LDL's NHCI Hurricane 2022-2024 DWSD Level 2 Data

Lagrangian Drifter Laboratory -10 April 2025
Martha Schönau, Luca Centurioni

1 Introduction

Directional Wave Spectra Barometer Drifters (DWSBD) and A-size Directional Wave Spectra Drifters (DWSD) were deployed as part of the NOPP NHCI project. This document describes the **Level 2** data that is made available as netCDF files. The dataset encompasses six storms: Hurricane Ian (2022), Hurricane Idalia (2023), Hurricane Lee (2023), Hurricane Francine (2024), Hurricane Helene (2024) and Hurricane Milton (2025). The four levels of wave data are:

- **Level 1 (L1)**: Raw data that is acquired by the instrument. This would be the actual time series of the drifters' moments, providing a time series of u, v, and w. This is available for moored buoys as it can be stored locally, but unavailable for drifting buoys that telemeter the data as the battery and iridium costs would be prohibitive (or the instrument would be exceptionally short-lived.)
- **Level 2 (L2)**: Observations that are delivered via Iridium. This provides calculated bulk wave statistics and the wave spectral energy and directional moments. The resolution and degrees of freedom (ie., spectral certainty) will depend on the length of time series, and segmenting of the raw-GPS time series (ie., FFT size). There is no QC performed on data, but an advised QC flag is made available. L2 data has 8 DOF for 120 spectral bins, and 16 DOF for 60 spectral bins.
- **Level 3 (L3)**: Observations with quality flag applied, and additional processing to provide directional spectra with higher degrees of freedom by averaging adjacent spectral bins. Depending on original sampling this could be 24-, 32- or 48- DOF depending on the originally sampled data.
- **Level 4 (L4)**: These include L3 observations with additional parameters such as Stokes Drift, wave-slope and partitioning of swell and wind-sea components

*Note that L2 data is typically minimally processed. Please contact us for further data or questions.

Links:

- Lagrangian Drifter Laboratory
- Directional Wave Spectra Barometer Drifter
- LDL ERDDAP Server
- Contact: ldl-datasets@ucsd.edu

DOI: The DOIs and citation information for the datasets are found on the ERDDAP server and in the netCDF file.

References:

General:

- Longuet-Higgins, M.S., Cartwright, D.E., & Smith, N.D. (1963). Observations of the directional spectrum of sea waves using the motions of a floating buoy. Ocean Wave Spectra. Prentice-Hall, Engelwood Cliffs, NJ, pp. 111-136.
- WMO Guide to wave analysis and forecasting: `https://community.wmo.int/en/bookstore/guide-wave-analysis-and-forecasting` (Note- .pdf versions can be found online)
- Benoit, M., Frigaard, P., & Schäffer, H. A. (1997). Analysing multidirectional wave spectra. In E. Mansard (Ed.), Proceedings of the 27th IAHR Congress, San Francisco, 10–15 August 1997: IAHR seminar: Multidirectional waves

and their interaction with structures. Canadian Government Publishing.

GPS Wave buoy:

- Centurioni, L. R., Braasch, L., Di Lauro, E., Contestabile, P., De Leo, F., Casotti, R., et al. (2017). A new strategic wave measurement station off Naples port main breakwater. Coastal Engineering Proceedings, 1(35), waves.36. https://doi.org/10.9753/op.v35.waves.36
- Herbers, T. H. C., Jessen, P. F., Janssen, T. T., Colbert, D. B., & MacMahan, J. H. (2012). Observing ocean surface waves with GPS-tracked buoys. Journal of Atmospheric Technology, 29(7), 944–959. https://doi.org/10.1175/JTECH-D-11-00128.1
- Clarence O. Collins, Patrick Dickhudt, Jim Thomson, Tony de Paolo, Mark Otero, Sophia Merrifield, Eric Terrill, Martha Schonau, Lancelot Braasch, Theresa Paluszkiewicz & Luca Centurioni (30 Jan 2024): Performance of moored GPS wave buoys, Coastal Engineering Journal, DOI: 10.1080/21664250.2023.2295105

DWSD in Hurricanes:

- Schönau, M. C., Paluszkiewicz, T., Centurioni, L. R., Komaromi, W. A., Jin, H., & Doyle, J. D. (2024). In situ observations at the air-sea interface by expendable air-deployed drifters under Hurricane Michael (2018). Geophysical Research Letters, 51, e2023GL105730. https://doi.org/10.1029/2023GL105730

2 L2 Data

There are two files that are available. The **Sensor Data** containing SST, SLP and Bulk Wave Parameters, and the **First-Five Data** containing the frequency, spectral energy and directional coefficients. The sensor file and first-five file time series may have different lengths. See note below.

2.1 Sensor Data and Bulk Wave Parameters

- **platform_ID**: platform identification number
- **latitude**: Latitude of SST / SLP and bulk wave parameters (if wave measurement occurred)
- **longitude**: Longitude of SST/ SLP and bulk wave parameters (if wave measurement occurred)
- **time**: Time of observations
- **sea_surface_temperature:** near-surface ocean temperature (0.184 m below surface for DWSD)
- **sea_surface_pressure:** air pressure at 0.3 m about sea surface
- **significant_wave_height**

$$Hs = 4 * \sqrt{m_0}; \tag{1}$$

where

$$m_n = \int_0^\infty f^n E(f) df. \tag{2}$$

Here, we integrate them as:

$$m_0 = \sum_{f=0.035}^{0.5} a_0(f) * \Delta f. \tag{3}$$

- **peak_period:** wave period of the spectral energy maximum
- **average_period:** wave period corresponding to the mean frequency of the spectral range: $T_{m01} = m_0/m_1$
- **dominant_wave_direction:** direction of waves at the spectral energy maximum
- **wave_quality_flag**: Range is from 0 (no flags) to 12 (all flags), based on the quality criteria described below. The QC flag for the individual criteria are in the quality_flag in the First-Five file. If the First-Five are not reported, the wave_quality_flag will be -999 (missing).
- **aggregate_wave_quality_flag**: cumulative sum of the 12 wave_qcflags listed below
- **wave_qcflag1**: quality flag for significant wave height
- **wave_qcflag2**: quality flag for average period
- **wave_qcflag3**: quality flag for a spike in significant wave height
- **wave_qcflag4**: quality flag for the first value of spectral wave energy: a0(1)
- **wave_qcflag5**: quality flag for the second value of spectral wave energy: a0(2)

- **wave_qcflag6**: quality flag for the third value of spectral wave energy: a0(3)
- **wave_qcflag7**: quality flag for the gradient of spectral wave energy: a0(1) to a0(2)
- **wave_qcflag8**: quality flag for the gradient of spectral wave energy: a0(2) to a0(3)
- **wave_qcflag9**: quality flag for the gradient of spectral wave energy: a0(3) to a0(4)
- **wave_qcflag10**: quality flag for missing data: less than 95% data reporting
- **wave_qcflag11**: spectral continuity check: frequency bands above 0.08 Hz do not change more $0.006\text{f}^{-}4$ m^2/Hz in one hour
- **wave_qcflag12**: low-power mode: only one segment reporting

2.2 First-Five Data

First 5 wave data have the following variables:

- **platform_ID**: platform identification number
- **time**: time of wave observations (can match to time in sensor file for location and bulk wave parameters
- **frequency:** spectral frequency
- $\mathbf{a_0}$: wave variance spectral energy
- $\mathbf{a_1}$: first-directional coefficient
- $\mathbf{b_1}$: first-directional coefficient
- $\mathbf{a_2}$: second directional coefficient
- $\mathbf{b_2}$: second directional coefficient

The bulk wave parameters can be calculated directly from the first-five coefficients, and are provided to the user for ease of use. **The first-five data are not always available, even when bulk wave parameters are reported.** This can be caused by drifter programming (saving energy by not transmitting the full spectra), or GPS transmission time-outs (rare). In this case, quality of the data may be unknown. SST and SLP may also be measured more frequently than waves. In these cases, the length of the time series of the sensor file and first-five file may differ.

3 Wave quality flag description and how to use:

The quality flag follows NDBC/CDIP guidelines to identify outliers. This involves finding the mean and standard deviation of the dataset, and flagging data that is greater than a certain number of standard deviation from the mean. For NOPP, we flagged data that fell outside four-standard deviations. Additionally, there can be spectral continuity issues or missing data. In the chaotic wave field of a hurricane, spectral continuity should not be expected, and this flag can largely be ignored. All QC flags are considered soft flags. Data should not be discarded outright but should be considered on a case-by-case basis. The user should determine the usability of data by looking at the bulk wave parameters and spectra at the flagged point and measurements before and after the flagged observation to assess validity. Outliers can be caused by crossing seas, a change in the spectral content, or arrival of a storm.

3.1 QC flags based on PDFs from a dataset:

- **Hs**: The significant wave height.
- **Ta**: Average period
- **Hs spikes**: The significant wave height minus a 3-point median filter of significant wave height
- **a0 (wave energy)** first three values: a0(1), a0(2), and a0(3): The GPS-style wave buoys can have spurious low frequency noise. A large value of a0 in the first few frequency bins can cause unrealistic wave energy. Flagging these values helps identify these locations
- **Gradient between the first a0 values**: Similar to to the values themselves, strong gradients in the first three values may indicate low-frequency noise contamination.
  - $\diamond$ $grad\_a0(1) = a0(1) - a0(2)/df$;
  - $\diamond$ $grad\_a0(2) = a0(2) - a0(3)/df$;
  - $\diamond$ $grad\_a0(3) = a0(3) - a0(4)/df$;

3.2 QC flags based on data reporting and continuity

- **Missing data**: Flagged if the raw time series reports less than 95% of data. Missing data create gaps in the time series of drifter motion. These discontinuities can be filled with the mean or a zero, but they can create problems in wave energy. Inspection of the spectra directly and surrounding values can allow the user to see if it varied significantly from previous or following data. Data dropouts can be caused by the drifter being underwater or from issues with the GPS. This can vary geographically and with sea-state. The decision to use this data should be carefully considered.
- **Spectral Continuity:** Following NDBC temporal continuity of spectral values: Link
- **Number of segments:** The drifters are shipped in low-power mode. At times the re-programming is delayed when drifter deployment is unknown or a reprogramming message was sent but the drifter did not receive it. Wave observations in low-power mode have only 2-degrees of freedom with high uncertainty and should be discarded. This is the only ”hard flag”. For **L2** data, these observations have been removed from the first-five and sensor files.

Notes

***Trouble shooting:** Please report any questions about the data to ldl-datasets@ucsd.edu.

3.3 LDL Wave Drifters for NHCI: Hurricane Ian

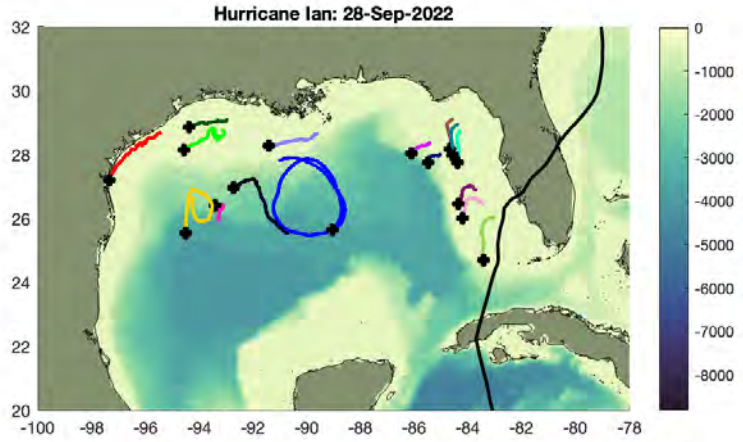


Figure 1

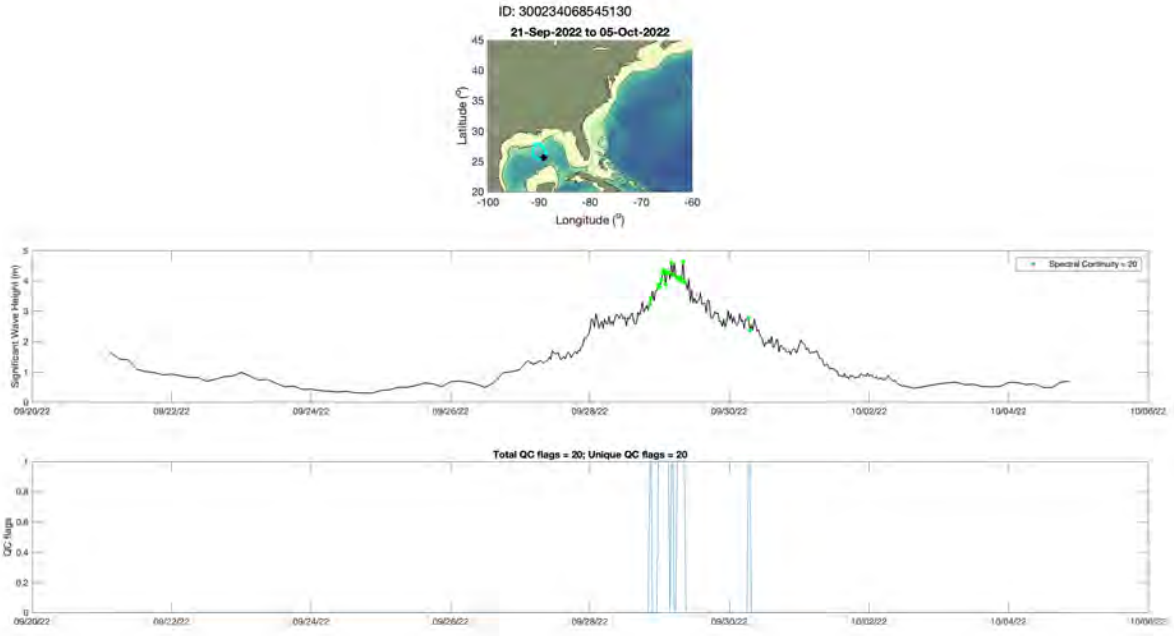


Figure 2

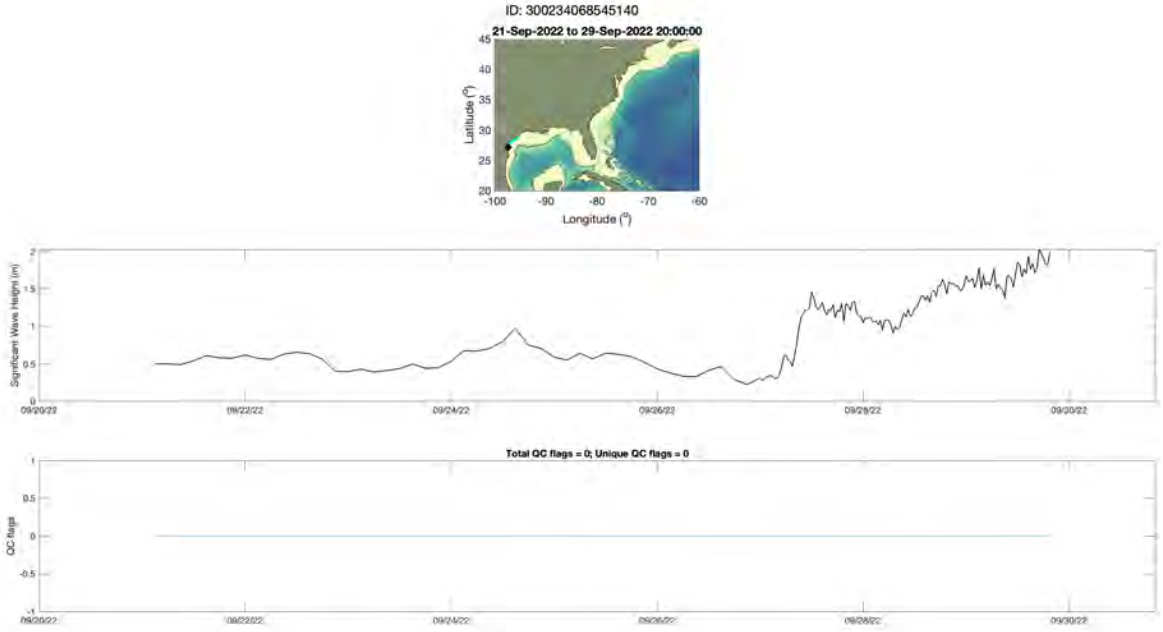


Figure 3

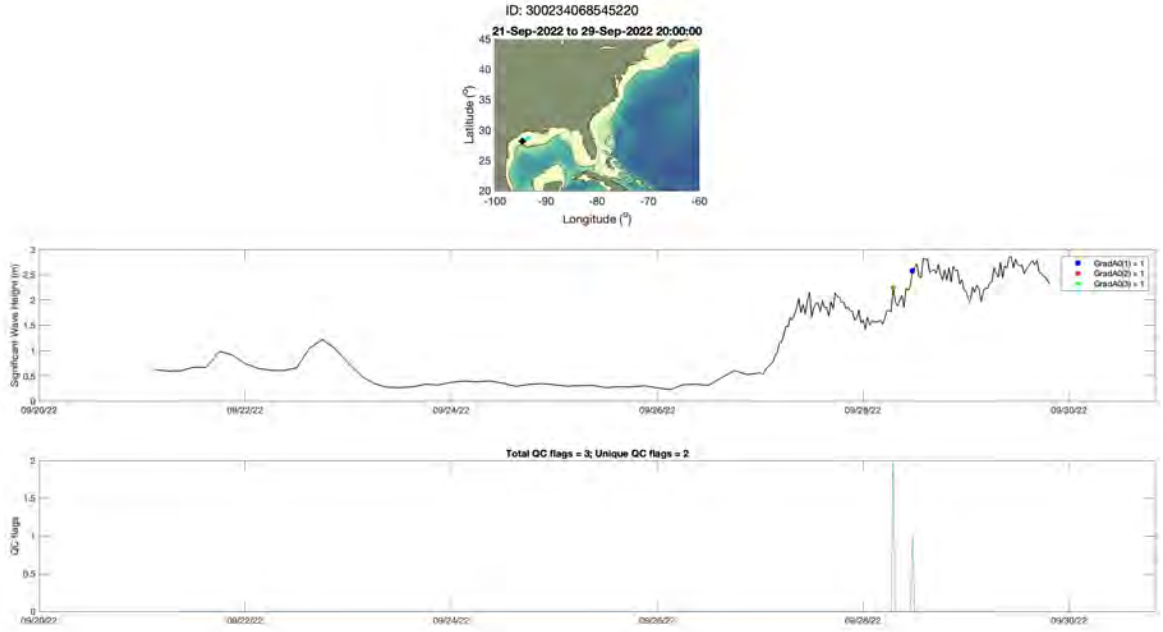


Figure 4

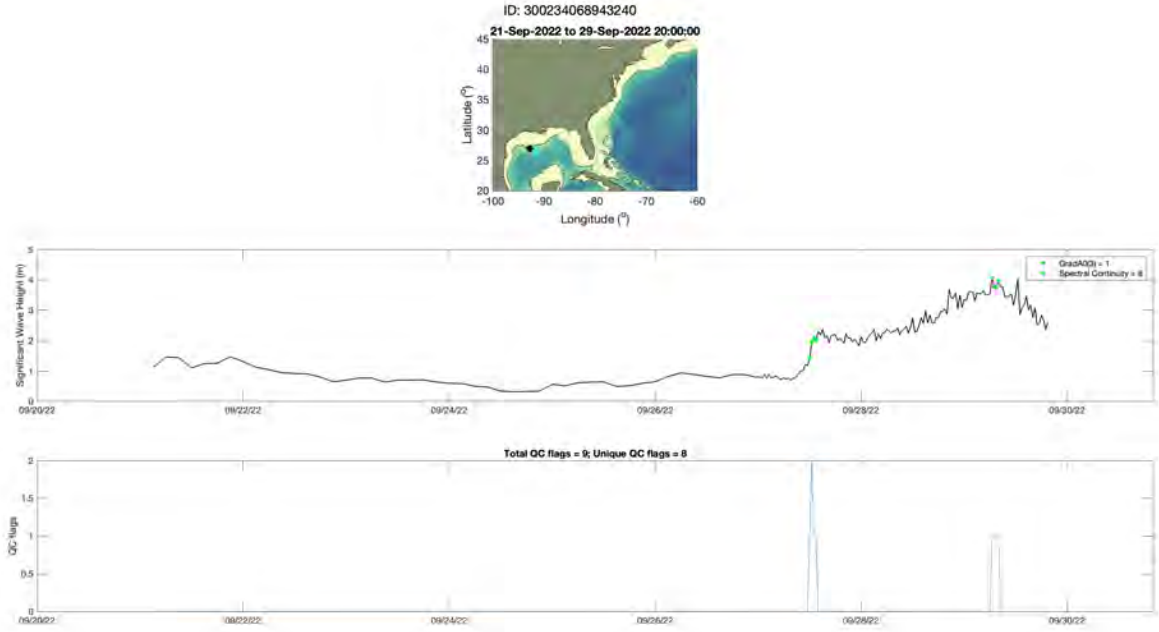


Figure 5

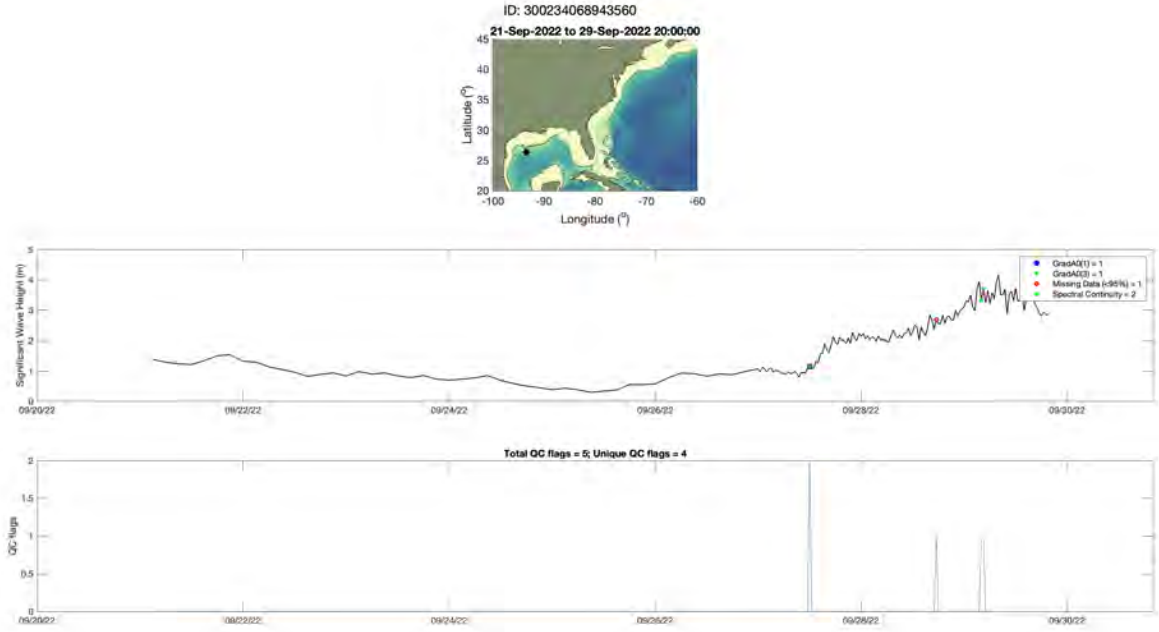


Figure 6

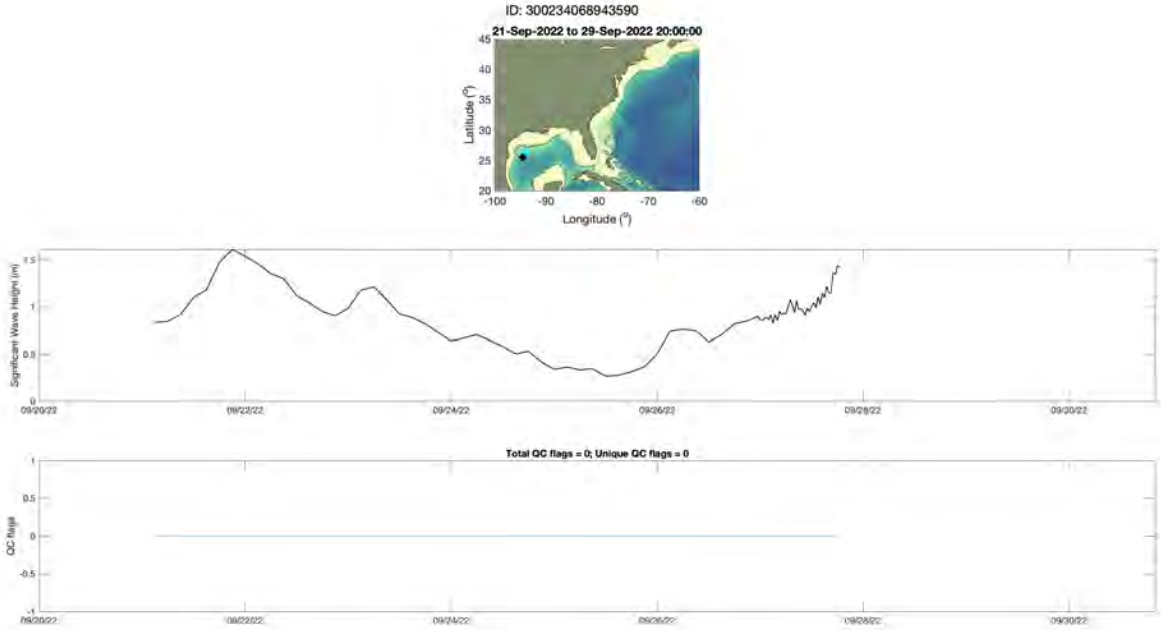


Figure 7

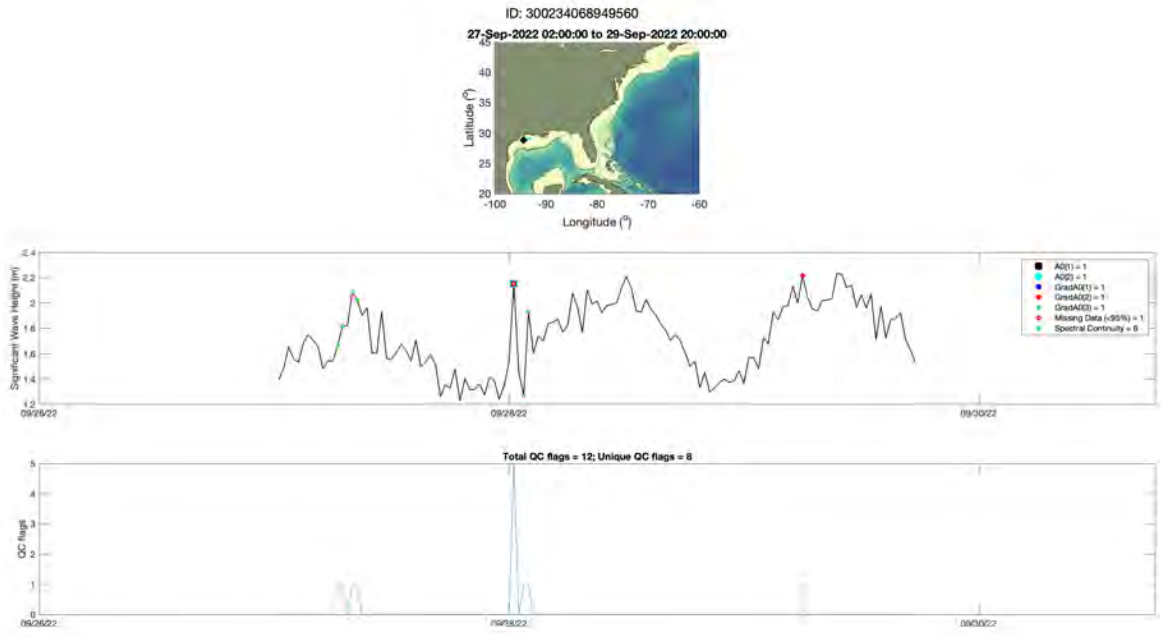
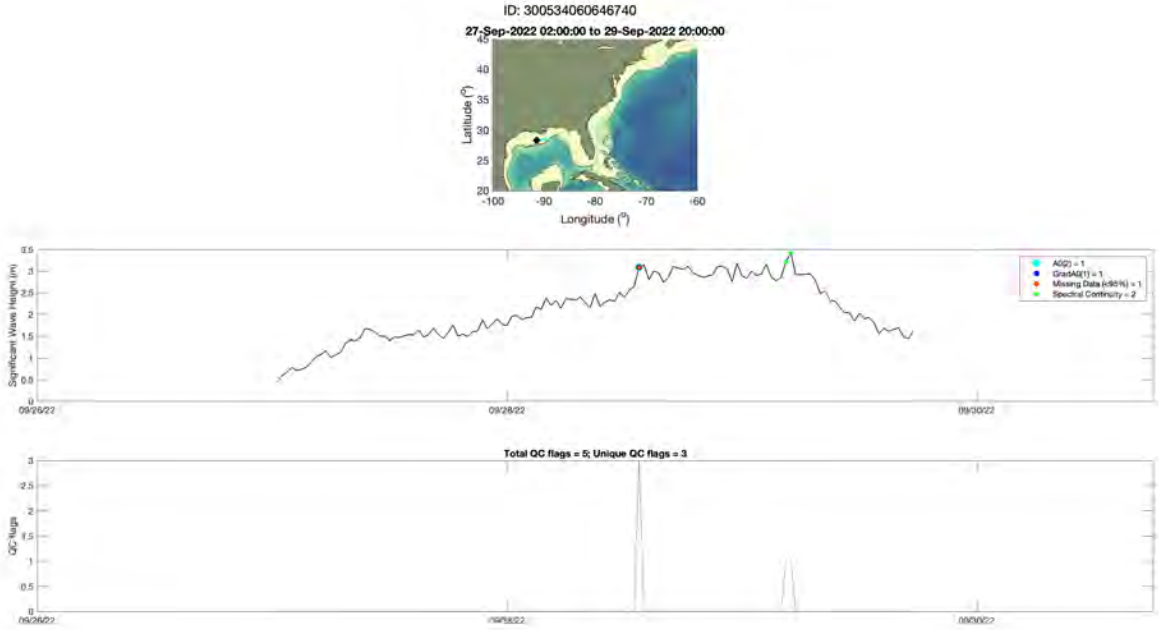


Figure 8



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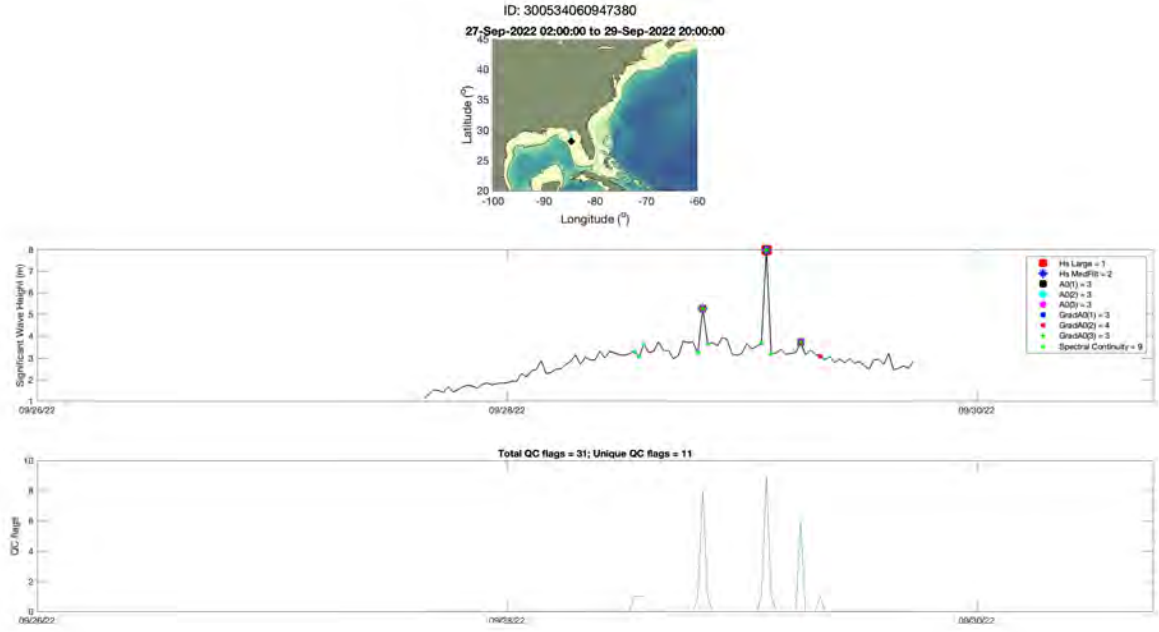

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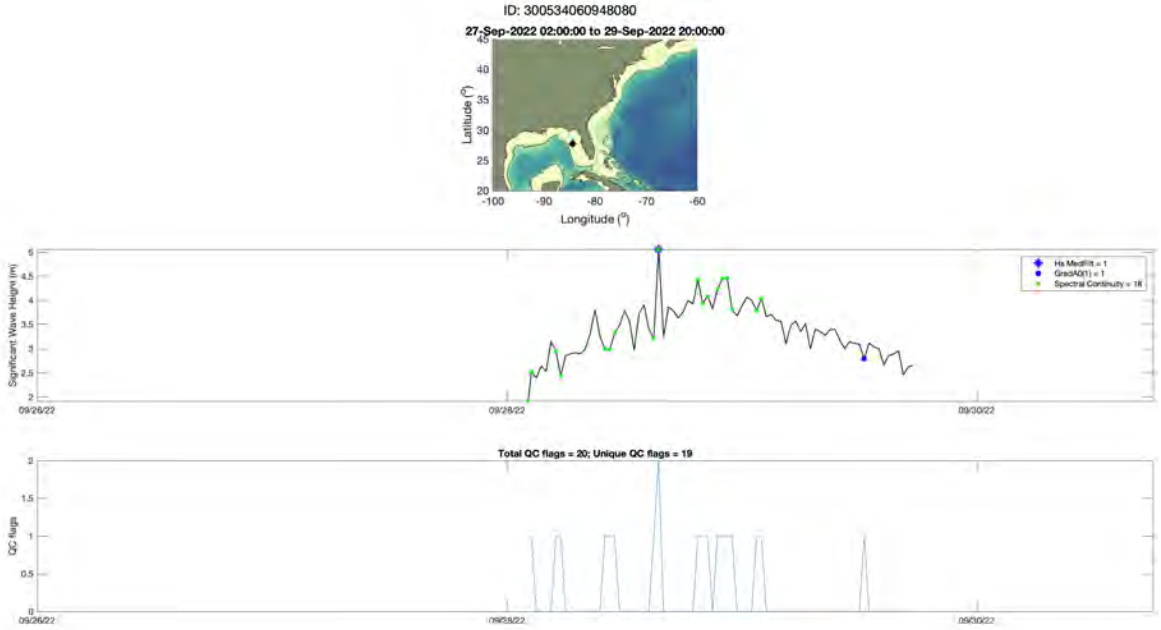

Figure 11

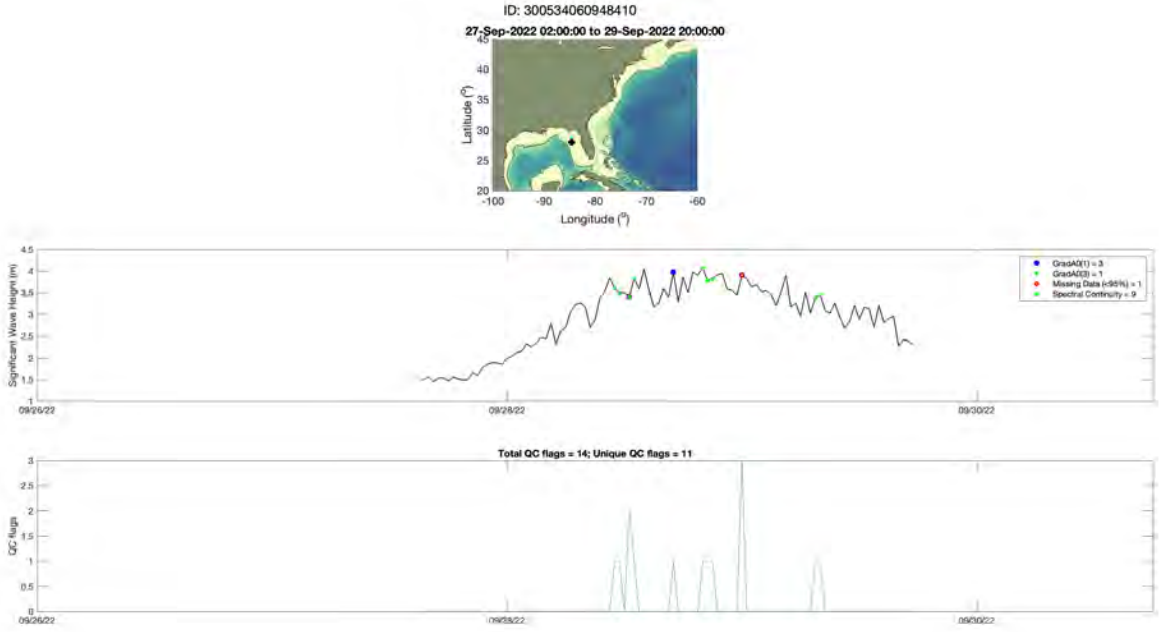

Figure 12

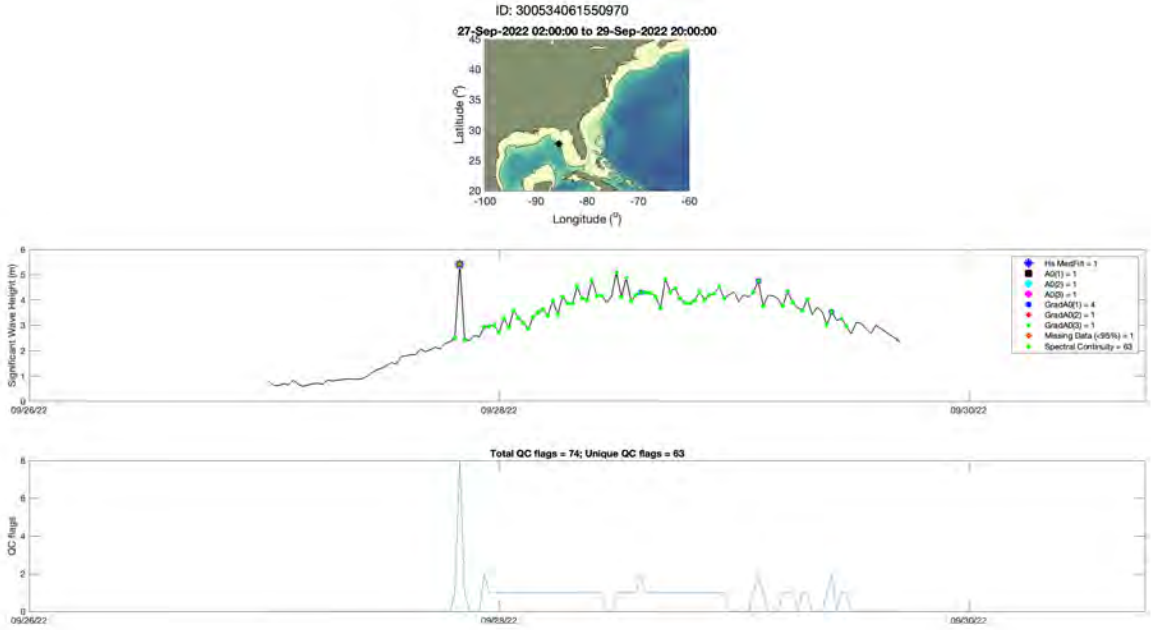

Figure 13

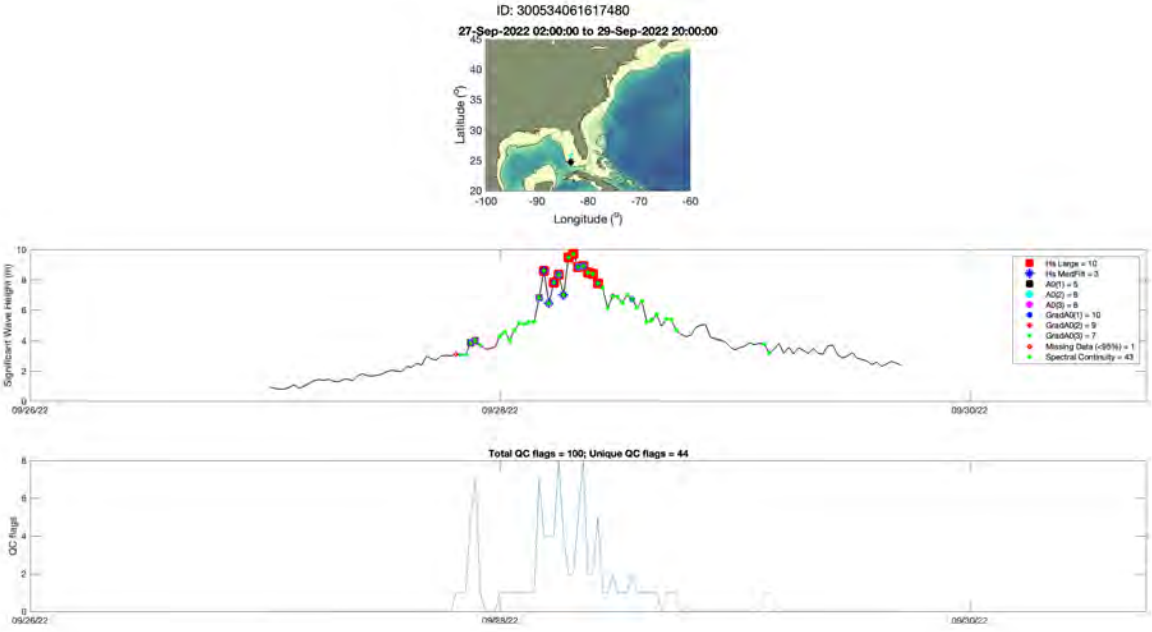

Figure 14

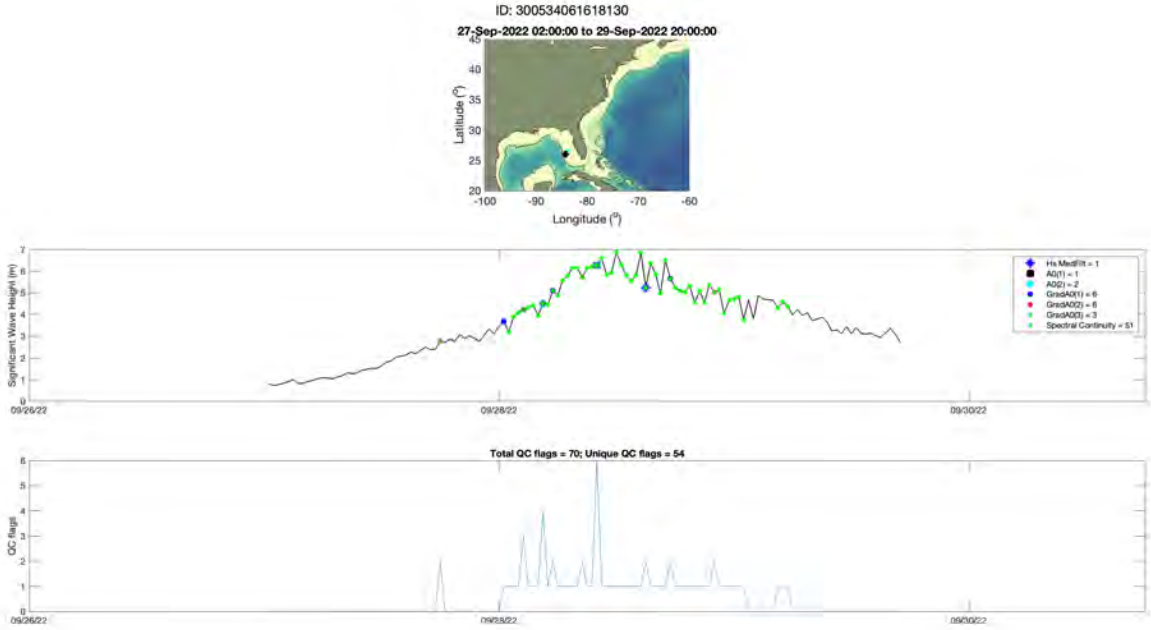

Figure 15

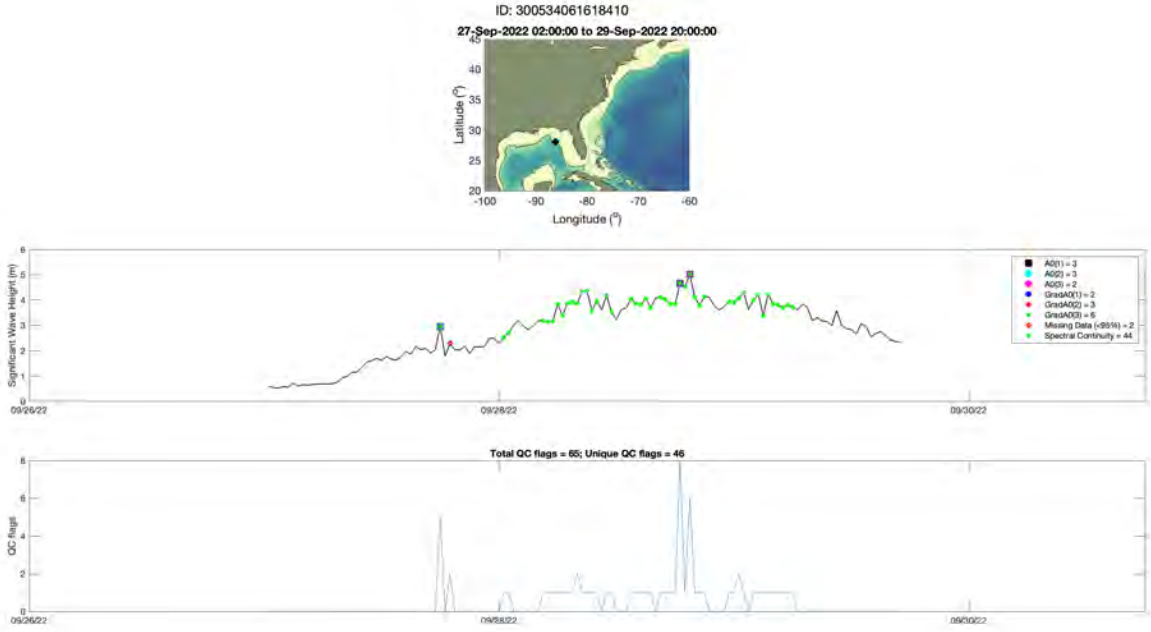

Figure 16

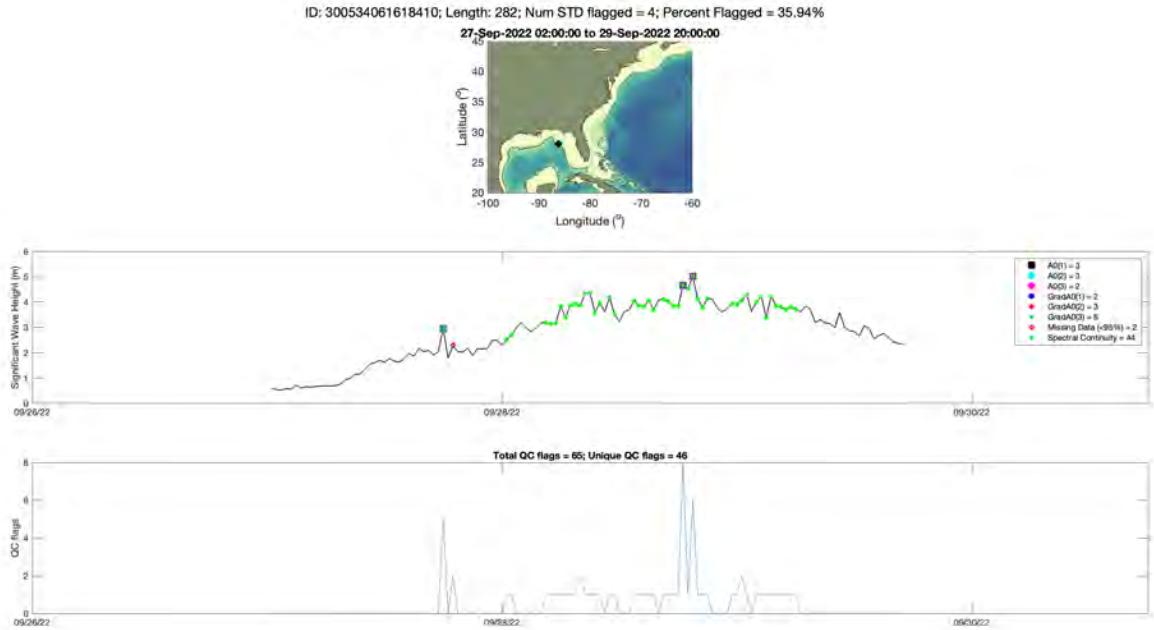

Figure 17

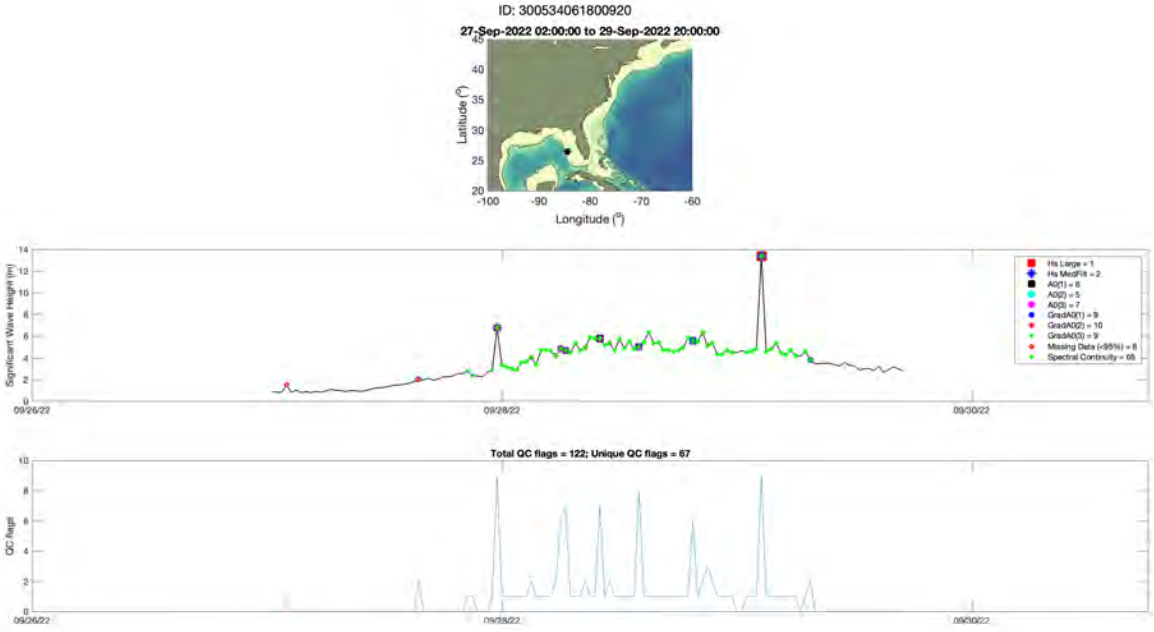

Figure 18

3.4 LDL Wave Drifters for NHCI: Hurricane Idalia

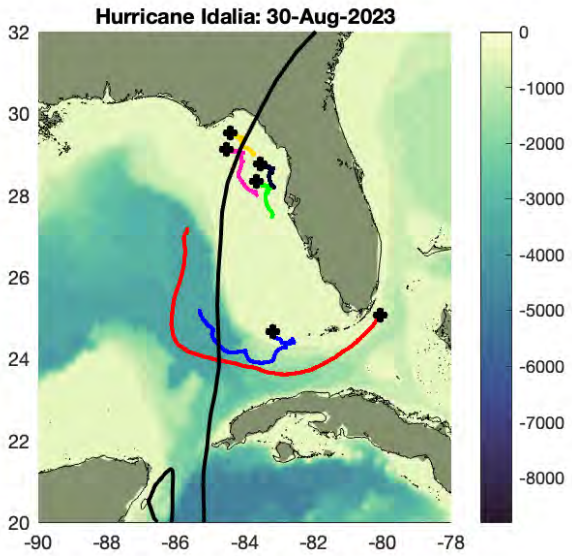

Figure 19

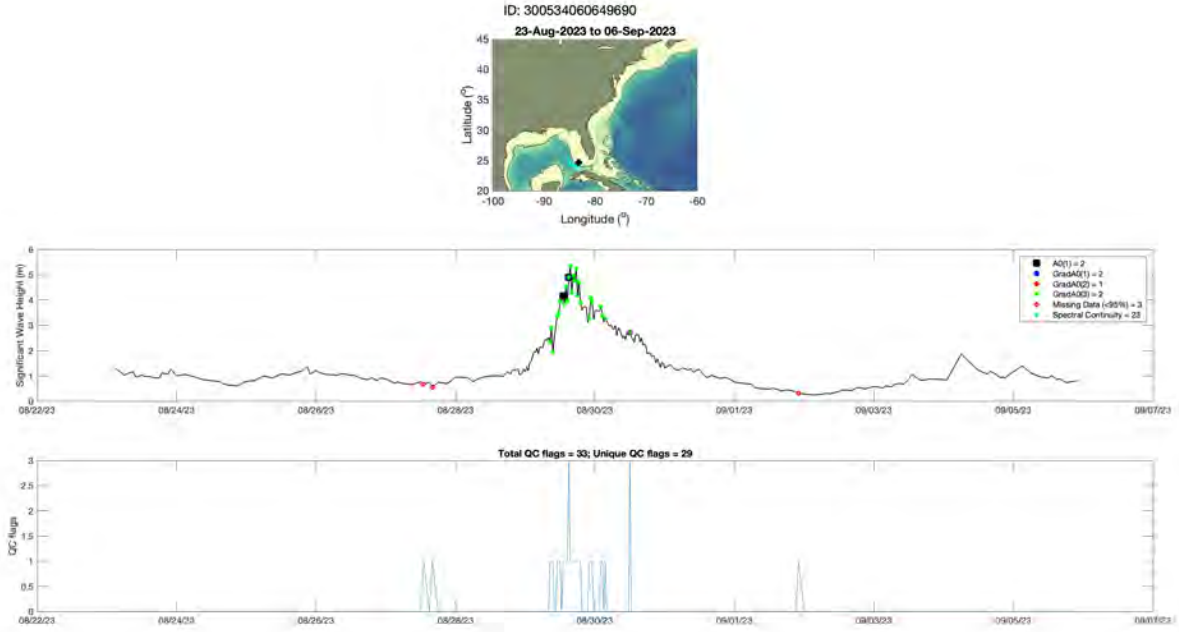

Figure 20

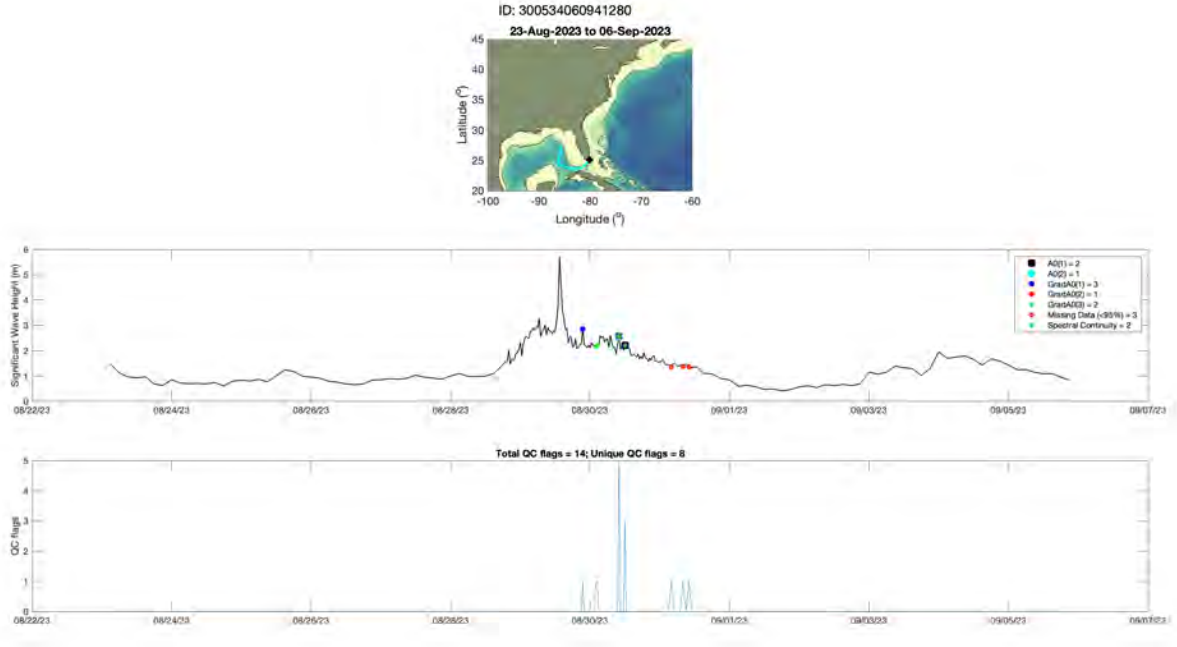

Figure 21

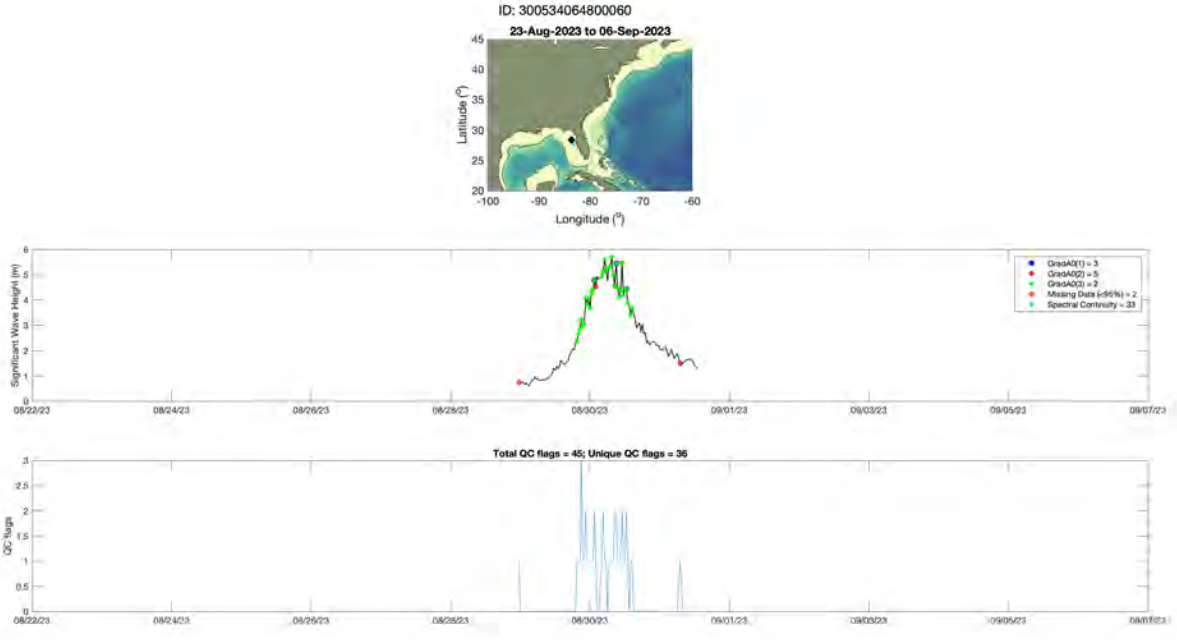

Figure 22

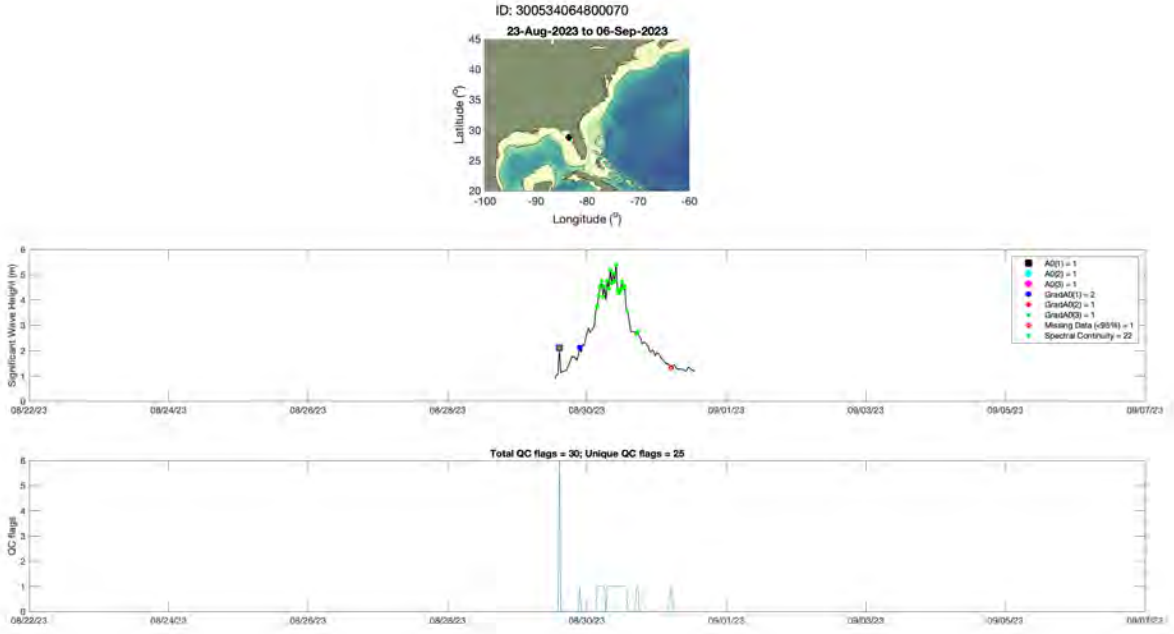

Figure 23

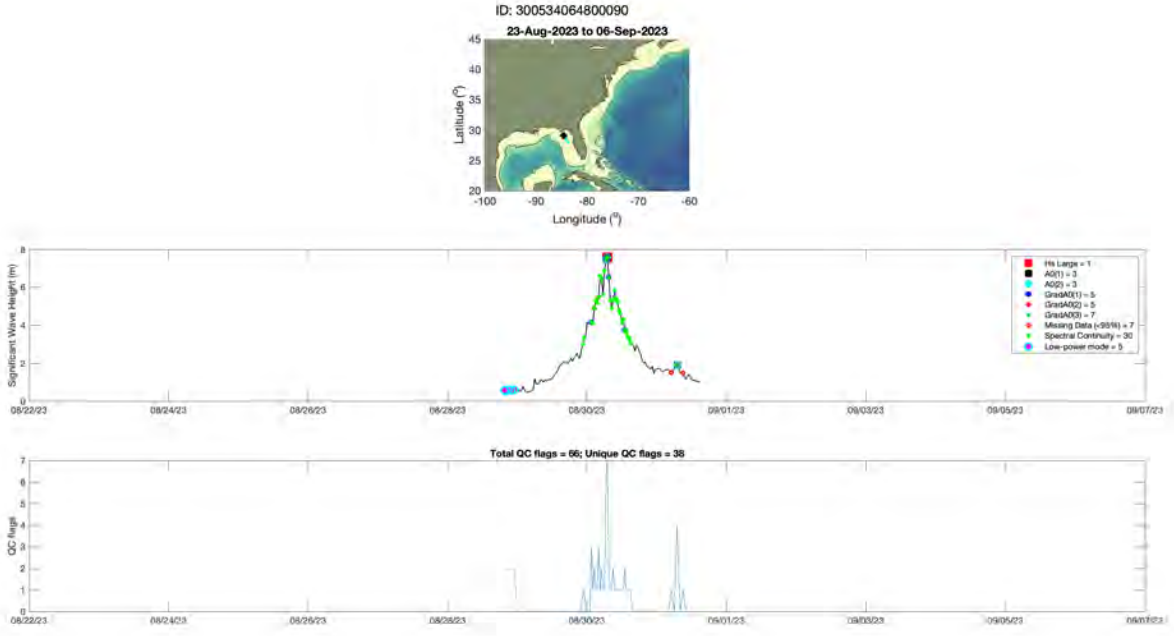

Figure 24

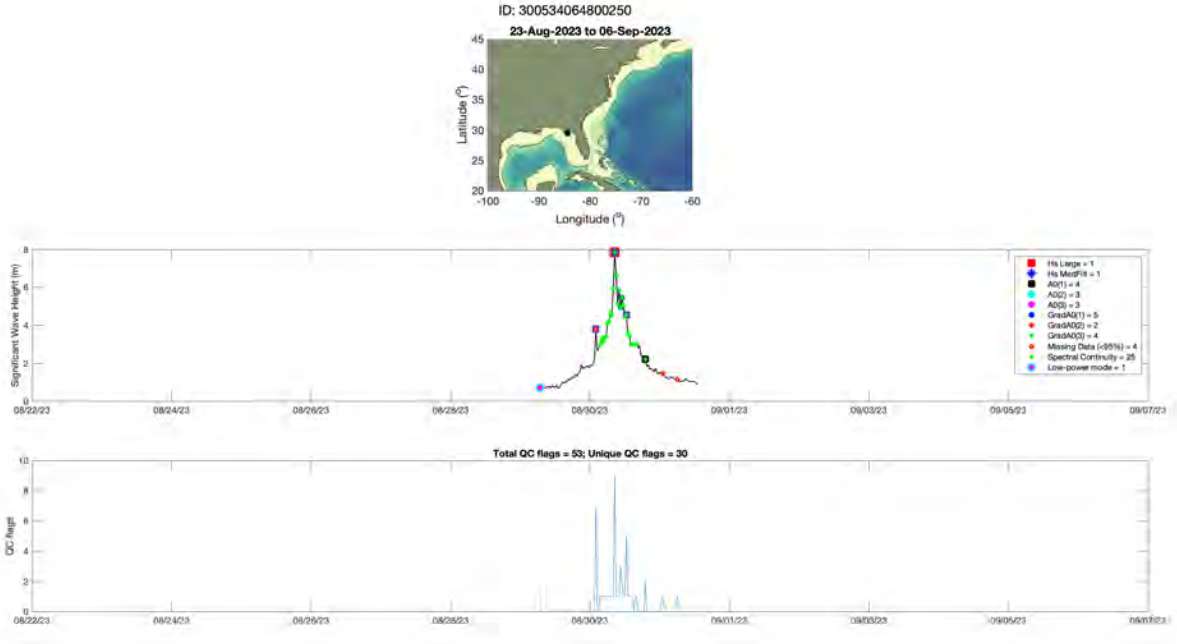
ID: 300534064800250
23-Aug-2023 to 06-Sep-2023
Latitude (°)
Longitude (°)
Significant Wave Height (m)
Hs Large = 1
Hs Med/Fit = 1
A0(1) = 4
A0(2) = 3
A0(3) = 3
GradA0(1) = 5
GradA0(2) = 2
GradA0(3) = 4
Missing Data (<95%) = 4
Spectral Continuity = 25
Low-power mode = 1
Total QC flags = 53; Unique QC flags = 30
QC flags

Figure 25

3.5 LDL Wave Drifters for NHCI: Hurricane Lee

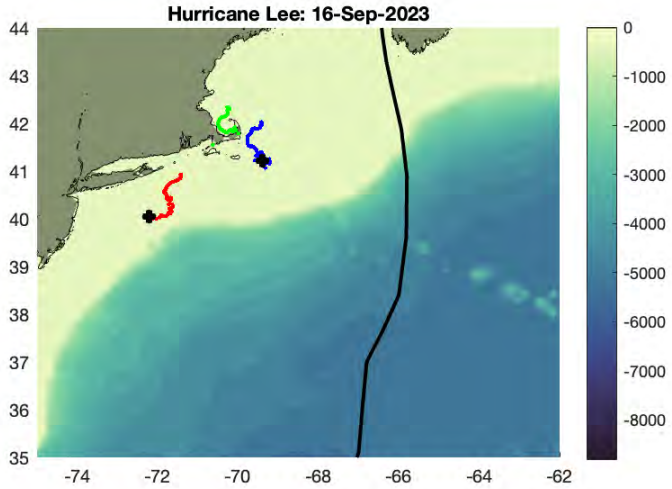

Figure 26

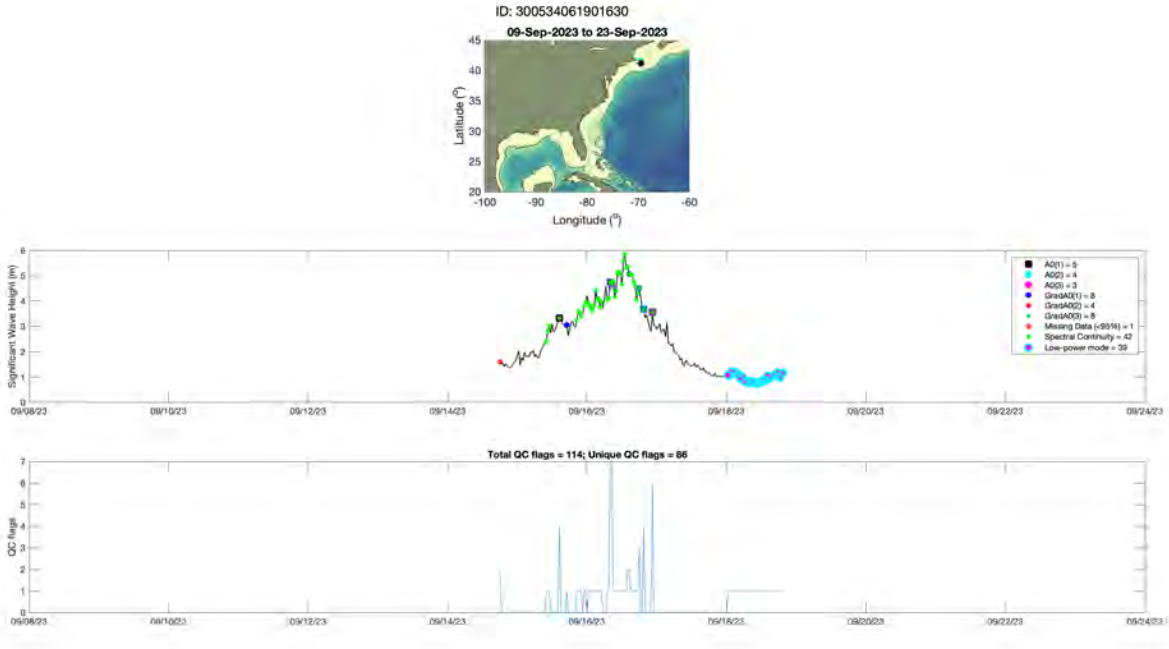

Figure 27

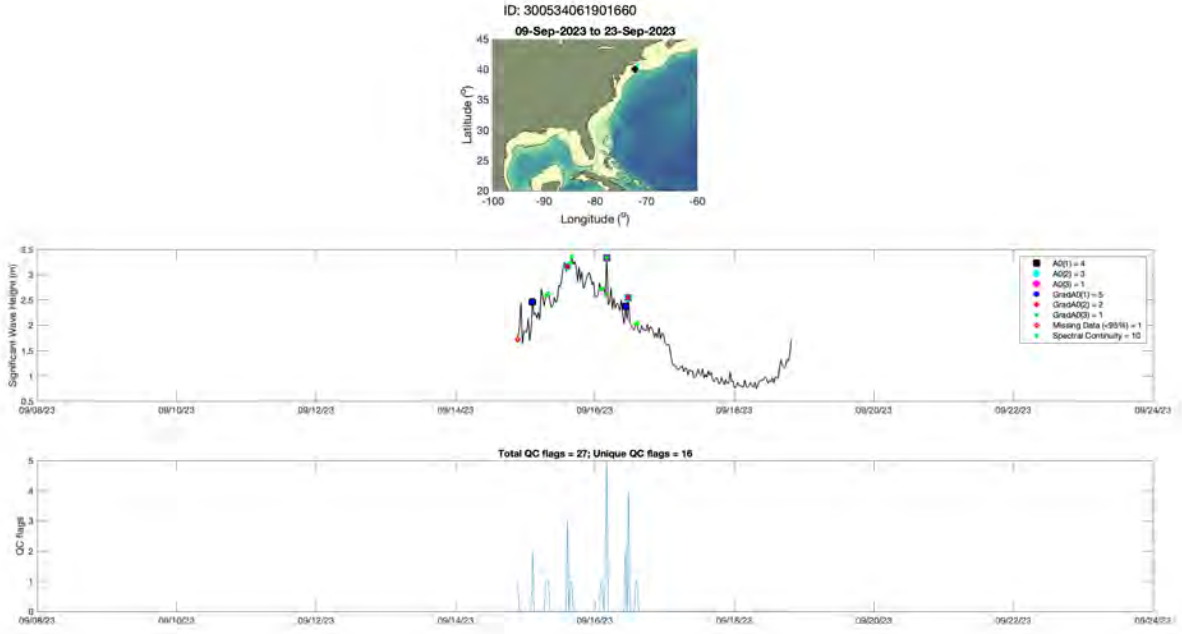

Figure 28

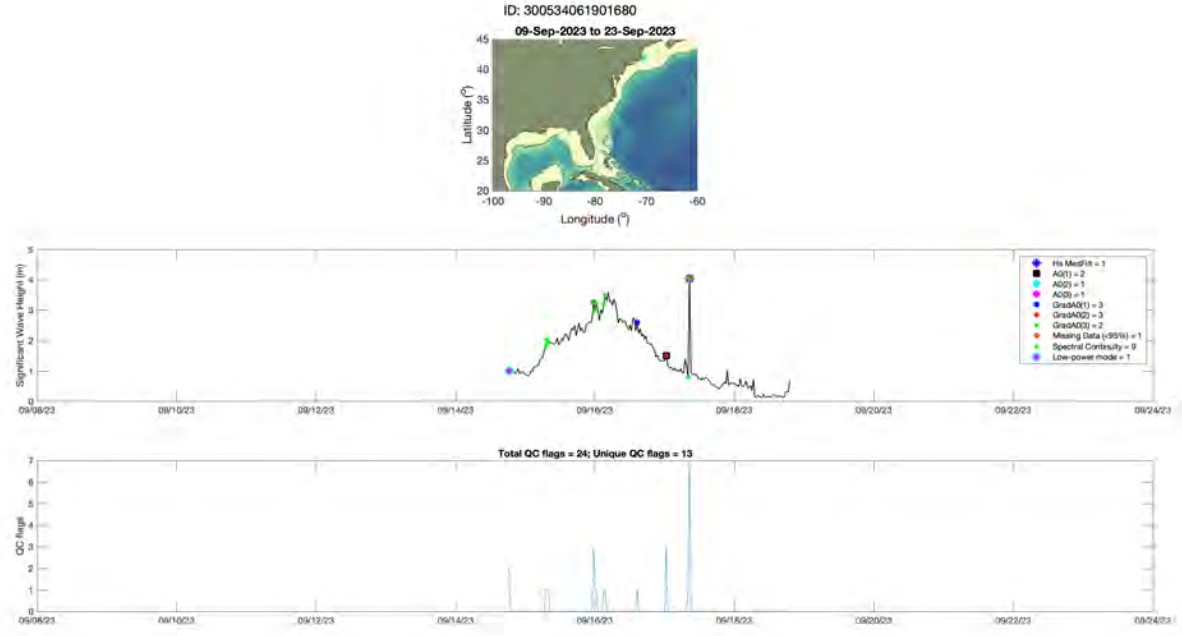

Figure 29

3.6 LDL Wave Drifters for NHCI: Hurricane Francine

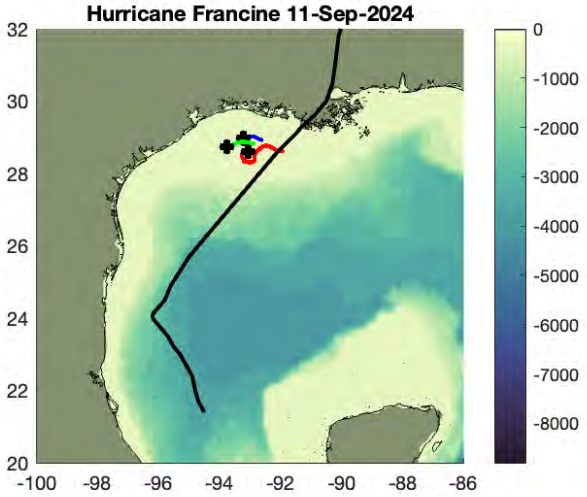

Figure 30

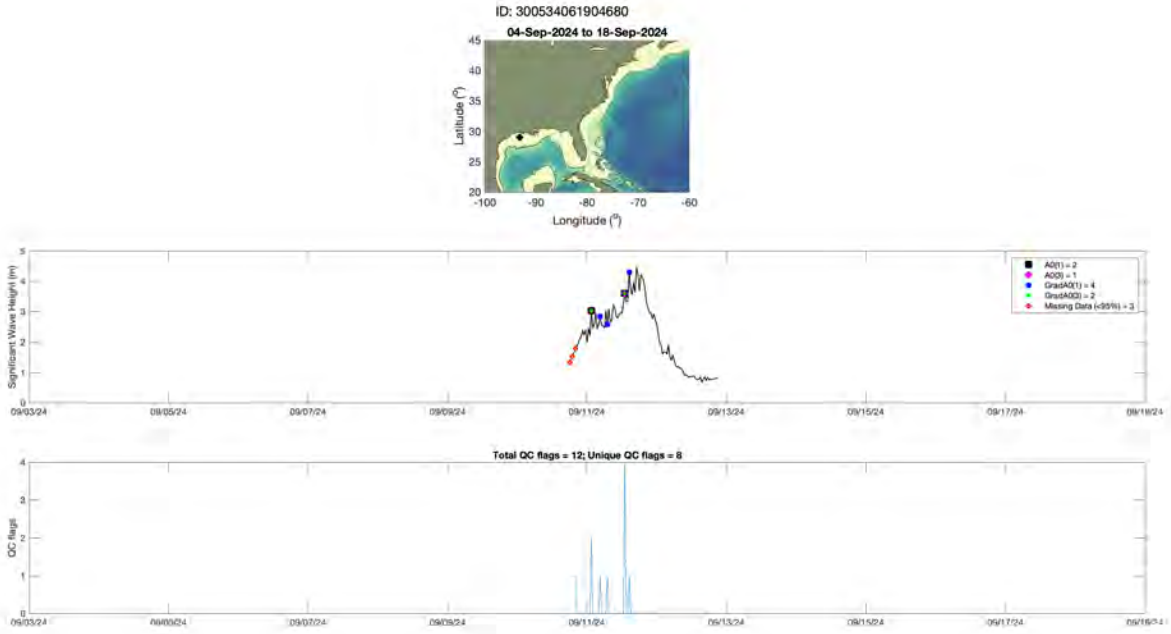

Figure 31

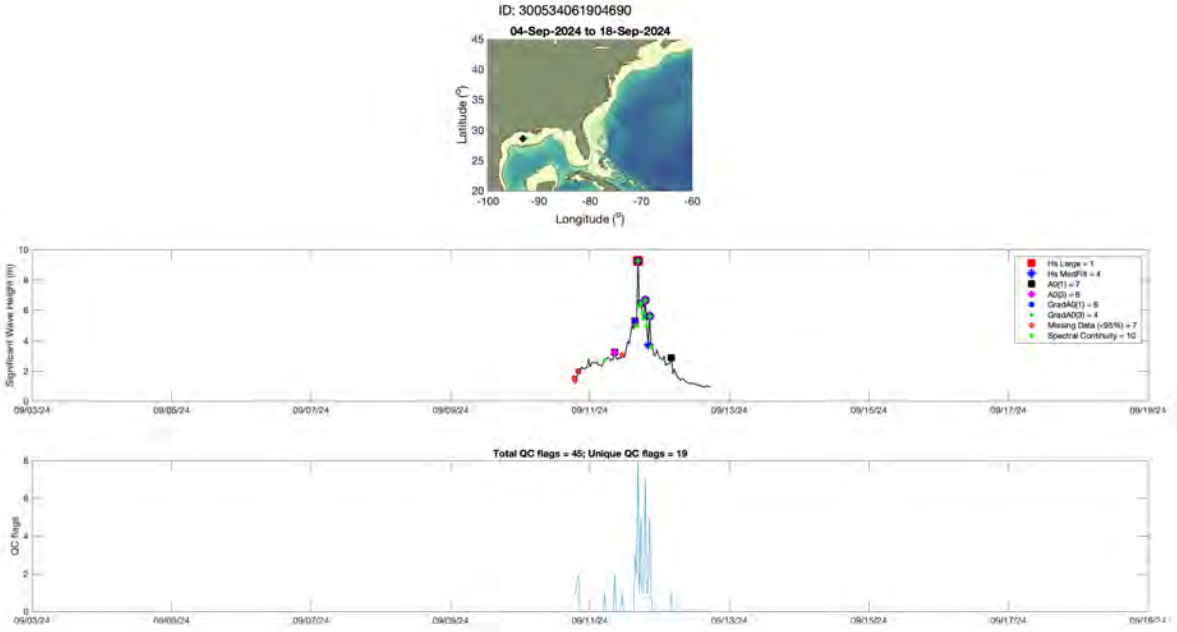

Figure 32

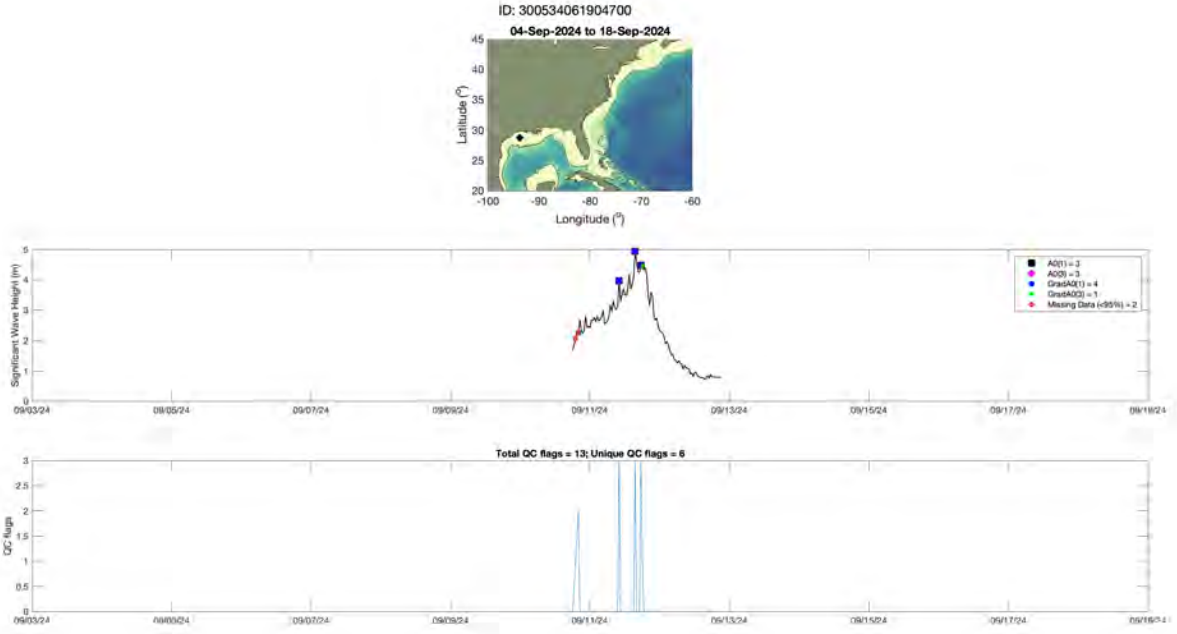

Figure 33

3.7 LDL Wave Drifters for NHCI: Hurricane Helene

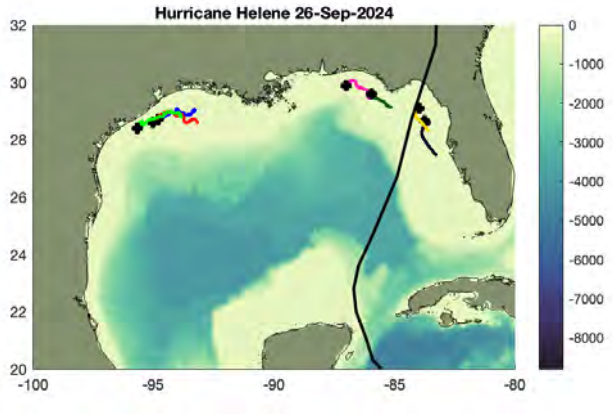

Figure 34

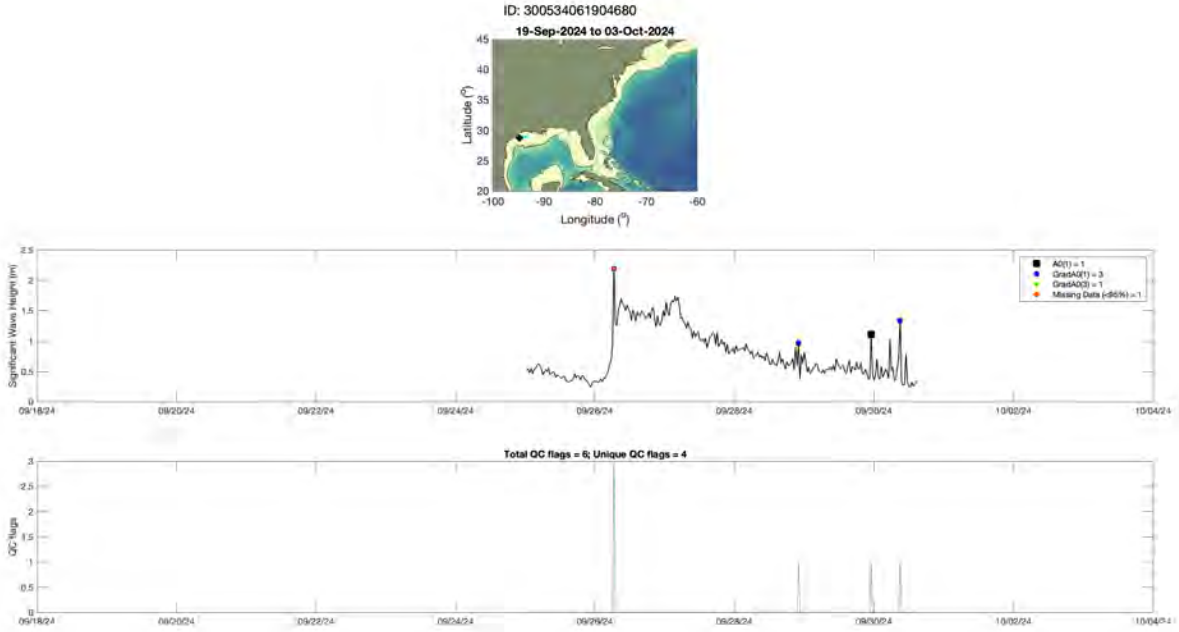

Figure 35

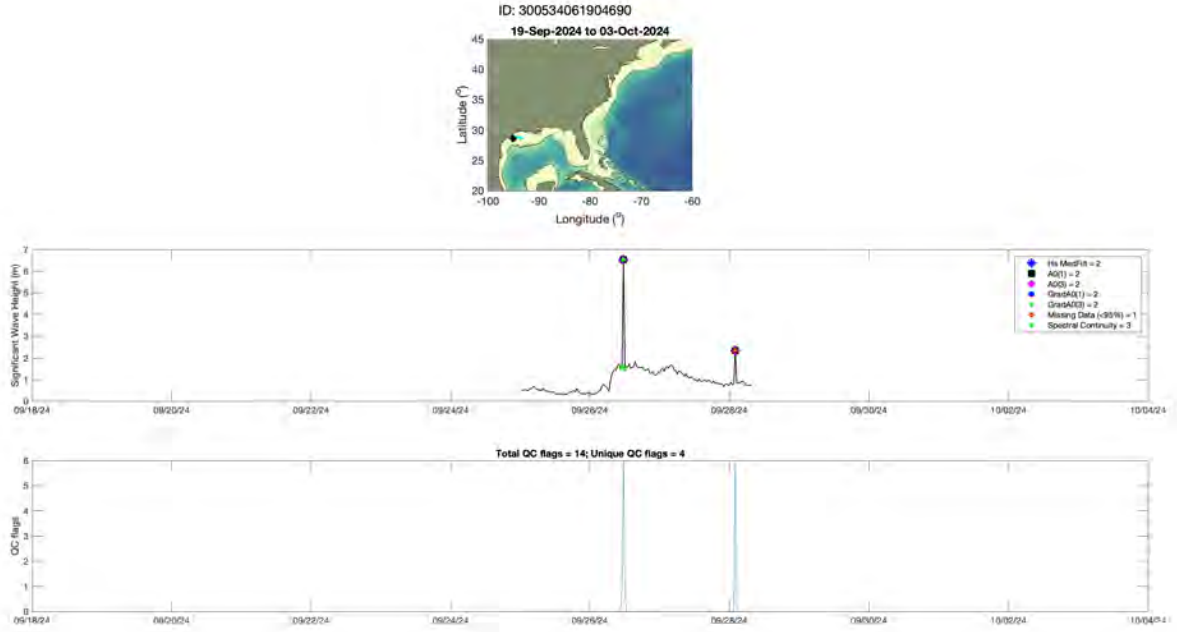

Figure 36

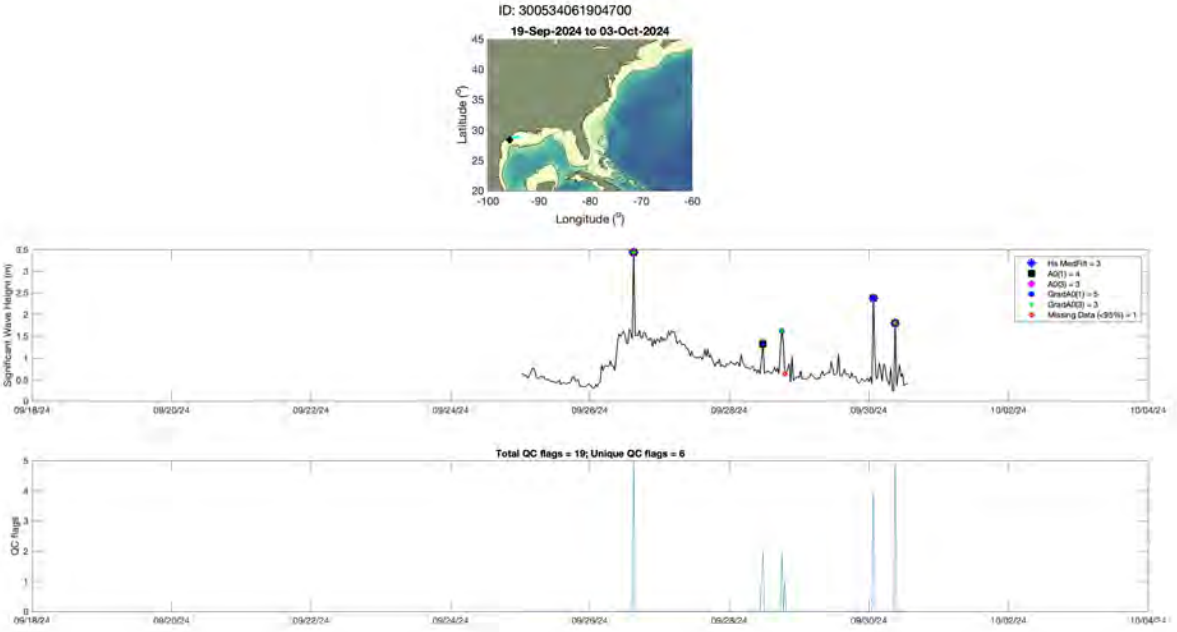

Figure 37

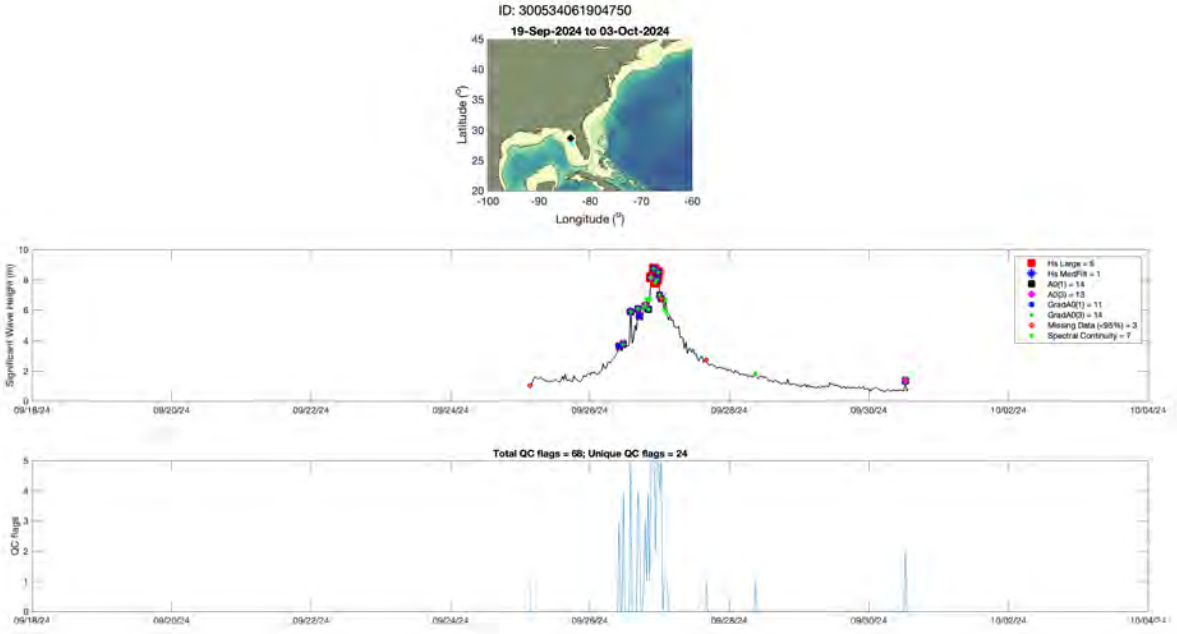

Figure 38

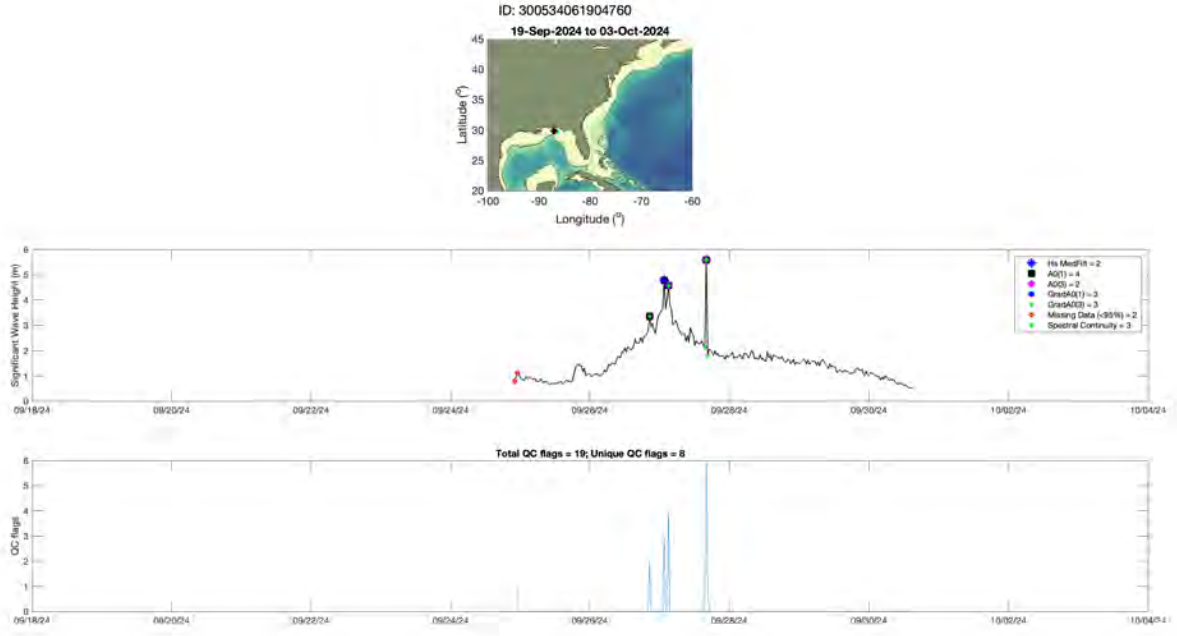

Figure 39

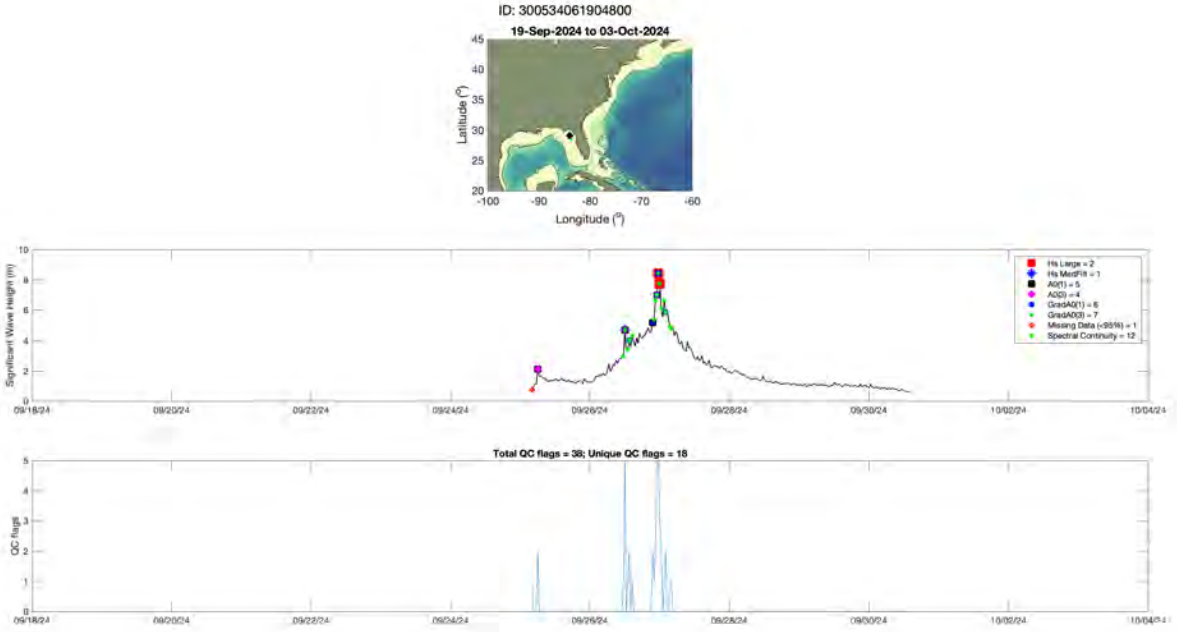

Figure 40

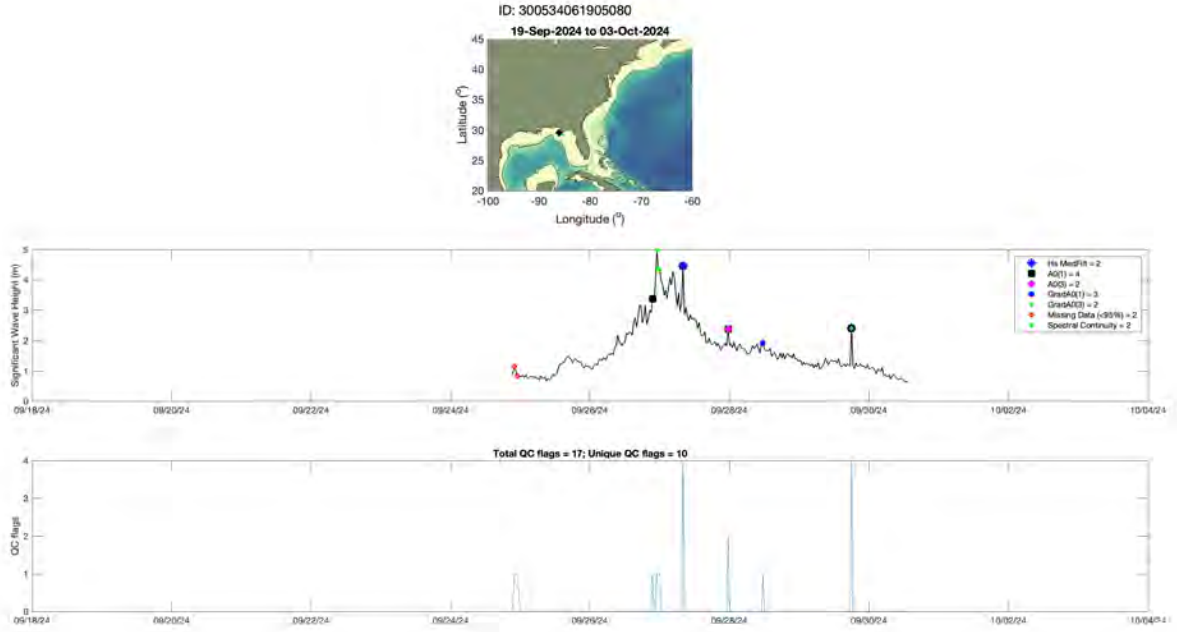

Figure 41

3.8 LDL Wave Drifters for NHCI: Hurricane Milton

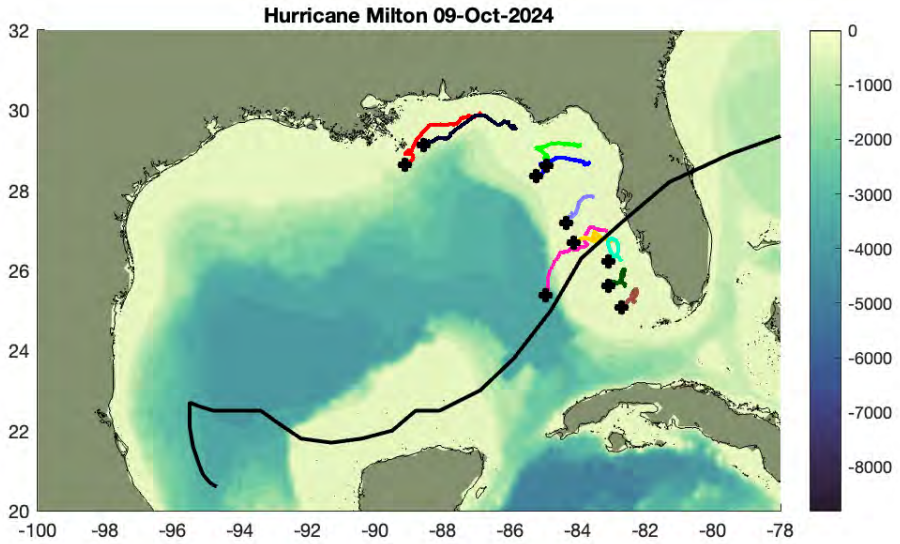

Figure 42

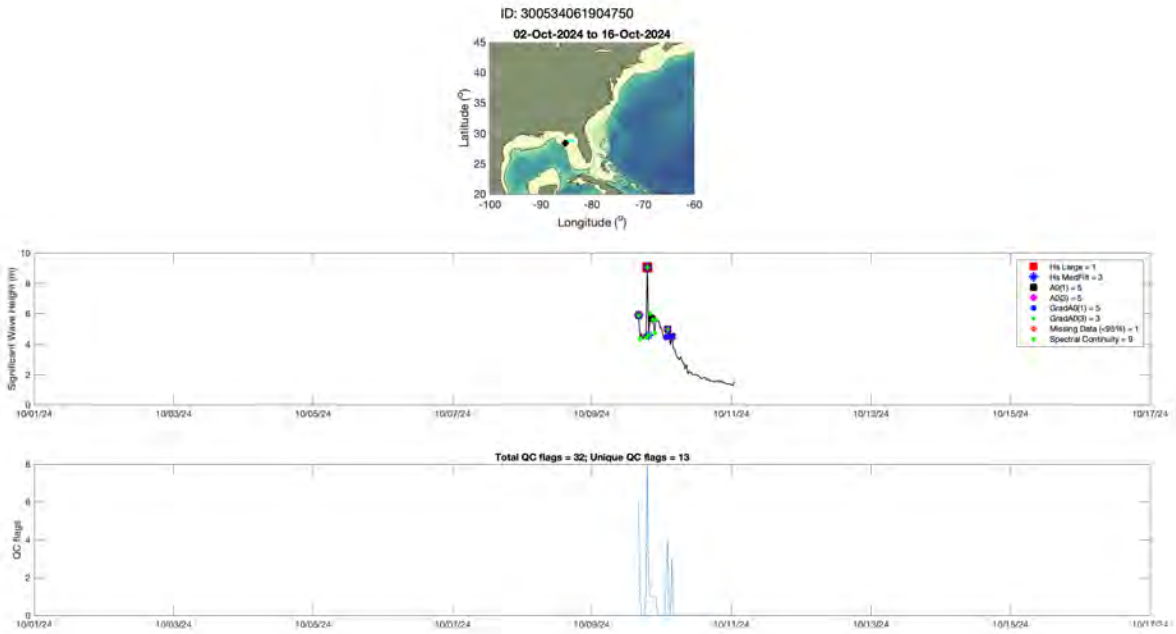

Figure 43

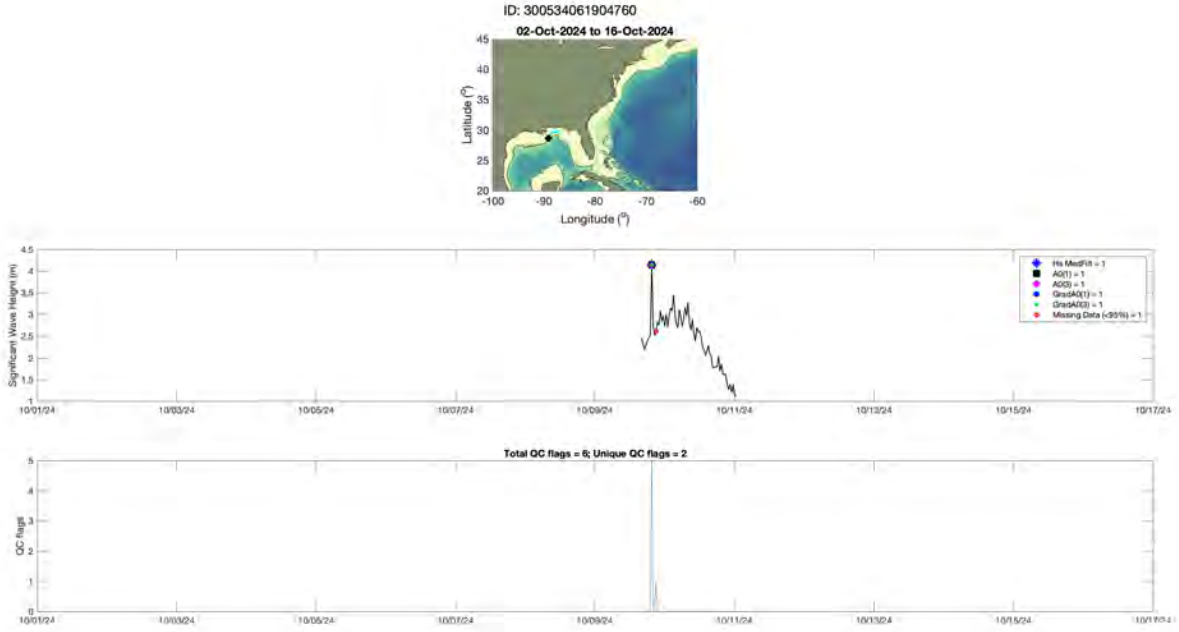

Figure 44

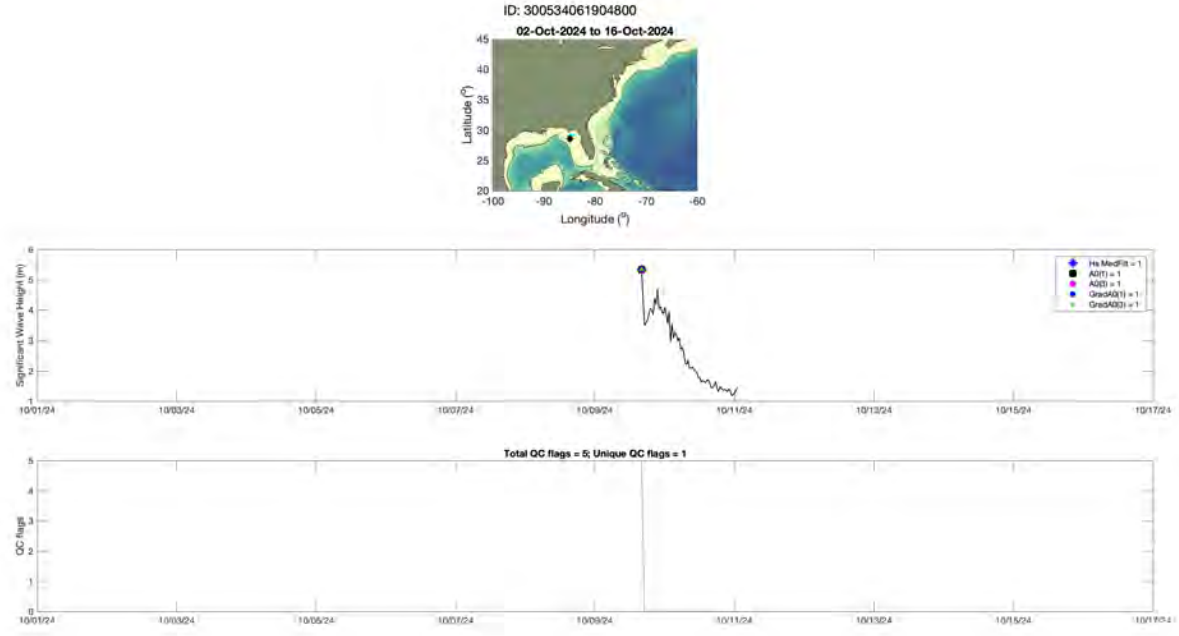

Figure 45

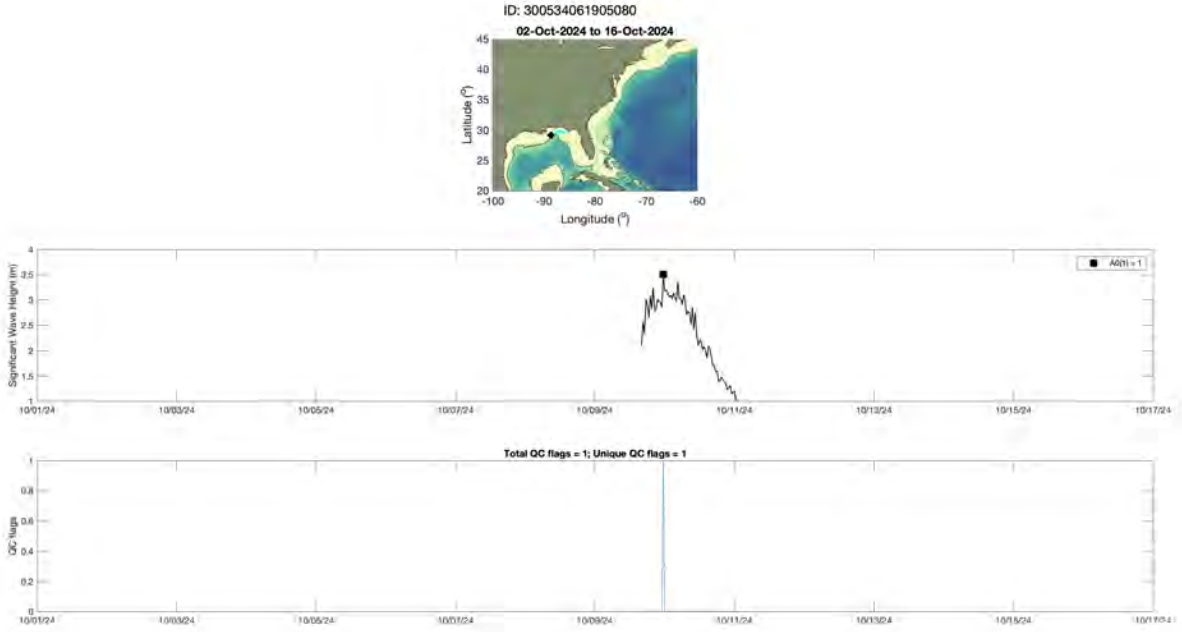

Figure 46

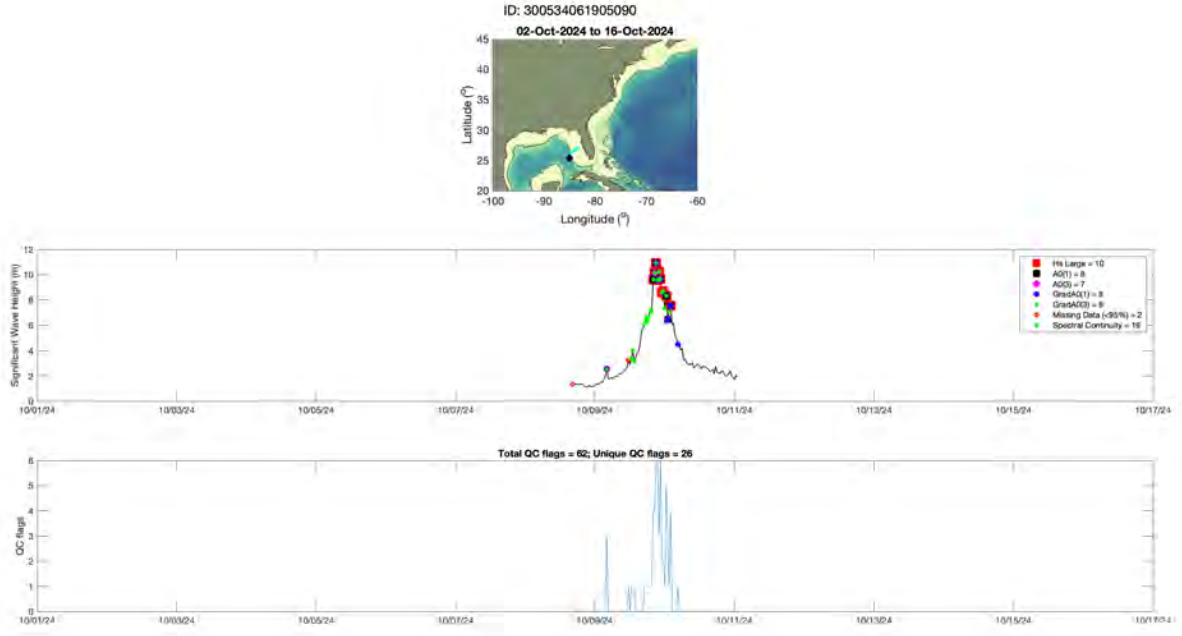

Figure 47

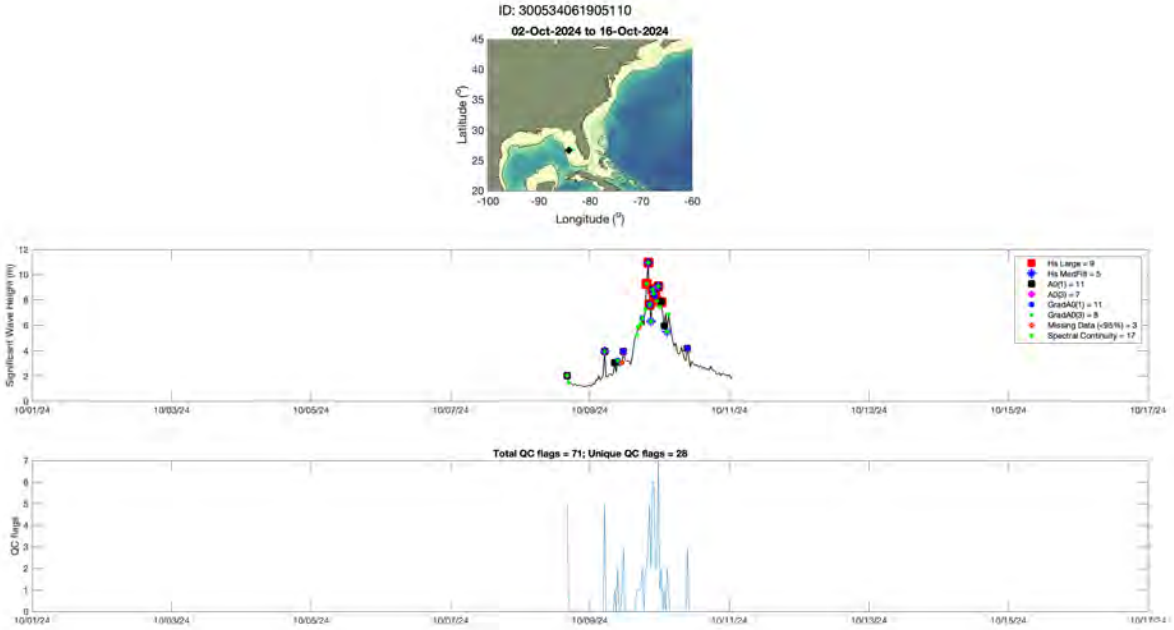

Figure 48

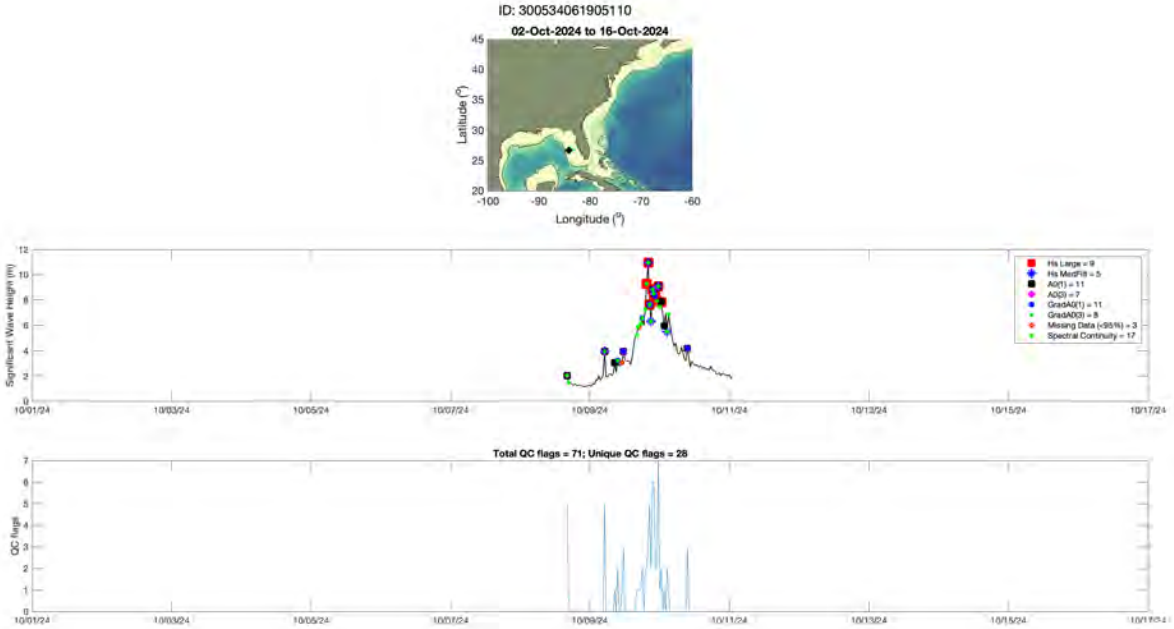

Figure 49

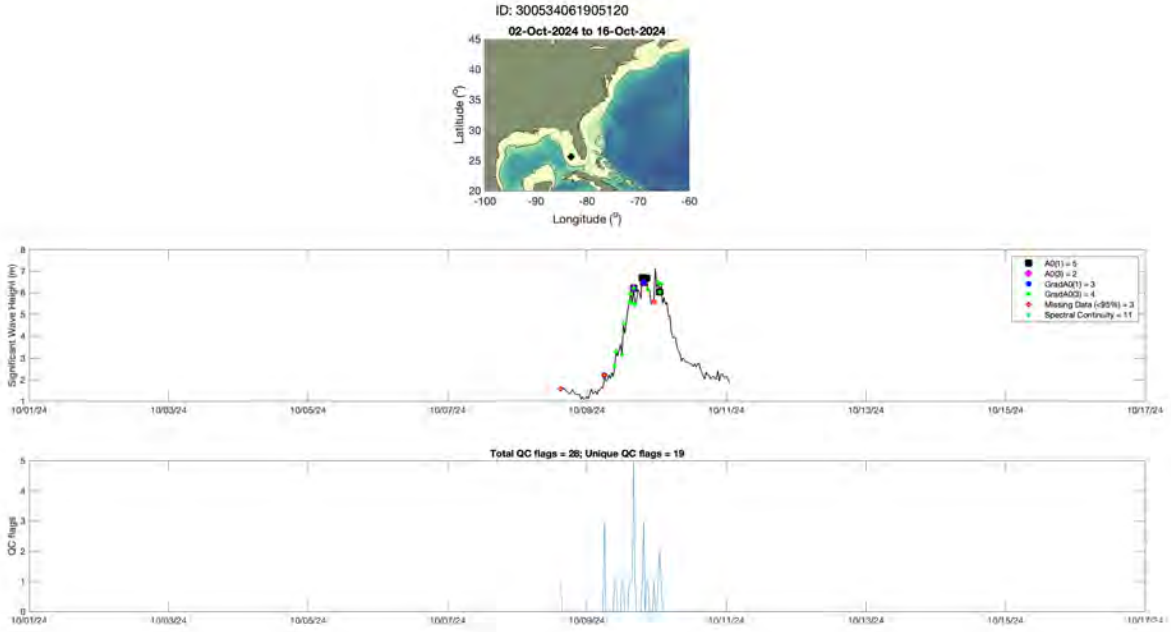

Figure 50

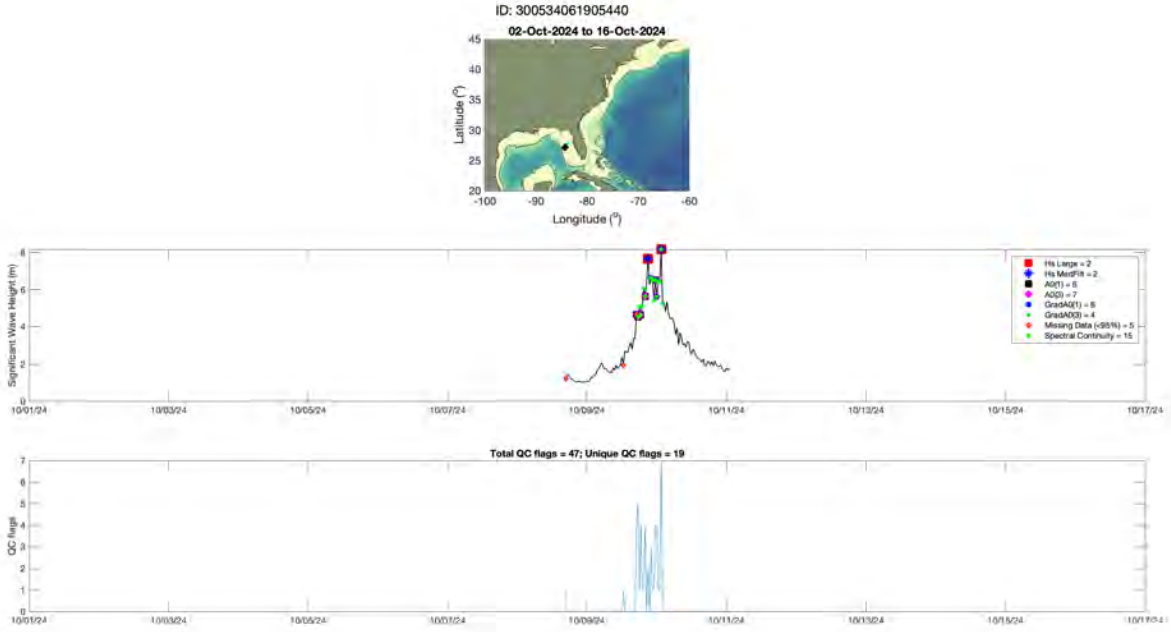

Figure 51

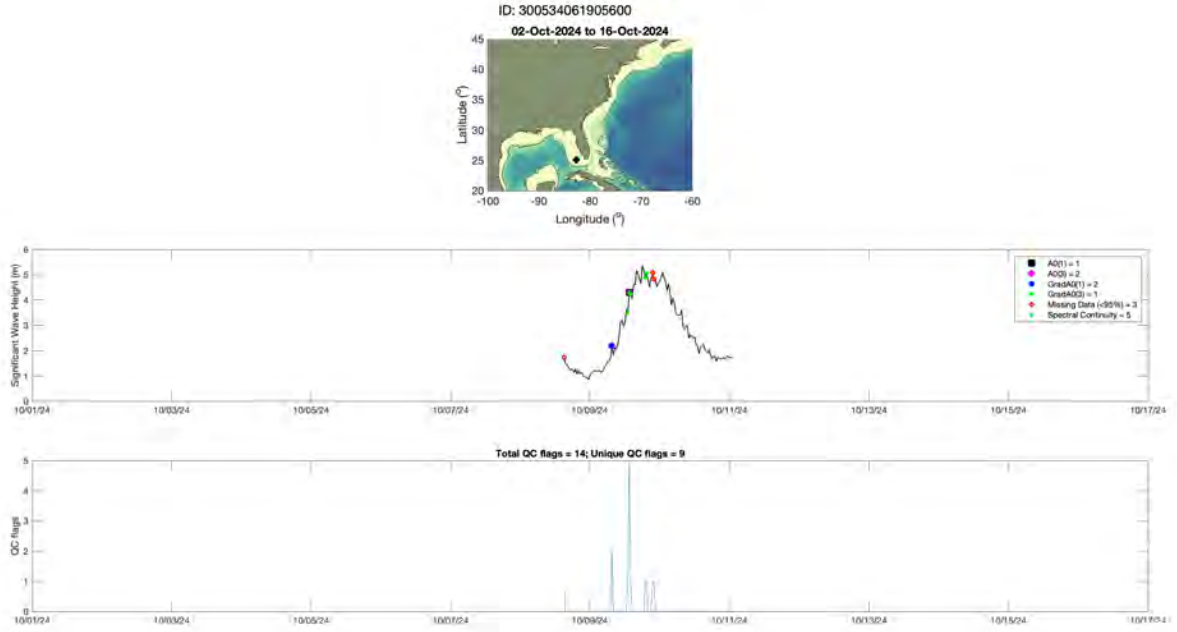

Figure 52

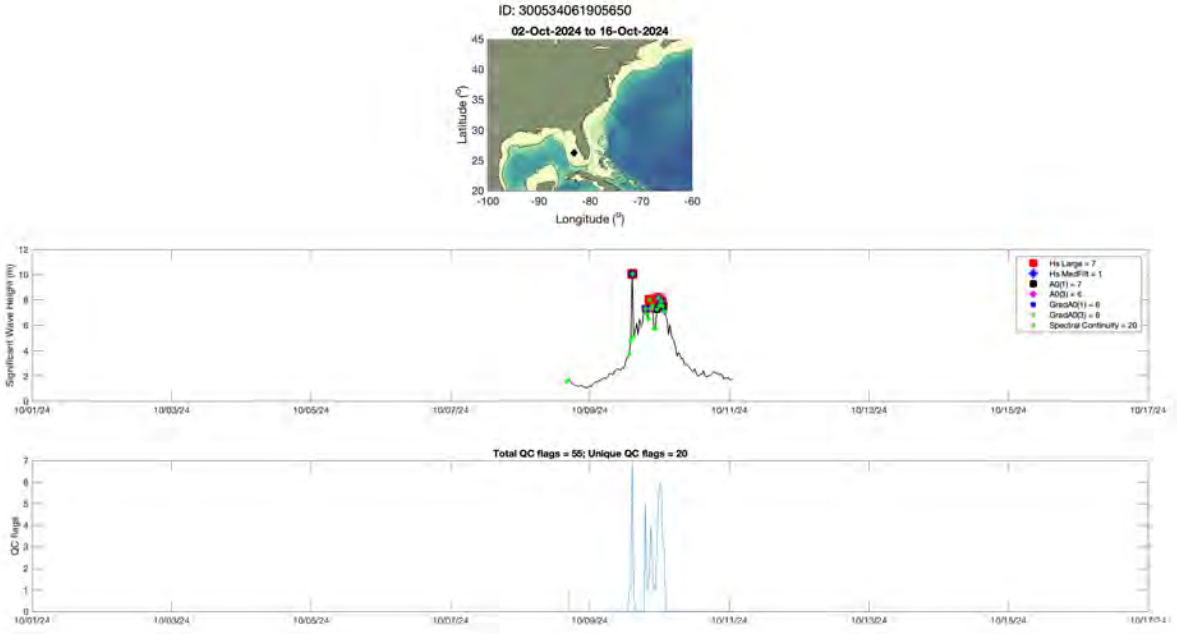

Figure 53