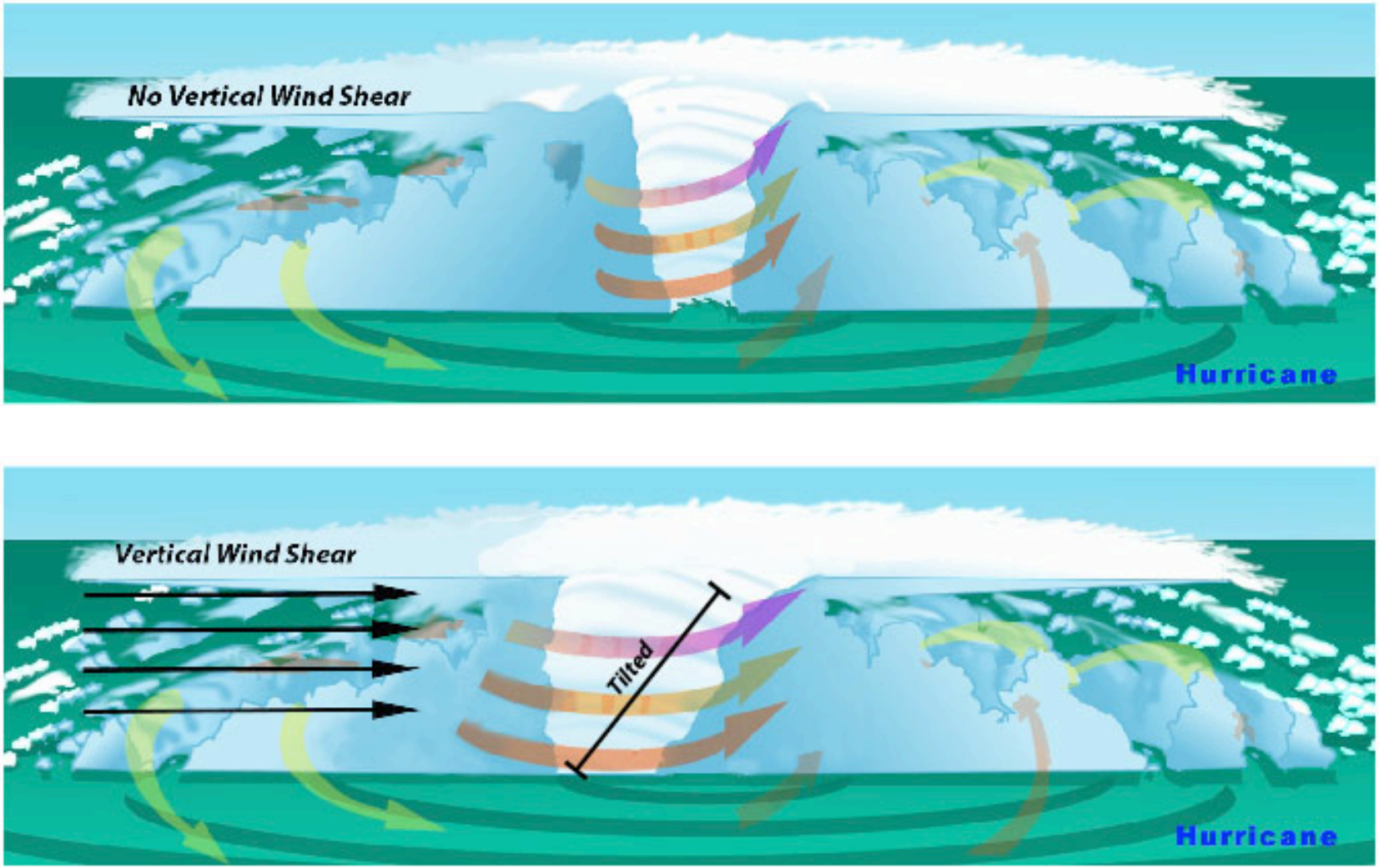


The intensity problem



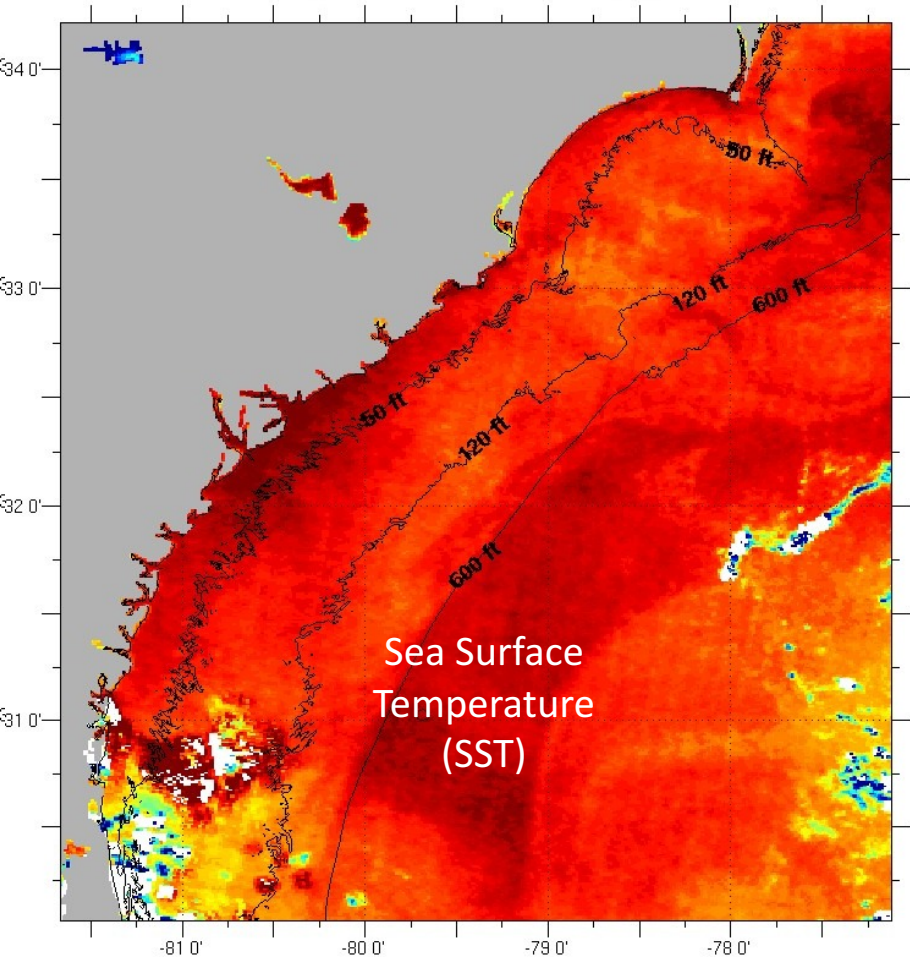

As the air cools it flows outward, but also down in the Eye Center
Warm air rises rapidly
Eye
Eyewall
Rainbands
Warm ocean transfers heat and moisture into the atmosphere
The COMET Program

Effects of Vertical Wind Shear on Hurricanes



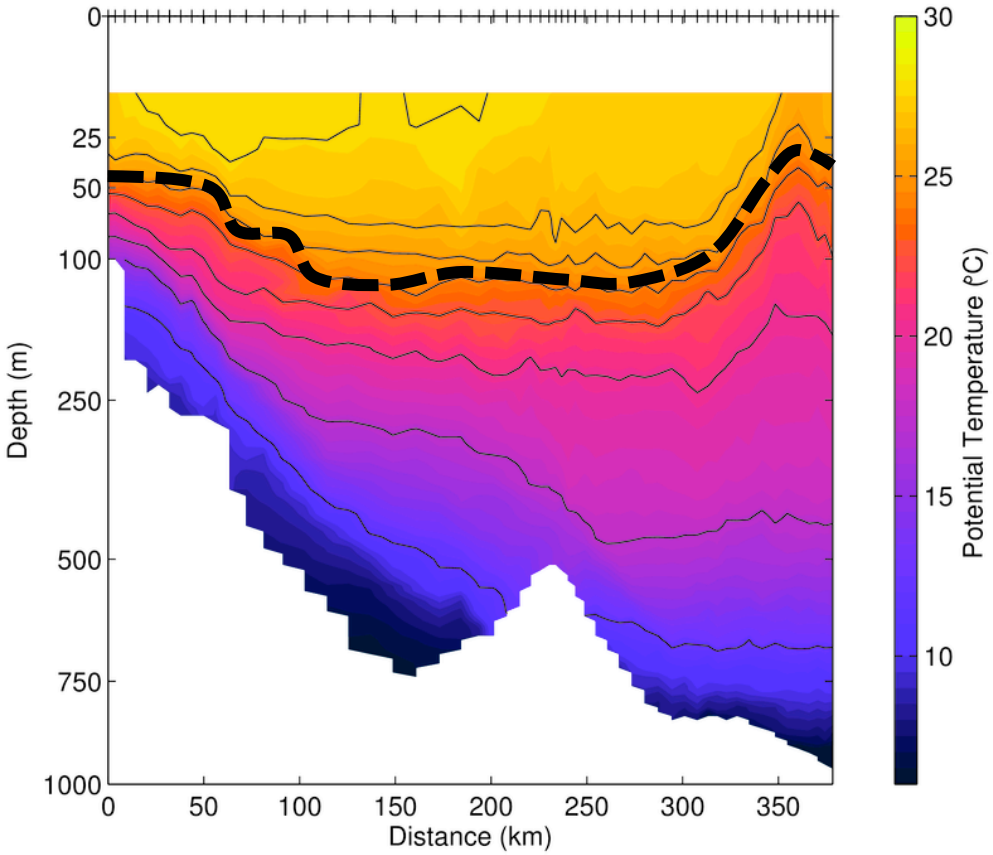
Courtesy NOAA/AOML

Ocean heat feeds hurricanes



but clouds can be problematic

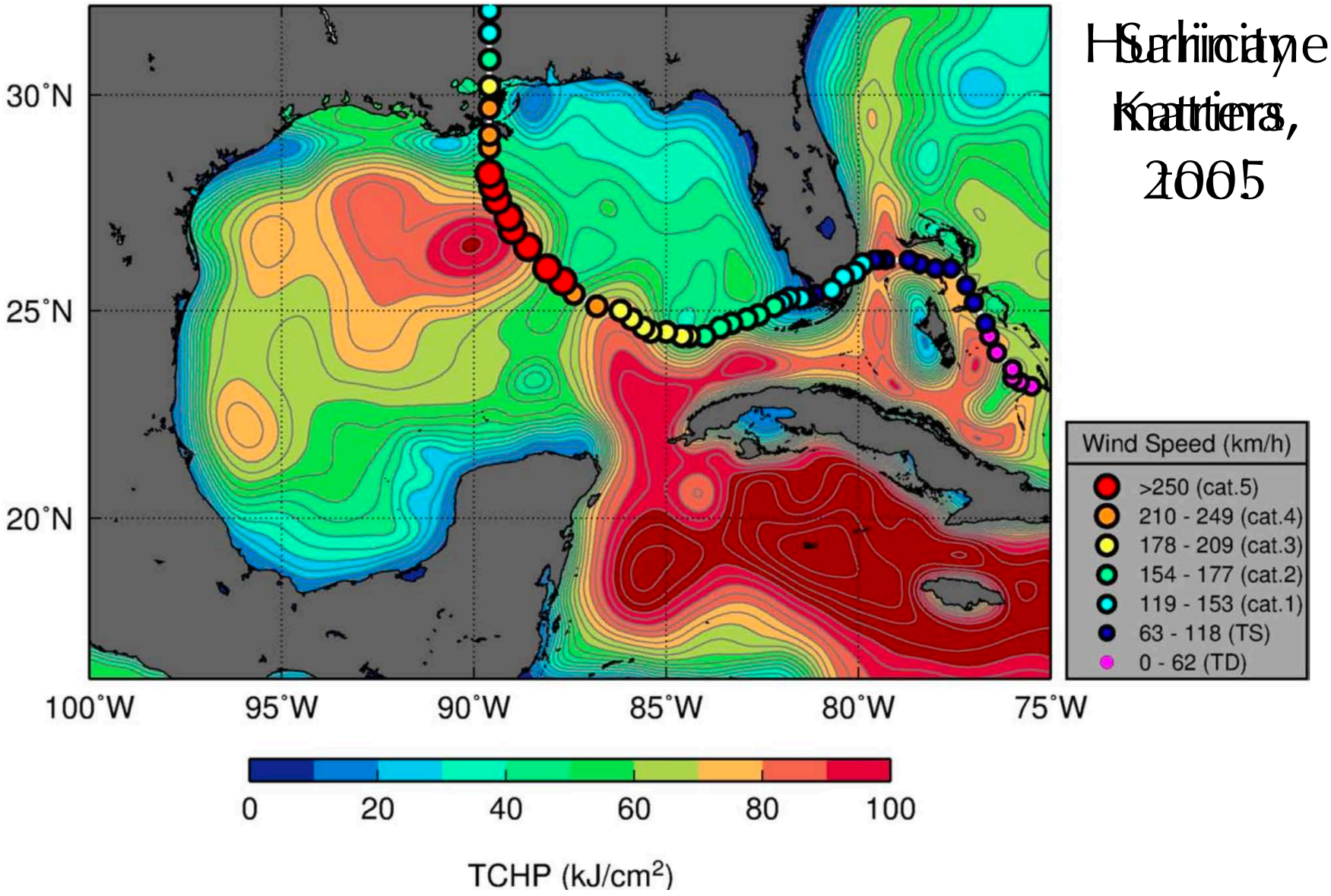
Subsurface heat matters



Tropical Cyclone Heat Potential (TCHP): T $\geq$ 26 deg C

Courtesy Rutgers, WHOI

Hurricane Katrina, 2005



Goni et al., 2019

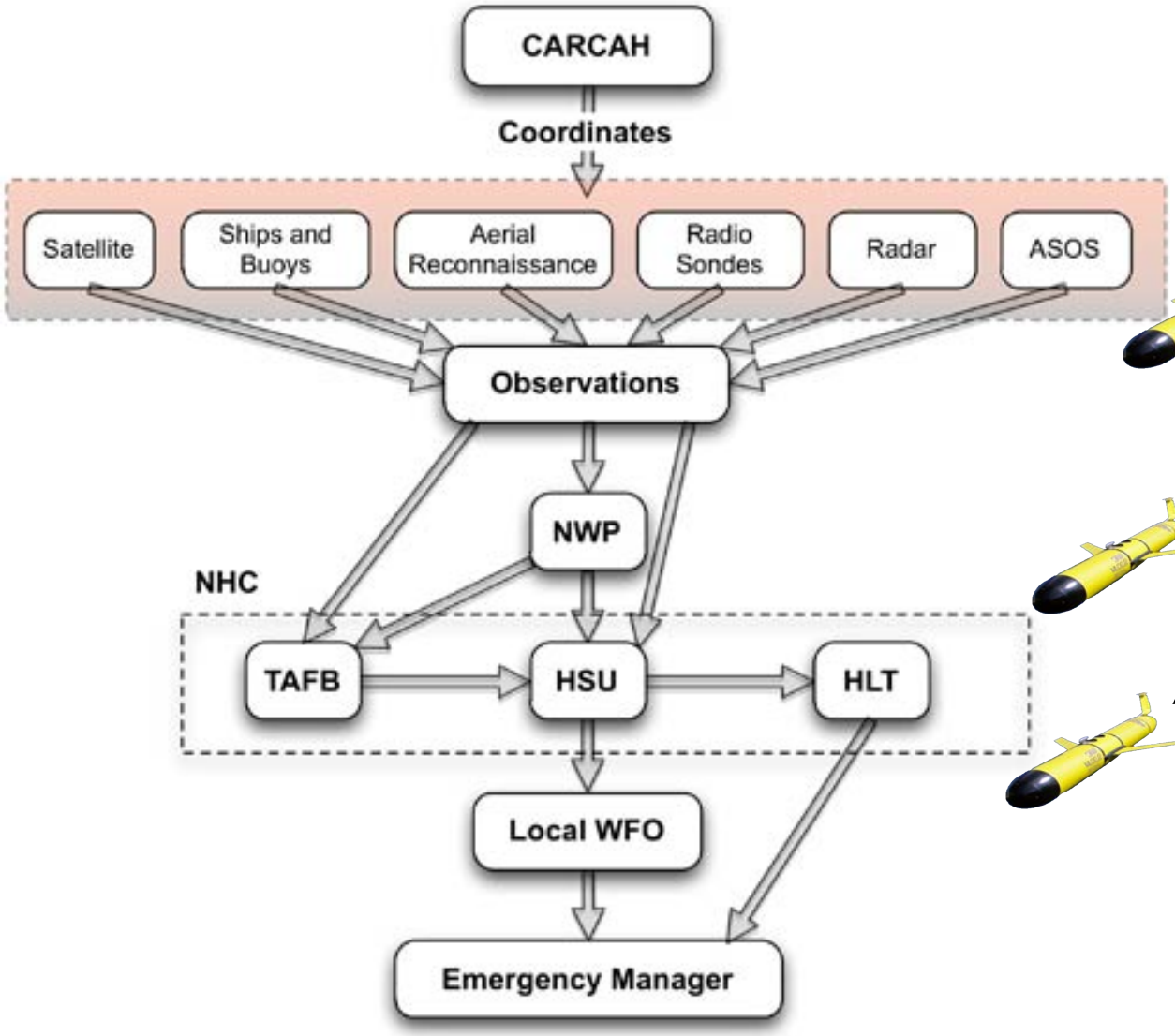
How can we (oceanographers) improve intensity forecasts?

Represent the ocean better with:

- 3-D temperature to estimate TCHP
- 3-D salinity to estimate mixing
- Capture processes too small for hurricane models

Real-time data

How forecasts are made – and how gliders inform models



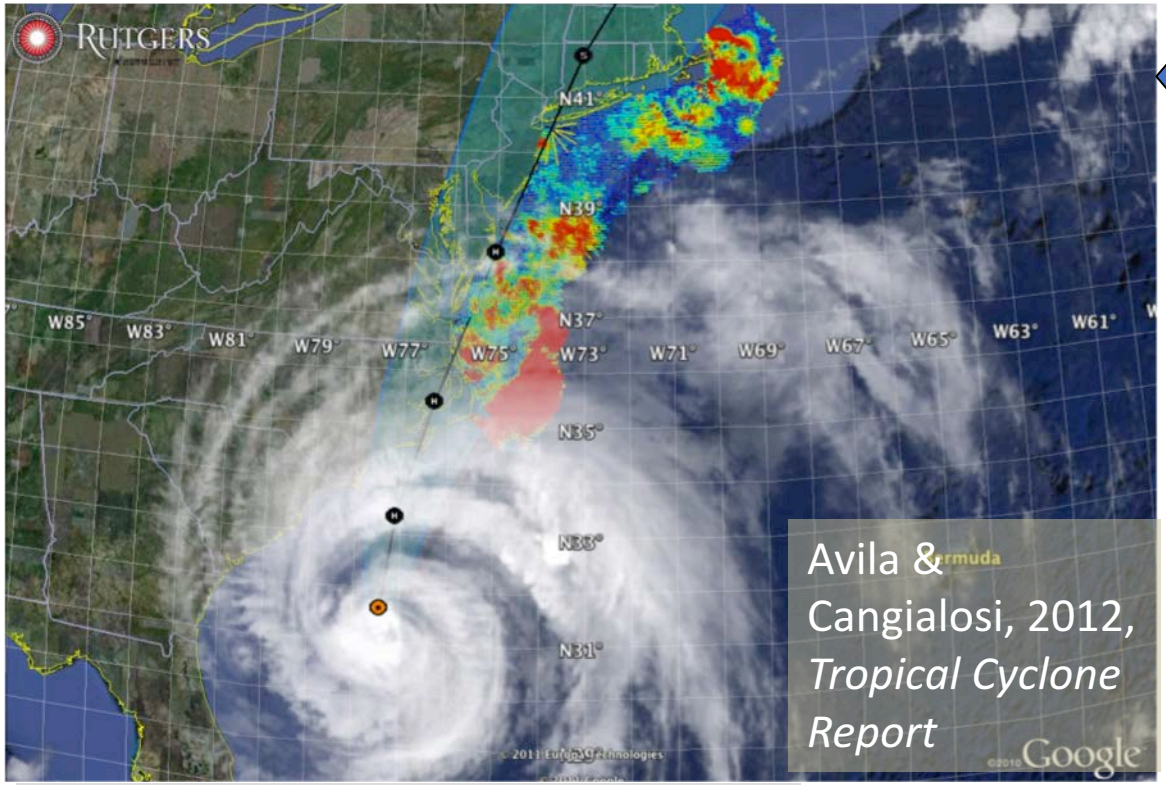
Collect data

Run weather, ocean models

Analyze data, models

Forecast issued to communities

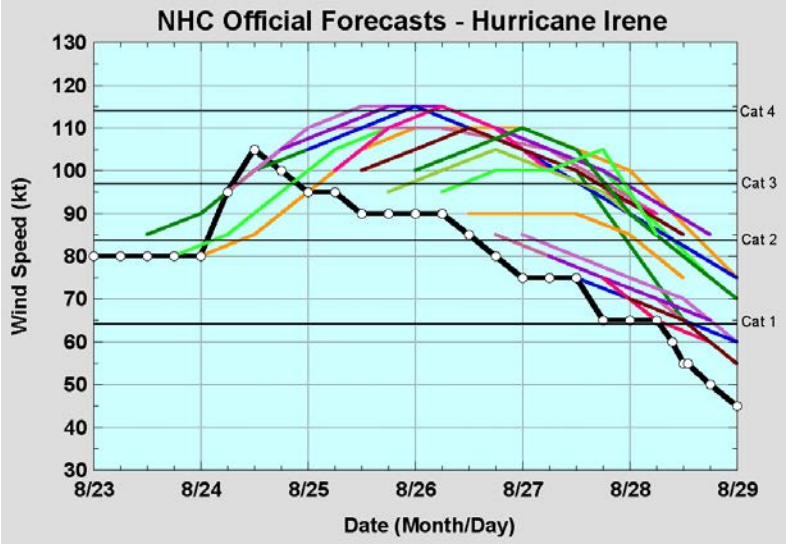
http://hurricanescience.org/science/forecast/forecasting/forecastprocess/

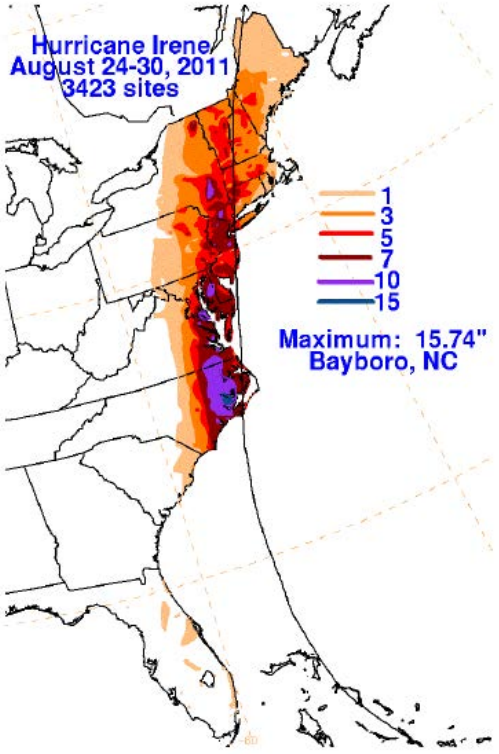


Hurricane Irene
August 28, 2011

NOAA/NHC Damage:
>$15 Billion, #15.

Track Accurate;
Intensity Over-predicted.





MARACOOS
Ocean Information for a Changing World

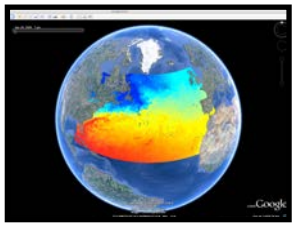
The Mid-Atlantic Regional Association Coastal Ocean Observing System

A view from the RUCOOL

L-Band & X-Band Satellite Receivers

46 Site CODAR Network

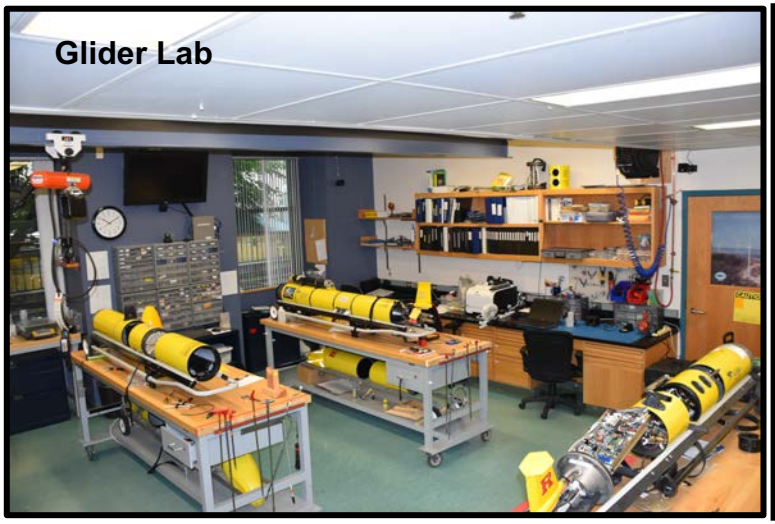
>500 Glider Deployments

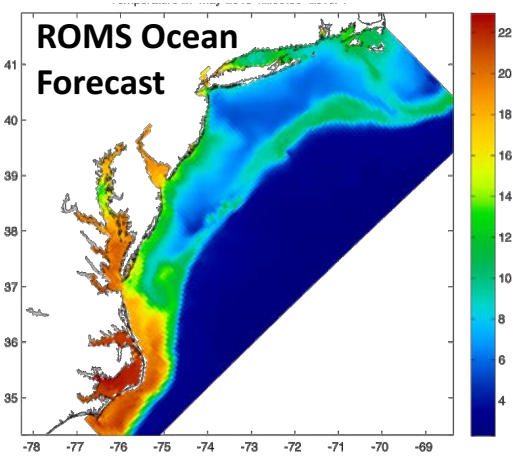


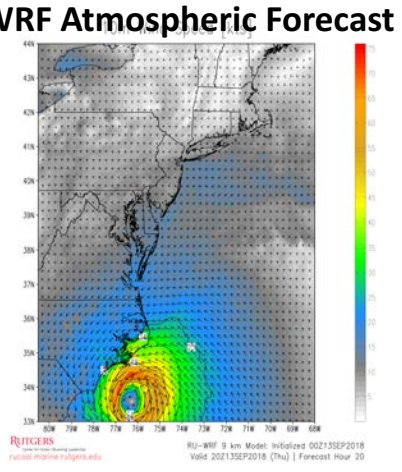
Ocean & Atmos. Forecasts

REGIONAL INFORMATION COORDINATION ENTITY
CERTIFIED
2016

MARACOOS is an IOOS Certified RICE





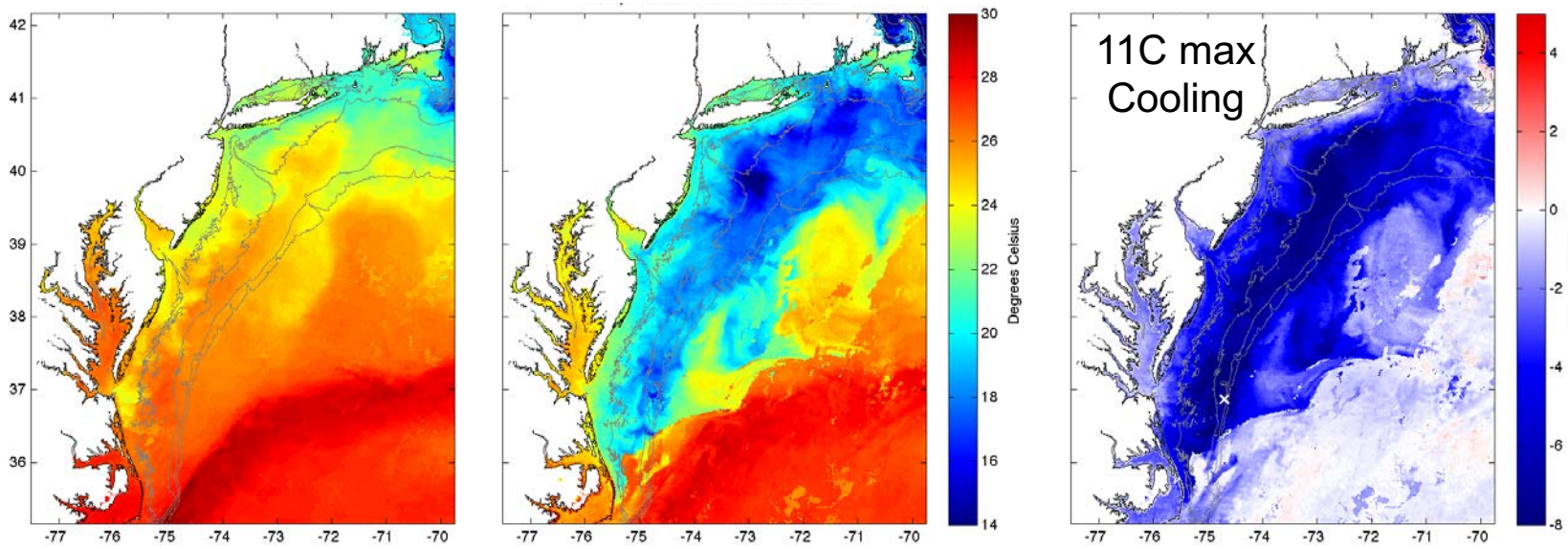


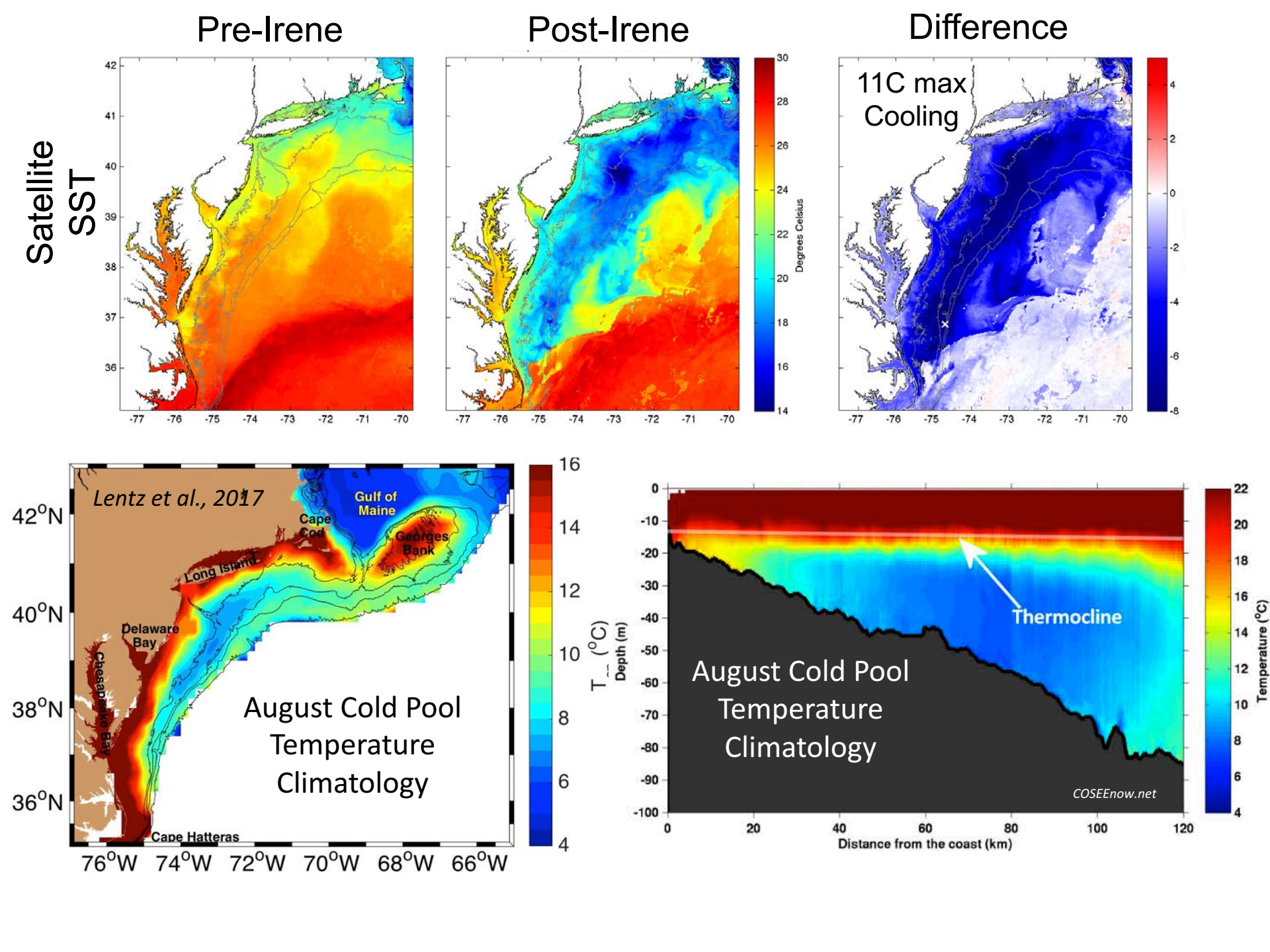
Satellite SST

Pre-Irene

Post-Irene

Difference




Pre-Irene
Post-Irene
Difference
Satellite SST
11C max Cooling
Degrees Celsius
Lentz et al., 2017
Gulf of Maine
Cape Cod
Georges Bank
Long Island
Delaware Bay
Chesapeake Bay
Cape Hatteras
August Cold Pool Temperature Climatology
Thermocline
August Cold Pool Temperature Climatology
COSEEnow.net
Depth (m)
Distance from the coast (km)
Temperature (°C)

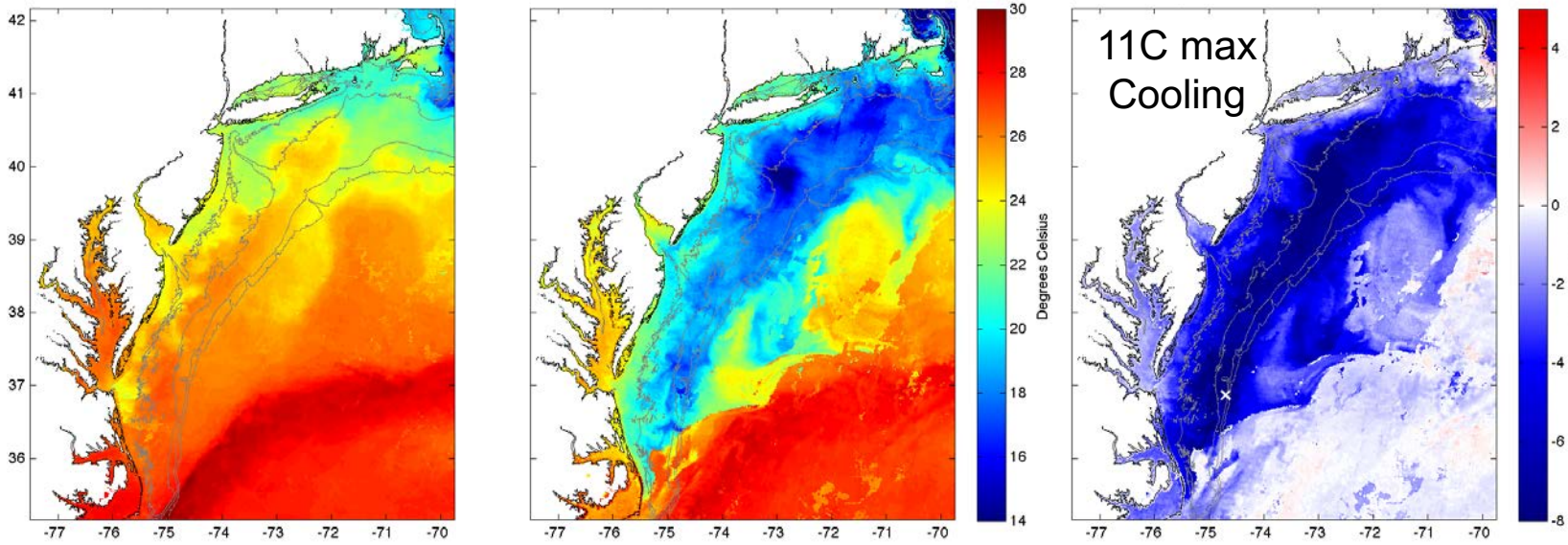
Pre-Irene

Post-Irene

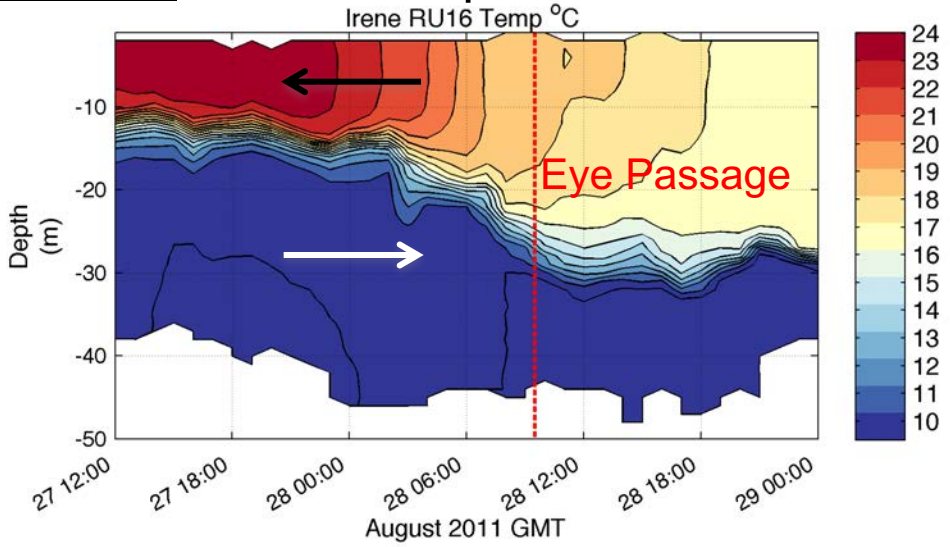
Difference

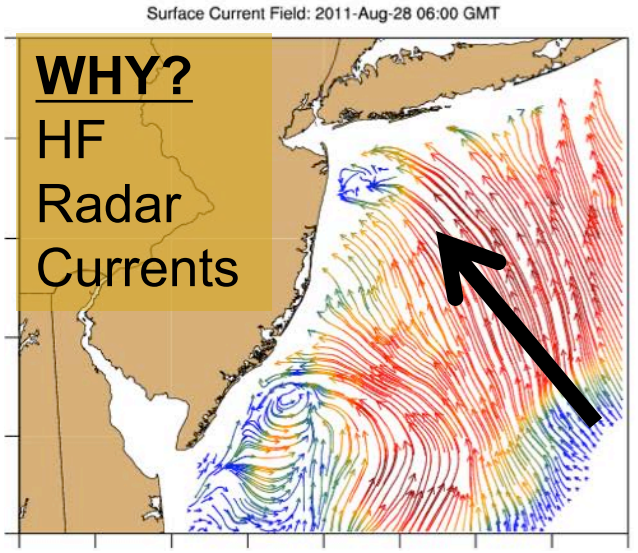
WHAT?

Satellite SST



WHEN? Glider Temperature





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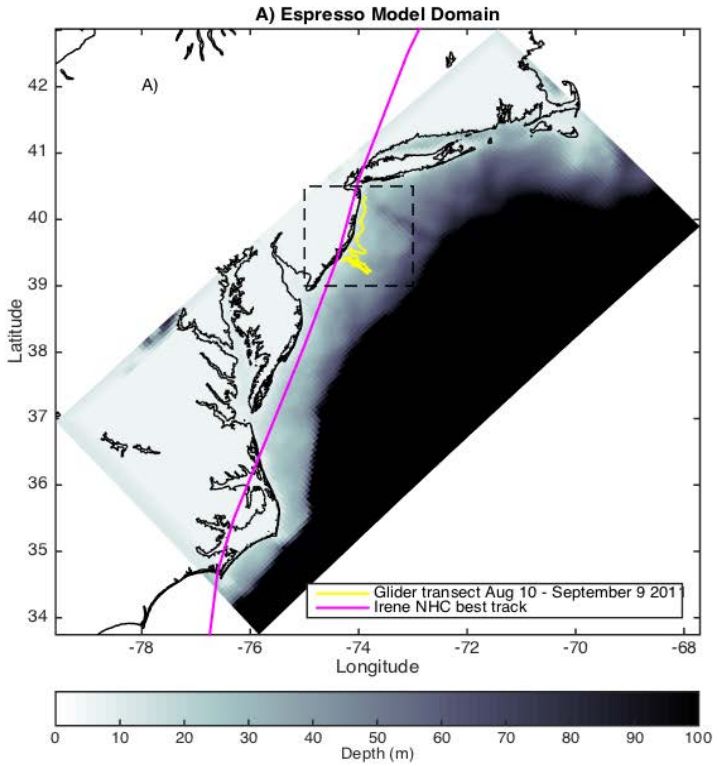
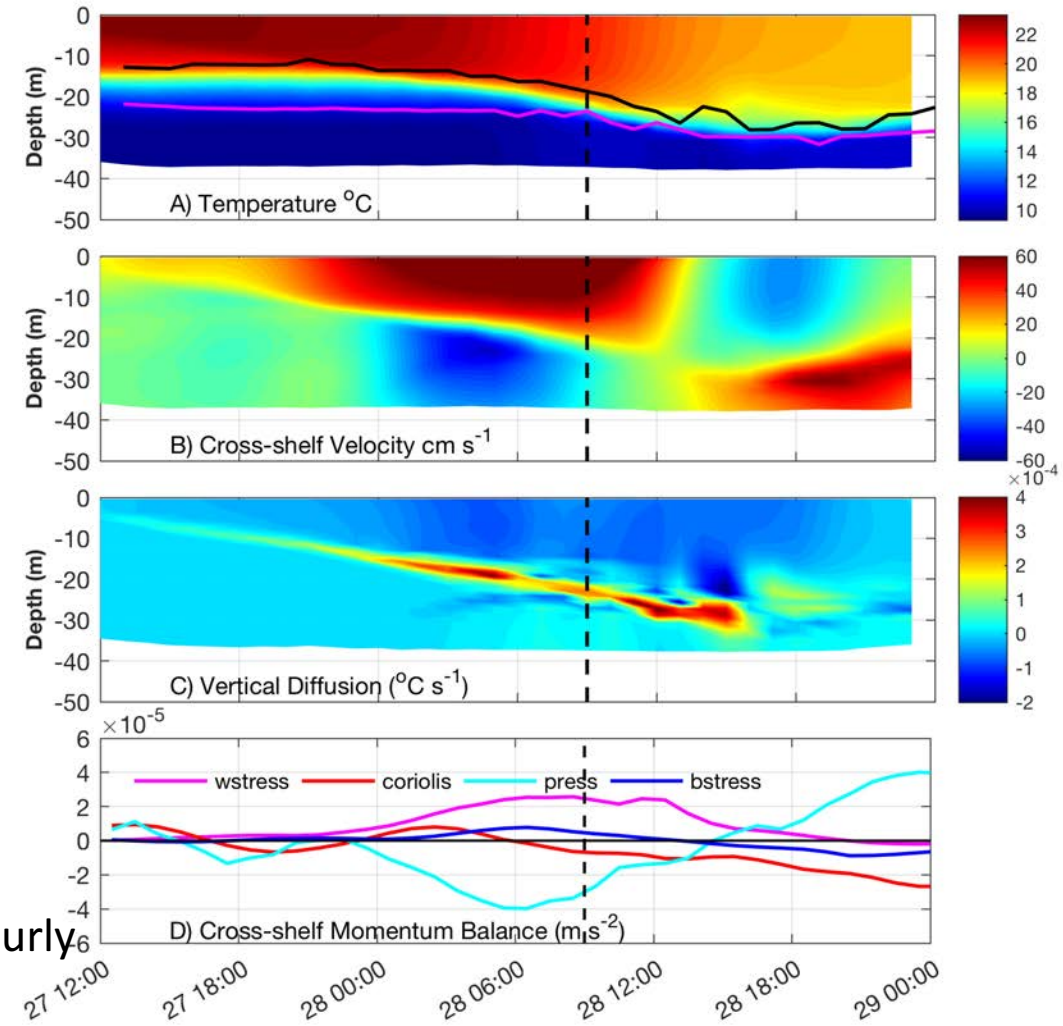
Ahead-of-Eye-Center Cooling in Irene: Ocean Modeling





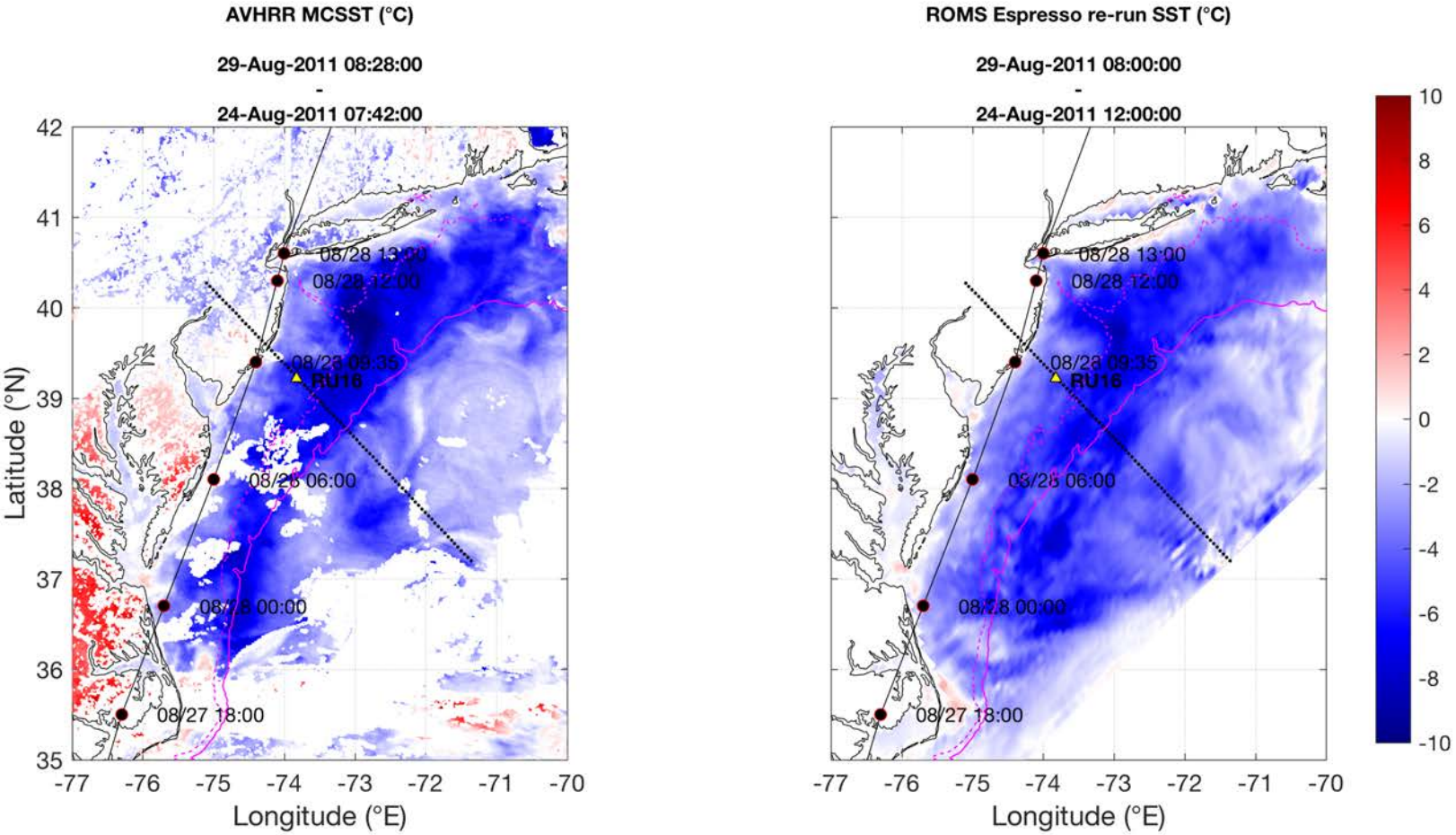
Rutgers ROMS on the ESPreSSO domain

- http://www.myroms.org/espresso/
- 36 Levels, ~5 km resolution, output hourly
- HYCOM-NCODA Boundary Conditions
- NCEP North American Mesoscale (NAM) 12km 3 hourly Wind forcing

Nature Communications (2016)

Hurricane Irene ROMS Ocean Forecast

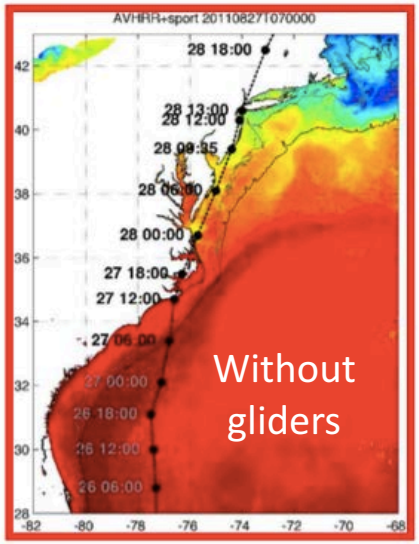
Satellite AVHRR vs. ROMS Model

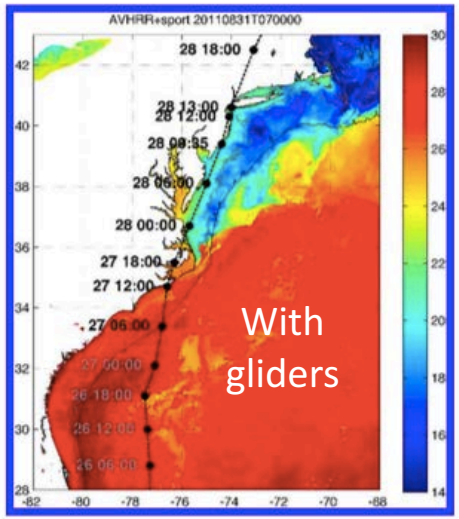


(After – Before) SST Difference

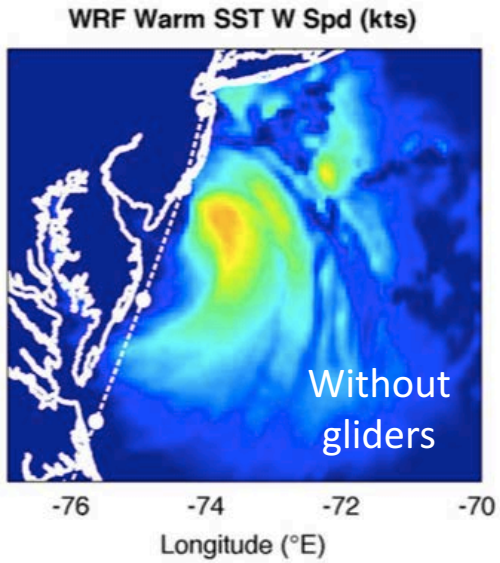
Gliders improve wind, storm surge models (Irene)

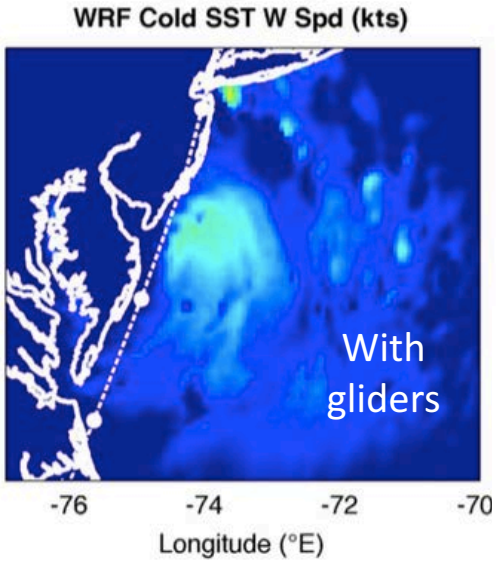
Ocean model



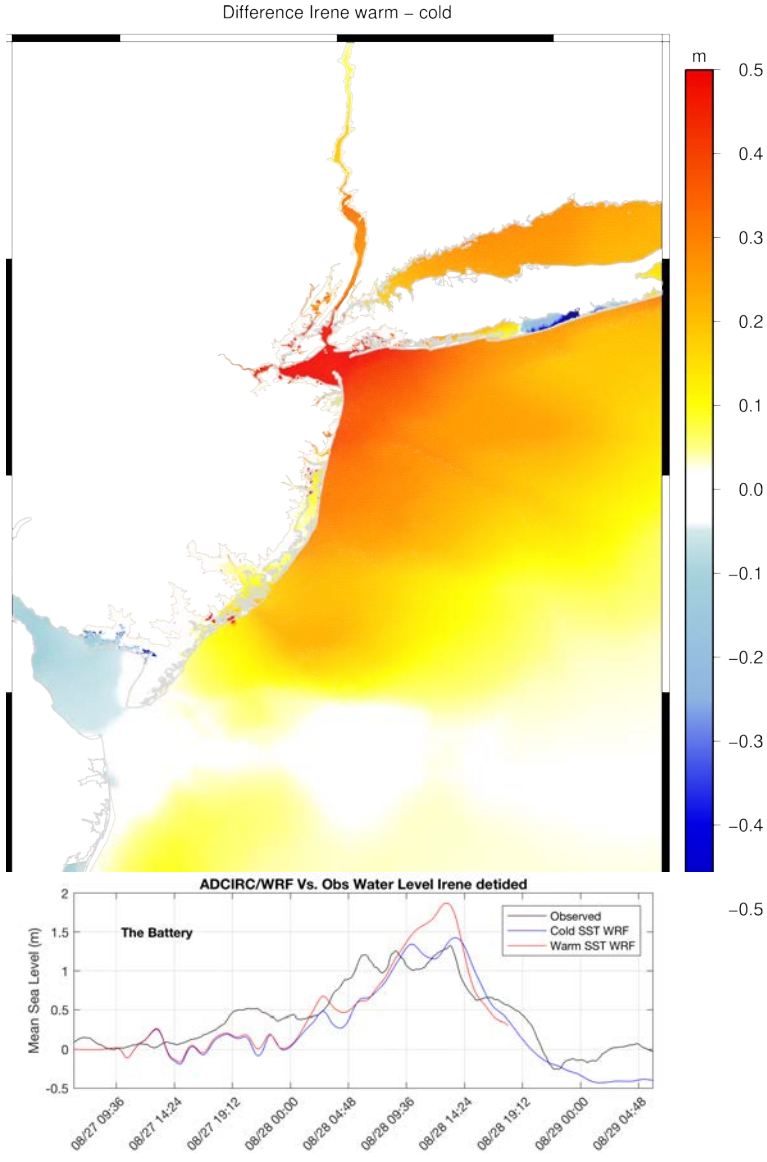


Hurricane wind model



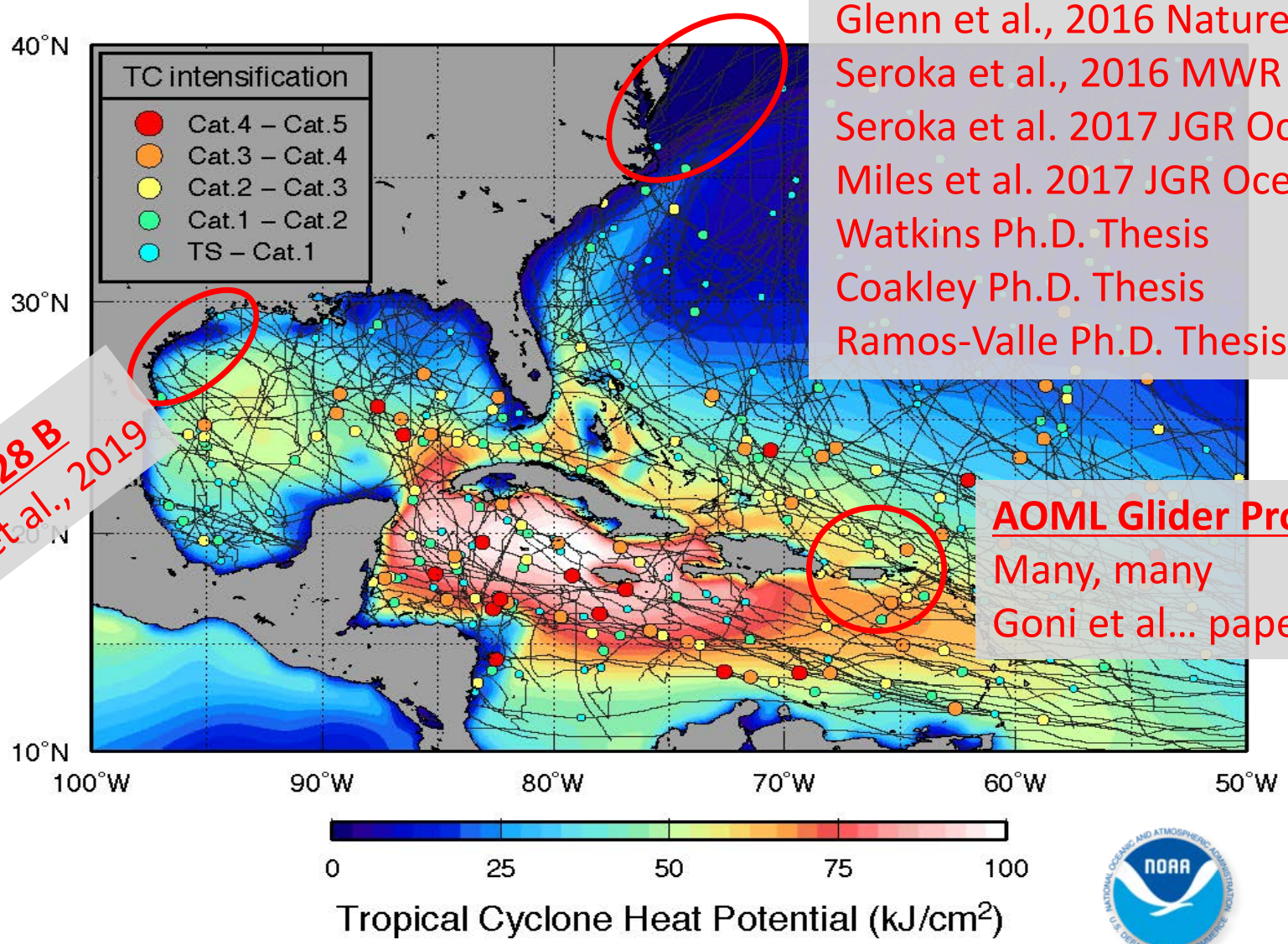


Δ (storm surge)



Tropical Cyclone Heat Potential – Ocean Impacts Map

But TCHP in not universal….



Irene & Sandy $87 B

Glenn et al., 2016 Nature Comms
Seroka et al., 2016 MWR
Seroka et al. 2017 JGR Oceans
Miles et al. 2017 JGR Oceans
Watkins Ph.D. Thesis
Coakley Ph.D. Thesis
Ramos-Valle Ph.D. Thesis

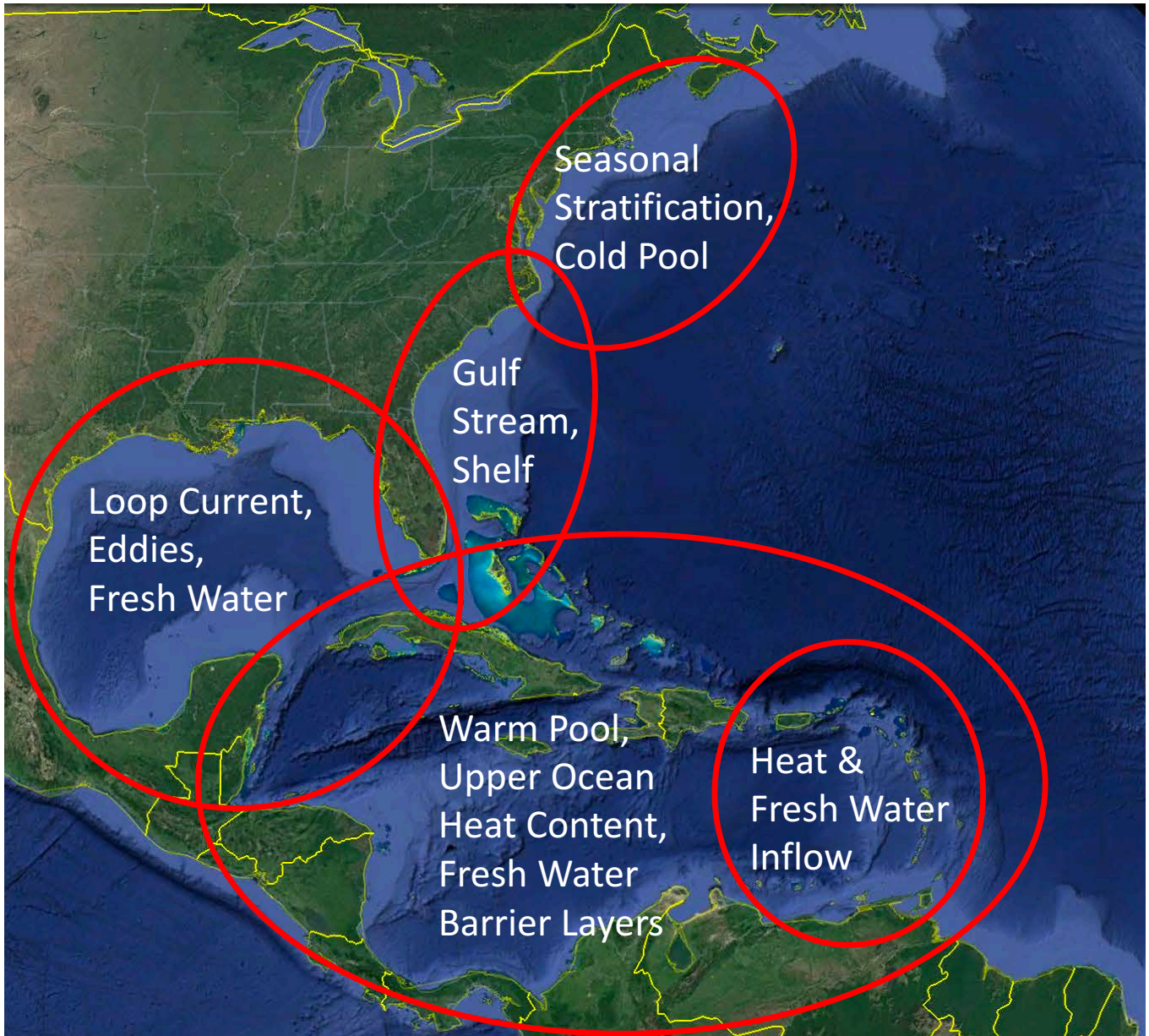
Harvey $128 B

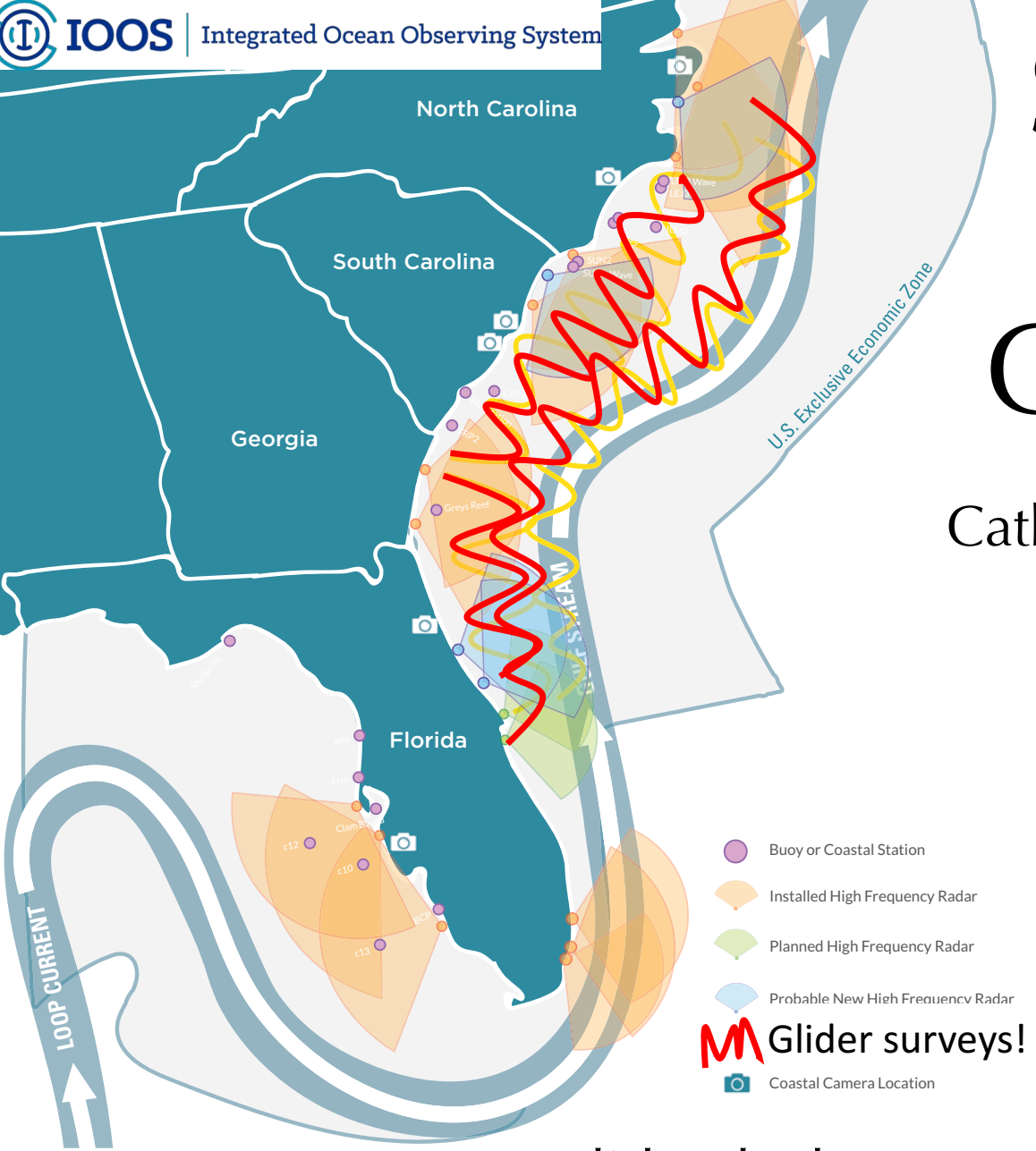
Potter et al., 2019

AOML Glider Program

Many, many
Goni et al… papers

Regionally-Specific Essential Ocean Features Affect Atlantic Hurricane Intensity





SECOORA Glider Observatory

Catherine Edwards, SkIO/UGA

Chad Lembke, USF
Harvey Seim, UNC
Fumin Zhang, GT
Ruoying He, NCSU

Data available via
secoora.org,
Glider DAC
gliders.ioos.us

3-5 glider deployments per year,
2019-2020: additional 2 HurricaneGliders

Hurricane Florence, September 2018

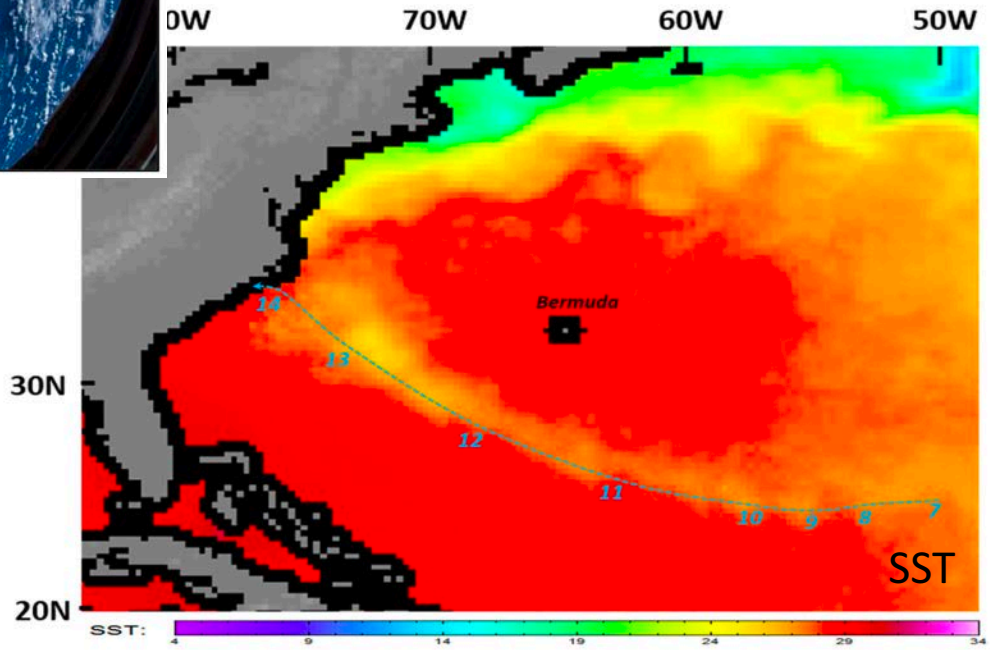
Approached NC coast as category 4 hurricane

Weakened from peak (~18:00 UTC 9/11/2019)

Stalled over NC, causing significant rainfall, flooding

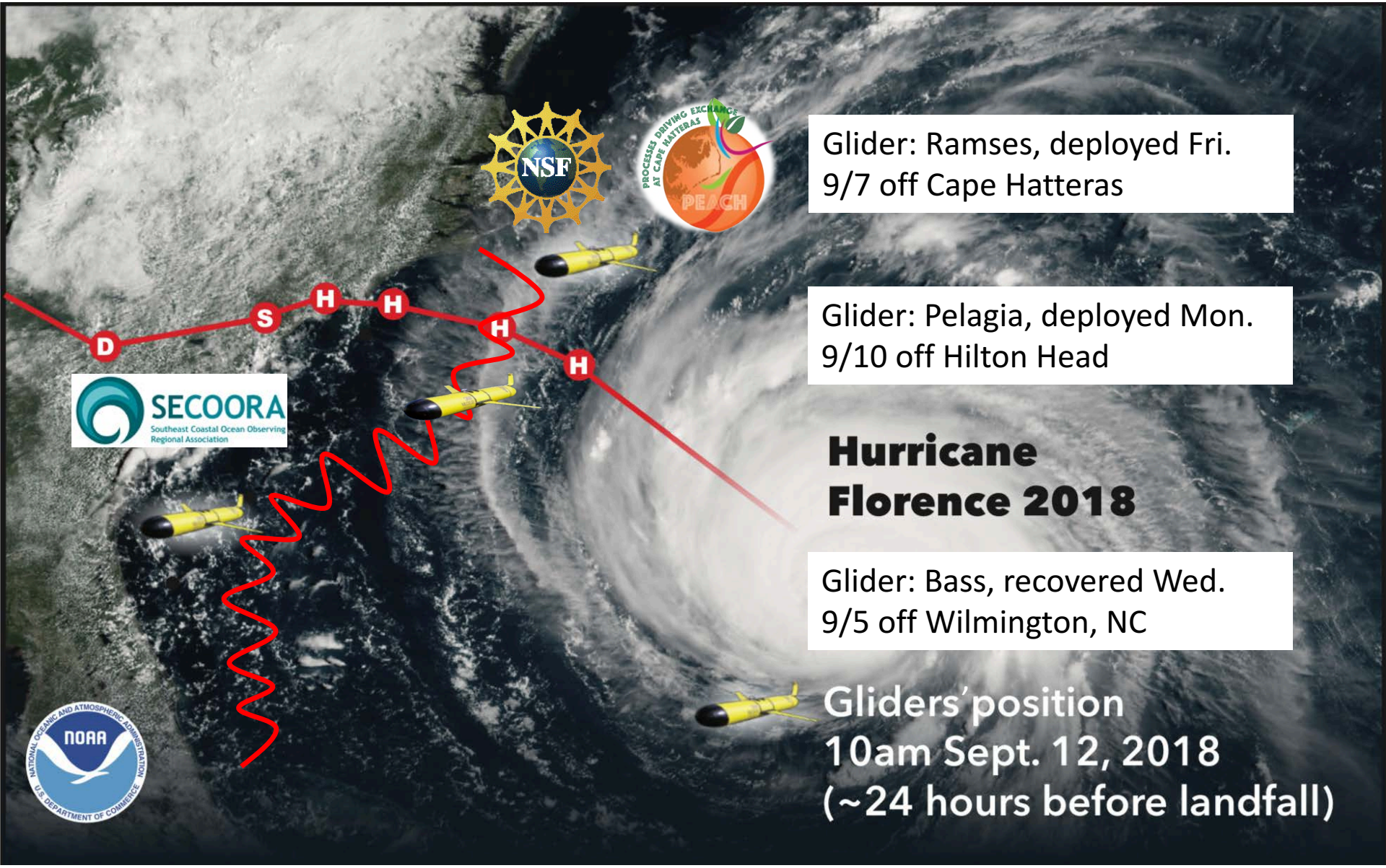
Intensity 130 kt peak, ~80 kt at landfall

Minimum pressure 937 mb, 952 mb at landfall

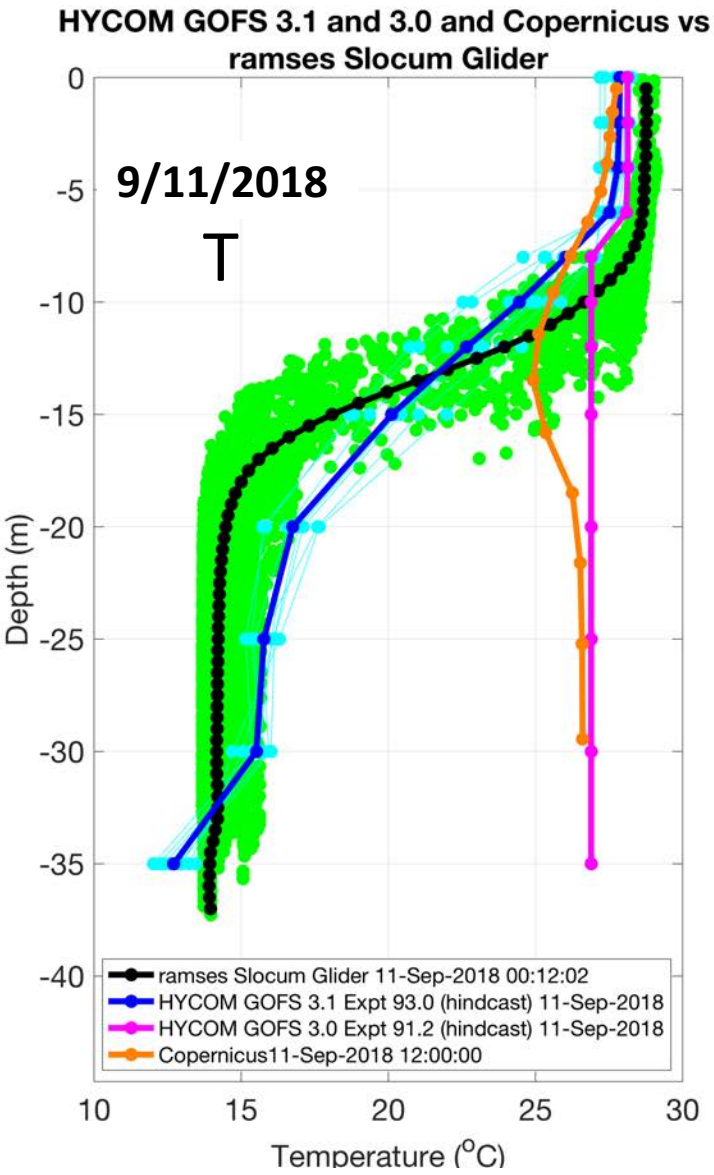


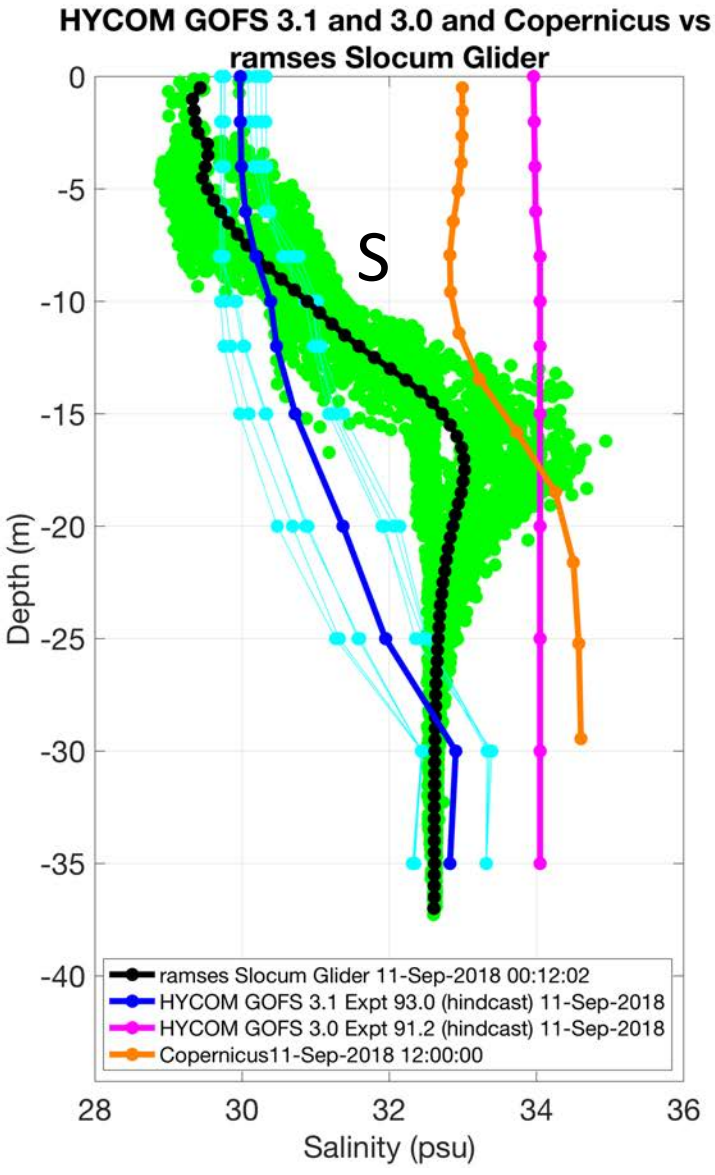
Stewart and Berg, NHC, 2019

Hurricane Florence deployments



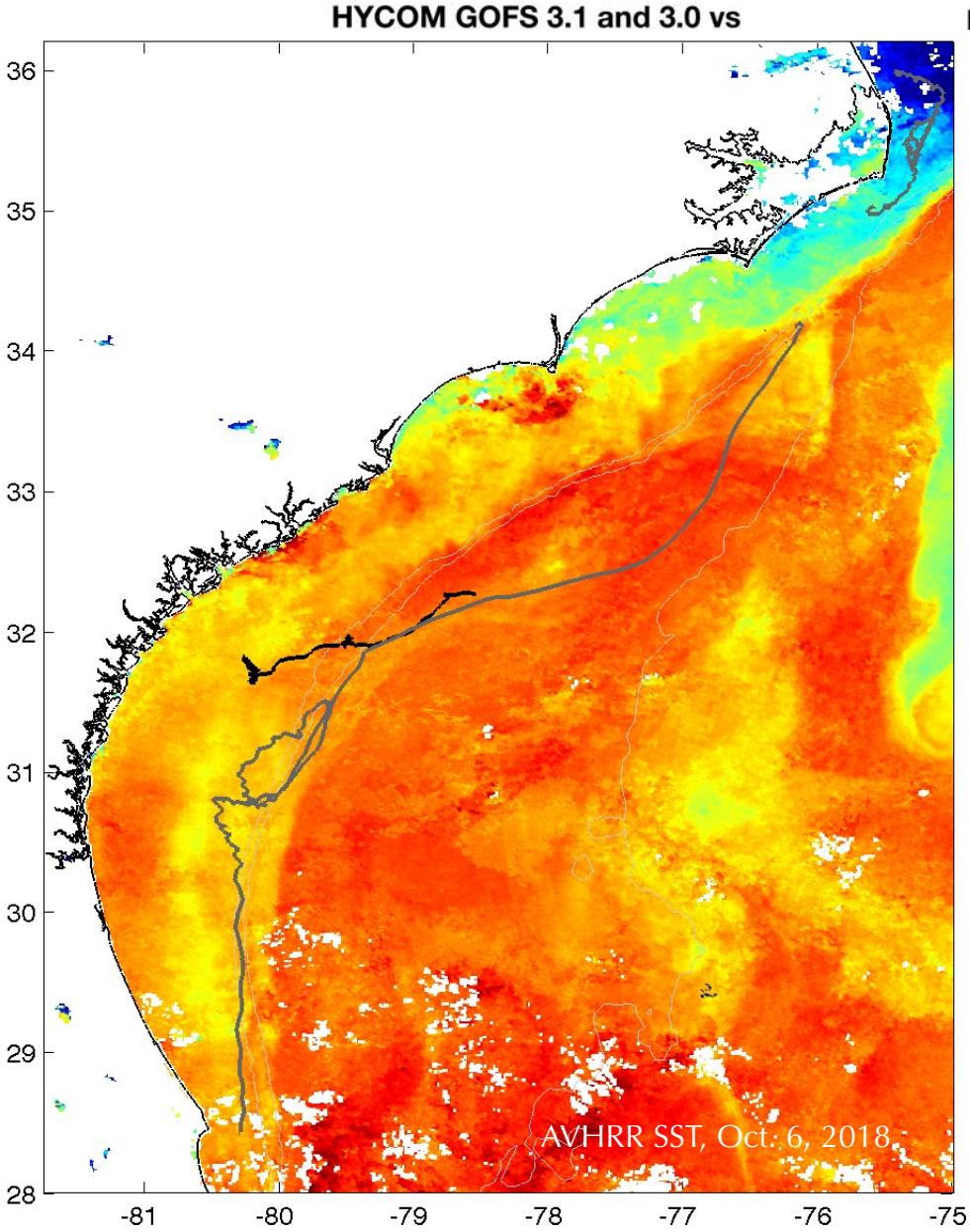
Ramses, off Cape Hatteras @ Florence peak

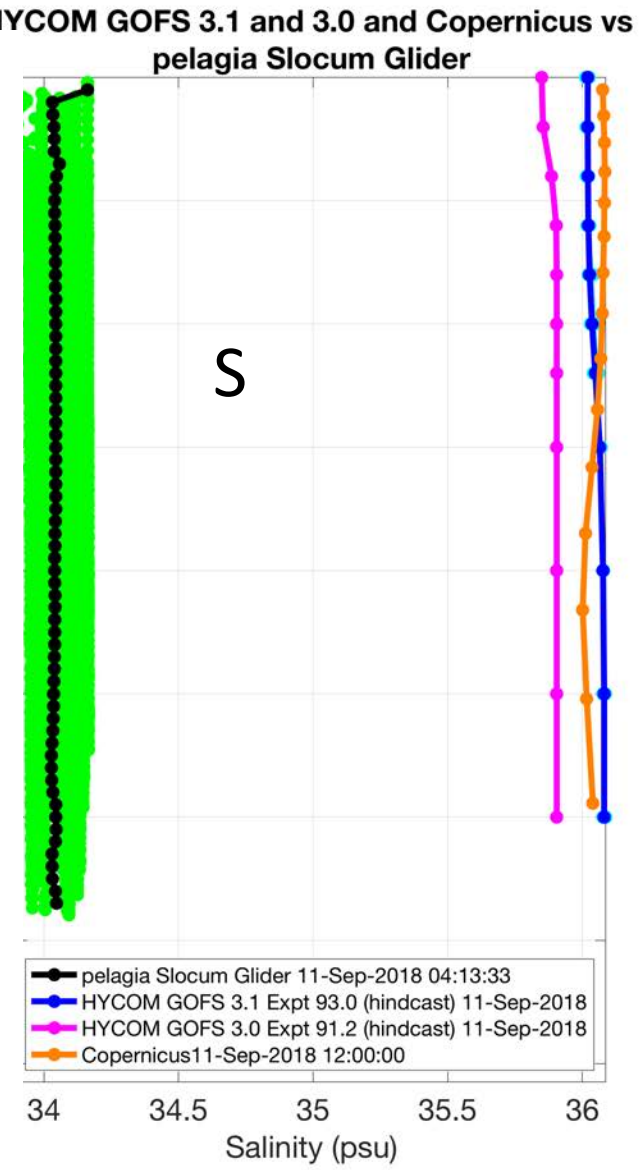




Stratification underpredicted, salinity overall high, GOFS3.1>>3.0

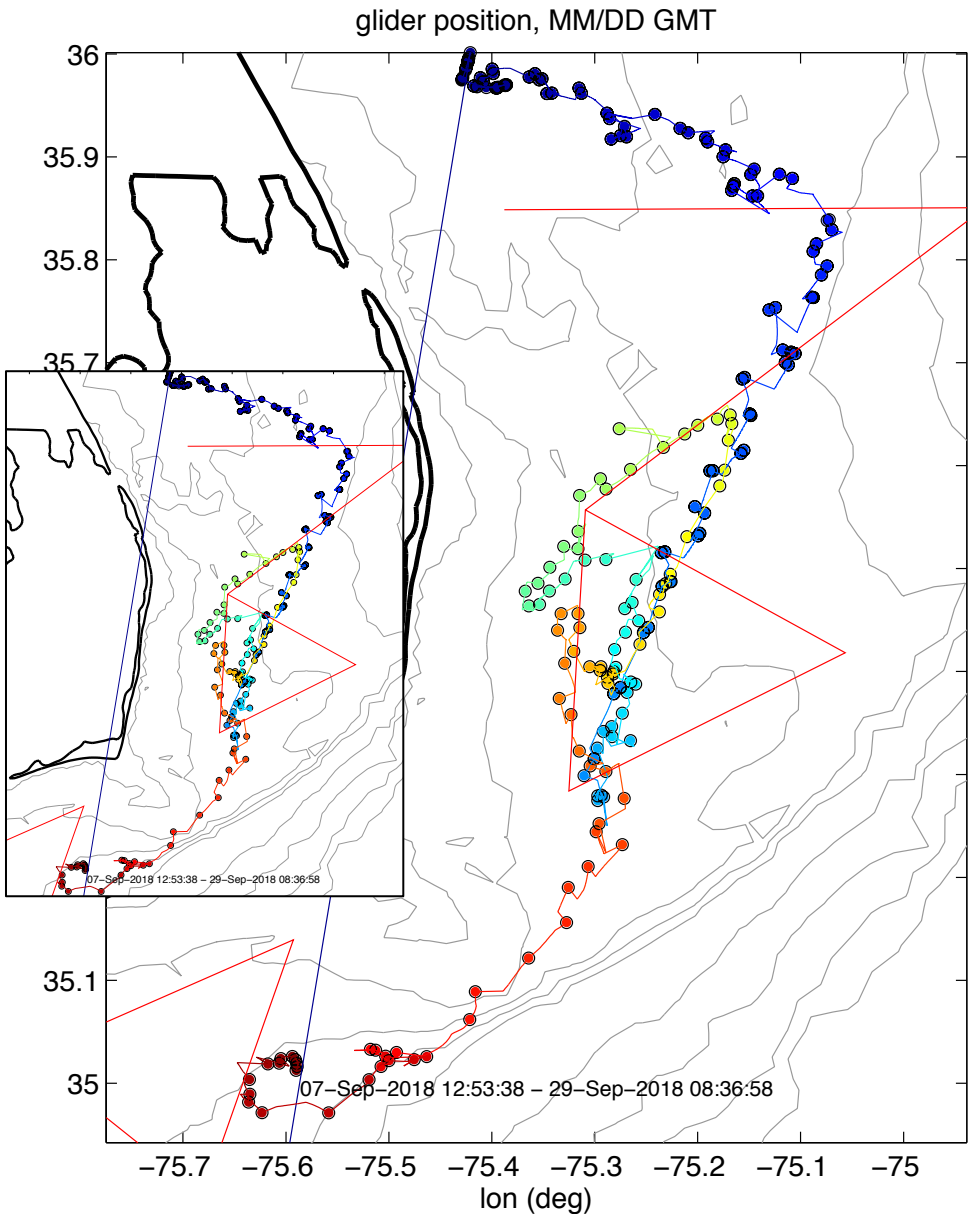
Pelagia, off SC/GA border @ Florence peak

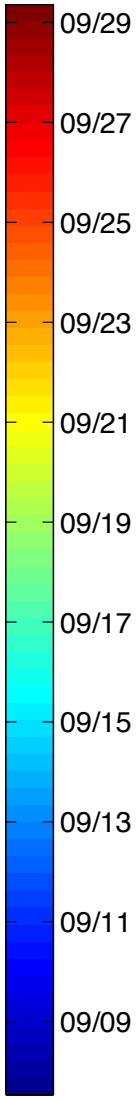


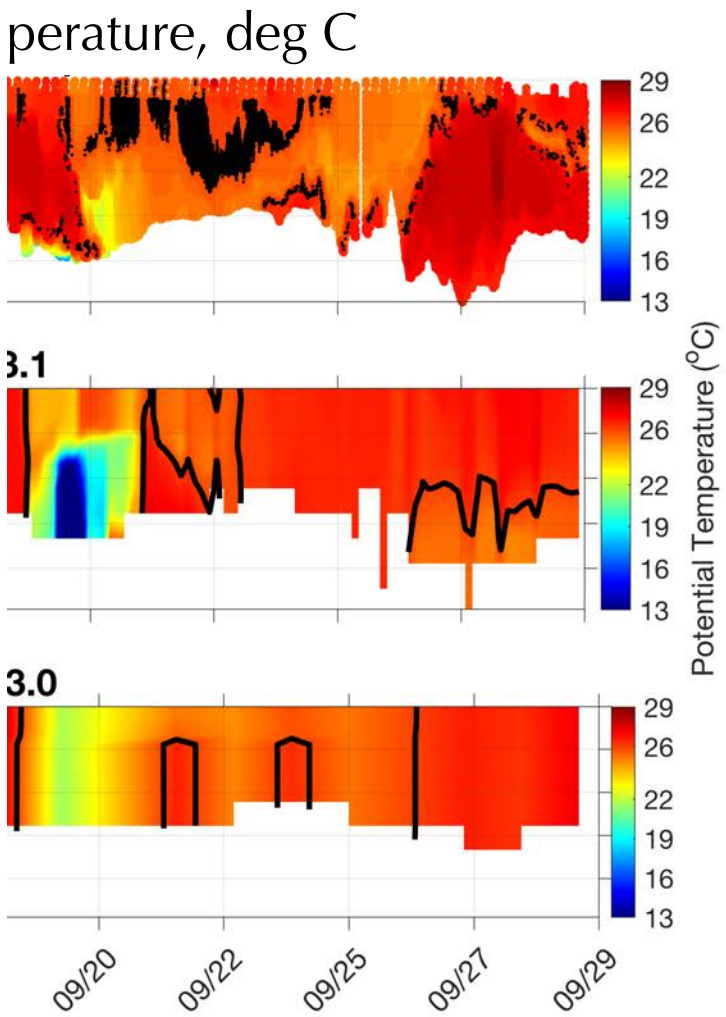


overall high; GOFS3.1>3.0

Ramses temperature time series



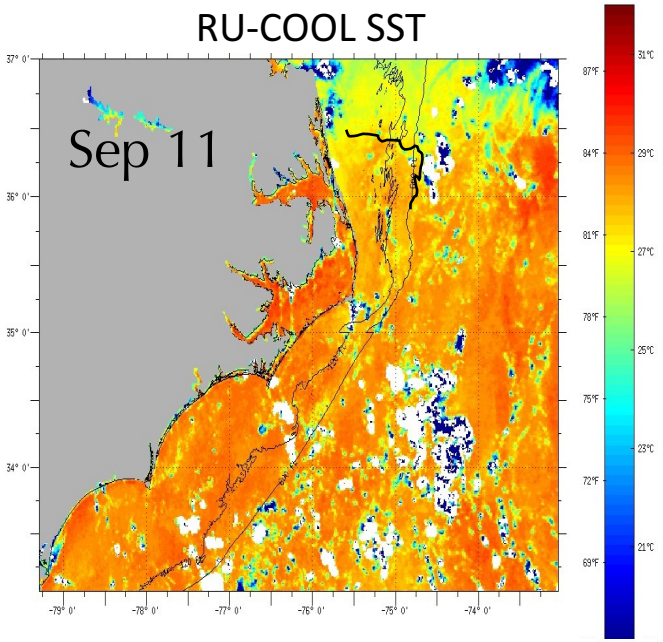


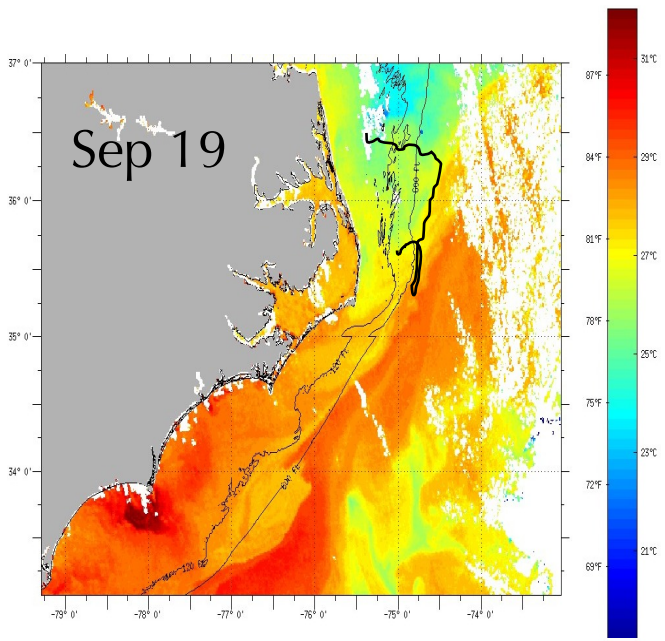


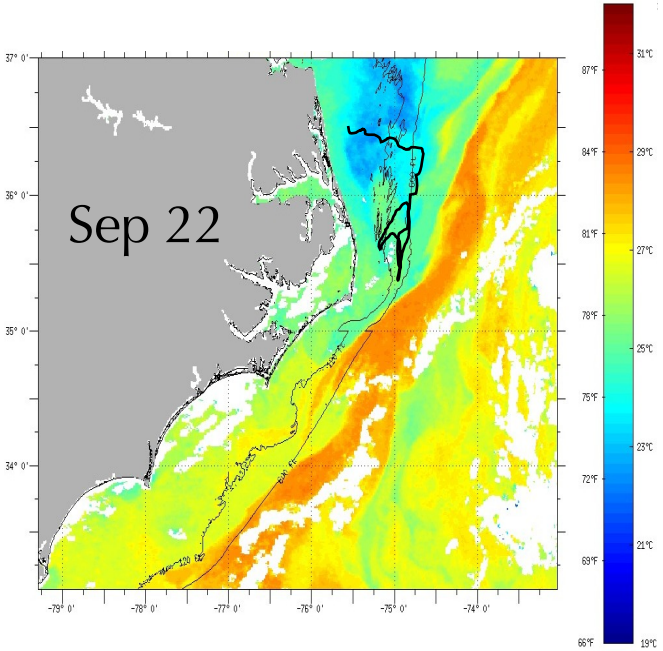
GS and Hatteras Fronts, vertical structure better but scale challenging

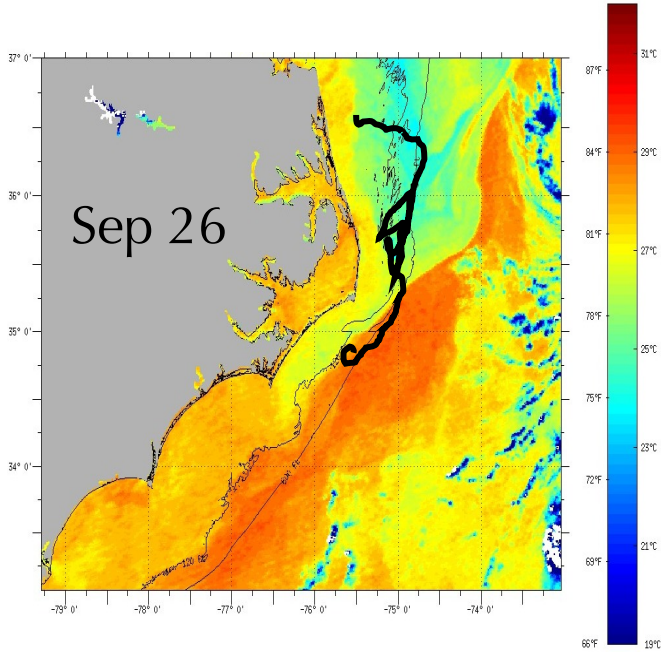
Getting the Gulf Stream right

RU-COOL SST





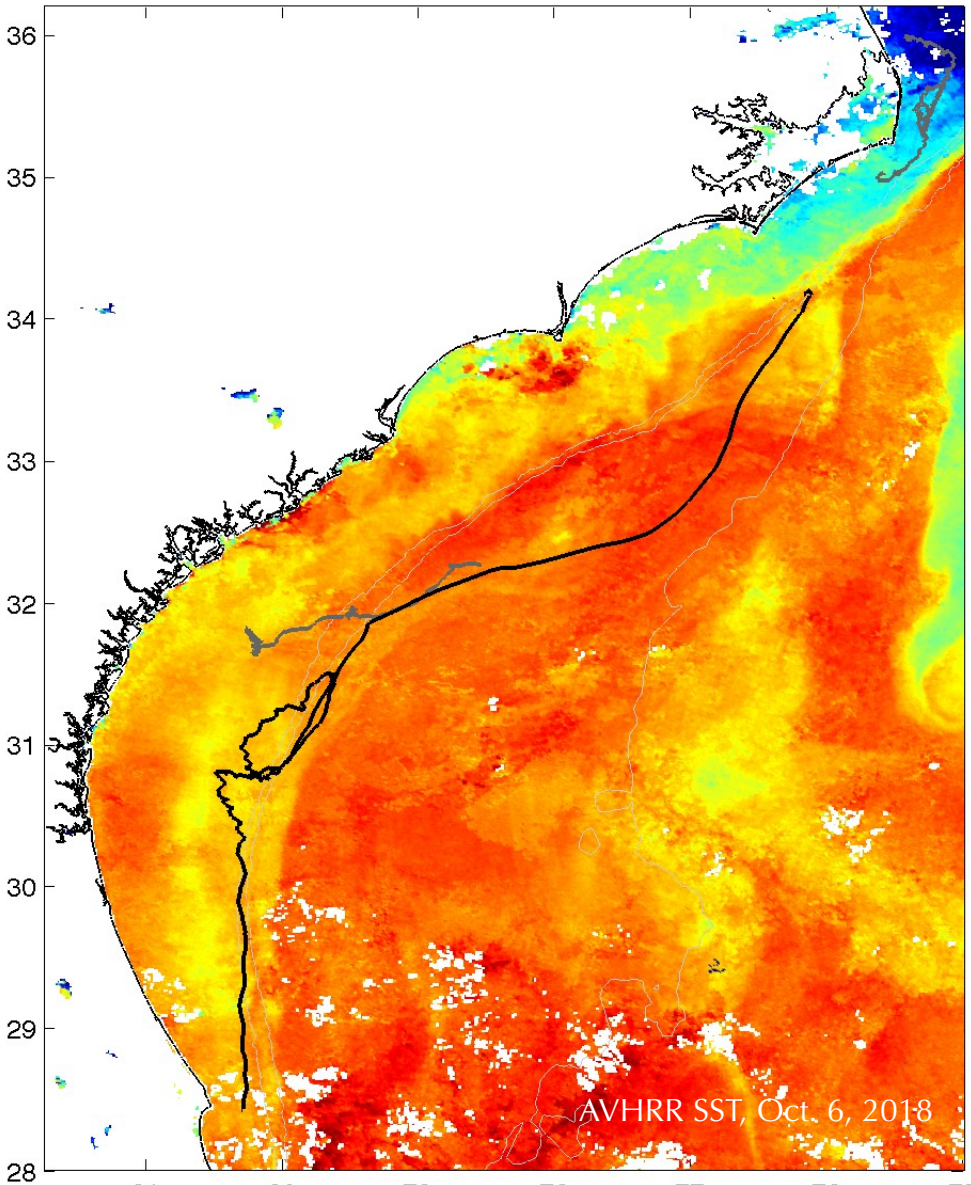




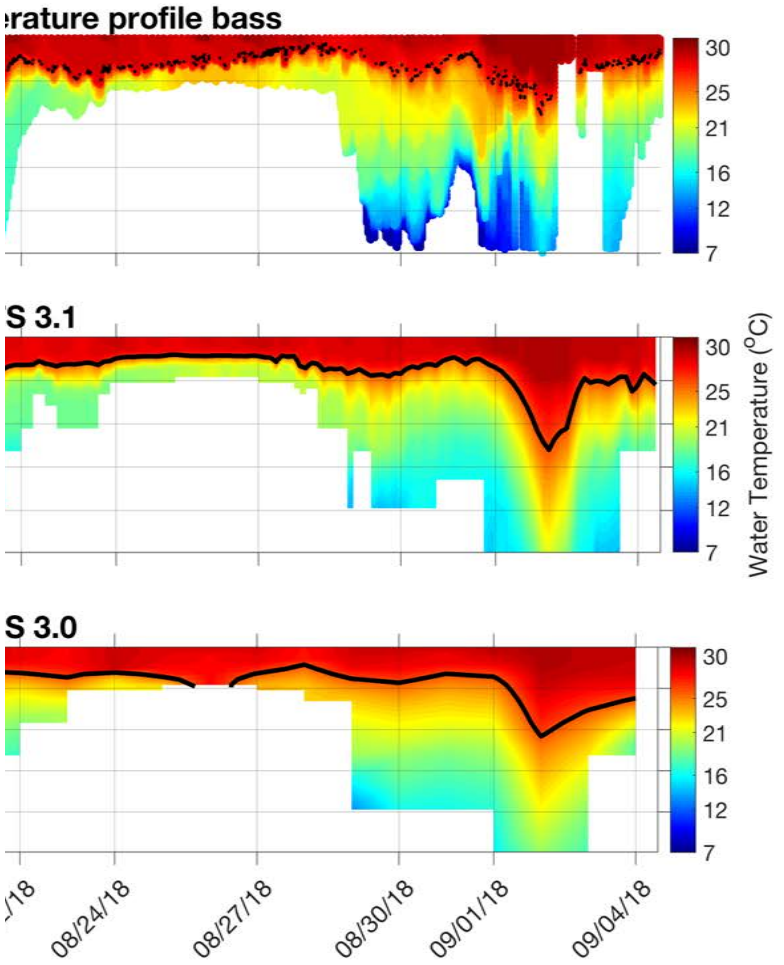
Gulf Stream front defines our coast, from FL to NC

Getting fronts right is essential for ocean forecast

Gulf Stream edge (Bass)

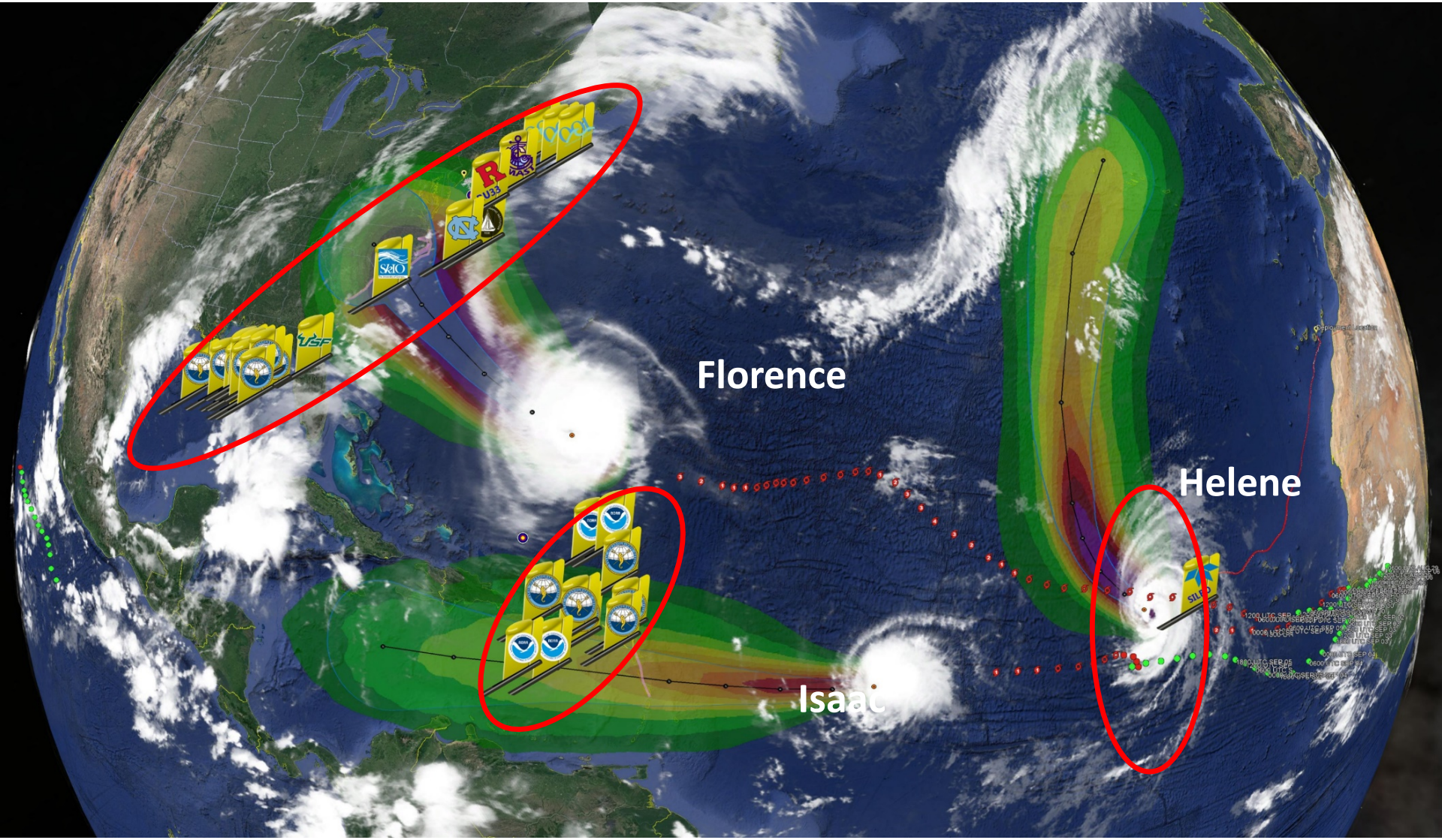


AVHRR SST, Oct. 6, 2018



ted, GOFS3.1>3.0
ve small-scale variability

Time series courtesy M. Aristizabal Vargas, Rutgers



~30 Hurricane Sentinel Gliders from the Navy, NOAA, NSF, Academic & Industry Partners reporting ocean conditions through the U.S. IOOS Glider Data Assembly Center (DAC) ahead of Hurricanes Florence, Isaac and Helene on September 11, 2018.

Hurricane Glider Picket Line Concept of Operations

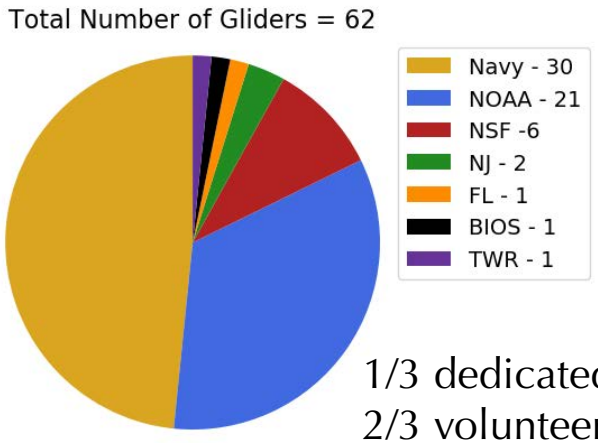
1) All gliders monitor Essential Ocean Features
2) Some gliders document Essential Ocean Processes during a storm
3) Full glider community involvement enabled by IOOS Glider DAC

Since 1946

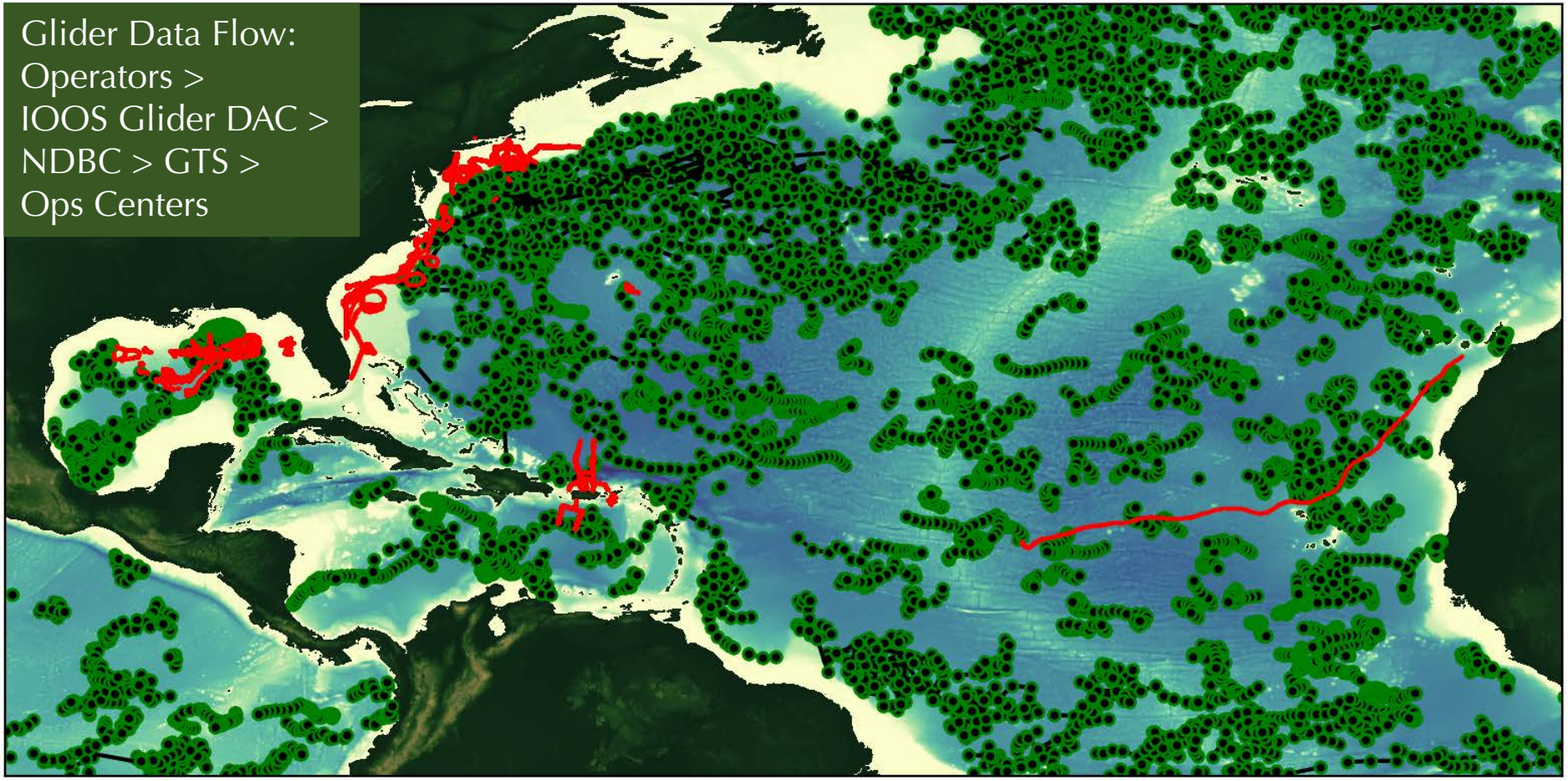
Since 2018

Glider Tracks & ARGO Floats
2018 Hurricane Season

Total number of Glider profiles = 123335
Total number of Argo profiles = 17264

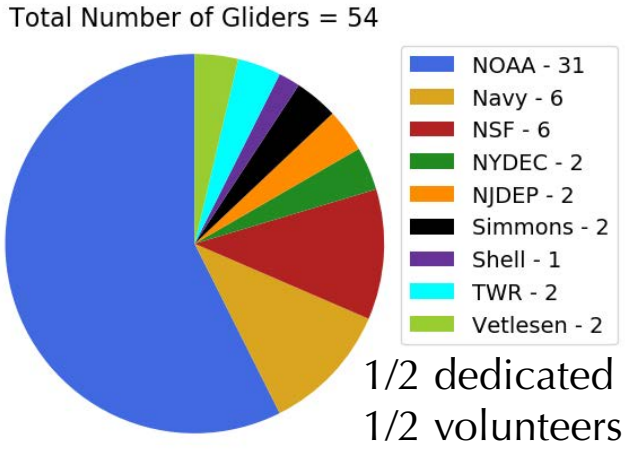


1/3 dedicated
2/3 volunteers

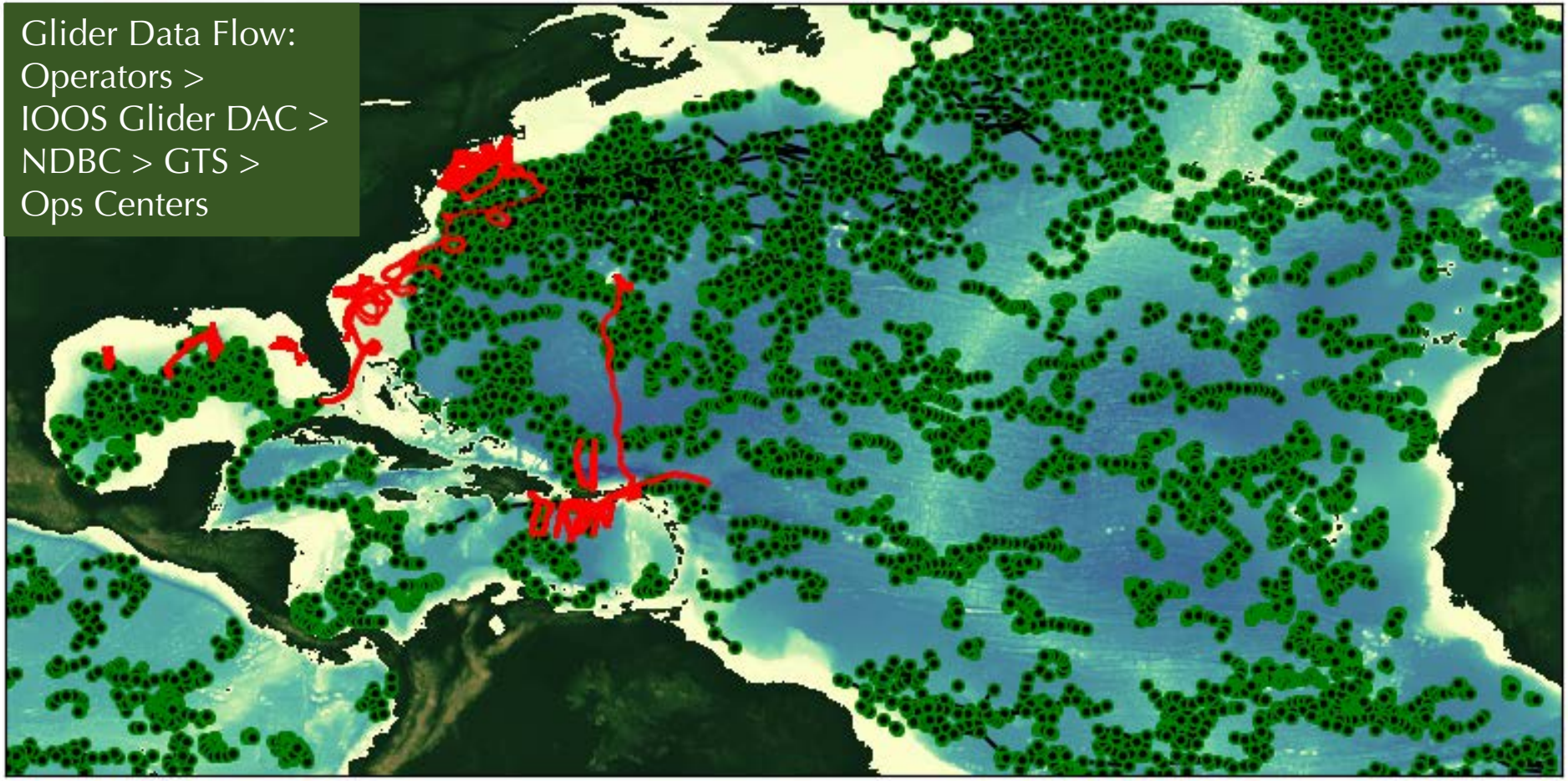


Glider Tracks & ARGO Floats
2019 Hurricane Season

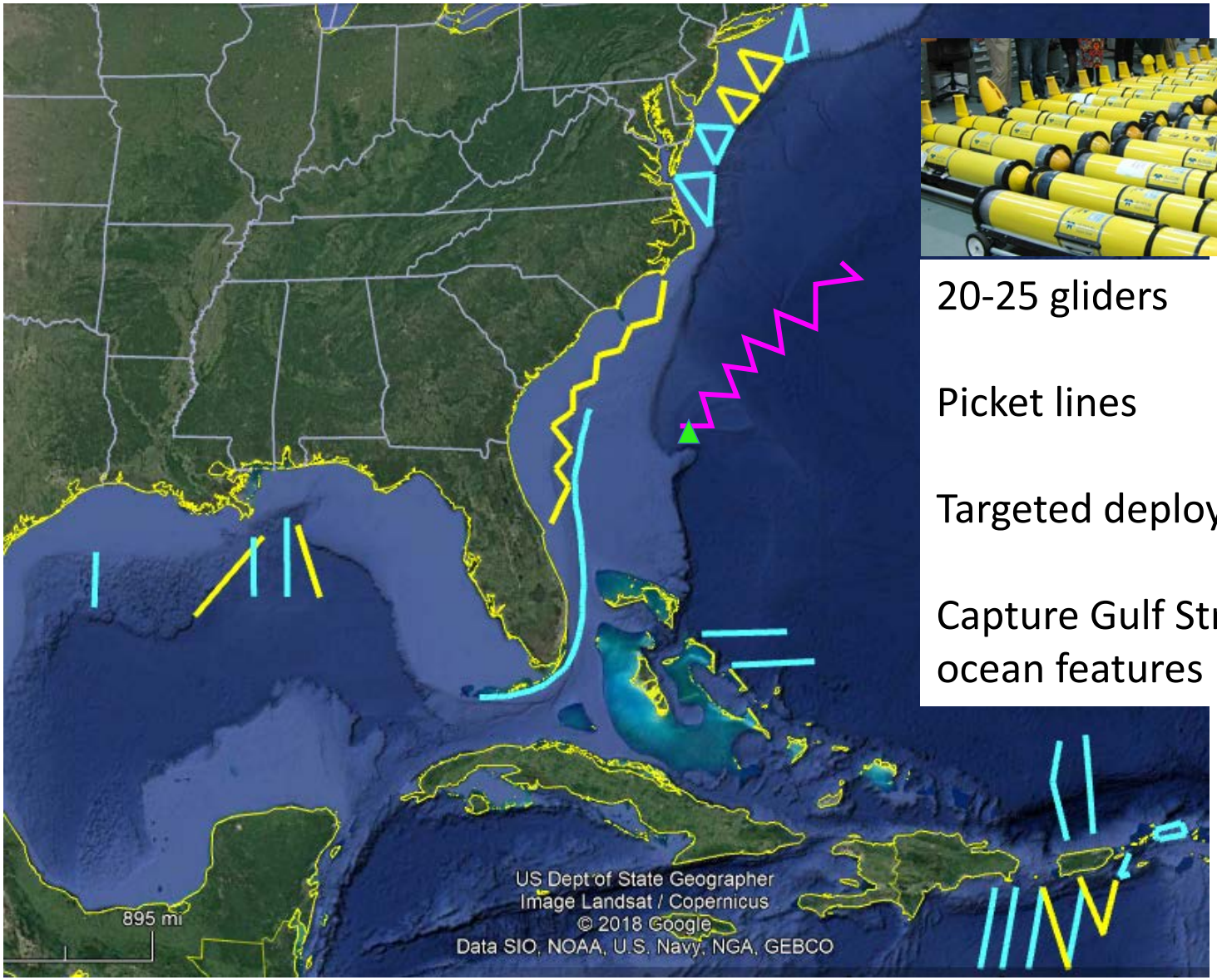
Total number of Glider profiles = 103511
Total number of Argo profiles = 13164



1/2 dedicated
1/2 volunteers



HurricaneGliders 2020 (getting ready!)



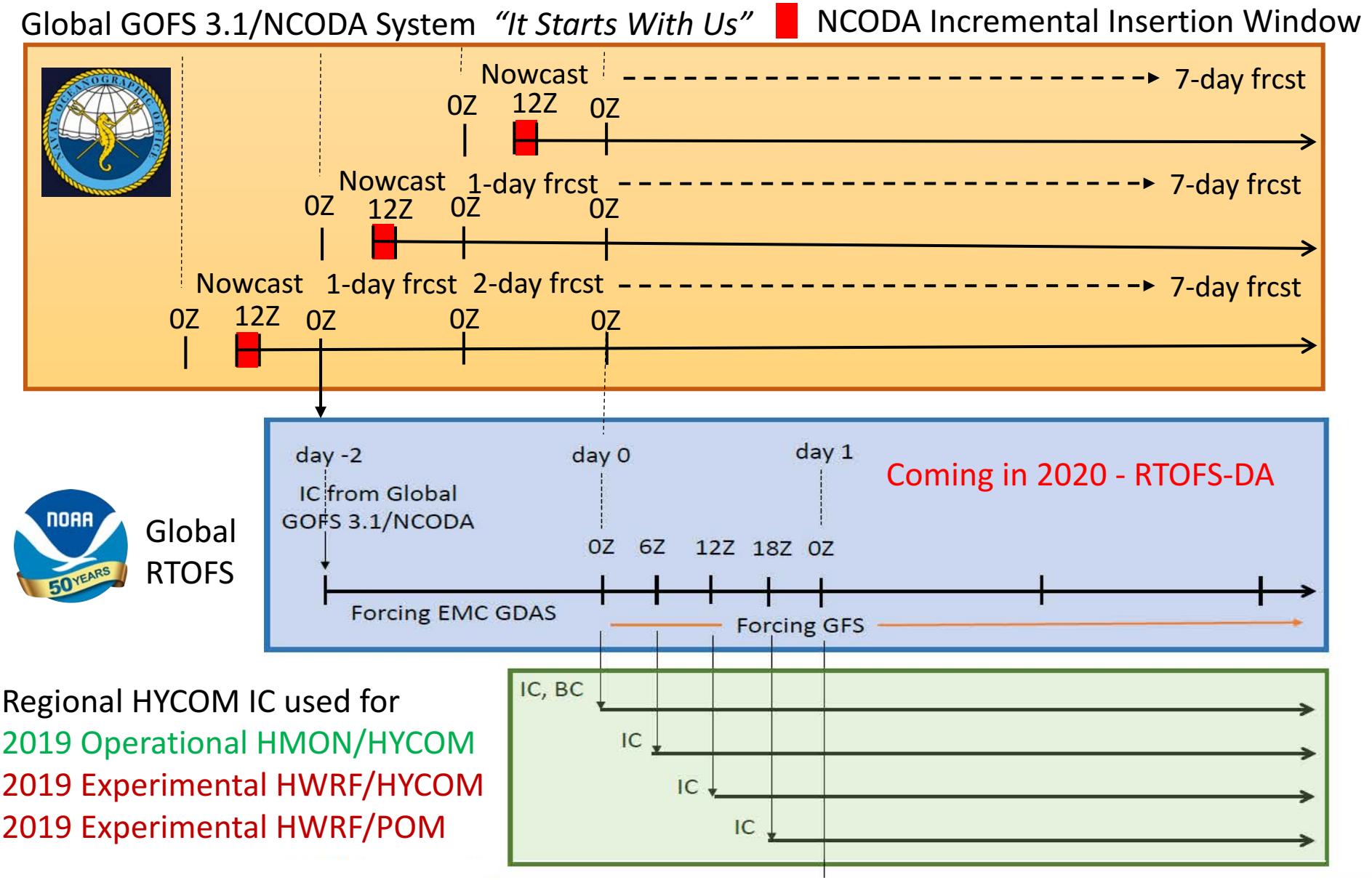
20-25 gliders

Picket lines

Targeted deploys

Capture Gulf Stream, essential ocean features

North Atlantic Hurricanes Ocean Forecast Work Flow



Regional HYCOM IC used for
2019 Operational HMON/HYCOM
2019 Experimental HWRF/HYCOM
2019 Experimental HWRF/POM

2019 Operational HWRF/POM initialized with ocean climatology modified by feature models

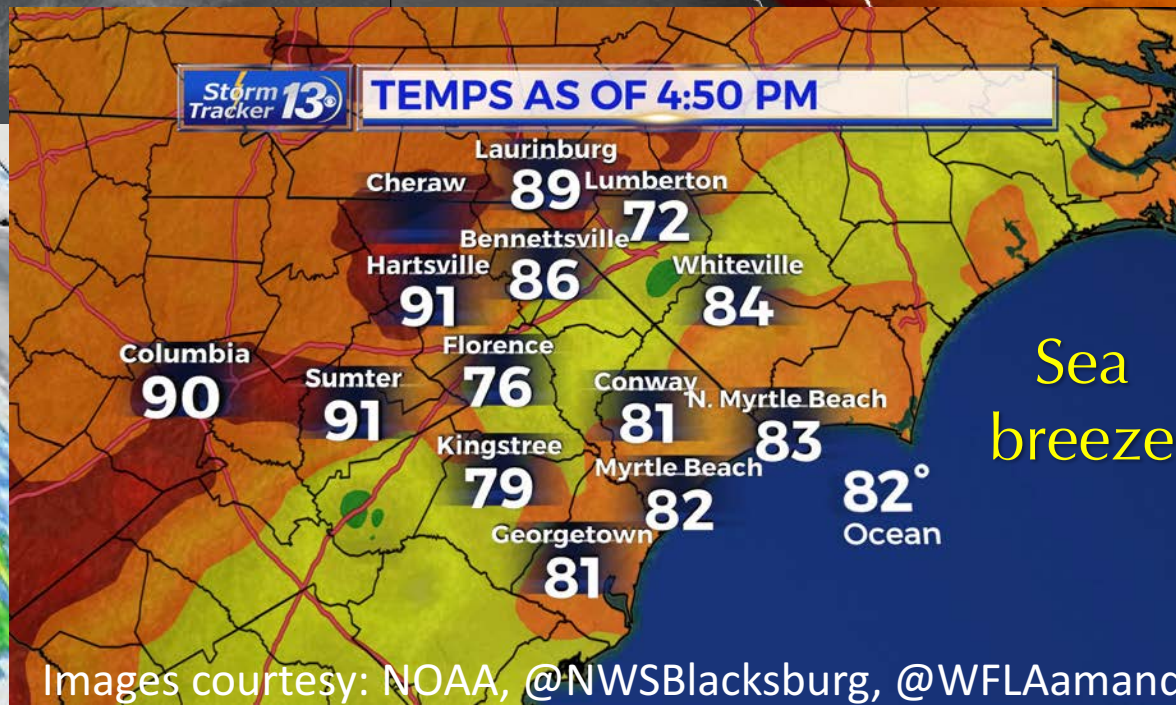
Beyond hurricanes

Bomb cyclones

Sting jets

Sting jet signature indicates very strong winds

Other weather systems



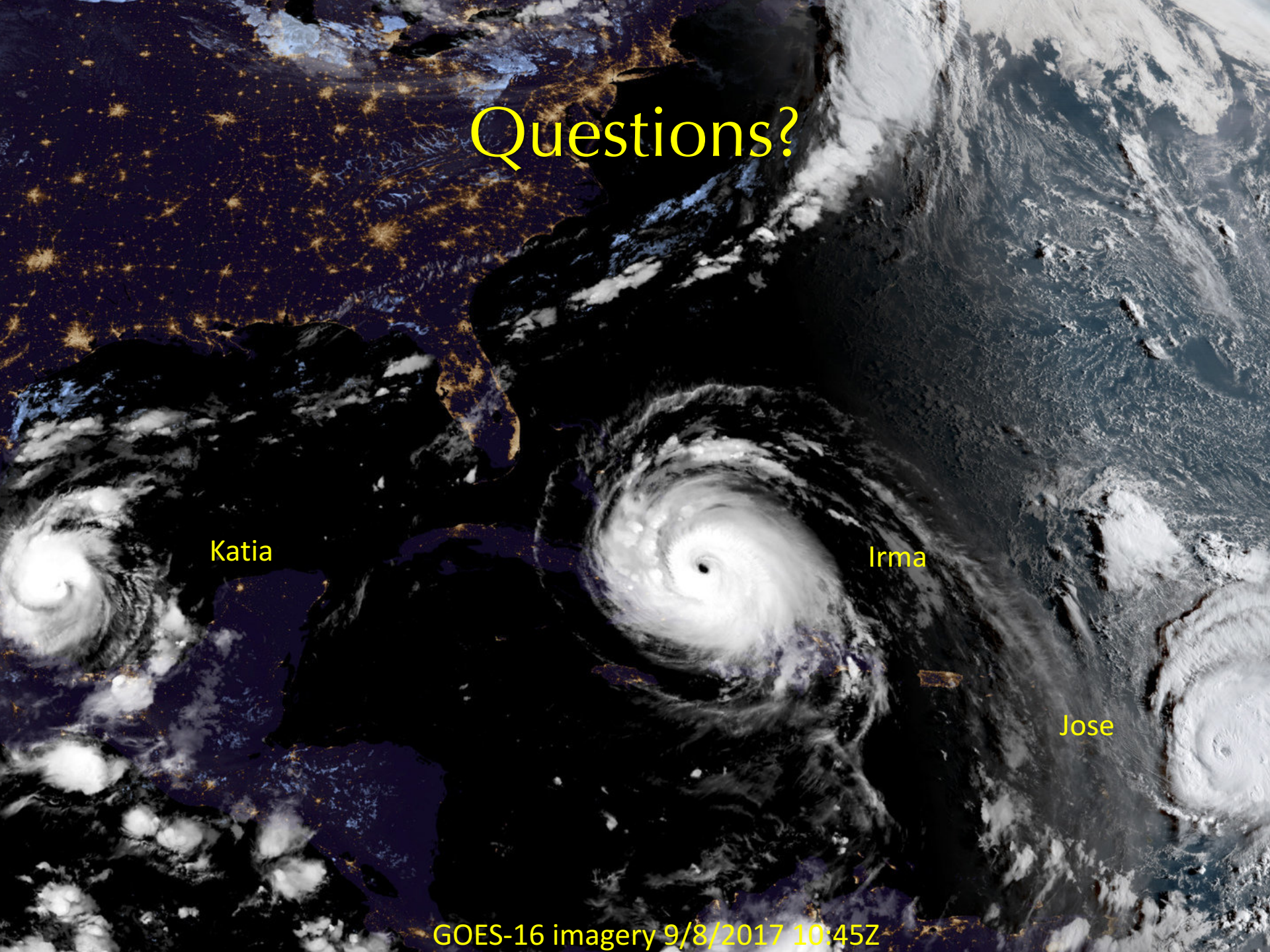
Sea breeze

Images courtesy: NOAA, @NWSBlacksburg, @WFLAamand

Larger role for gliders (and the ocean) in weather prediction

=

Tropical Cyclone Research Partnerships


Questions?
Katia
Irma
Jose
GOES-16 imagery 9/8/2017 10:45Z