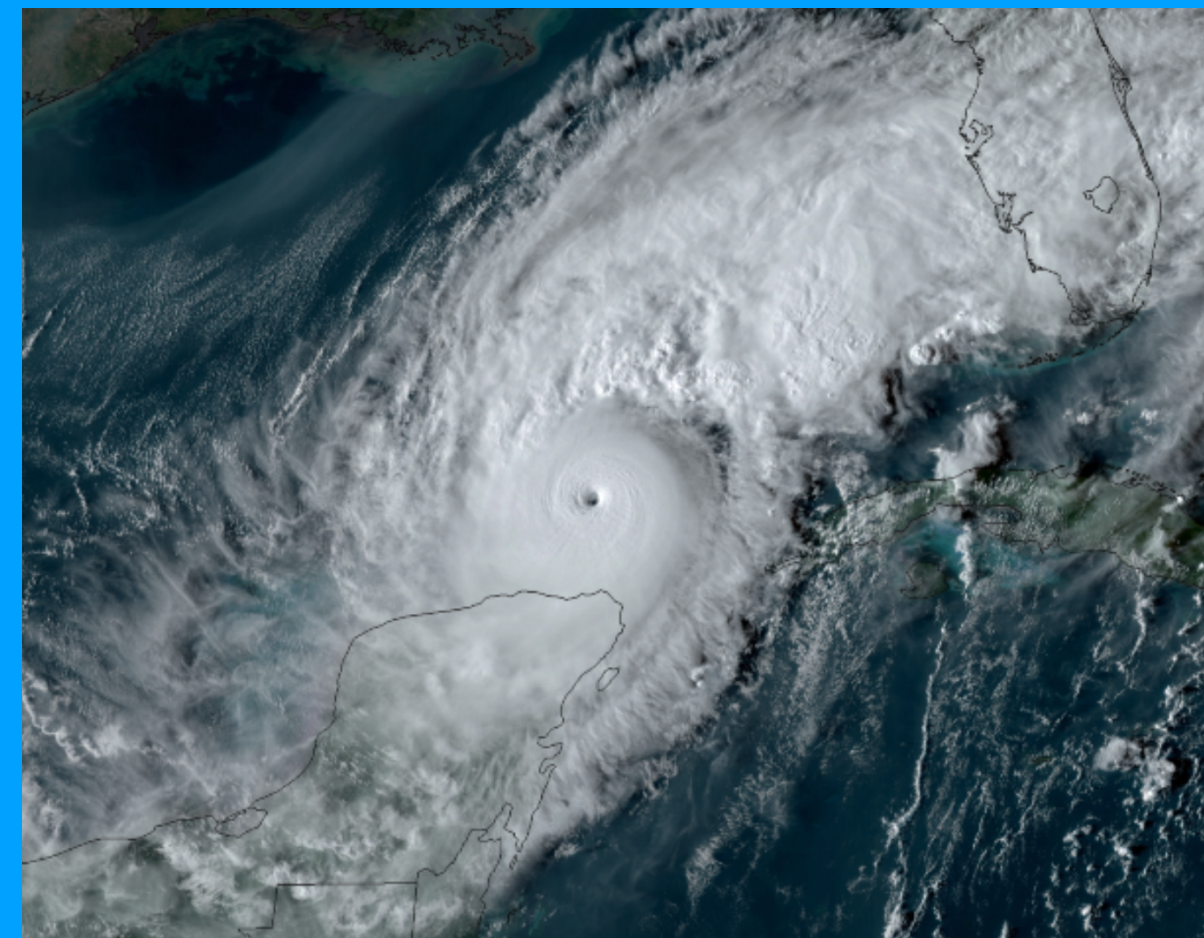
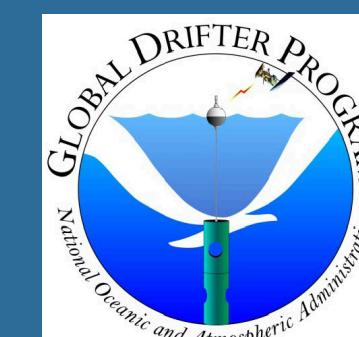


Atlantic Hurricane Observations by Directional Wave Spectra Drifters 2018-2024

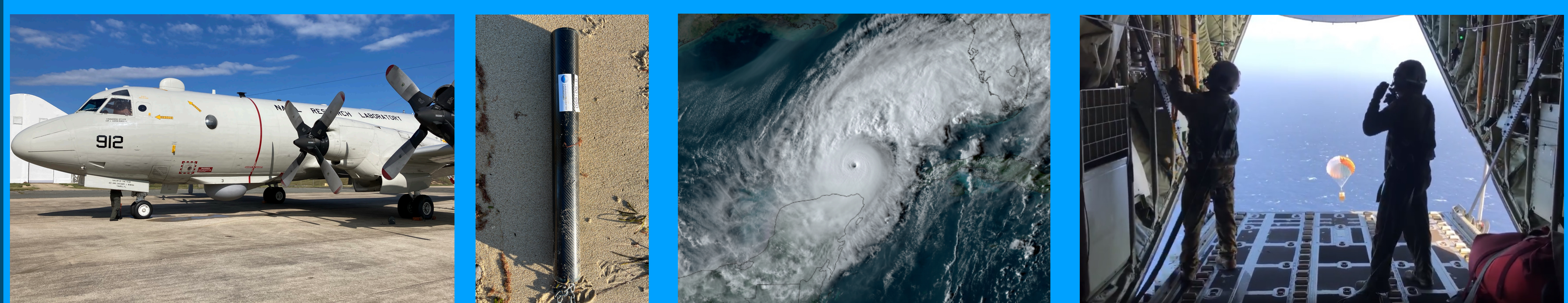


**Martha Schöнау, Luca Centurioni,
Terri Paluszkievicz**
**Lagrangian Drifter Laboratory,
Scripps Institution of Oceanography**
International Meeting on Waves and Storm Surge,
University of Cantabria, Santander, Spain, 22 September 2025



Atlantic Hurricane Observations by Directional Wave Spectra Drifters 2018-20~~24~~ 2025

what we have learned



Martha Schöнау, Luca Centurioni,
Terri Paluszkievicz
Lagrangian Drifter Laboratory,
Scripps Institution of Oceanography
International Meeting on Waves and Storm Surge,
University of Cantabria, Santander, Spain, 22 September 2025

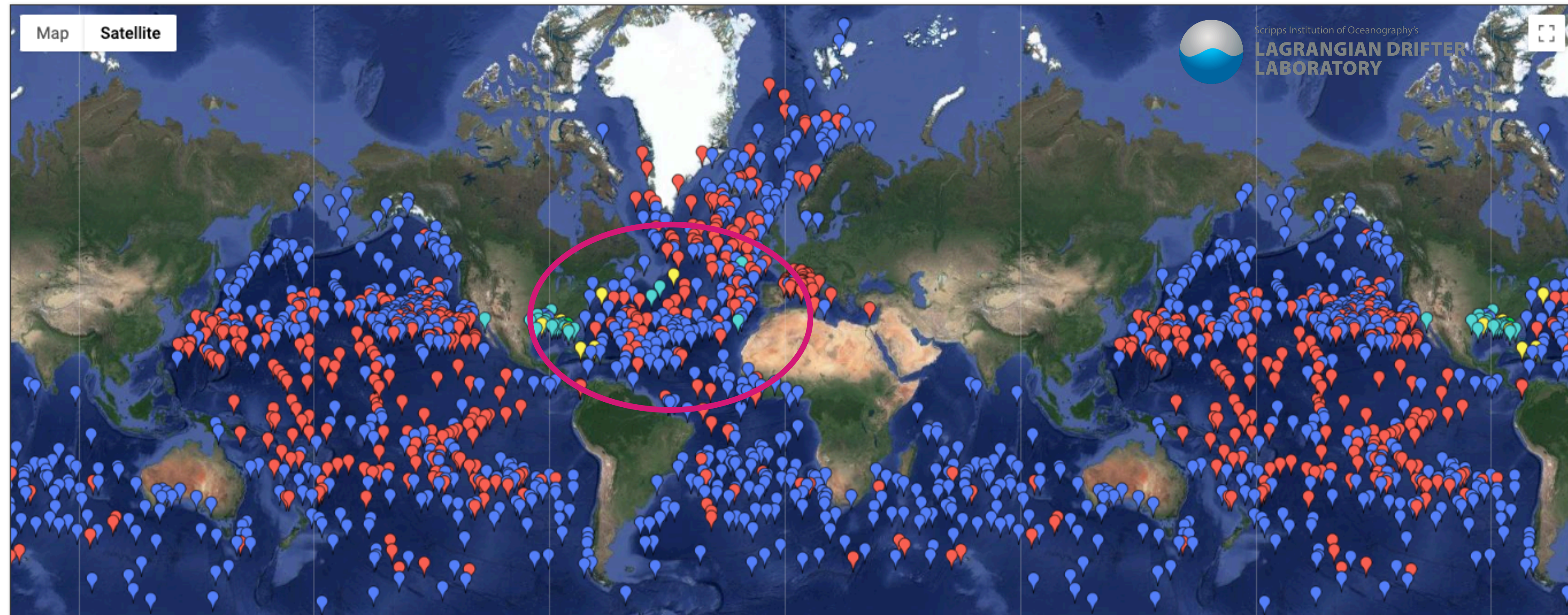




- **Directional wave spectra drifters: sustain, adapt and target**
- **Resolving directional wave spectra across hurricanes**
- **Sampling importance: spectral resolution and quality control**
- **Data is available via ERDDAP server . . .**

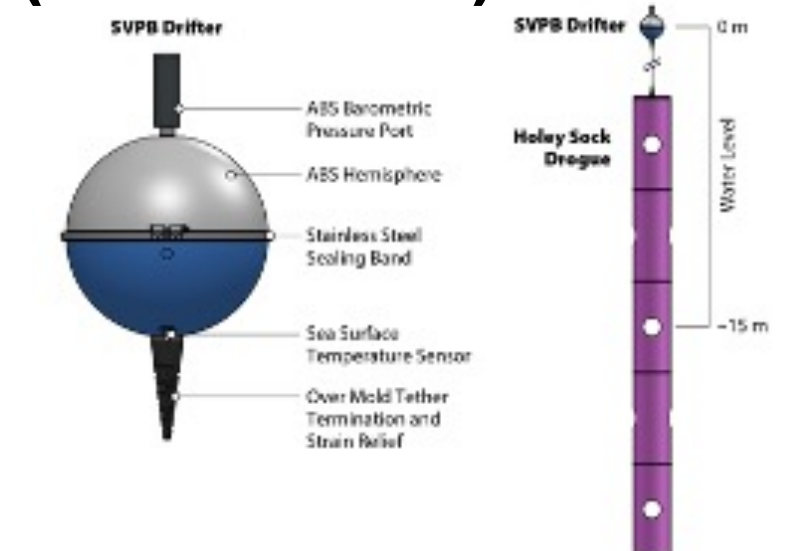
DRIFTER SCIENCE AT THE AIR-SEA INTERFACE

<https://ldl.ucsd.edu>



- Ocean surface velocity
- Sea surface temperature
- Sea level pressure (blue)
- Wave conditions
- Surface winds
- Mixed-layer structure

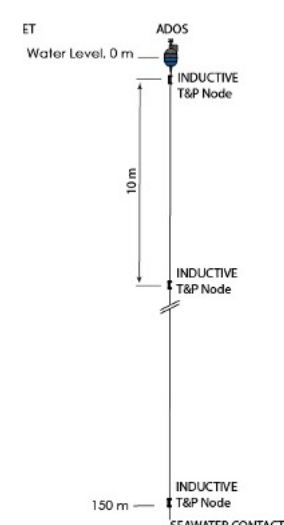
Surface Velocity Program (SVP/SVPB) Drifters



Atmospheric data,
currents, SST

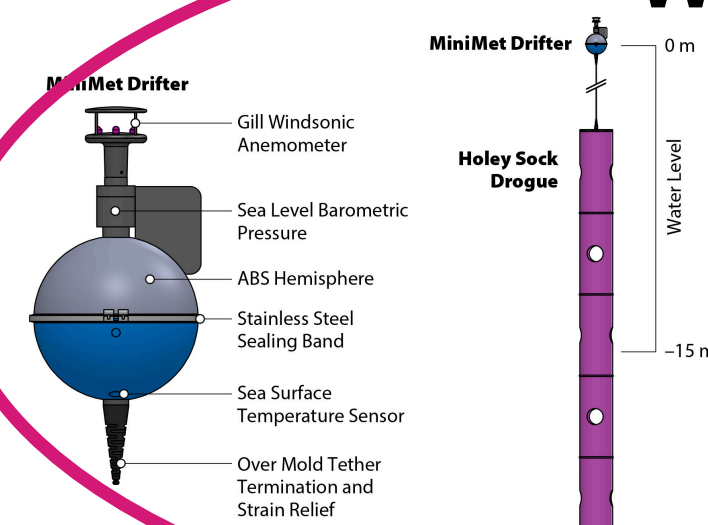
ADOS

Atmospheric and
Upper Ocean Heat
Content



WIND!

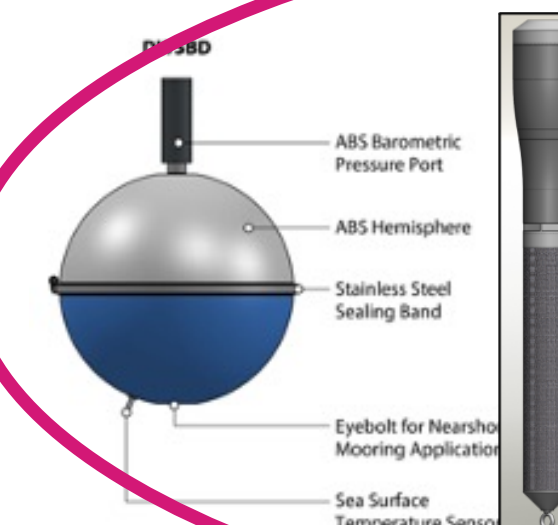
MiniMet
Atmosphere and
currents (SLP and
winds, SST)



WAVES!

**Directional Wave Spectra
Drifters (DWSD)**

Atmosphere and
waves, SST



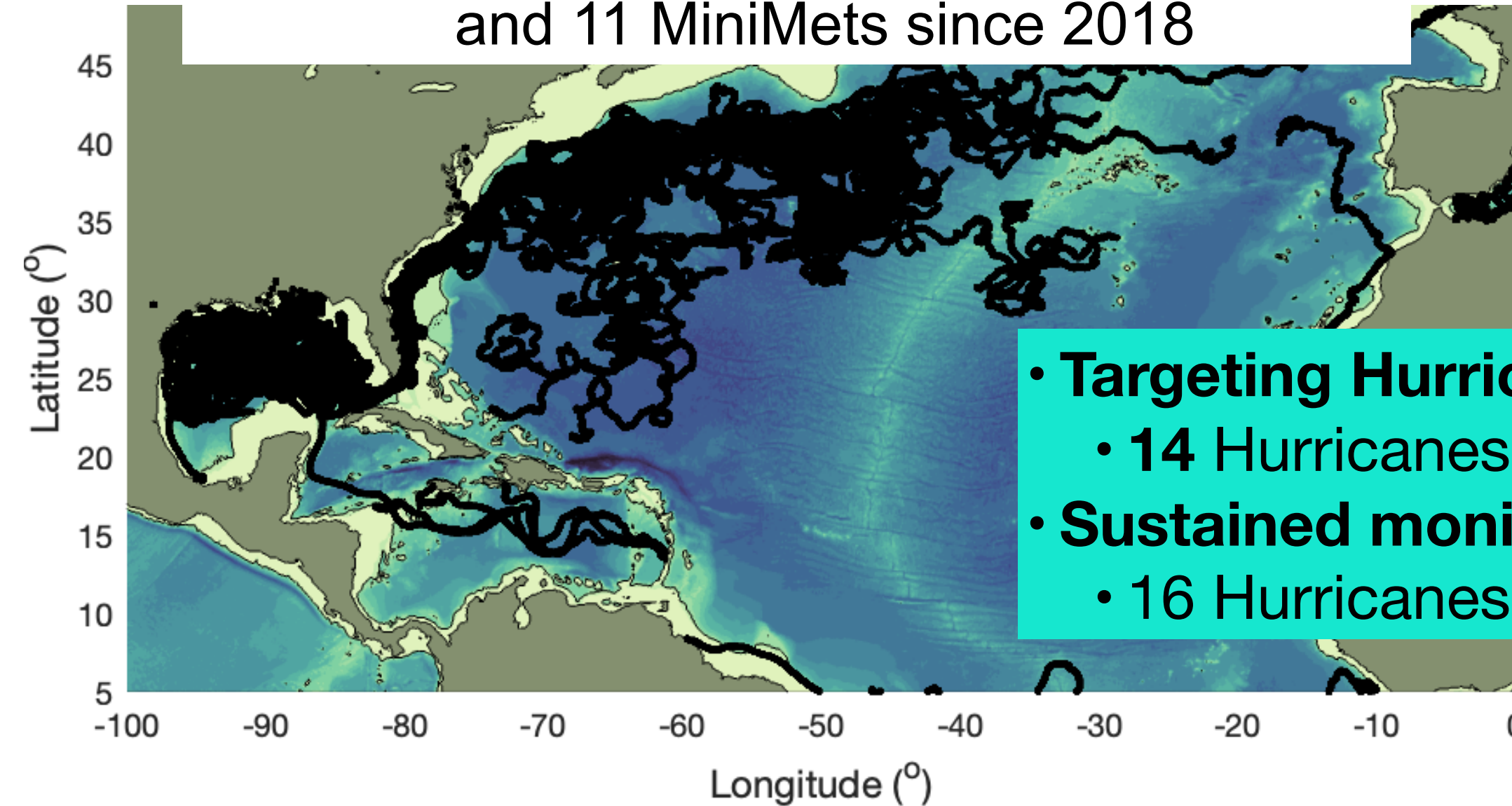
Lagrangian Drifter Lab: A-DWSD/Full-size DWSD

DWSD Buoys: Waves, SST, Barometer, Wind

- GPS wave buoy
- Deliver “first-five”
- Adaptive sampling
- SST, optional barometer



230 Hurricane DWSBD/ADWSD/ADWSBD and 11 MiniMets since 2018



- **Targeting Hurricanes:**
 - 14 Hurricanes - 2018-2025
- **Sustained monitoring:**
 - 16 Hurricanes ~6 Tropical Storms

2003 2005

2015

2018

2019

2021

2022

2024

CBLAST

DWSDs developed,
global barometer

DWSDs released to global array

DWSD targeting of
hurricane (Hurricane
Michael)

Targeting of
Atmospheric
River, DWSBD

Release of
A-DWSD

Targeting of
Hurricane Ian
with ADWSD

ADWSBD

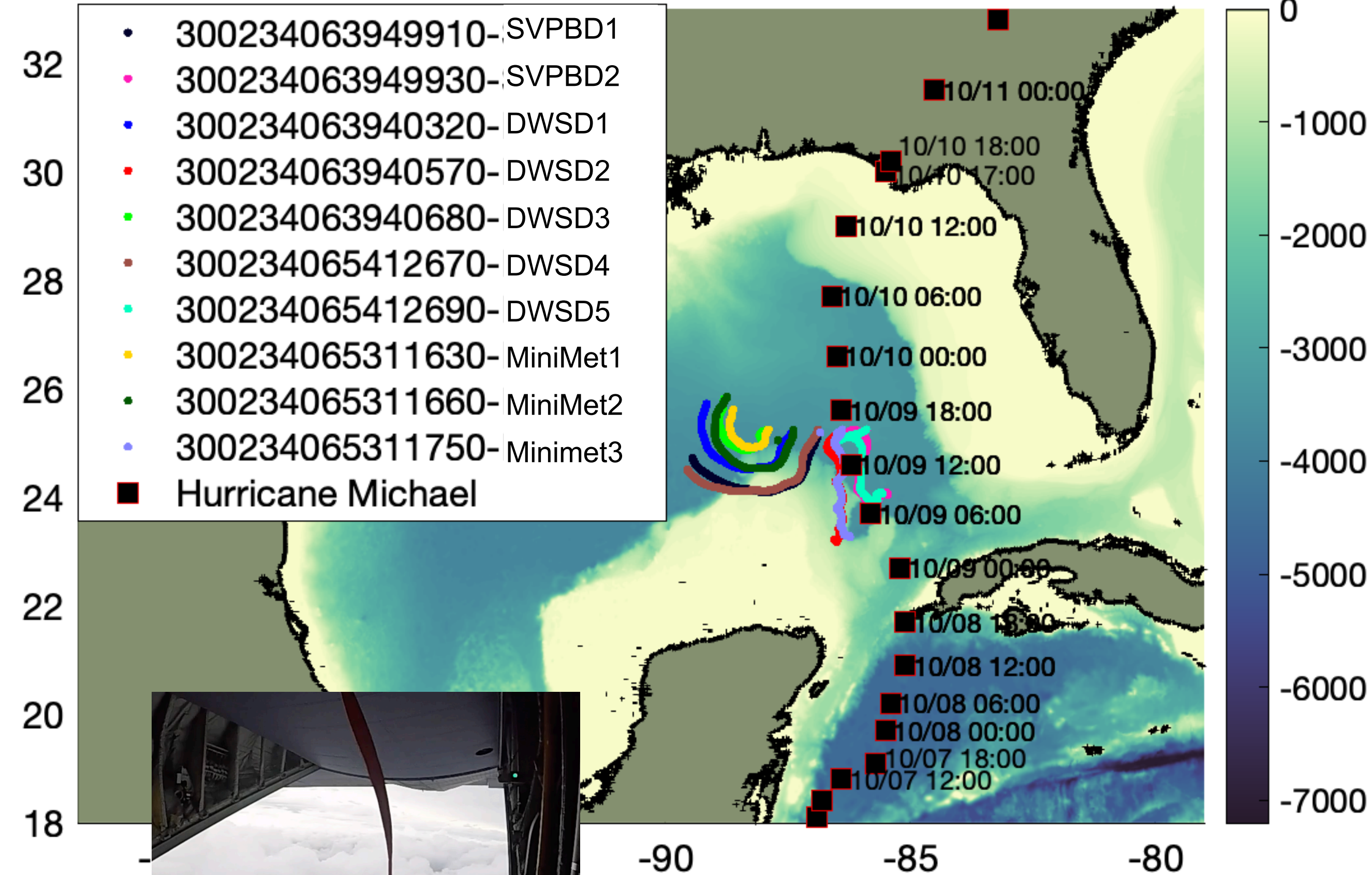


Photo: Steve Jayne



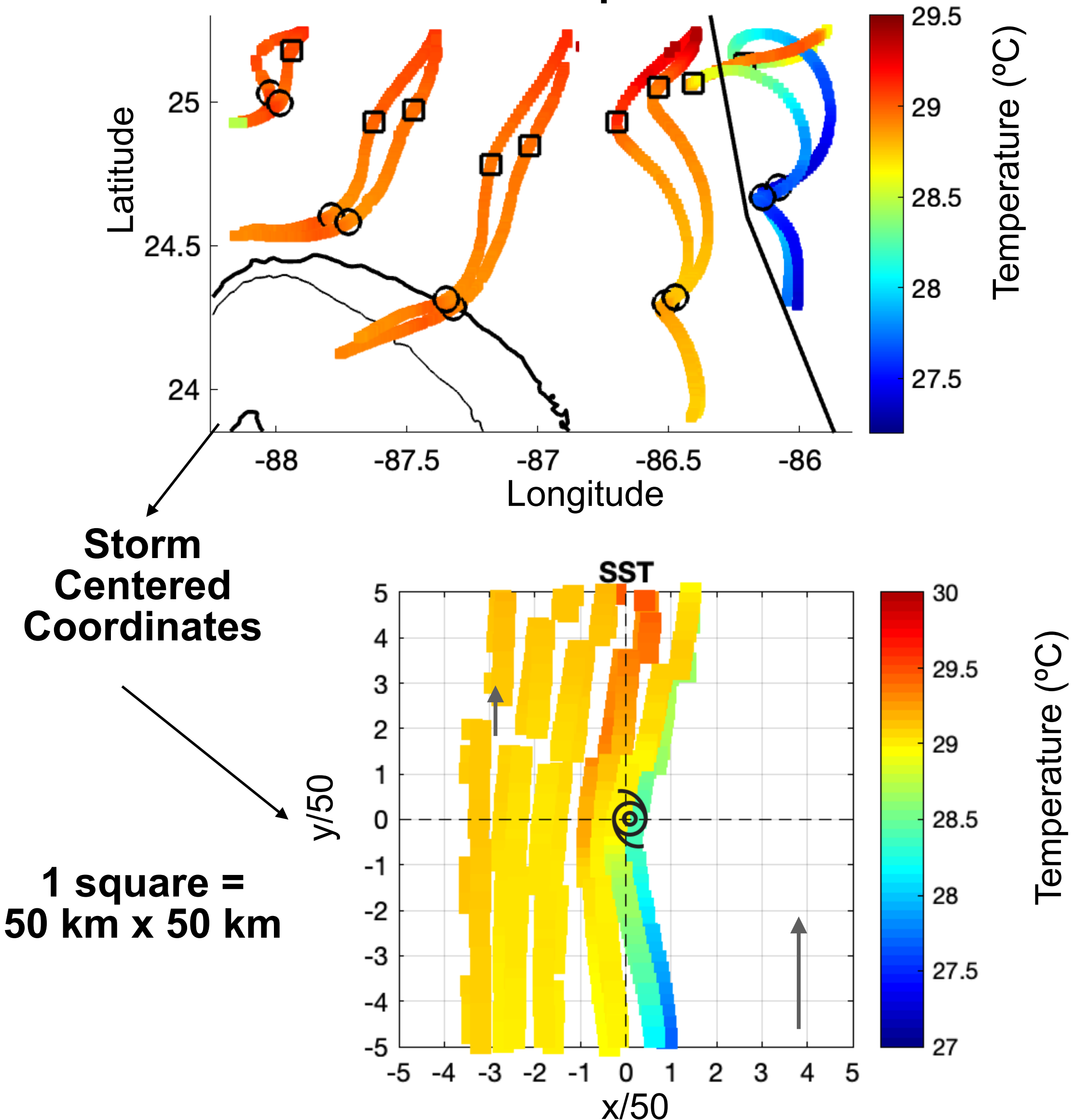
TARGETED ARRAYS: HURRICANE MICHAEL (2018)

Michael and Drifters: 2018-10-07 to 2018-10-15



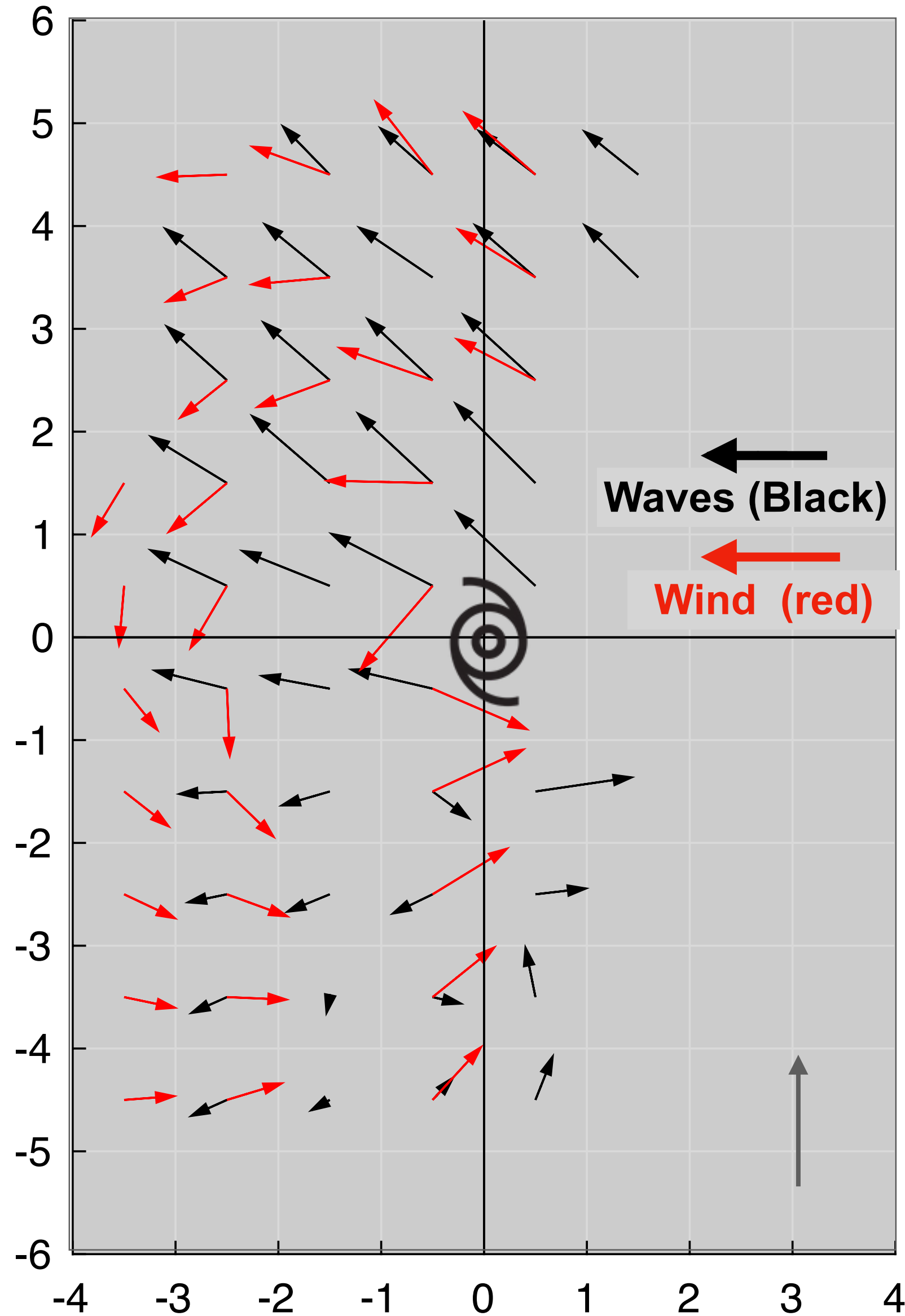
Schönau et al, GRL, 2024

Sea surface temperature

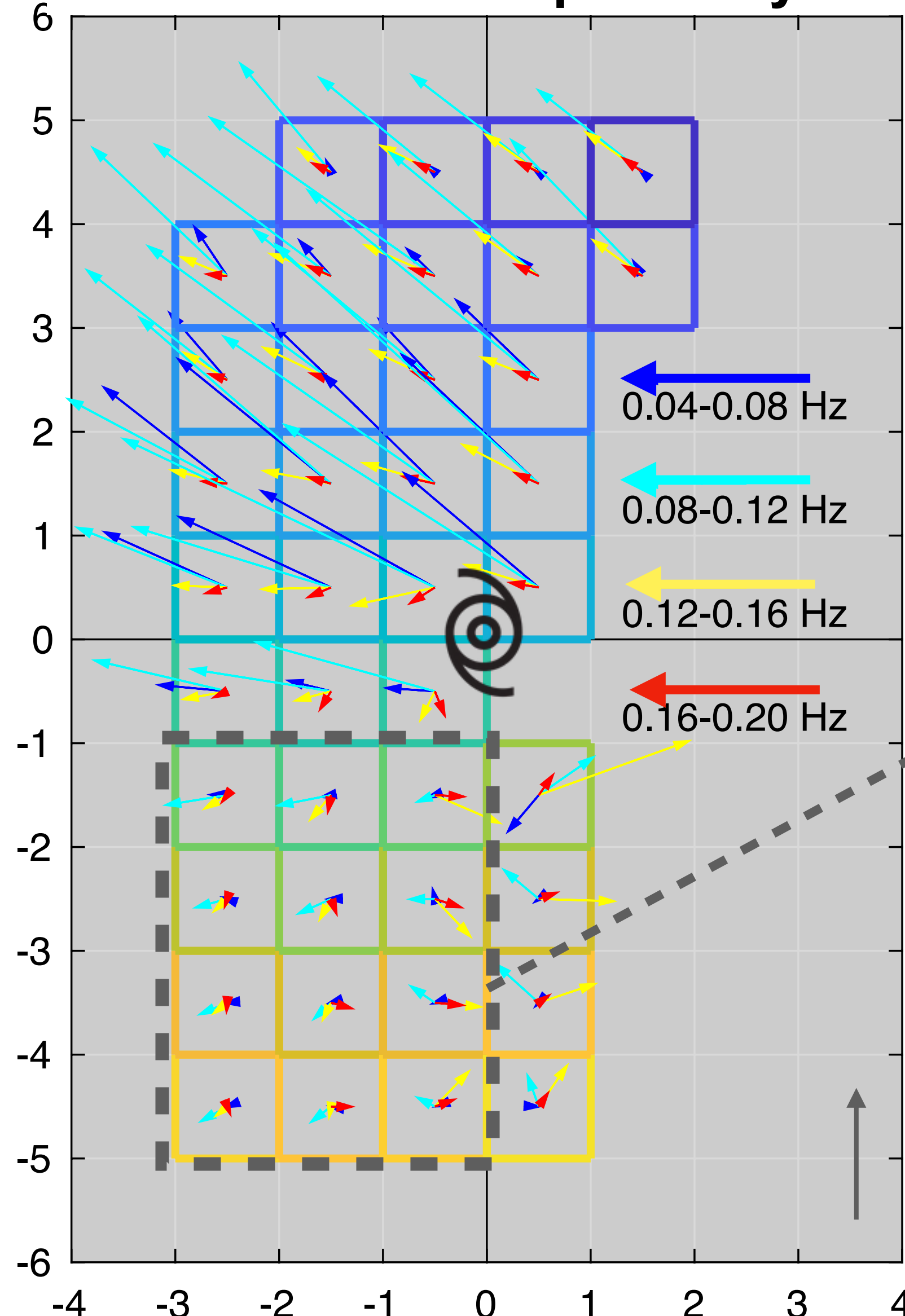


HURRICANE MICHAEL: DIRECTIONAL WIND AND WAVES

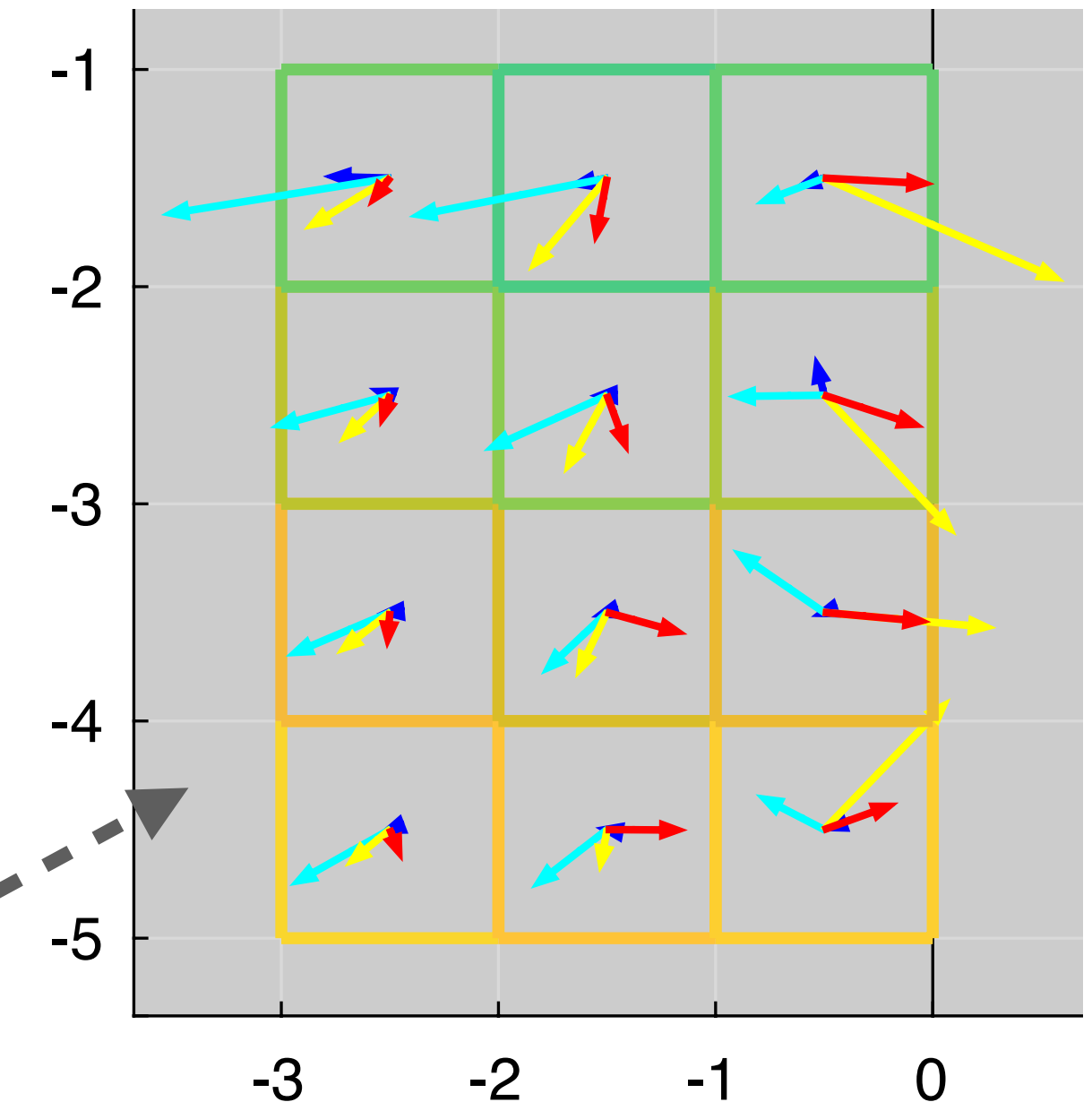
Mean Wind and Waves



Directional Wave Spectra by Bin



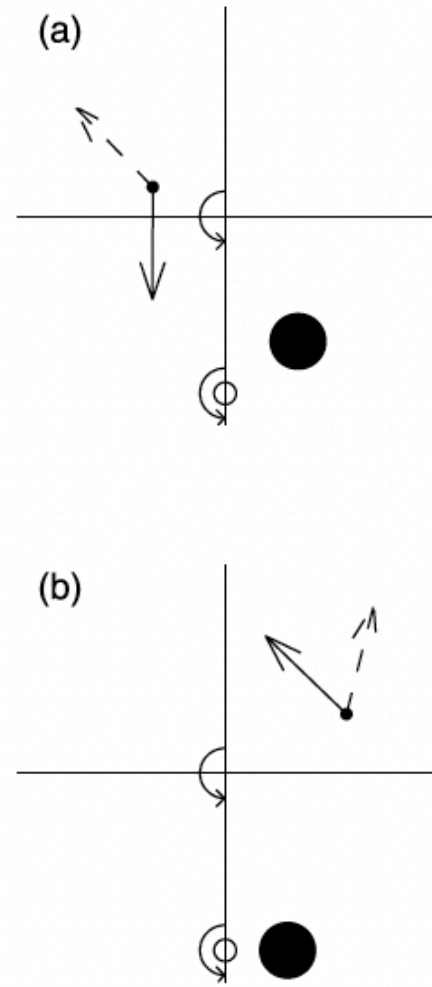
1 square =
50 km x 50 km
Rear-Quadrant



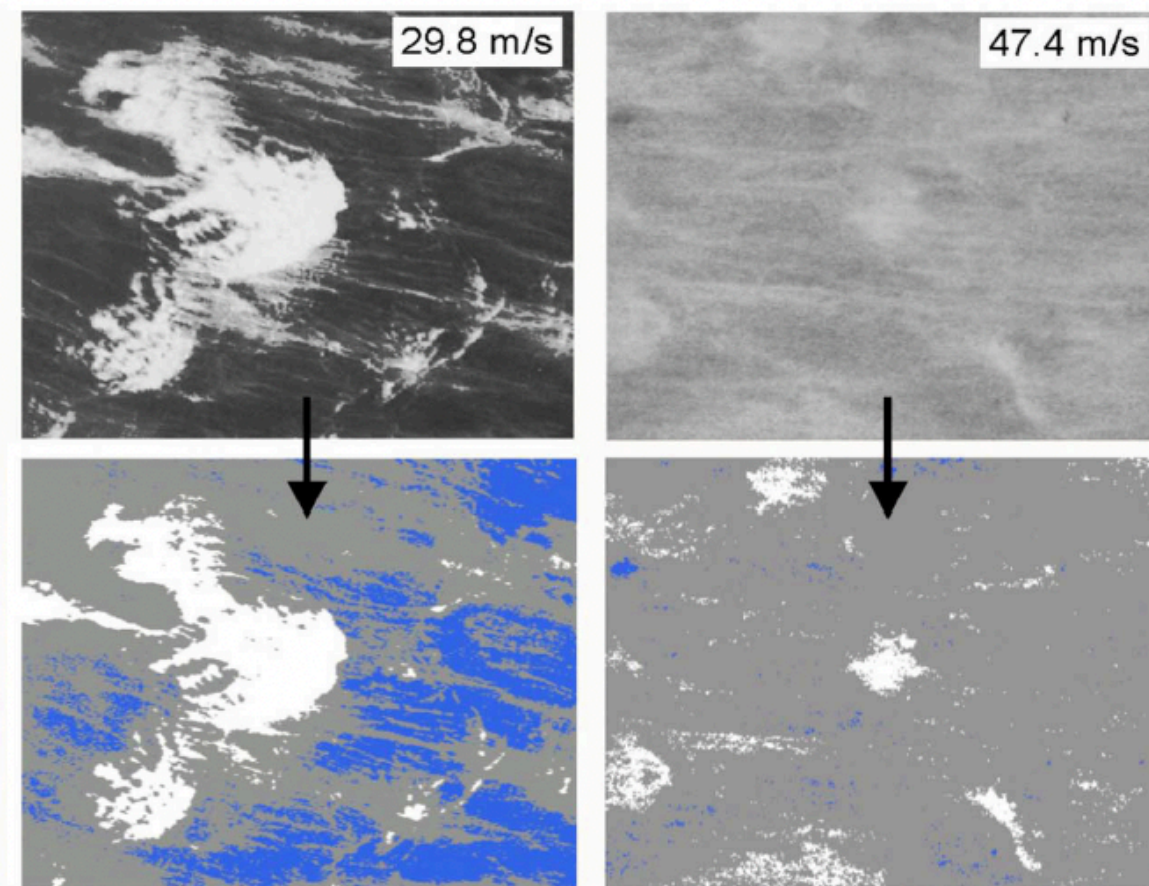
- **Opposing** wind and waves and spectral energy in rear-quadrant
- **Schönau et al. (2024) GRL**

HURRICANE WAVES

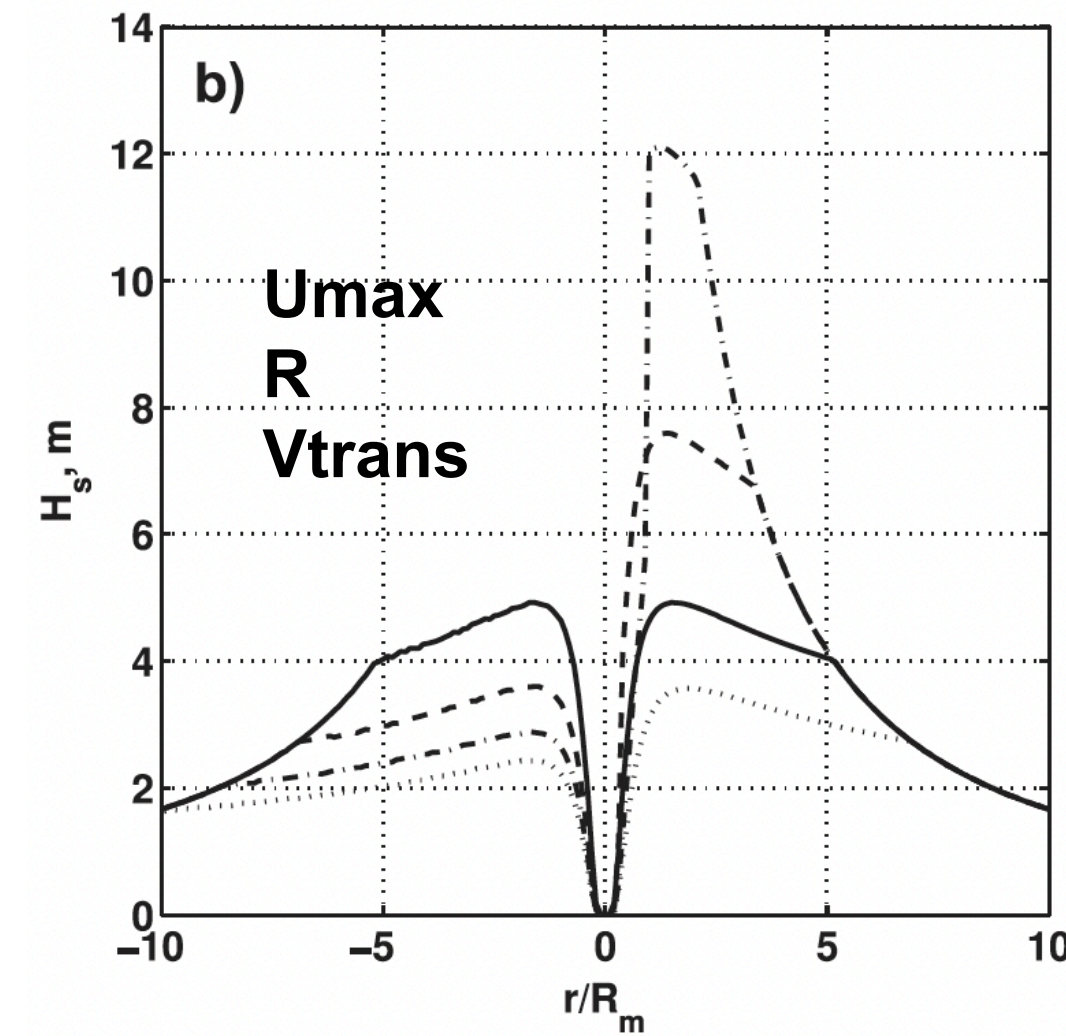
Young (2006)



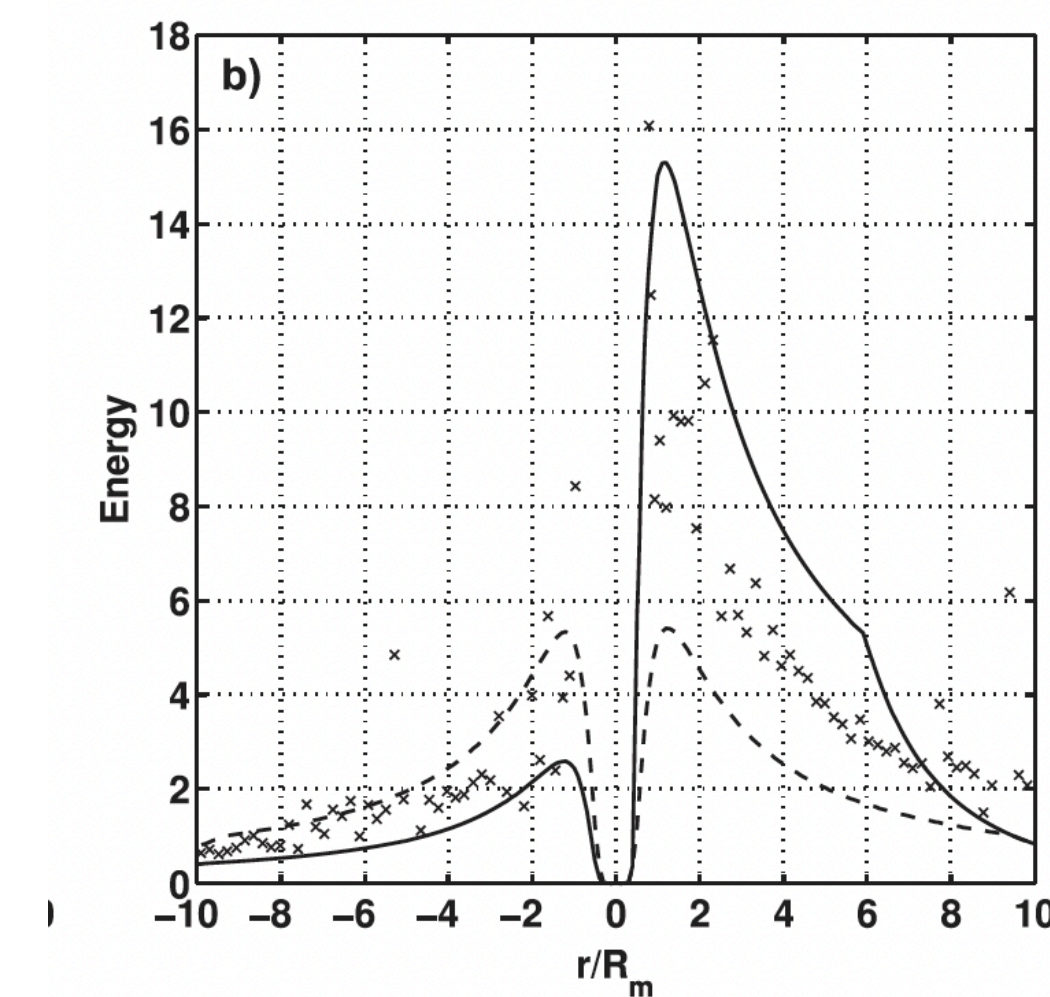
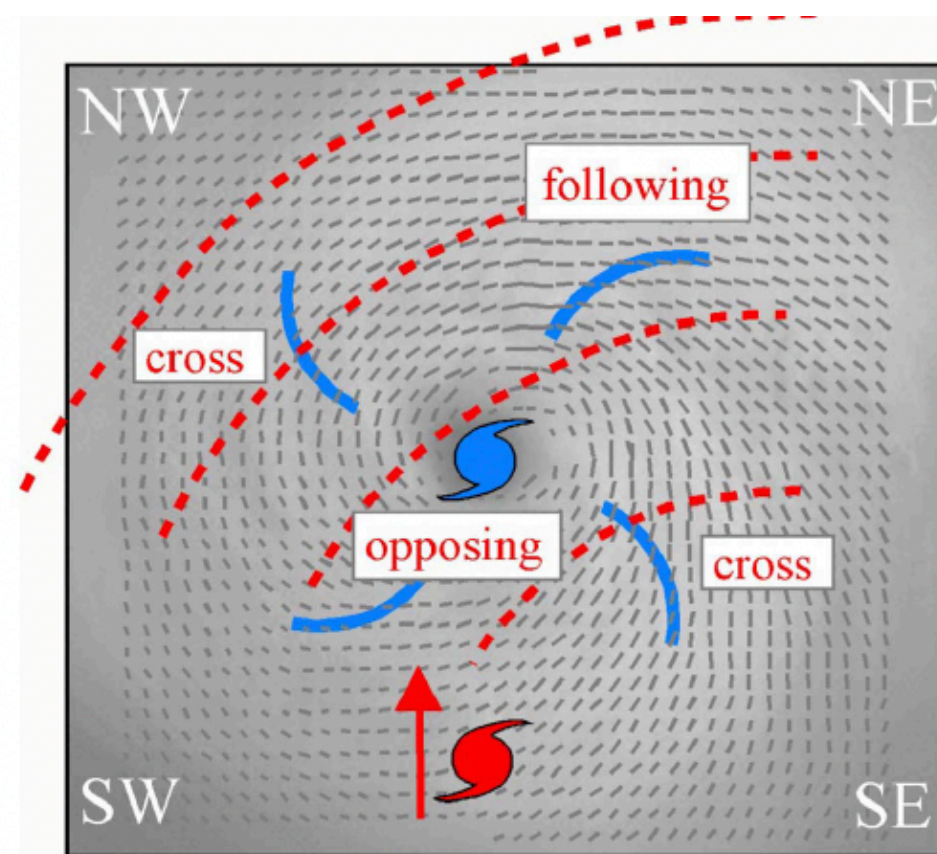
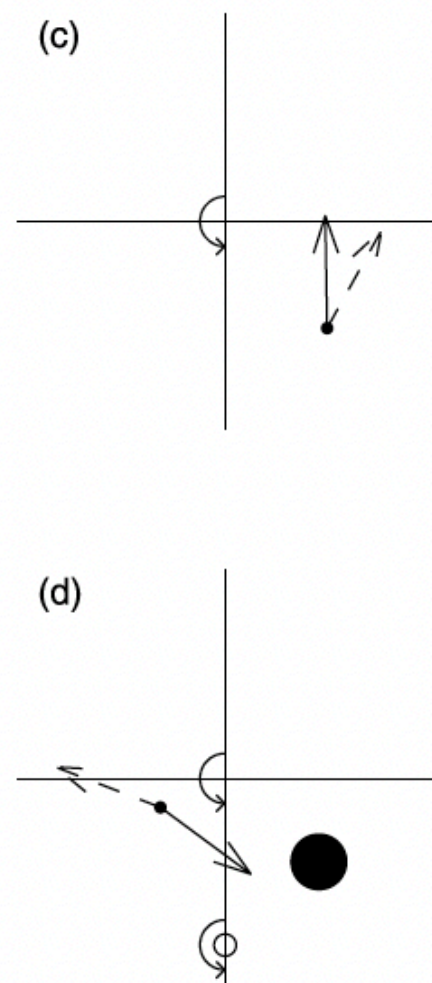
Holthuisen et al. (2012)



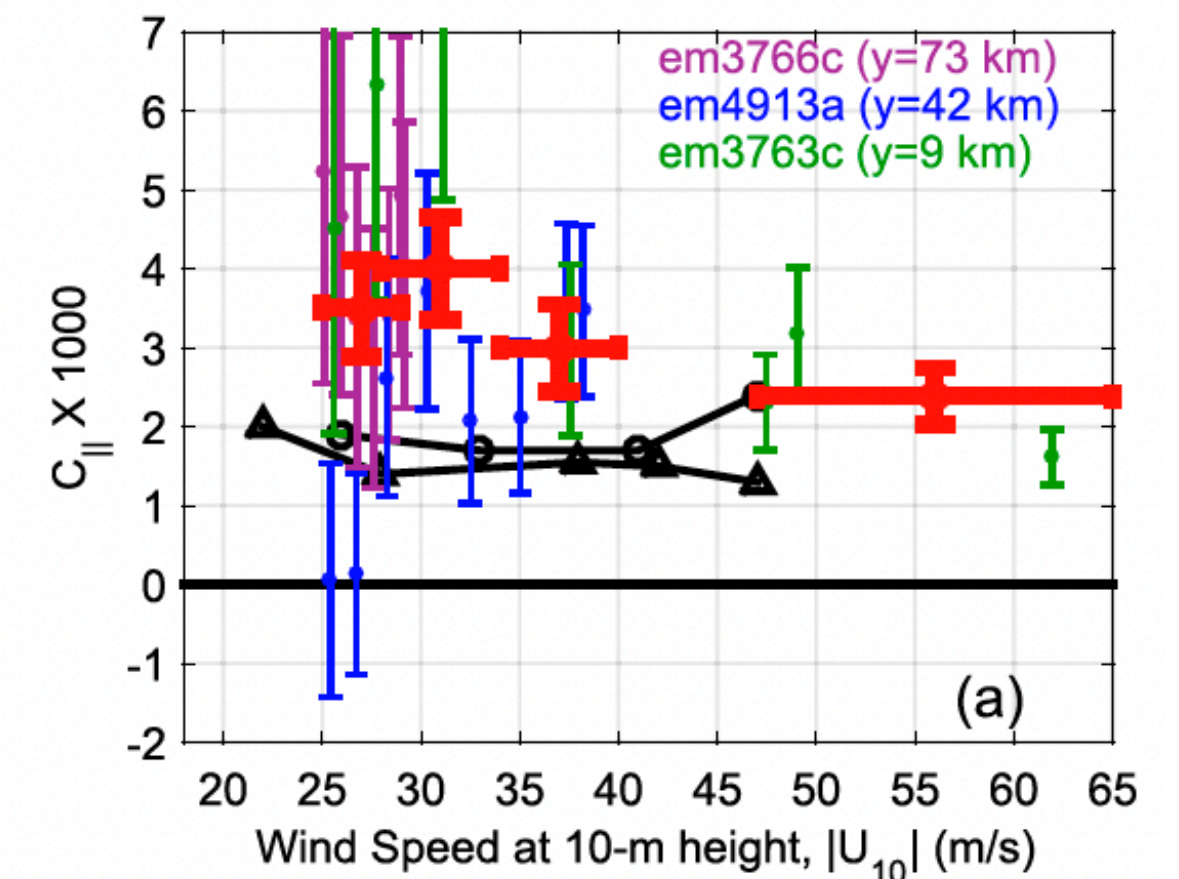
Kudryavtsev et al. (2015)



- Studied for decades
- Crossing seas/following seas
- Theoretical comparisons
- Importance to momentum flux!



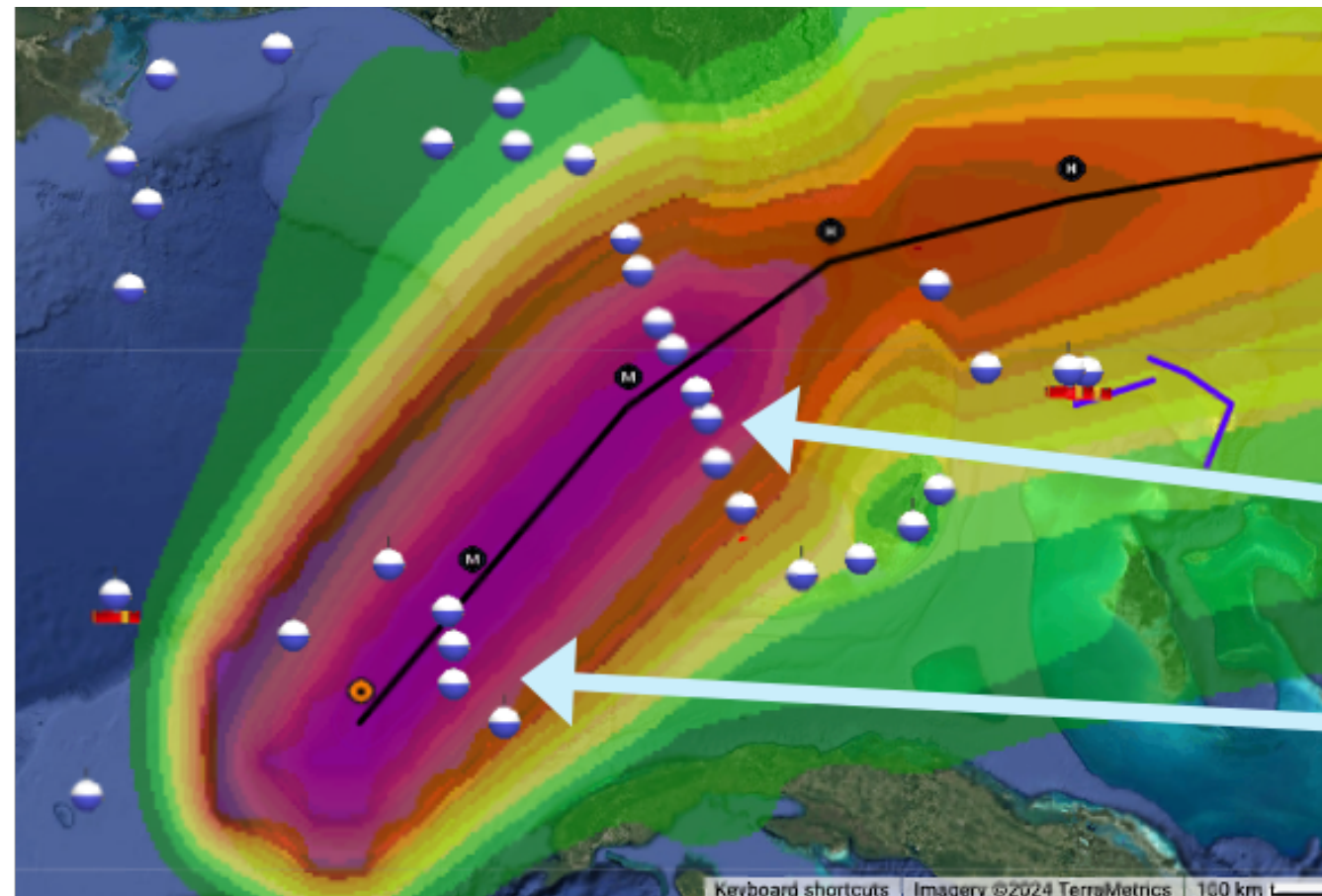
Hsu et al. (2017)



RESOLVING WAVE ENERGY ACROSS STORMS

Before... Composite of many storms or large field campaigns

Now...



**Hurricane Milton
(2024)**

Deployment two days
ahead of storm

Deployment during
RECON flights

DWSD/DWSBD/ADWSD in...

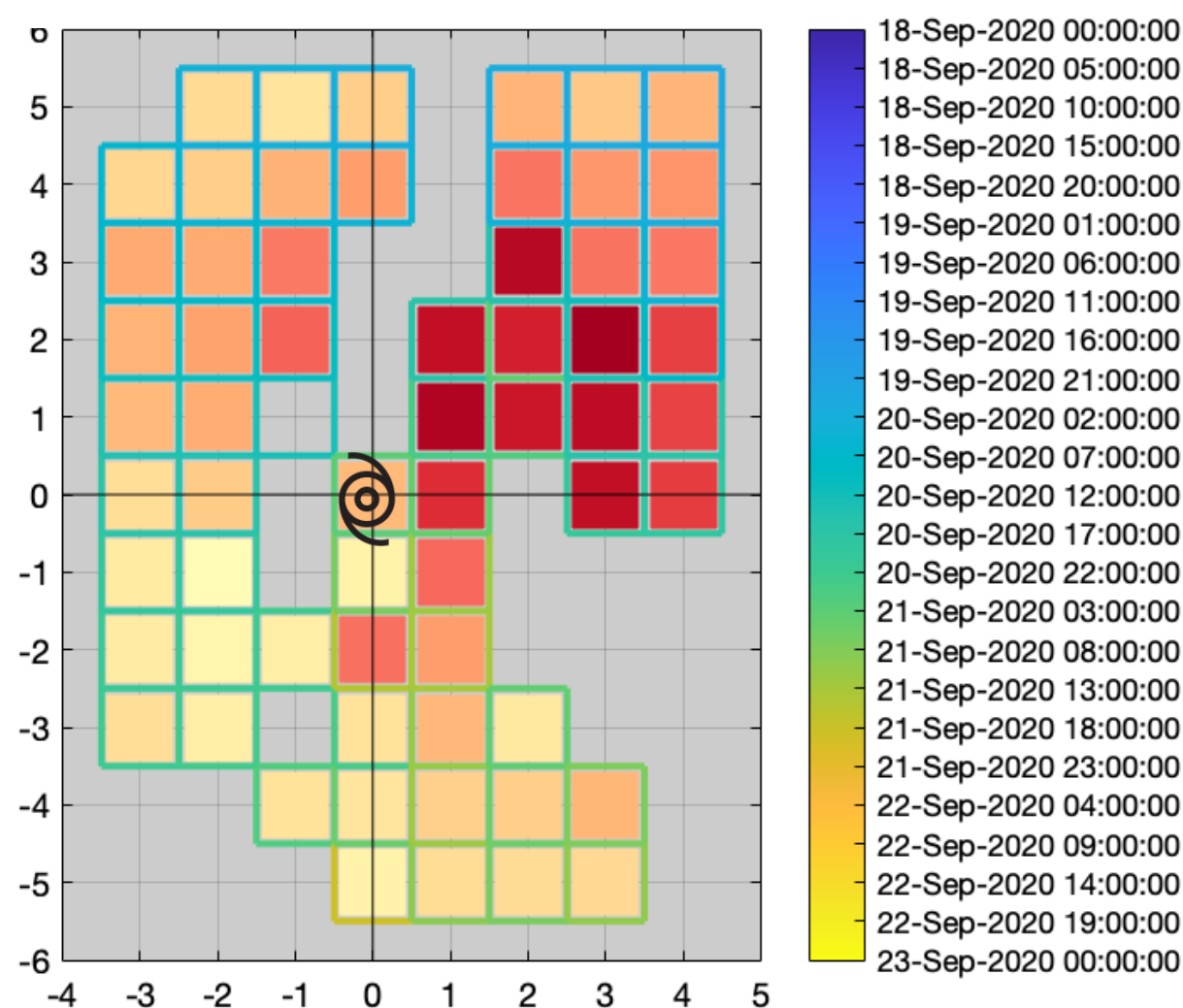
- Hurricane Isaias, Hurricane Teddy (2020)
- Hurricane Ian (2022)
- Hurricane Lee, Idalia (2023)
- Hurricanes Francine, Helene, and Milton (2024)
- Hurricane Raphael (2024)
- Hurricane Erin and Gabrielle (2025)



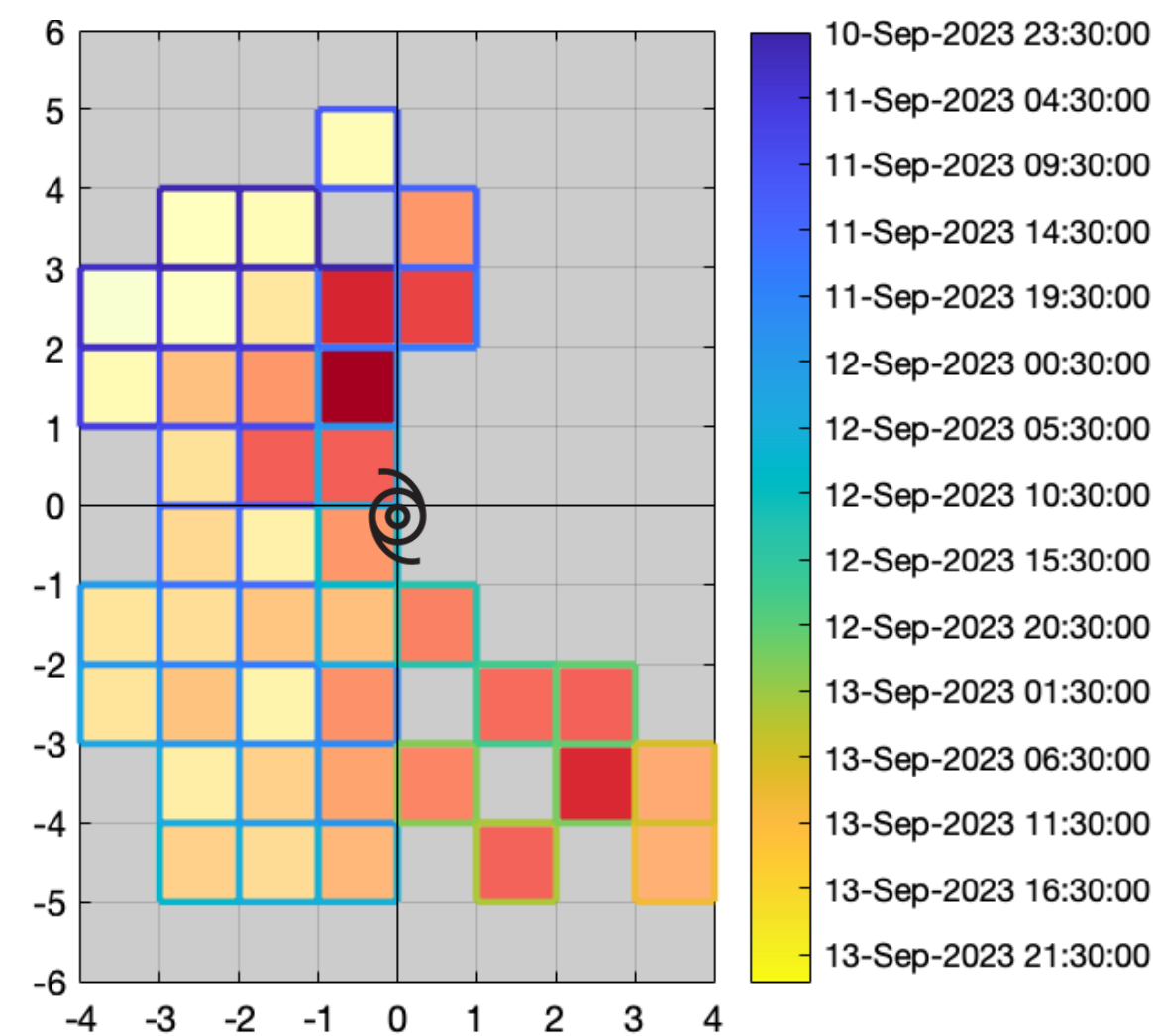
NOPP Hurricane Coastal Impacts (NHCI)

Data available: erddap.idl.ucsd.edu

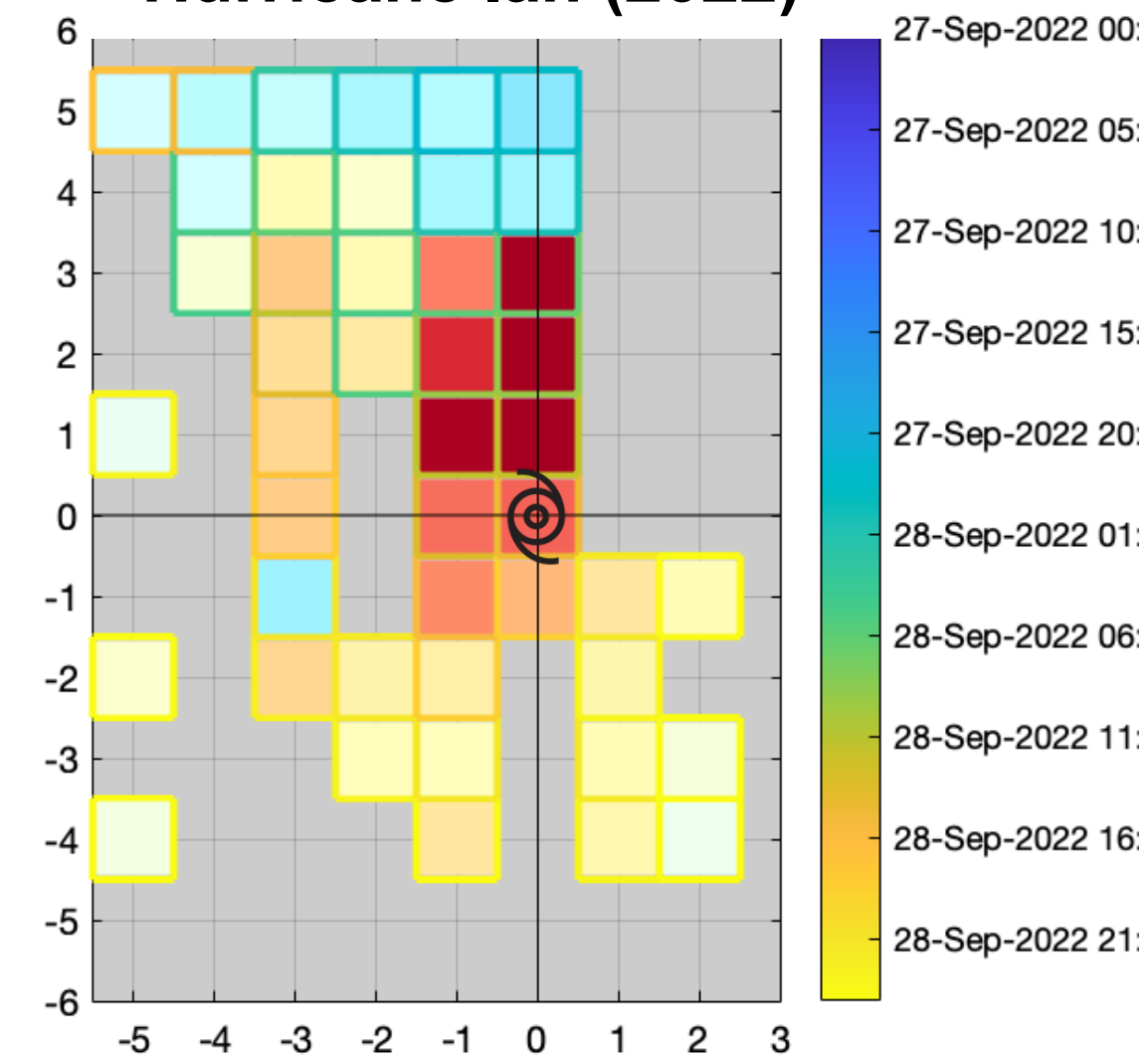
Hurricane Teddy (2020)



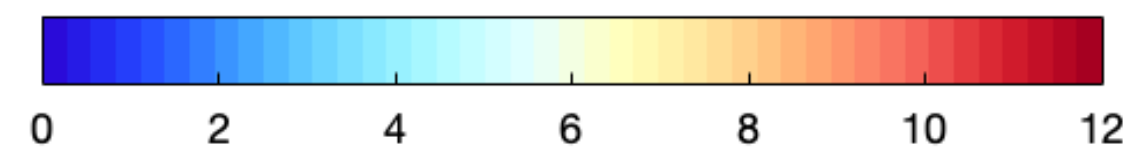
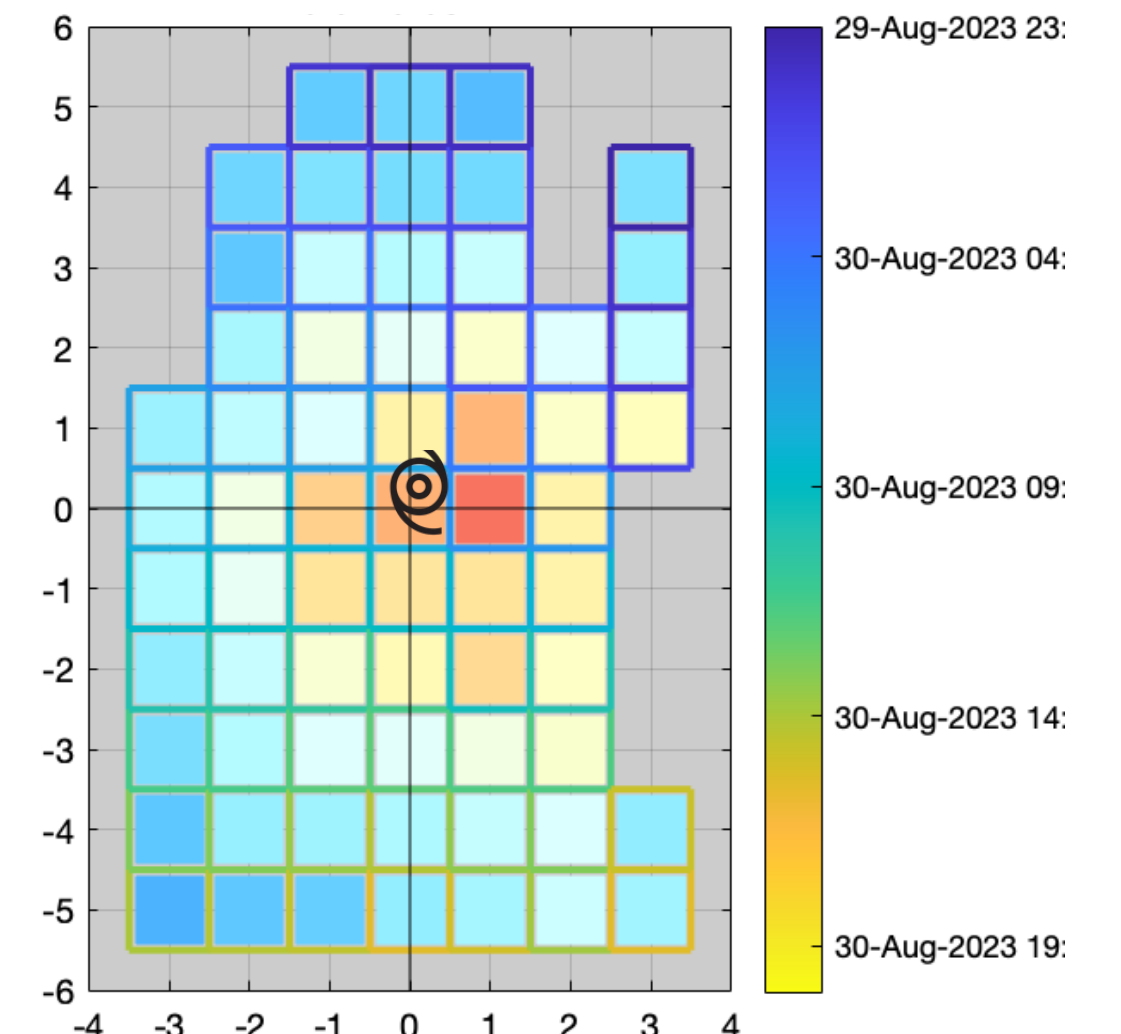
Hurricane Lee (2023)



Hurricane Ian (2022)



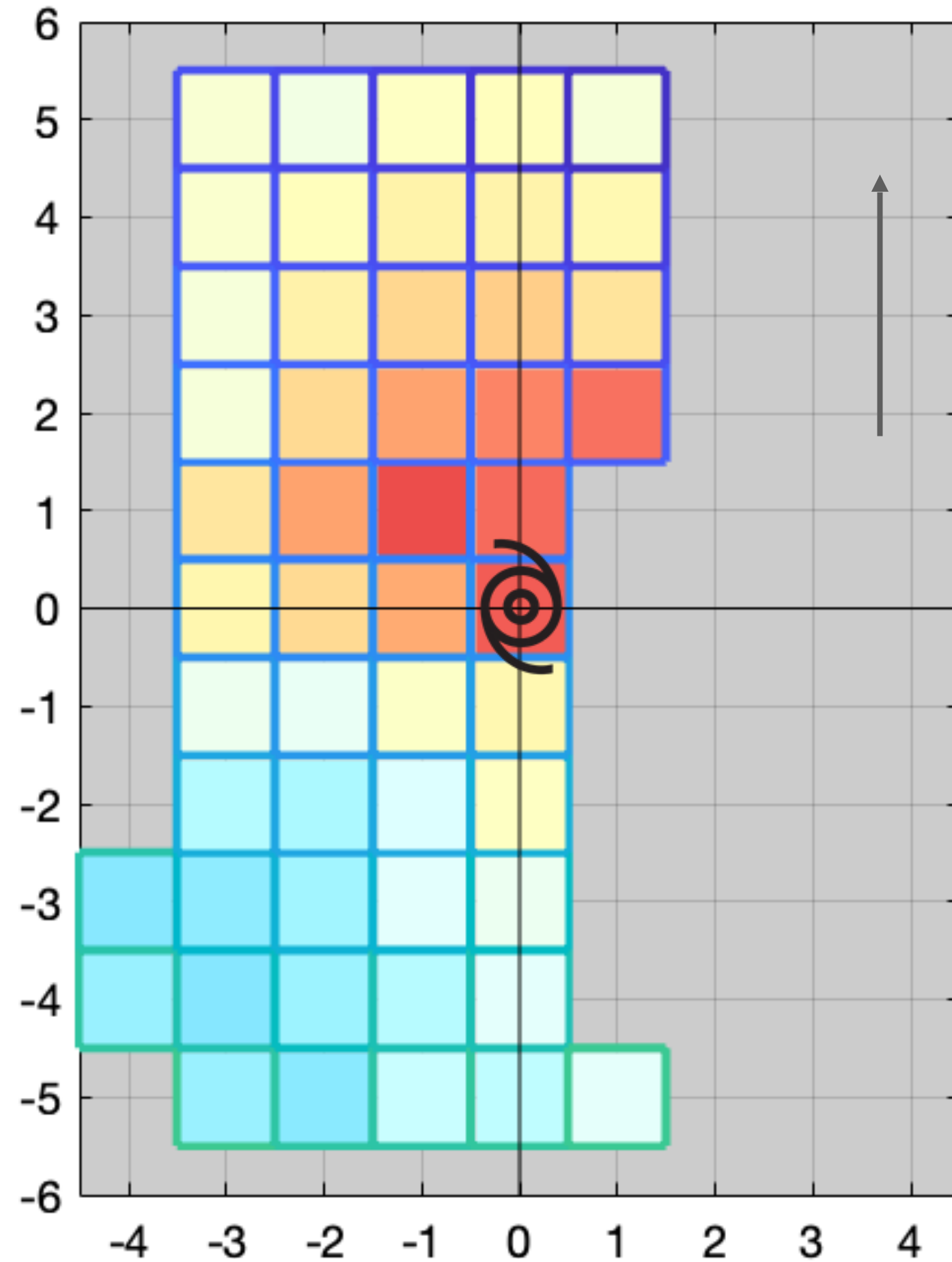
Hurricane Idalia (2023)



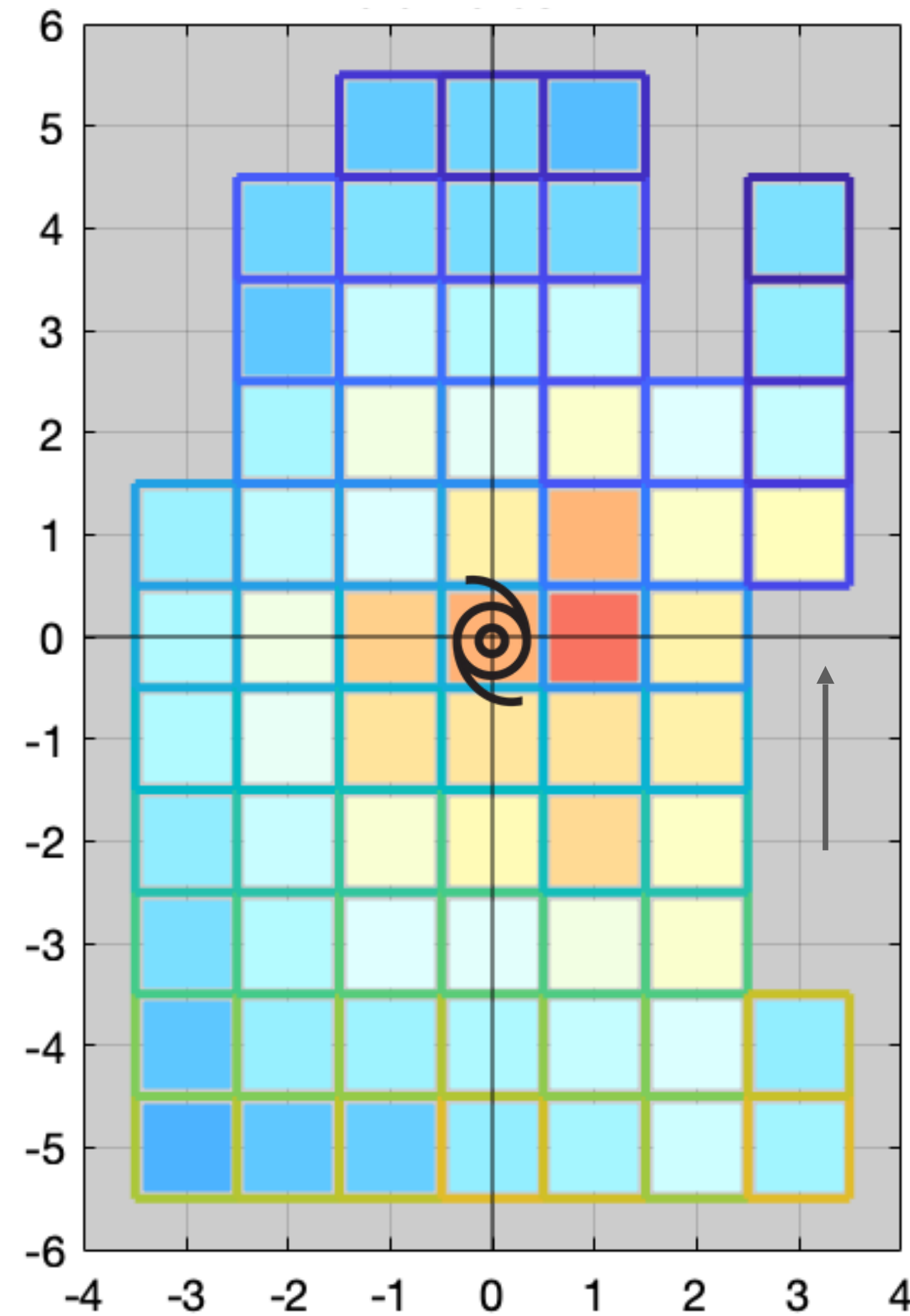
Significant Wave Height (m)

SIGNIFICANT WAVE HEIGHT COMPARISON

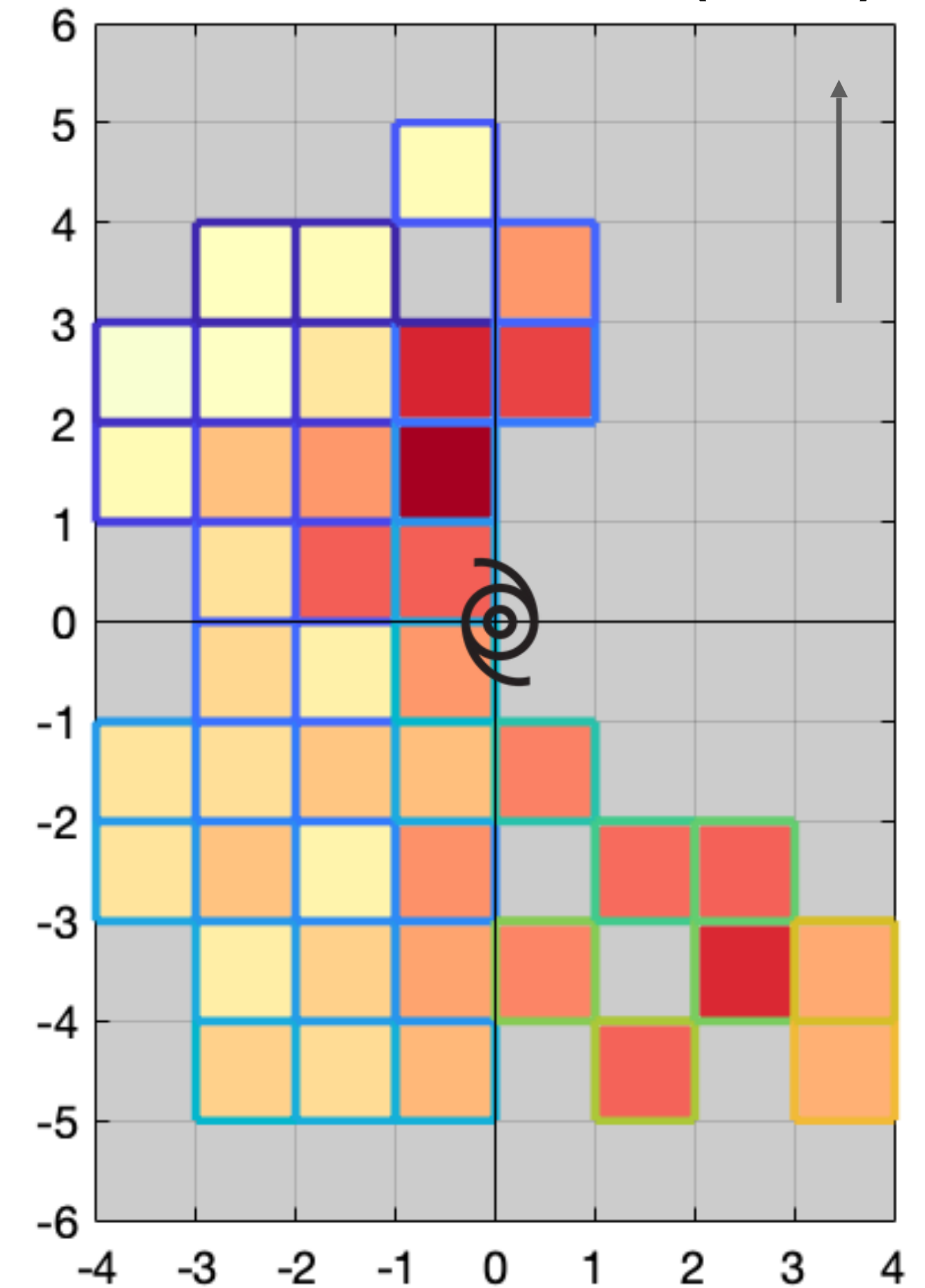
Hurricane Michael



Hurricane Idalia (2023)



Hurricane Lee (2023)

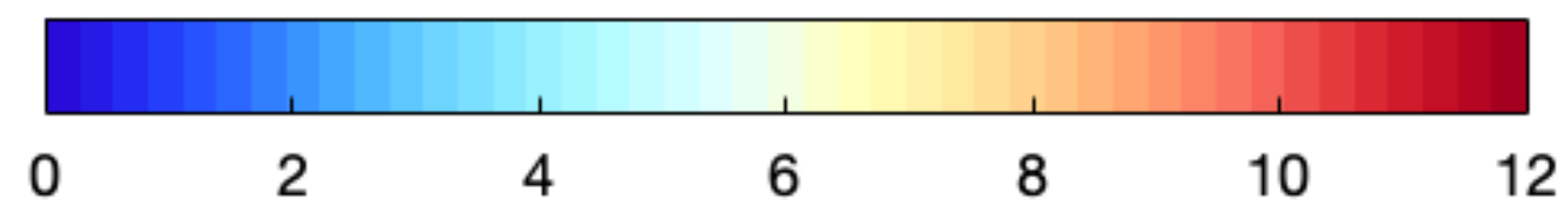


**Transit Speeds when
encountering drifters:**

~10 m/s

~15 m/s

~5 m/s



Significant Wave Height (m)

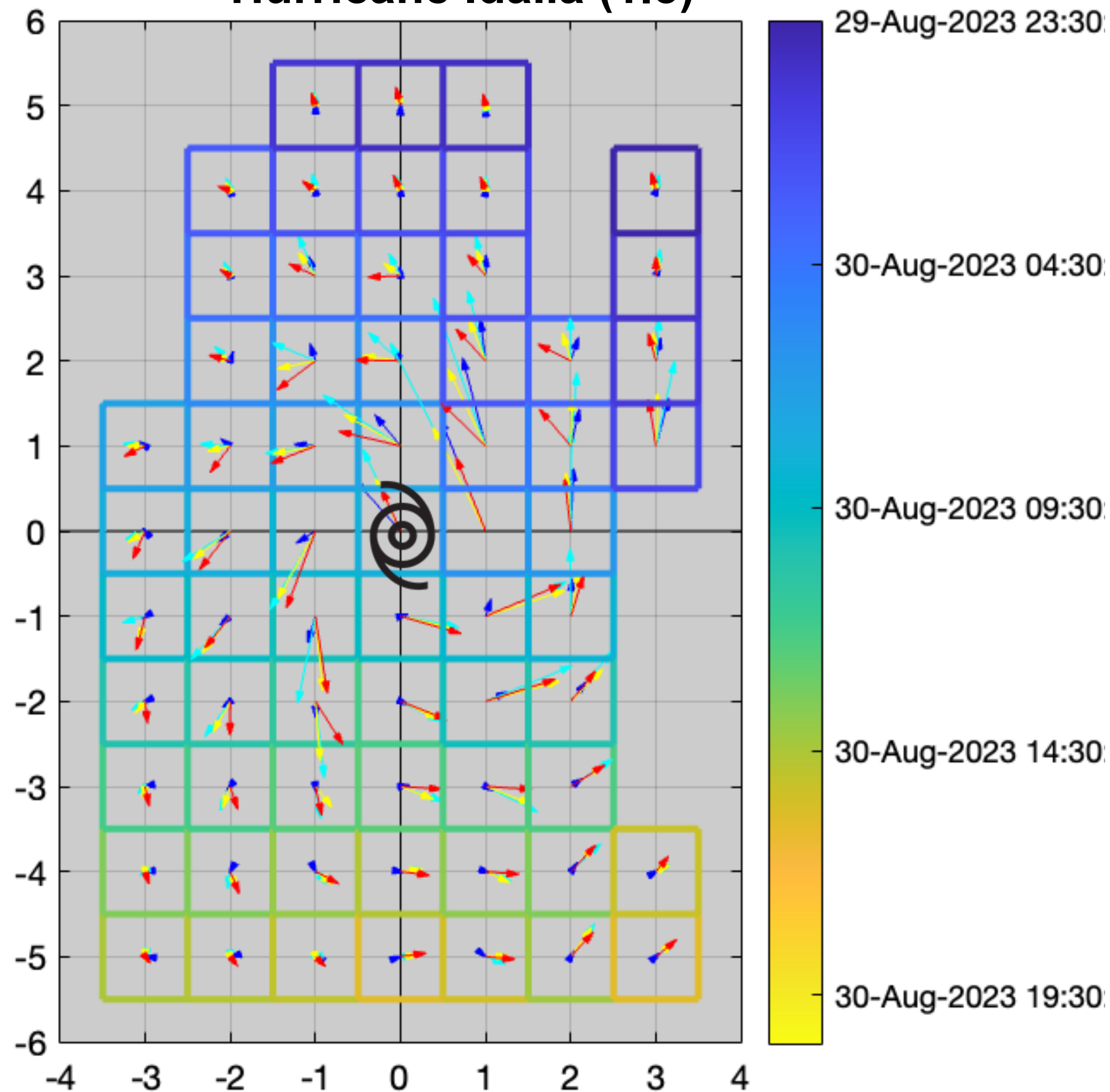
DIRECTIONAL SPECTRA COMPARISON



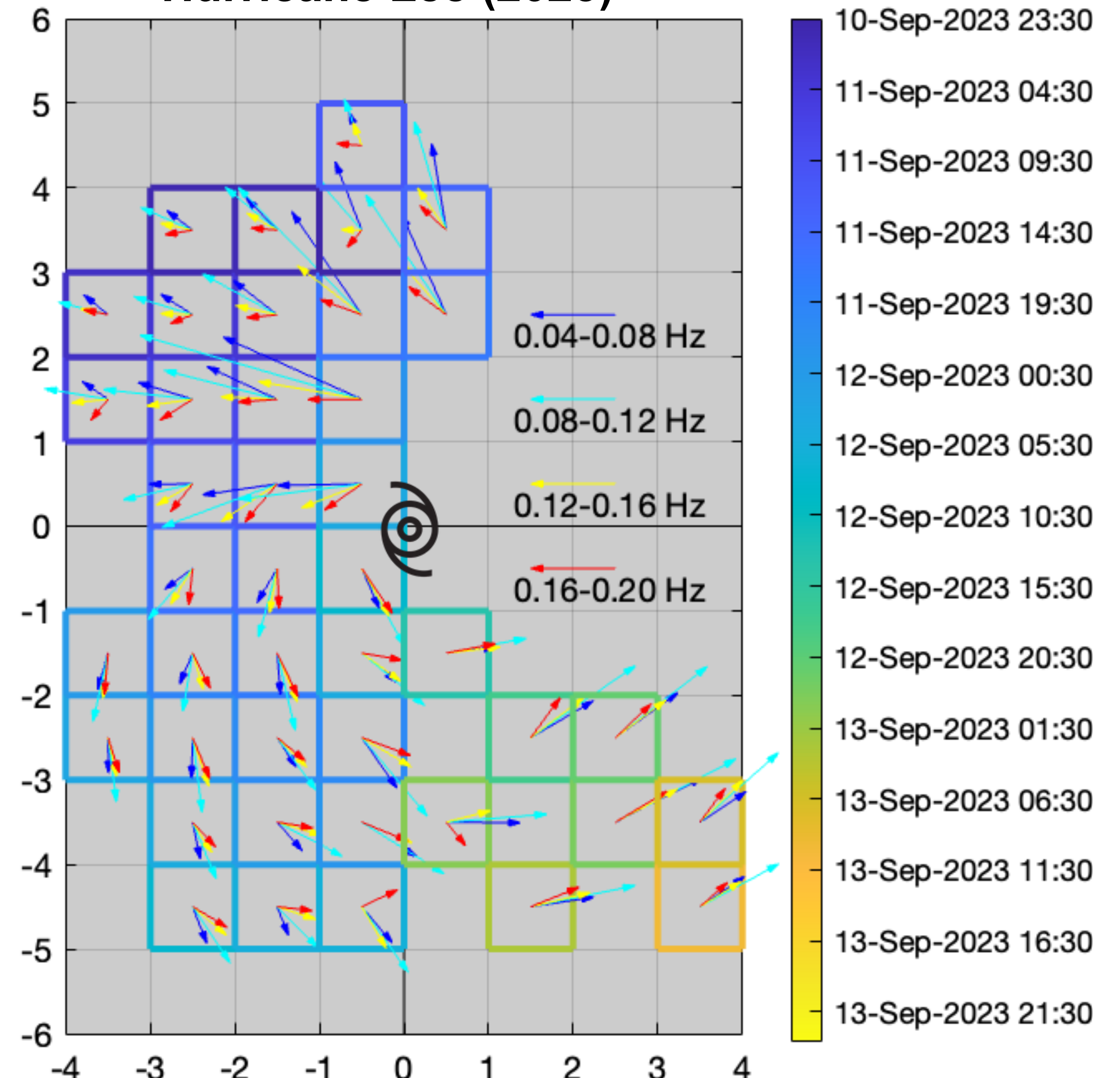
Scripps Institution of Oceanography's
**LAGRANGIAN DRIFTER
LABORATORY**

← 0.04-0.08 Hz ← 0.08-0.12 Hz ← 0.12-0.16 Hz ← 0.16-0.20 Hz

Hurricane Idalia (1.5)



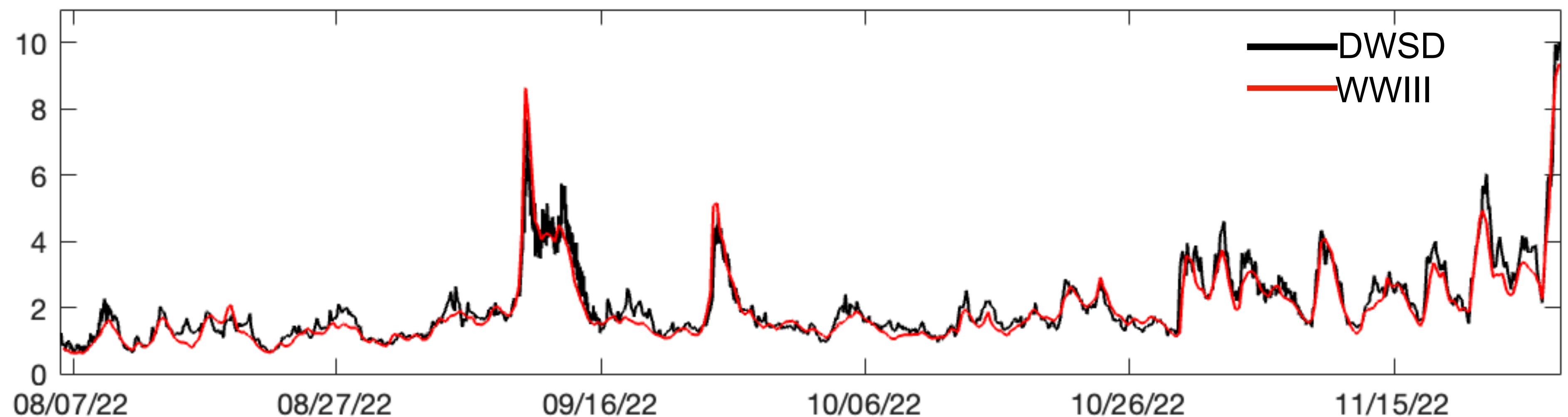
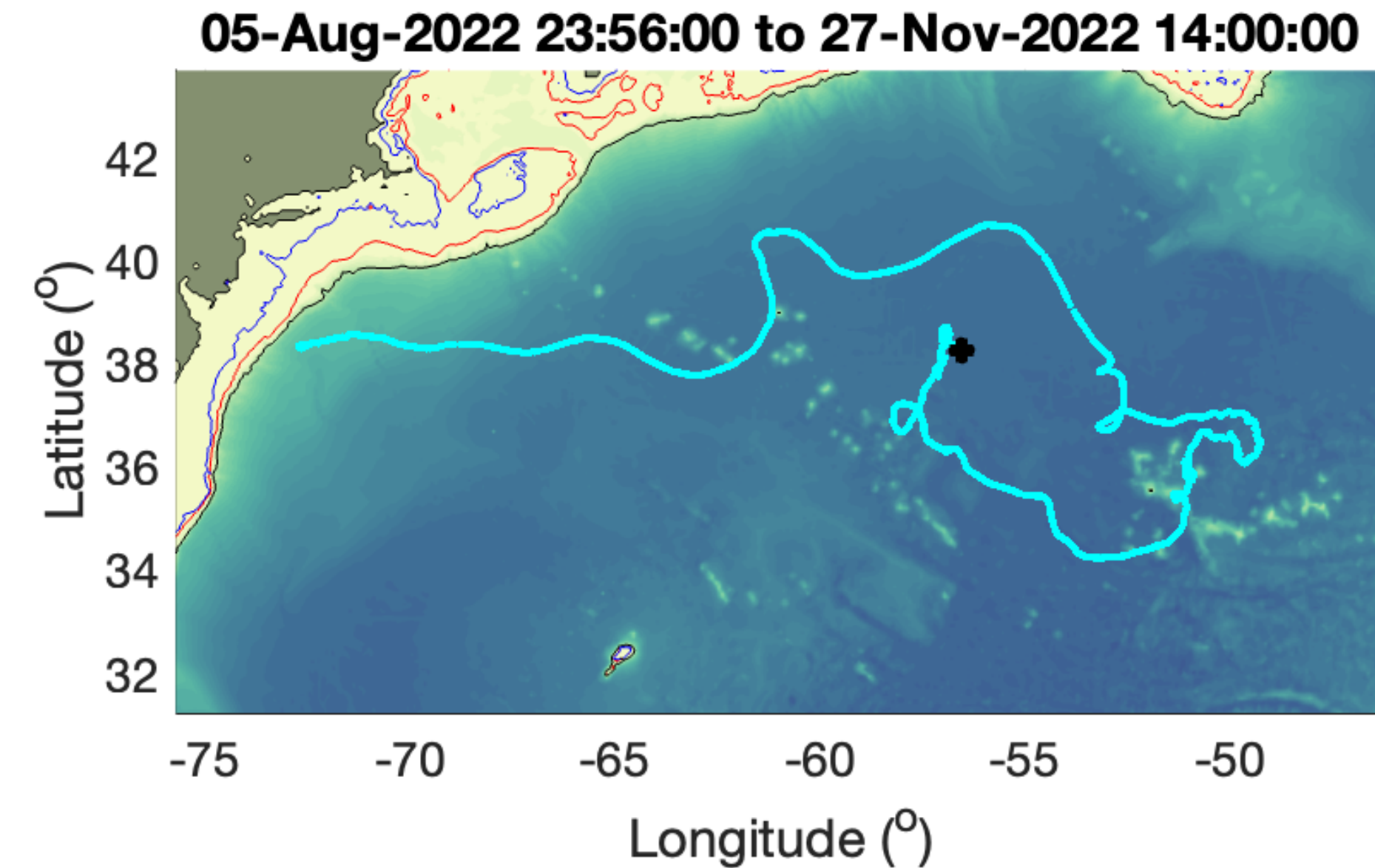
Hurricane Lee (2023)



QUALITY CONTROL PROCEDURES

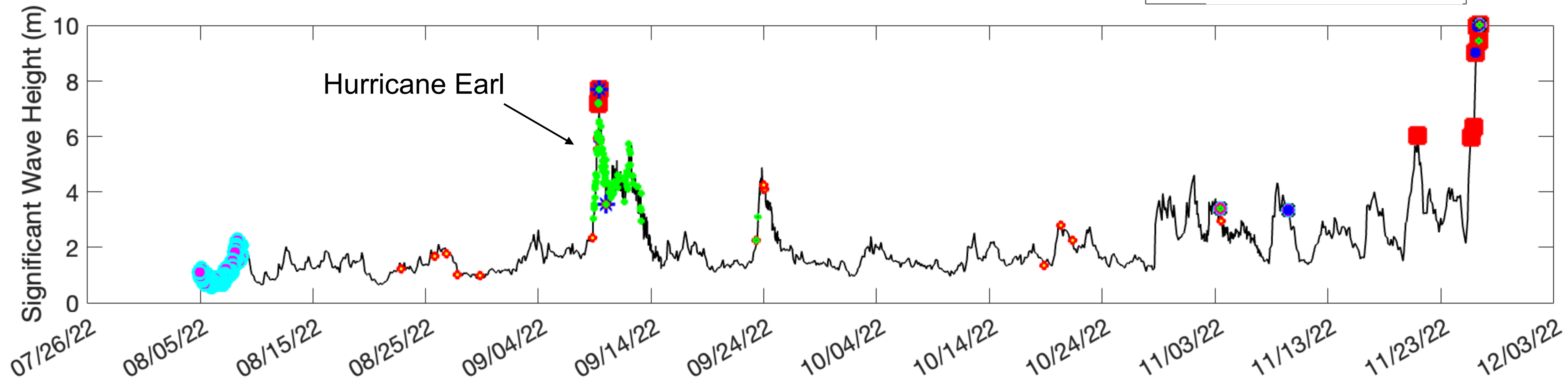
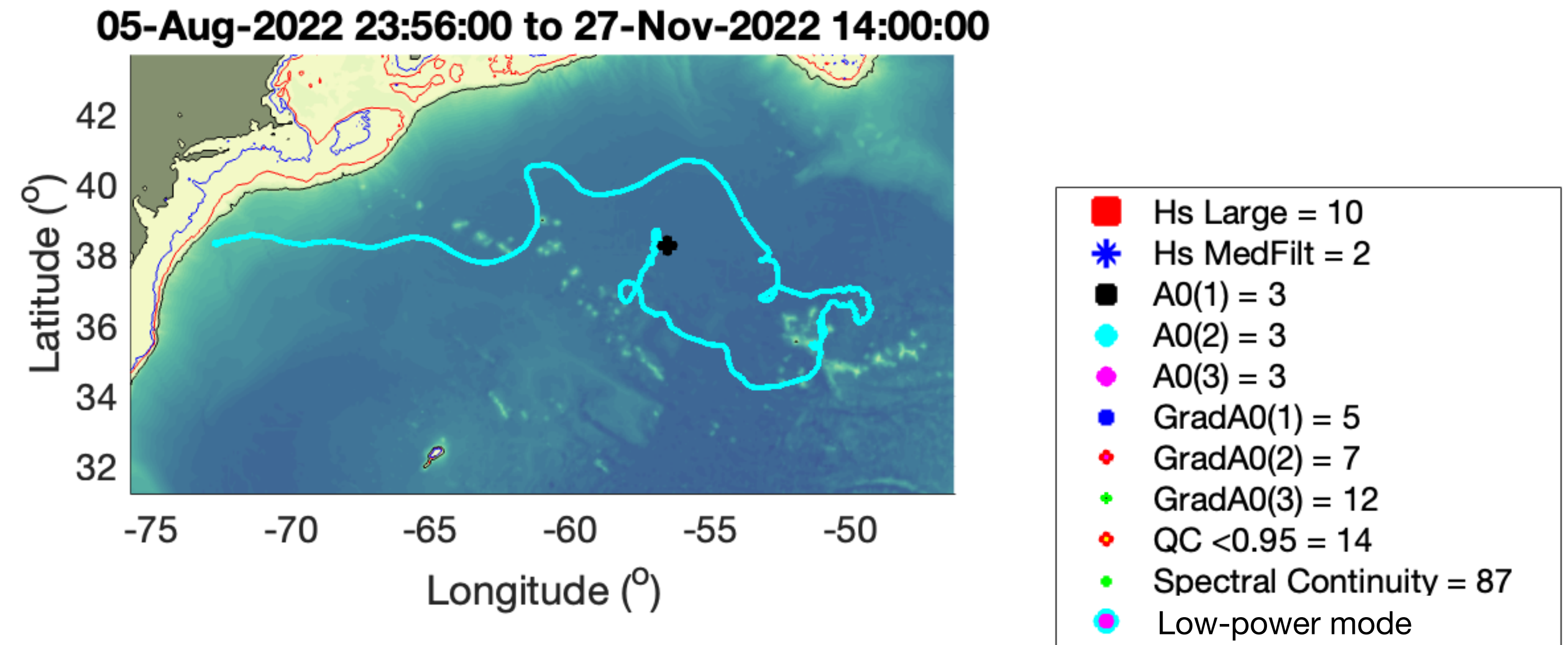
Quality Control Parameters

- Well established for moored wave buoys (NDBC/CDIP)
- standard deviations, flags for missing data, spectral/bulk parameter discontinuity, check factors

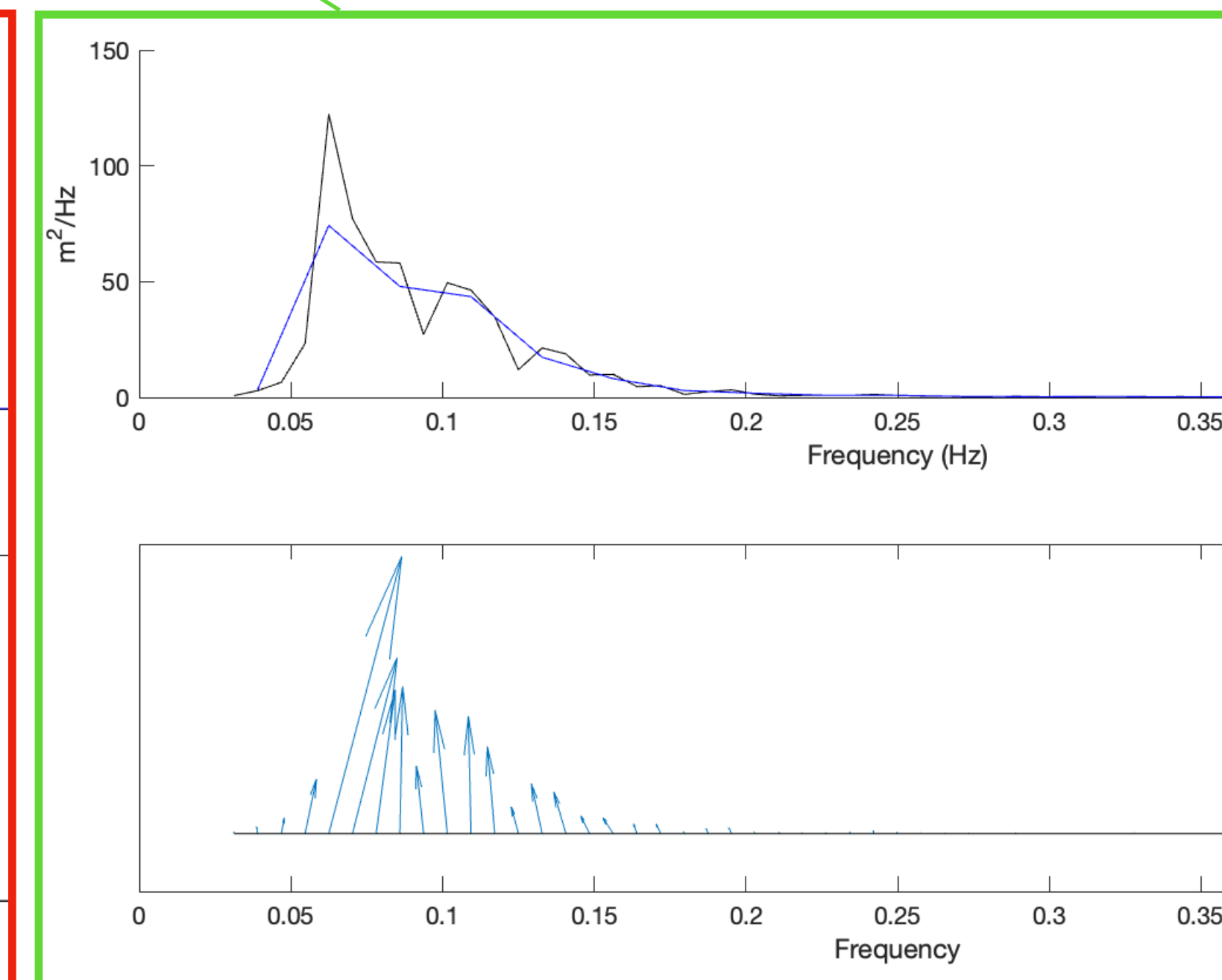
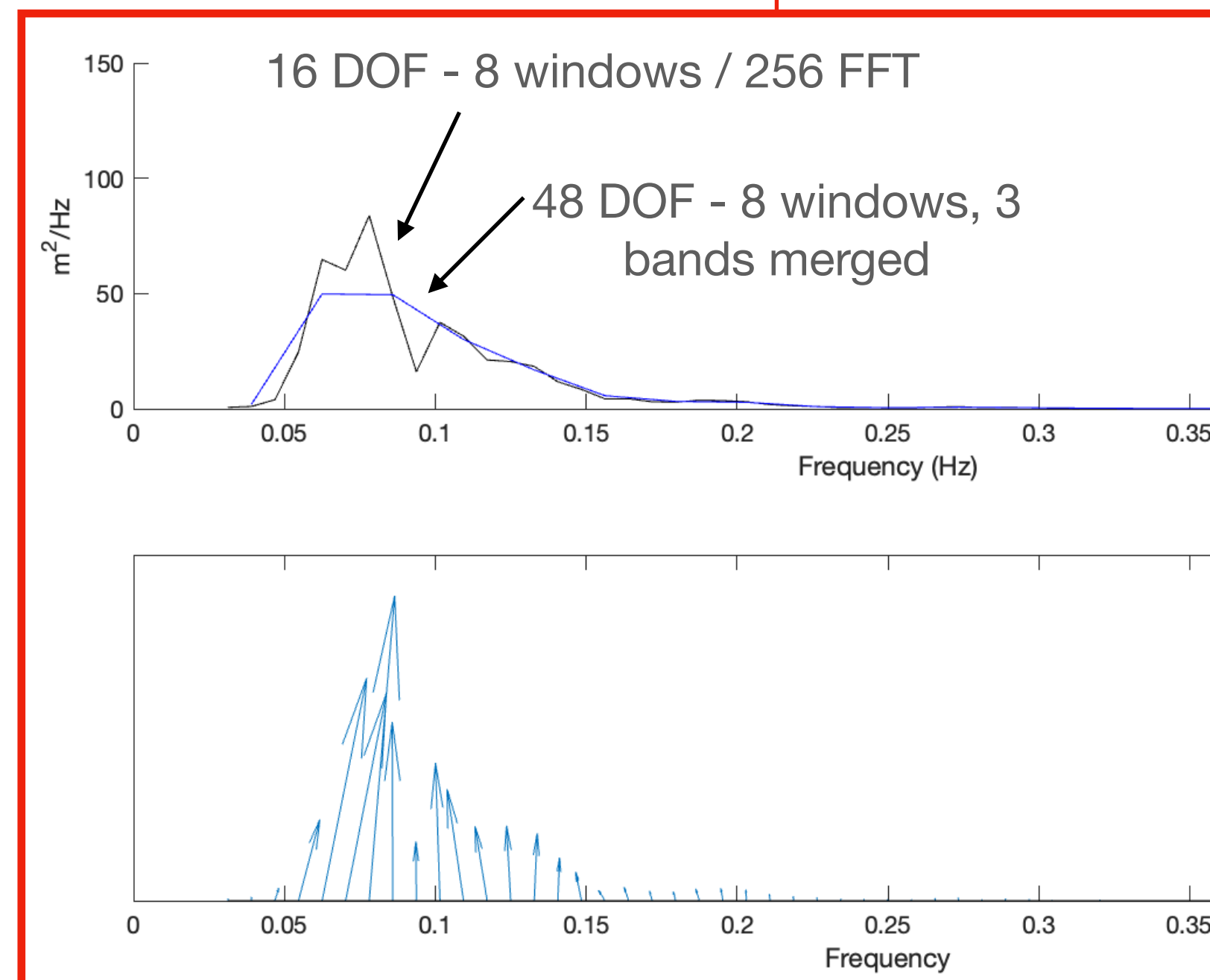
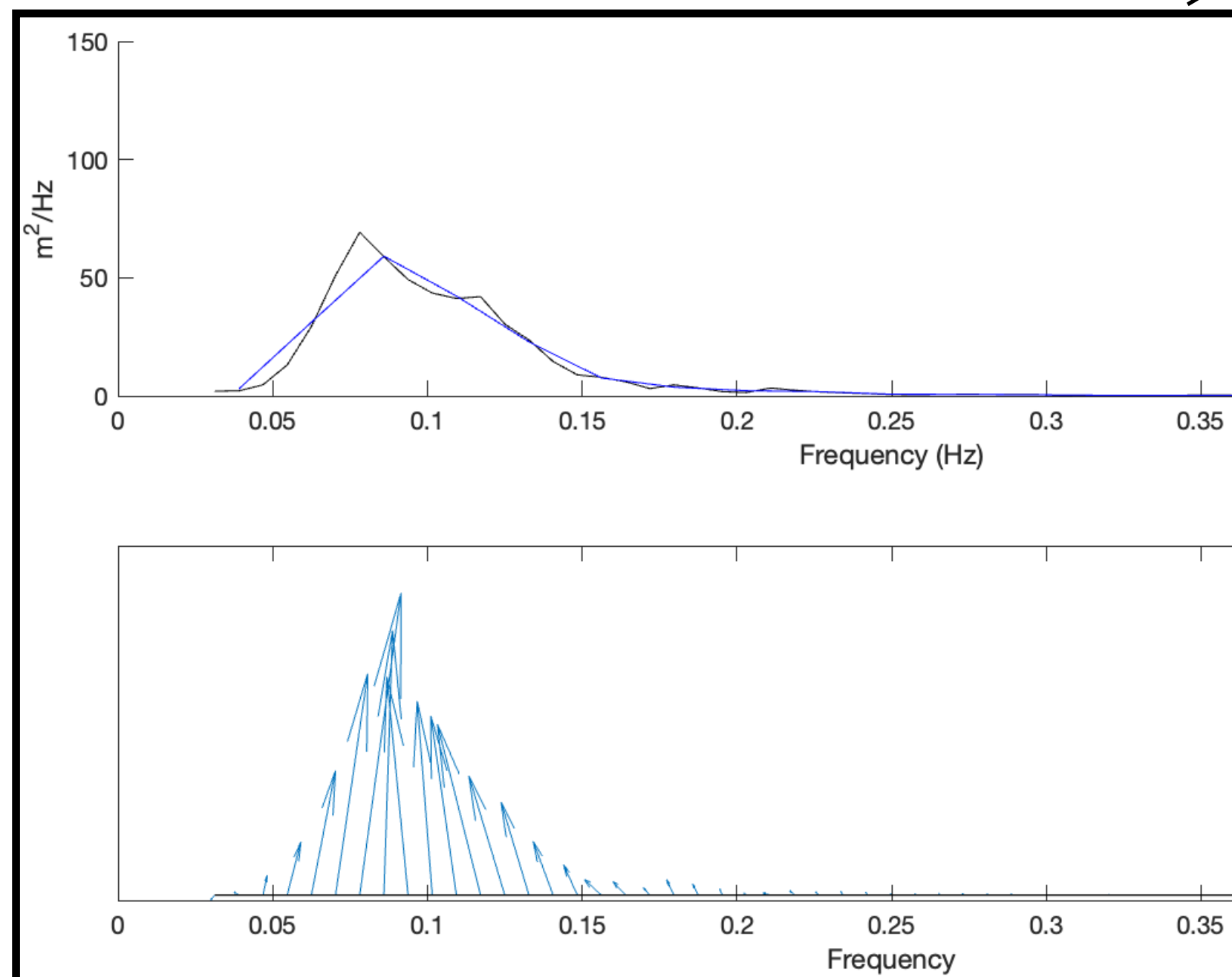
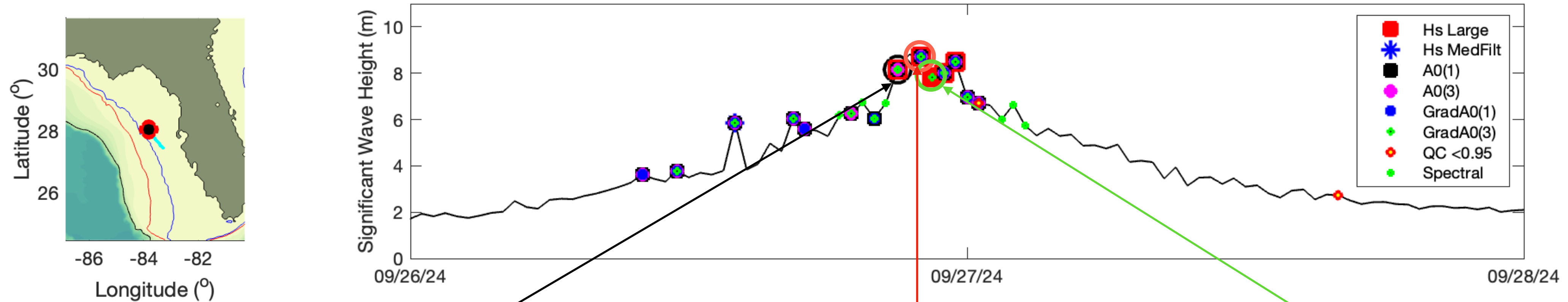


Applying QC to DWSD measurements

- Flagging high values of standard deviation: H_s , T_a
- Spurious low-frequency noise: anomalous first values of a_0
- Spectral continuity (can use to pick out Hurricanes)
- What is “normal” for a hurricane wave?



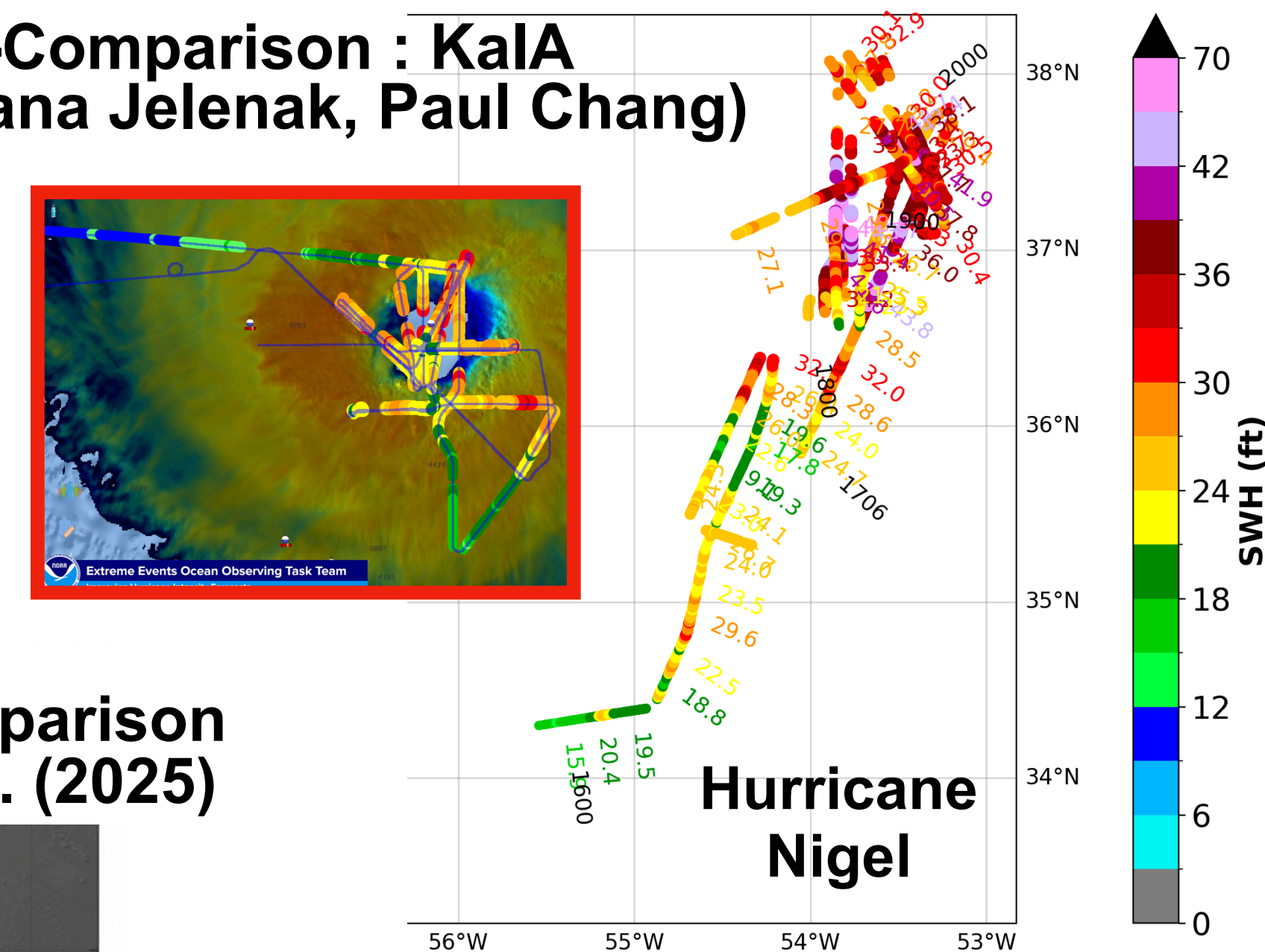
What does this look like in a hurricane?



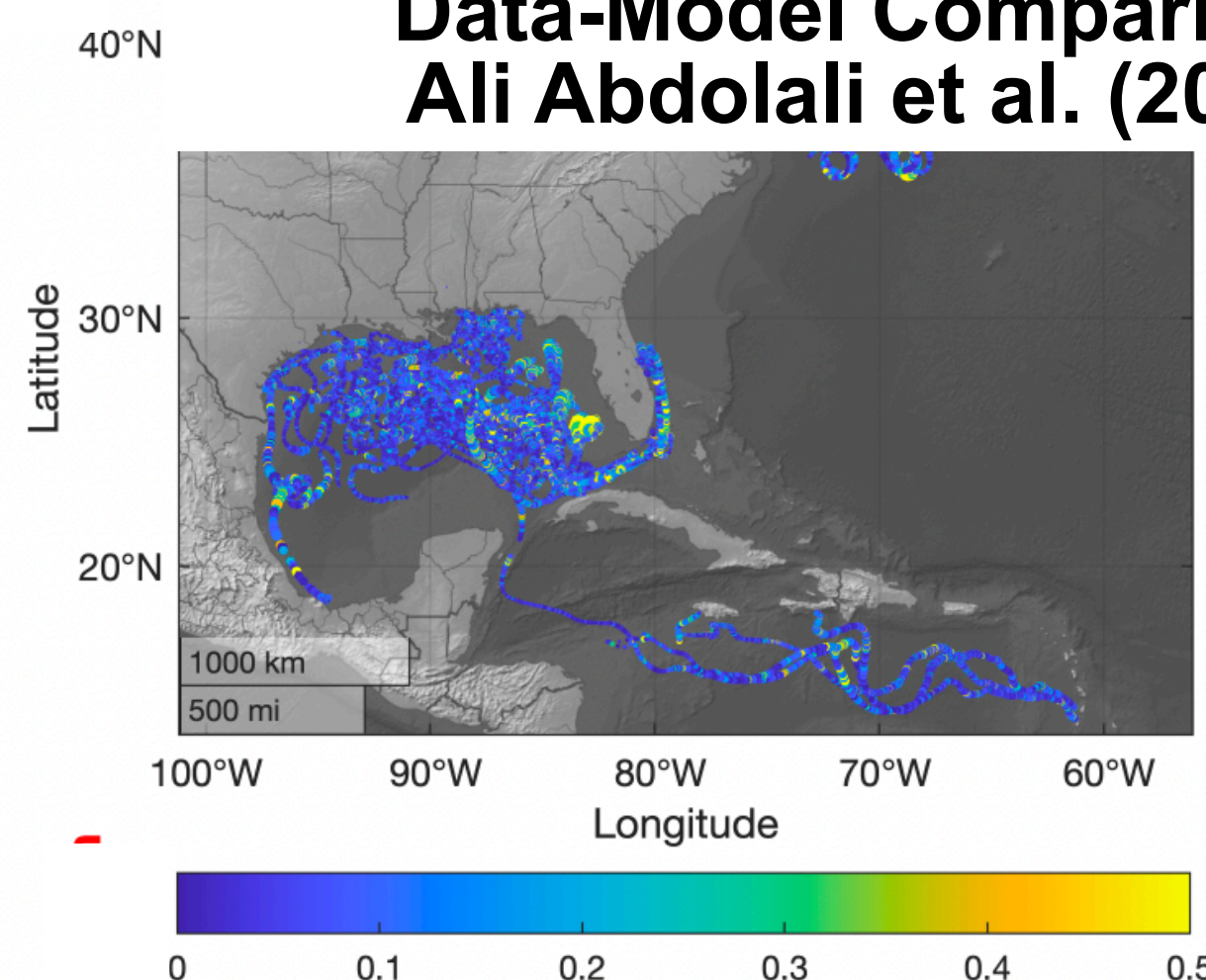
HOW IS THIS DATA USED?

- Data is readily available for **forecasting** via the GTS
 - Improve the forecast track and intensity with SLP and removing SST bias
- Provide **in-situ validation** for wave models and airborne observations
- Support **basic research**
 - Synthesize observations through curated datasets
 - Improve understanding of air-sea interaction processes: momentum, heat flux
- Deliver data directly to the **public, emergency managers** and broadcast networks

Airborne-Comparison : Kala (Joe Sapp, Zorana Jelenak, Paul Chang)



Data-Model Comparison Ali Abdolali et al. (2025)



**500,000 views per video during
Hurricane Milton**



- **Hurricanes: Sustain, Adapt and Target**
- **Resolve directional wave spectra across storms**
- **Sampling Importance: spectral resolution and quality control**
- **Data is available via ERDDAP . . .**