Improving Hurricane Intensity Forecasts with Gliders

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Navy, NOAA, academic partners
Improving Hurricane Intensity Forecasts with Gliders

Volunteer/leveraged partnerships

RESEARCH
NOAA
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

IOOS | Integrated Ocean Observing System

Volunteer/leveraged partnerships
UH OH.

IT'S TIME TO RUN.

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:
[Color indicators for Hurricane, Trop Stm]

Warnings:
[Color indicators for Hurricane, Trop Stm]

Current wind extent:
### Billion-Dollar Weather and Climate Disasters: Summary Stats

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

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

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

Tropical Storm Dorian
Tuesday August 27, 2019
5 AM AST Advisory 12
NWS National Hurricane Center

Current information: ✖
Center location 13.5 N 60.7 W
Maximum sustained wind 50 mph
Movement WNW at 13 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:
The intensity problem
Warm ocean transfers heat and moisture into the atmosphere.

As the air cools it flows outward, but also down in the Eye Center.

Warm air rises rapidly.
What affects hurricane intensity?

Effects of Vertical Wind Shear on Hurricanes

No Vertical Wind Shear

Vertical Wind Shear

Courtesy NOAA/AOML
What affects hurricane intensity?

Sea Surface Temperature (SST)

Ocean heat feeds hurricanes but clouds can be problematic

Subsurface heat matters

Tropical Cyclone Heat Potential (TCHP): T ≥ 26 deg C

Courtesy Rutgers, WHOI
What affects hurricane intensity?

Goni et al., 2019

Salinity matters, too!

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.

Avila & Cangialosi, 2012,
Tropical Cyclone Report
WHAT?
Satellite SST

WHEN?
Glider Temperature

WHY?
HF Radar Currents

Pre-Irene

Post-Irene

11C max Cooling

11C max Cooling

Eye Passage

Surface Current Field: 2011-Aug 28 06:00 GMT

MARACOOS
Ocean Information for a Changing World

IOOS Integrated Ocean Observing System
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

Without gliders

With gliders

Hurricane wind model

Without gliders

With gliders

Δ (storm surge)

Difference Irene warm – cold

ADCIRC/WRF Vs. Obs Water Level Irene detided

The Battery
But TCHP is 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

- Loop Current, Eddies, Fresh Water
- Warm Pool, Upper Ocean Heat Content, Fresh Water Barrier Layers
- Heat & Fresh Water Inflow
- Seasonal Stratification, Cold Pool
- Gulf Stream, Shelf
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
Hurricane Florence deployments

Glider: Ramses, deployed Fri. 9/7 off Cape Hatteras

Glider: Pelagia, deployed Mon. 9/10 off Hilton Head

Glider: Bass, recovered Wed. 9/5 off Wilmington, NC

Gliders' position
10am Sept. 12, 2018
(~24 hours before landfall)
Ramses, off Cape Hatteras @ Florence peak

Stratification underpredicted, salinity overall high, GOFS3.1>>3.0
Pelagia, off SC/GA border @ Florence peak

Stratification overpredicted, salinity overall high; GOFS3.1>3.0

AVHRR SST, Oct. 6, 2018

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

Gulf Stream front defines our coast, from FL to NC

Getting fronts right is essential for ocean forecast
Gulf Stream edge (Bass)

Stratification underpredicted, GOFS3.1 > 3.0 but both models unable to resolve small-scale variability

AVHRR SST, Oct. 6, 2018

Temperature profile bass

S 3.1

S 3.0

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
Glider Tracks & ARGO Floats
2018 Hurricane Season

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

Glider Data Flow:
Operators >
IOOS Glider DAC >
NDBC > GTS >
Ops Centers

1/3 dedicated
2/3 volunteers

Total Number of Gliders = 62

- Navy - 30
- NOAA - 21
- NSF - 6
- NJ - 2
- FL - 1
- BIOS - 1
- TWR - 1
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

Glider Data Flow:
Operators >
IOOS Glider DAC >
NDBC > GTS >
Ops Centers
HurricaneGliders 2020 (getting ready!)

- 20-25 gliders
- Picket lines
- Targeted deploys
- Capture Gulf Stream, essential ocean features
North Atlantic Hurricanes Ocean Forecast Work Flow

Global GOFS 3.1/NCODA System “It Starts With Us”  NCODA Incremental Insertion Window

Global RTOFS

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

Other weather systems

Images courtesy: NOAA, @NWSBlacksburg, @WFLAamanda
Larger role for gliders (and the ocean) in weather prediction
Tropical Cyclone Research Partnerships

Drawn from an expanding global network of 58 institutions

Thank you!