U.S. NAVAL RESEARCH LABORATORY

Ocean wave data assimilation impact on land falling tropical cyclone forecast

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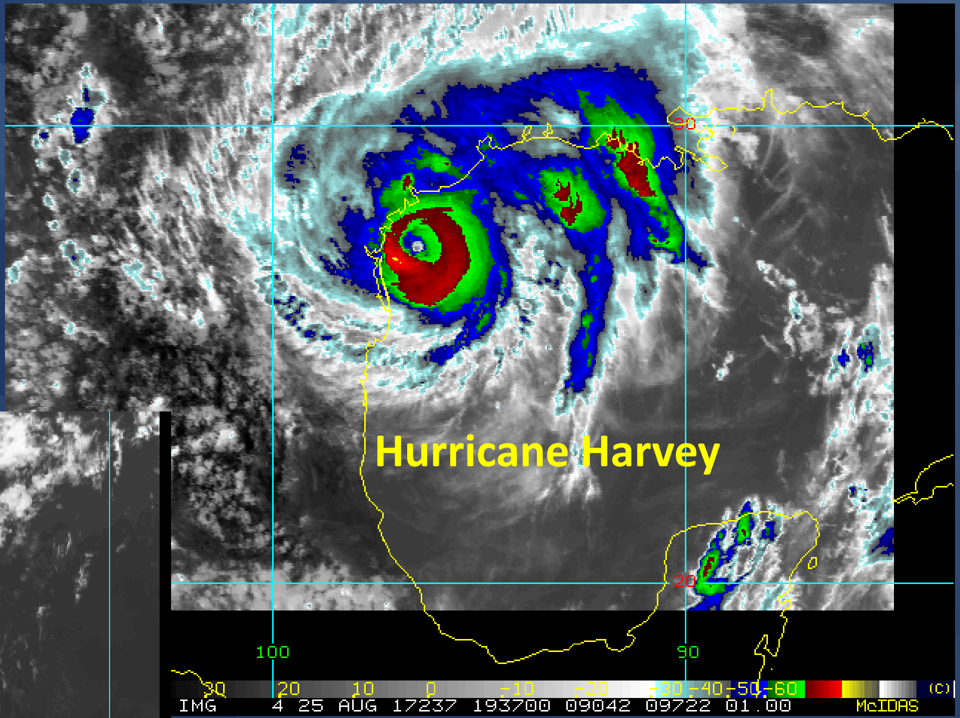
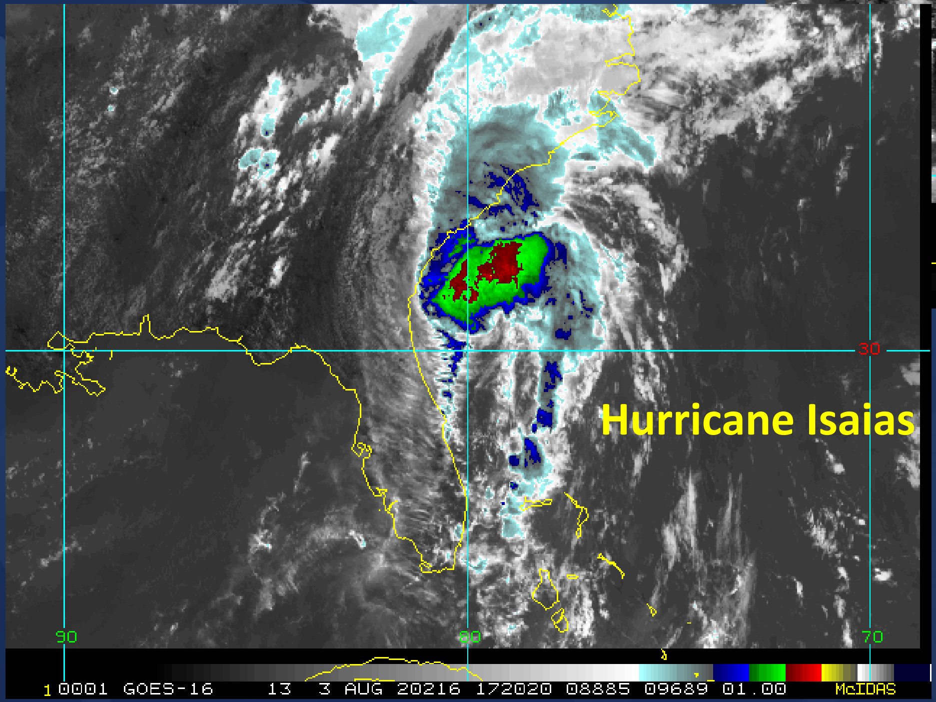
https://rammb2.cira.colostate.edu/





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Motivation

- Combination of landfall TC induced winds, tornados, flood, and storm surge wreak havoc in both coastal and inland regions make them one of the most severe natural disasters that cause devastating damage on societies worldwide
- Increased capabilities to observe the TC ocean and wave conditions by the **(a) operational buoy observing system** or **(b) targeted sampling of TC** provide an opportunity to investigate the wave spectra data assimilation impact on TC prediction

NCODA NDBC Wave Spectrum Assimilation Method

(a) Hurricane Harvey NDBC buoy wave assimilation (operational buoy observing system)

For fixed buoys the wave measurements are inferred from the accelerometers or inclinometers on board the buoys that measure the heave acceleration or the vertical displacement of the buoy hull during the wave acquisition time

Step 1: Apply a Fast Fourier Transform (FFT) to the data

Step 2: Transform the data from the temporal domain into the frequency domain

Step 3: Wave model prognostic variable is wave energy as a function of location, direction, and frequency

Step 4: Analysis updates or corrections to the wave model are done to the model forecast directional wave spectra at each model grid point

Step 5: Modify the error covariances to include not only correlations between observations and grid points but also correlations within wave spectra in terms of frequency and direction

NCODA NDBC Wave Spectrum Assimilation Method

- The NDBC buoy data are in a form of non-directional spectral wave density as a function of the frequency along with the normalized directional Fourier coefficients (r1, r2), the mean wave direction (alpha1) and the principal wave direction (alpha2) based on the Fourier series expansion originally developed by Longuet-Higgins et al. (1963).
- We use the method, maximum likelyhood method (MLM; Oltman-Shay and Guza 1984), commonly used to reconstitute the directional wave spectra
- Once the 2D spectral density is obtained from the values reported by the buoys, the observed spectra are compared to the model spectra using nearest neighbor.
- The differences in wave energy as a function of frequency and direction are computed which form the (**$y - H(x_b)$**) innovations in the 3DVAR

Altimeter Significant Wave Height (SWH) assimilation:

- Analyzed SWH increment field is added to the WW3 SWH forecast (**H^f**) to produce a corrected SWH analysis field (**H^a**)
- Analyzed wave model spectrum (**F^a**) as a function of frequency (**f**) and direction (**Θ**) is then obtained from the ratio of analyzed and forecast SWH fields to produce an updated forecast spectrum (**F^f**) using a simple scaling strategy

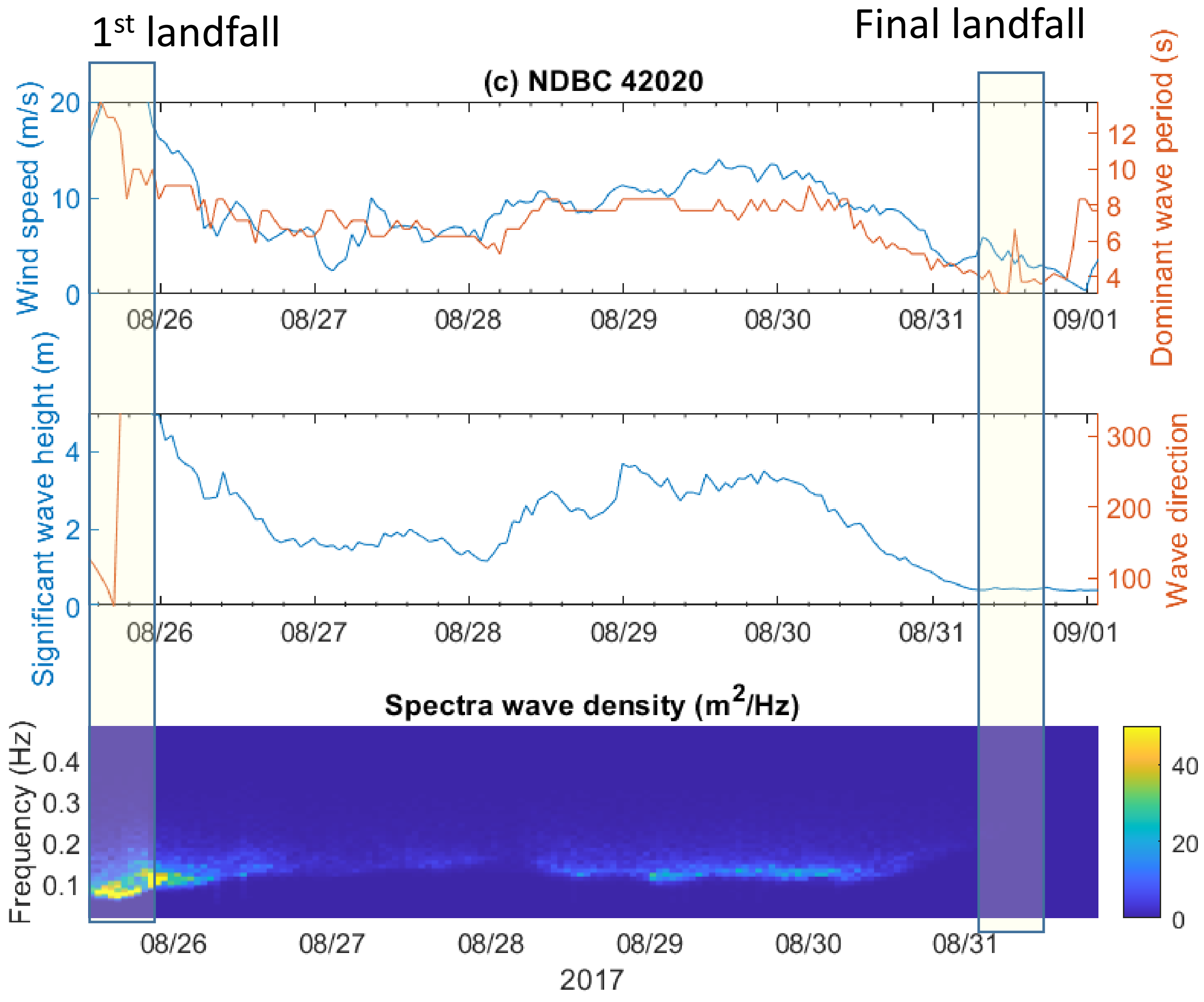
$$a = (H^a / H^f)^2$$

$$F^a(f,\Theta) = aF^f(f,\Theta)$$

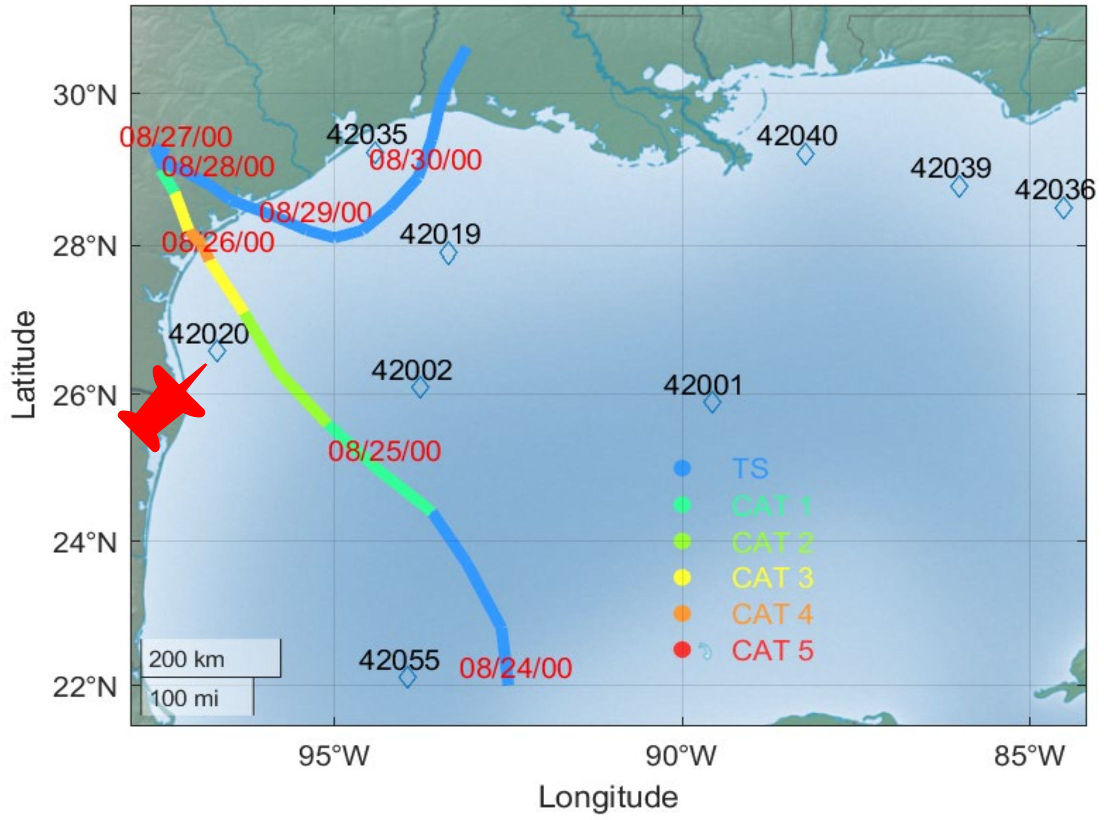
$$x_a = x_b + P_b H^T (H P_b H^T + R)^{-1} [y - H(x_b)]$$

Chen et al. 2024 (Frontiers in Marine Science)

NDBC Wave Spectrum

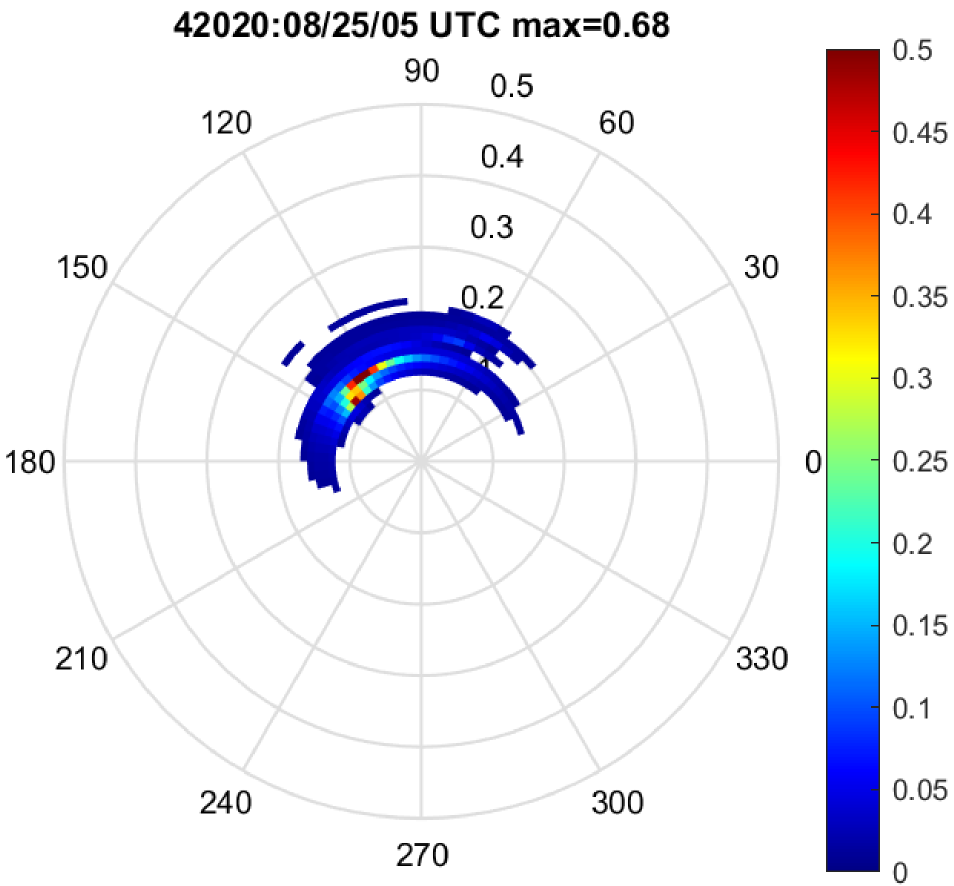


Hurricane Harvey (2017)



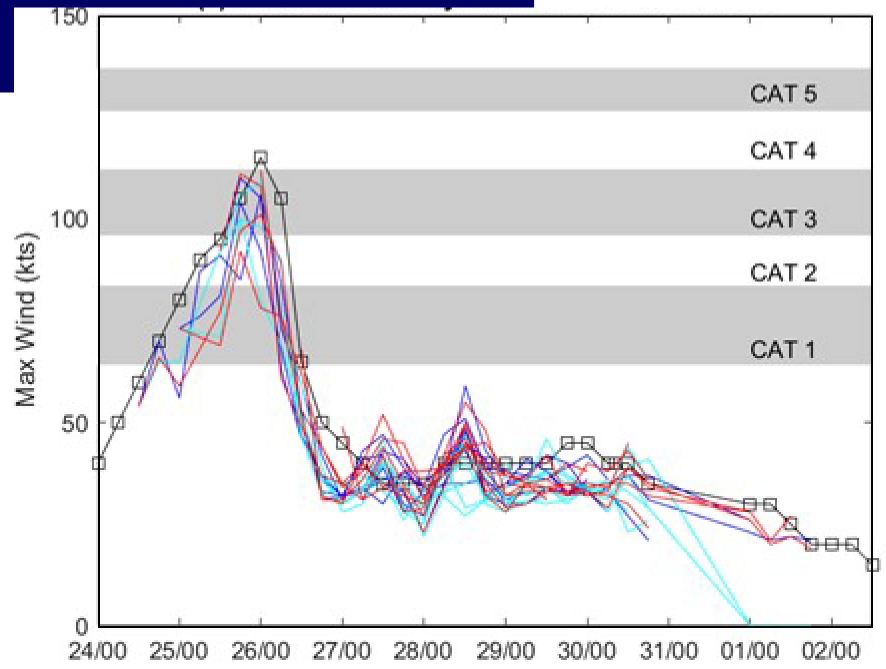
COAMPS Wave Assimilation Impact

Use MLM to get the wave spectrum direction



COAMPS Hurricane Harvey model configuration

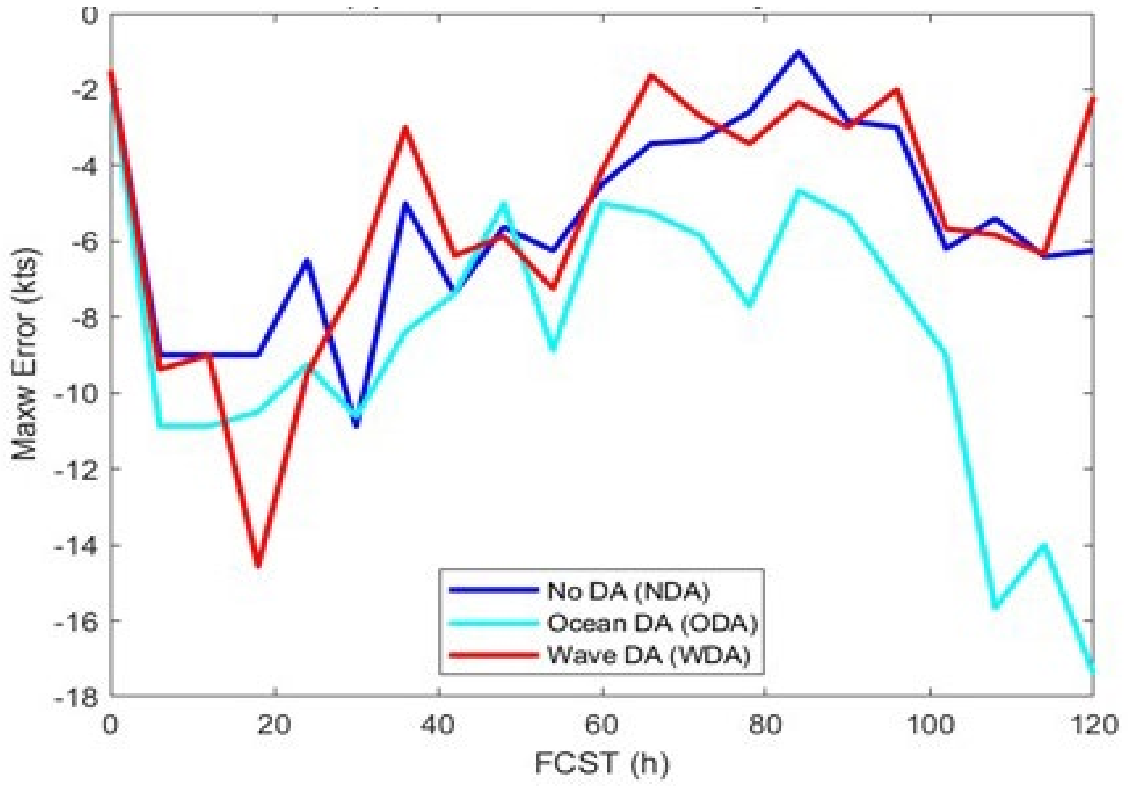
- ATM: 36x12x4 km
- OCN: 6 km
- WAV: 12 km
- DA: 12 hourly cycle
- Coupling interval: 12 min
- Coupled Experiments:
  - ❑ No ocean or wave DA
  - ❑ With ocean DA
  - ❑ With wave DA



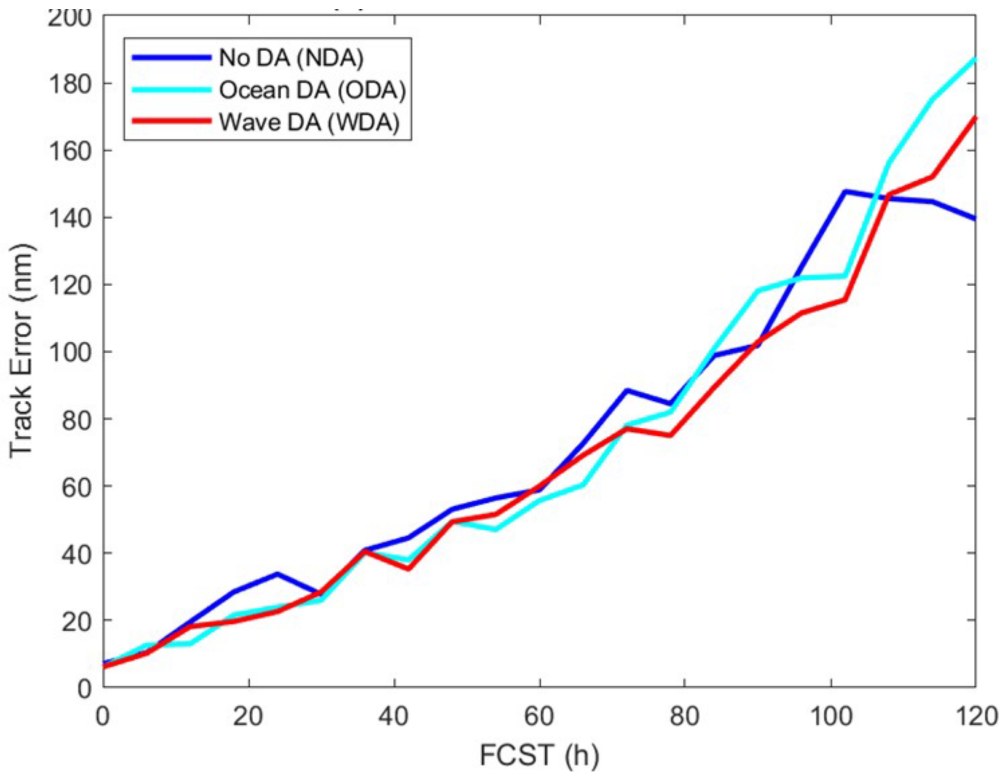
COAMPS Wave Assimilation Impact

Hurricane Harvey

Mean Intensity Error (kts)



Mean Track Error (nm)

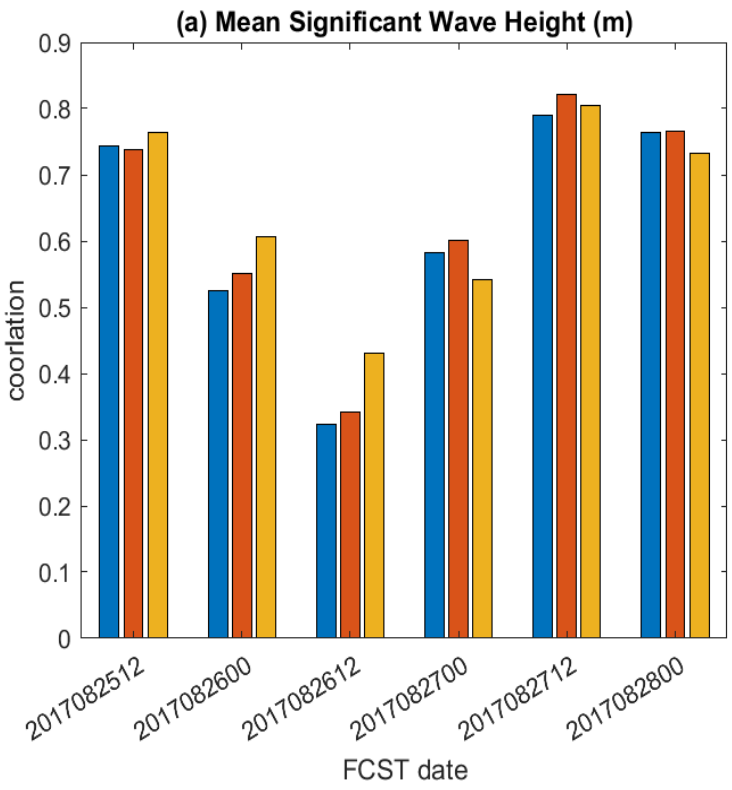


Experiment	0-5-day mean track error (nm)	0-5-day mean intensity error (kt)
No DA (NDA)	72.9	-5.5
Ocean DA (ODA)	73.2	-8.6
Wave DA (WDA)	69.1	-5.4

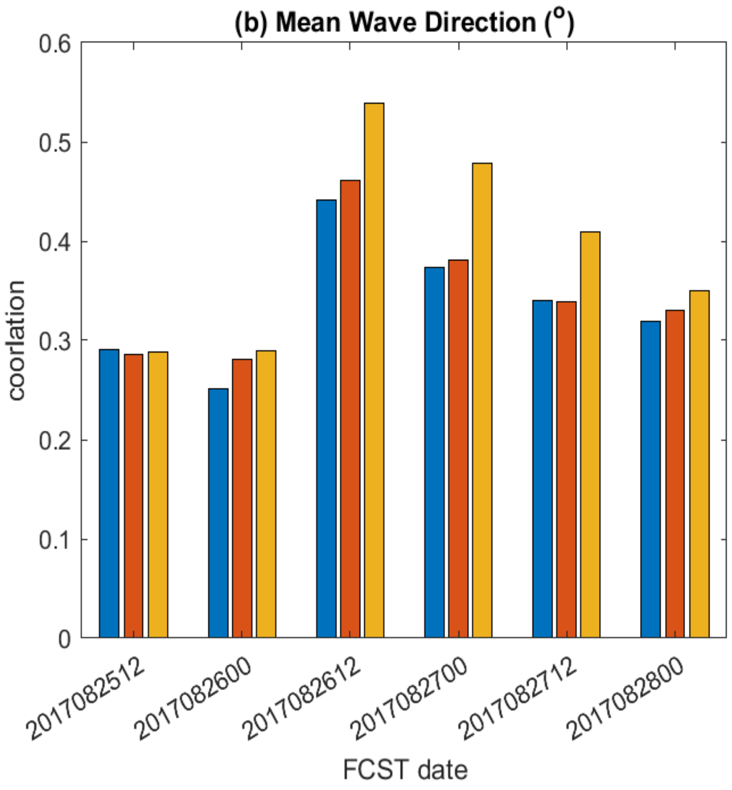
COAMPS Wave Assimilation Impact

Hurricane Harvey wave forecast correlation
(validate against hourly NDBC buoy observation at the buoy location)

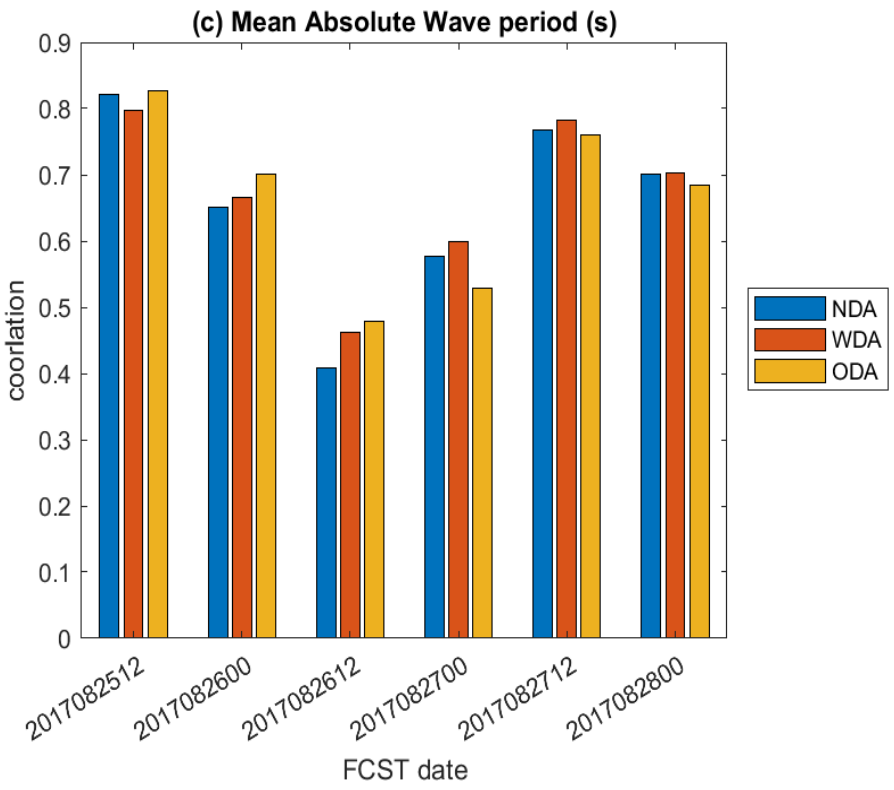
Mean Significant Wave Height



Mean Wave Direction



Mean Absolute Wave Period

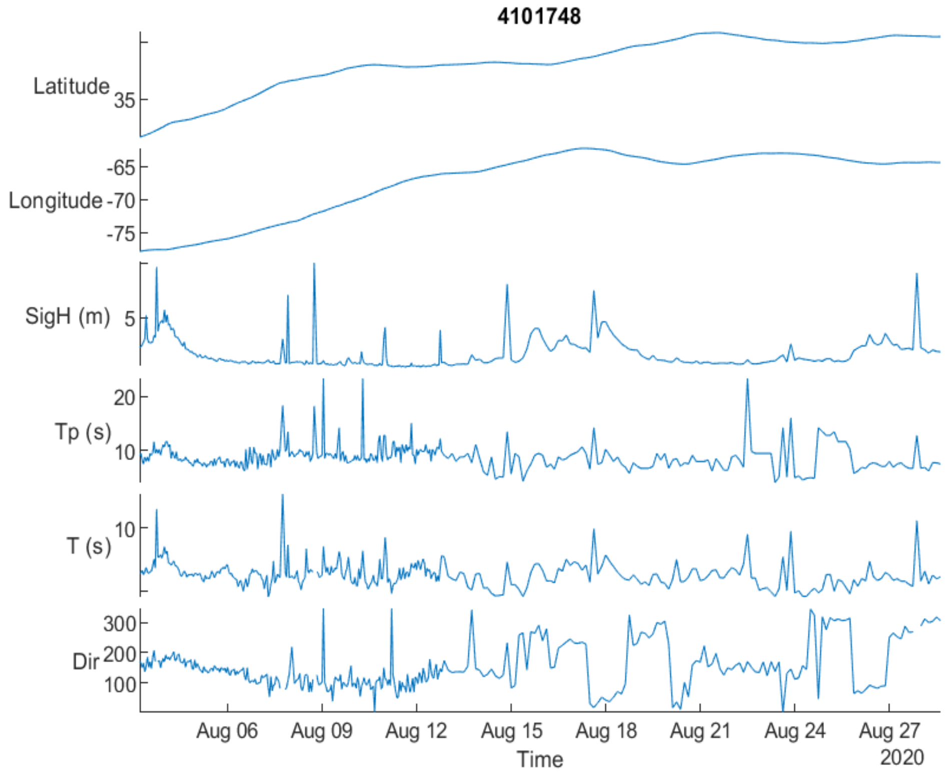


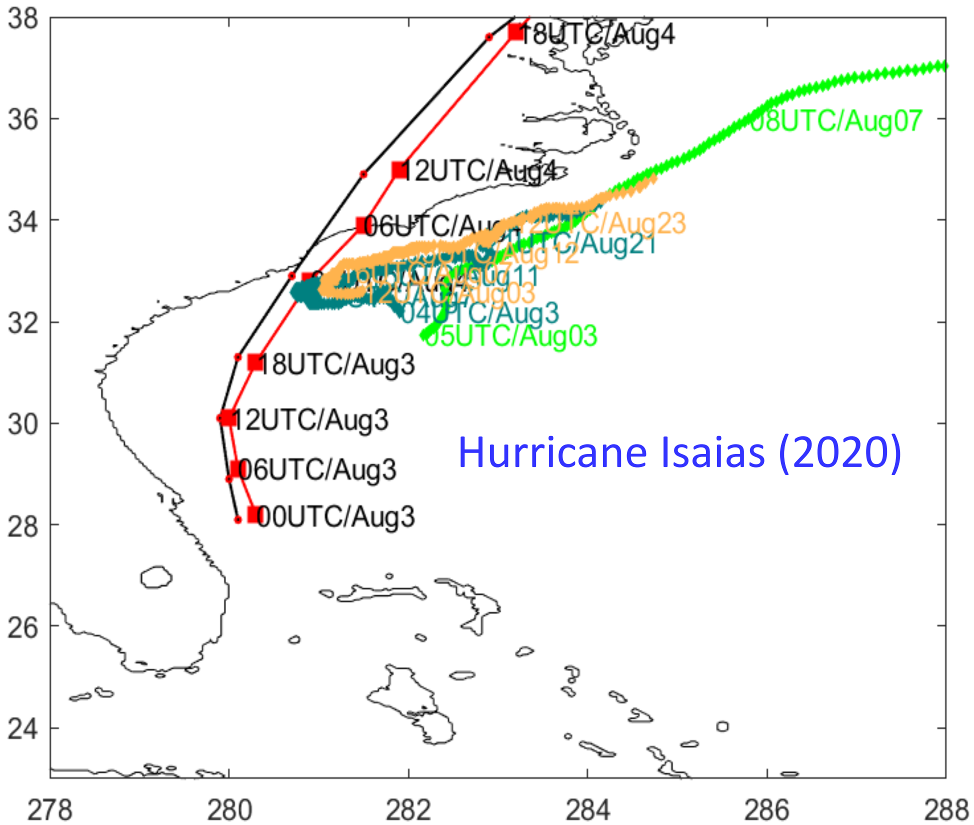
NCODA Drifter Wave Spectrum Assimilation

Hurricane Isaias

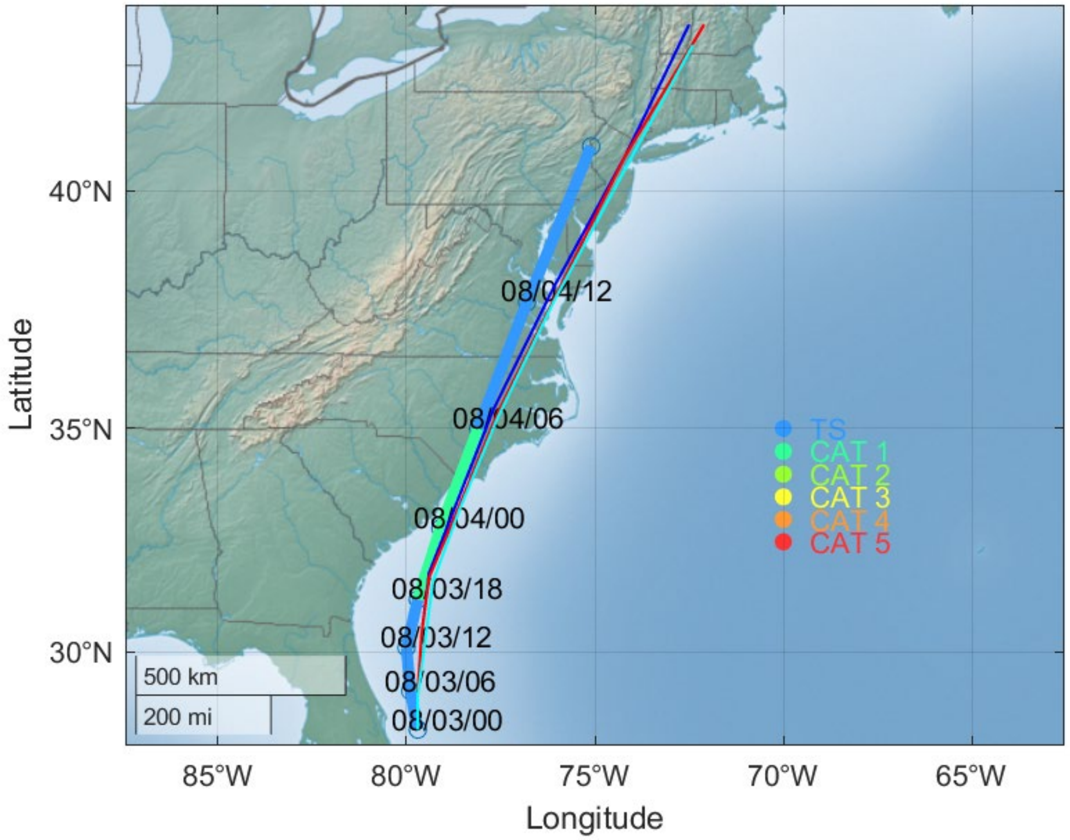
(b) SCRIPTS drifting wave buoy assimilation (targeted sampling)

- More complicated because wave drifter observations reference different model grid points
- Drifter SWH simulation is similar to the fixed buoy altimeter SWH assimilation that used a simple integration of wave energy across frequency and direction
- Max significant weight height recorded from the drifters was ~ 10 m





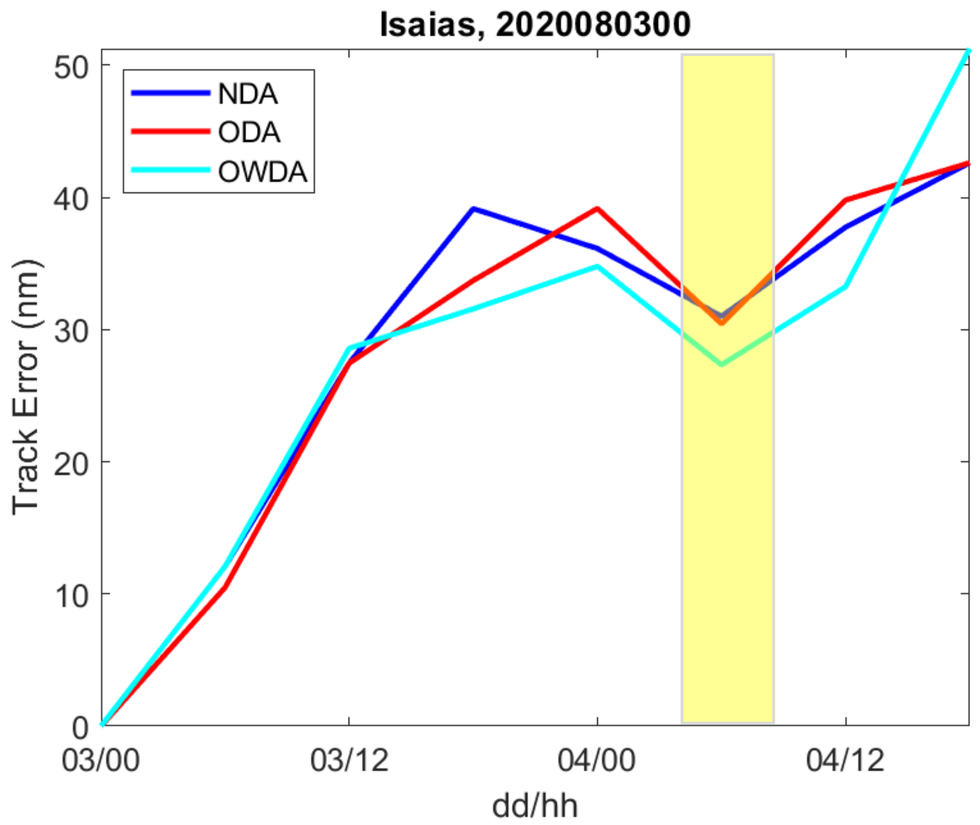
Isaias Drifter Wave Spectrum Assimilation

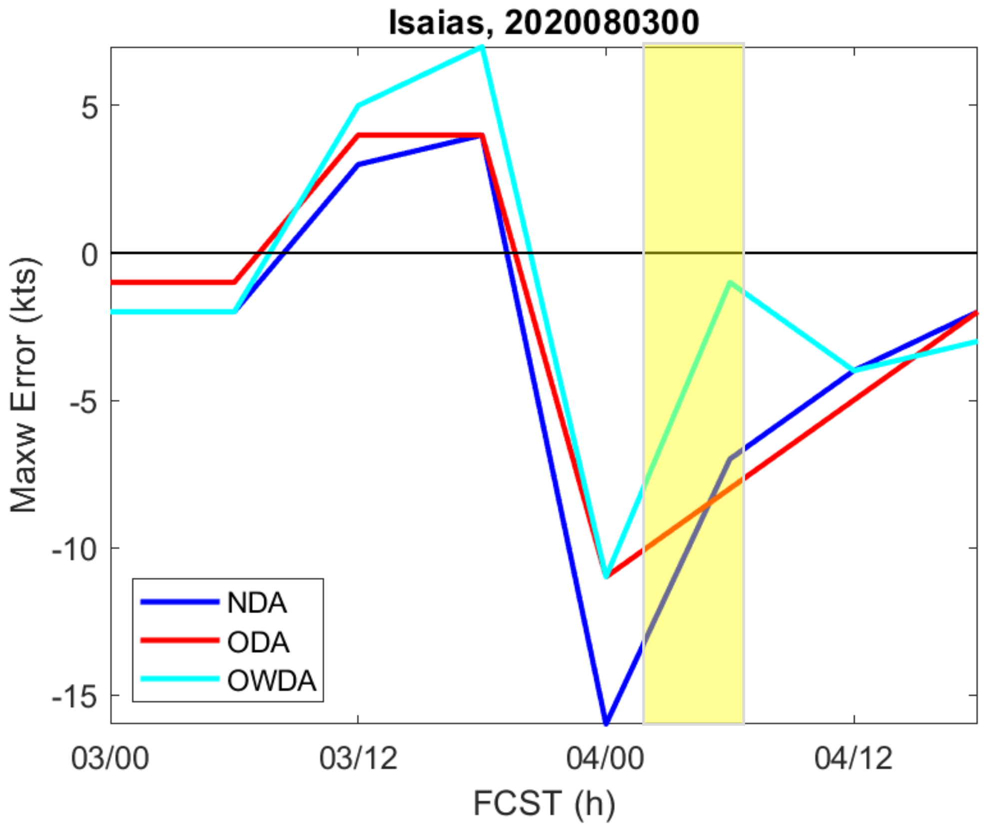


COAMPS Hurricane Isaias (2020) configuration:

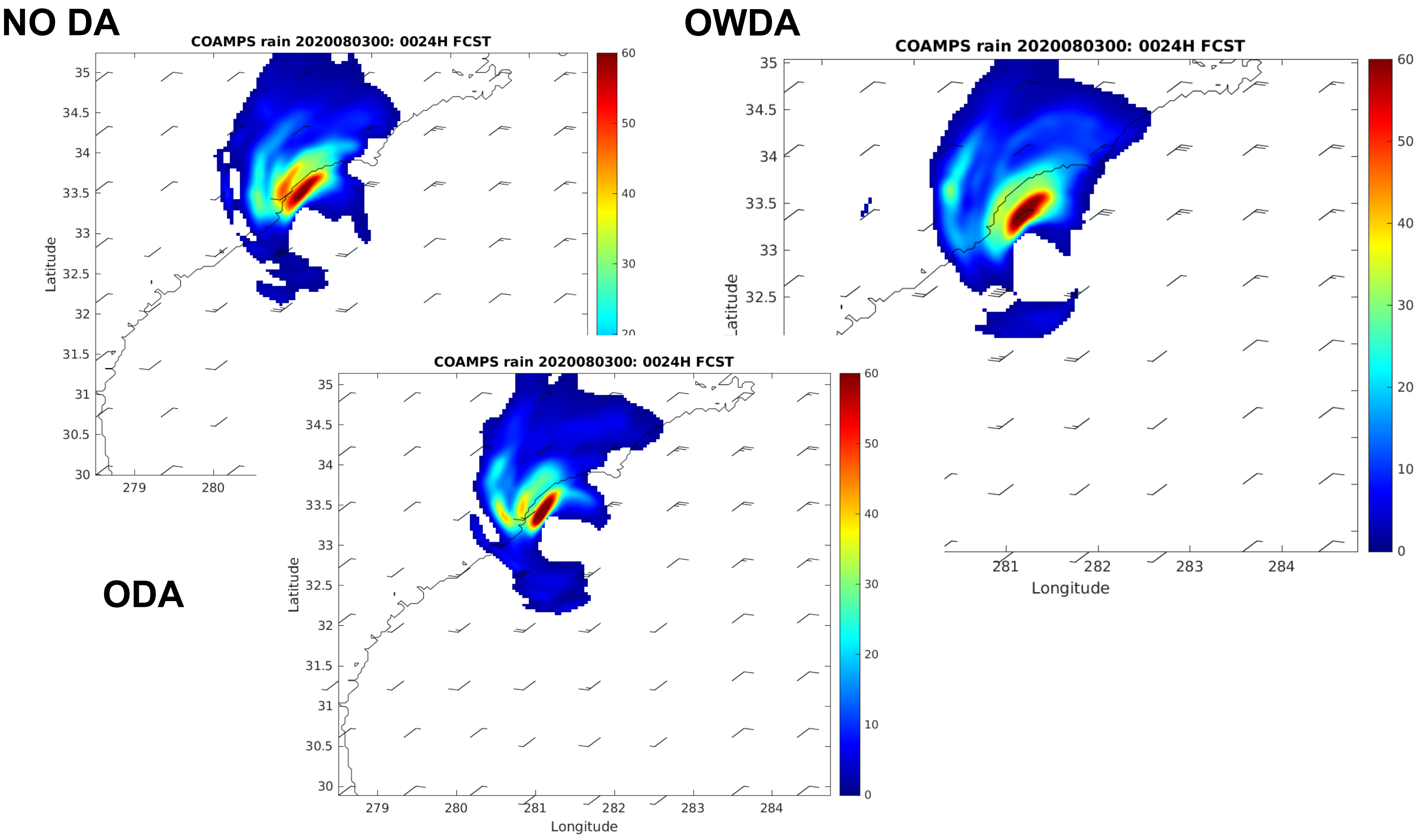
- Same 4 km grid spacing for air, ocean, wave model domains; Noah3.6 LSM
- Two-way coupling between air-ocean, ocean-wave, and air-wave
- Three SCRIPPS wave drifters deployed near 05 UTC Aug 3 prior to Isaias's landfall
- Coupled Experiments:
  - ❑No ocean or wave DA (NDA)
  - ❑With ocean DA (ODA)
  - ❑With ocean and wave DA (OWDA)

Isaias Drifter Wave Spectrum Assimilation





Isaias Drifter Wave Spectrum Assimilation

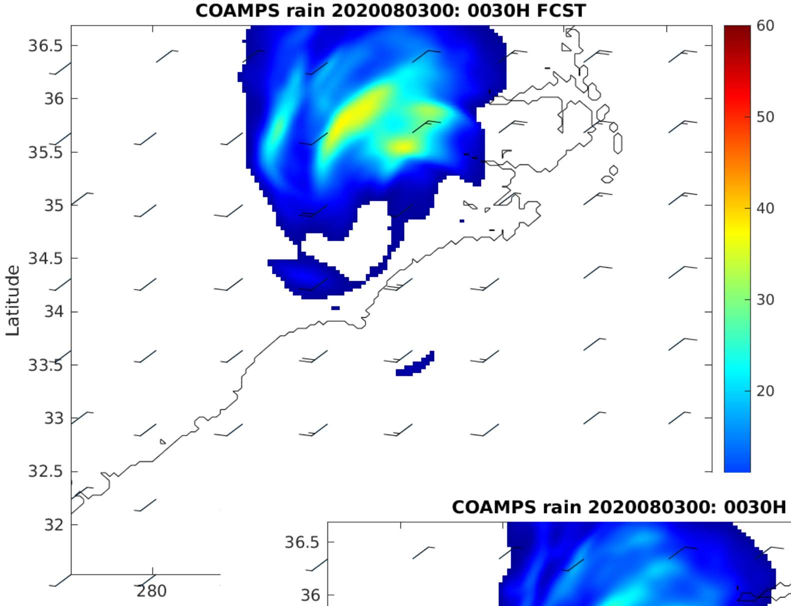


At the Hurricane Isaias landfall

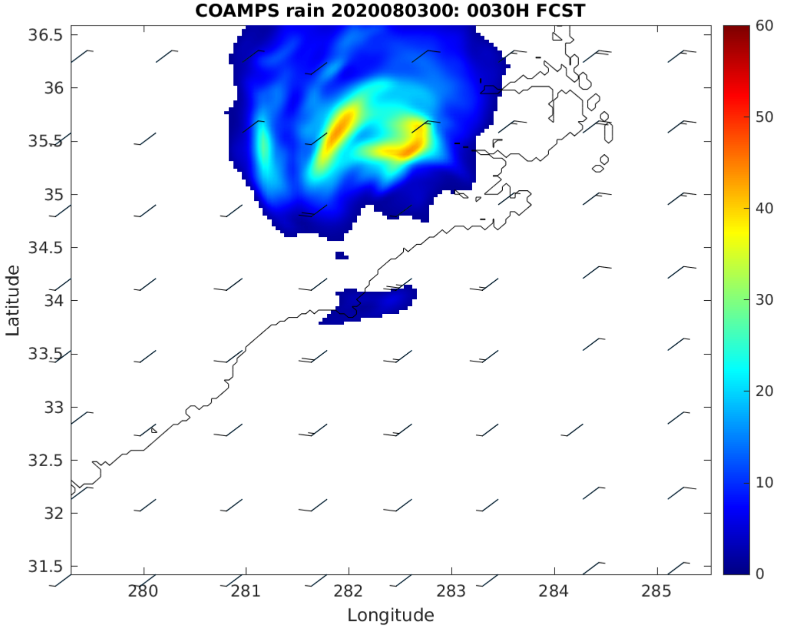
COAMPS 6 hourly precipitation amount and structure are sensitive to ocean and wave DA

Isaias Drifter Wave Spectrum Assimilation

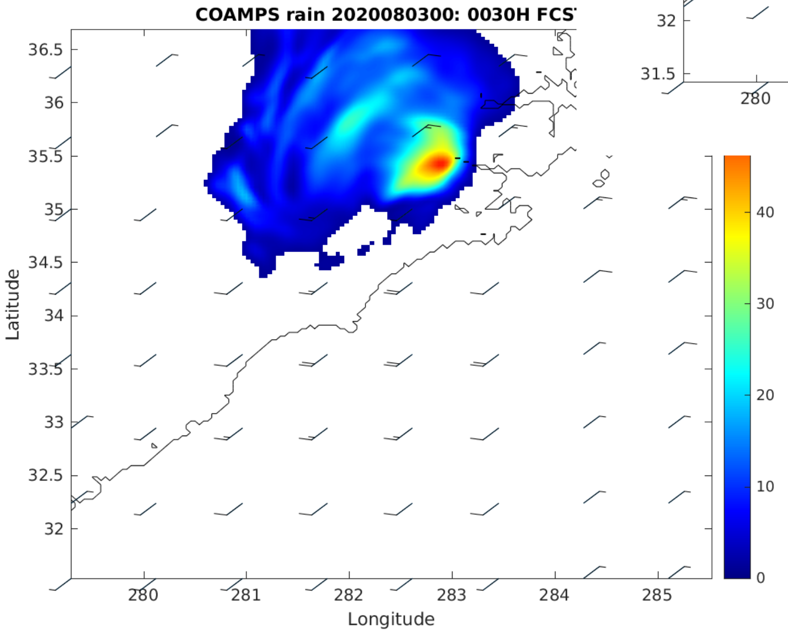
NO DA



OWDA



ODA



After Hurricane Isaias's landfall

COAMPS predicted precipitation structure is influenced by the land surface prediction

Summary

- We develop a NCODA wave data assimilation technique using routinely available NDBC buoy and targeted TC wave observations from wave drifters
- Overall evaluation of wave DA impact on the fully air-ocean-wave coupled COAMPS Hurricane Harvey forecasts shows that wave assimilation improved Harvey's track and wind intensity forecasts compared to the NDA and ODA experiments
- The wave DA experiment does not improve the correlation of mean wave direction suggesting possible limitation of using the MLM method to convert 1D wave spectral density observation from NDBC buoys to 2D directional wave spectral density. Donelan et al. (2015) shows MLM tends to broaden the wind direction compared to a wavelet method
- COAMPS Hurricane Isaias wind, wave, and precipitation forecast are sensitive to the ocean and wave DA
- Recent advancements in Hurricane airborne targeted 2D directional wave spectral density observations such as from the Wide Swath Altimeter Radar (WSRA; Walsh et al. 2021), Directional Wave Spectra Drifter (DWSD; Centurioni et al. 2017), Surface Wave Instrument Float with Tracking (SWIFT; Thomson et al. 2019), and Air-Launched Autonomous Micro Observer (ALAMO; Sanabia and Jayne 2020) float or satellite Synthetic Aperture Radar (SAR; Schuler et al. 2004) provide a new opportunity to directly assimilate the 2D directional wave spectral density and use a shorter wave data assimilation window for future hurricane wave research
- It remains unclear how large a sample size is needed to obtain a statistically significant evaluation of wave buoy assimilation impact on Hurricane given fewer major hurricanes have made landfall along the U.S. Gulf coastal zone