Evaluation and Transition Plans for the Use of High-Frequency Radar (HFR) Coastal Wave Observations within the National Weather Service (NWS)

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Introduction

NWS is moving to incorporate coastal wave height, period, and direction data from HFRs in collaboration with NOAA's U.S. Integrated Ocean Observing System (IOOS) Office and its Regional Associations. **Evaluation by Weather Forecast Offices (WFOs) resulted in a strong recommendation to use HFR wave data operationally.** The HFR wave data supplement existing buoys and **sometimes are the primary validation**. Coastal wave data contribute to marine safety, thus supporting the larger goals of the NWS Weather Ready Nation.

How does HFR wave measurement work?

1. Wave data extracted from 2nd-order Bragg Doppler spectra caused by the orbital motion of long traveling ocean waves.
2. Wave parameters are determined for each radar Doppler spectrum at concentric range rings from the HFR and collapsed into a single-value spatial average.
3. Spatial average and temporal resolution based on operating frequency: 3–50 km offshore & 15–60 min.
4. Assumes waves producing scatter do not interact with the ocean floor:
$$\frac{2\pi \cdot Depth}{\lambda(dominant)} > 0.8$$
5. 2nd-order scattering cross-section is given by Barrick [1977] and is similar to scattering by a sinusoidal grating.
6. Wave direction extracted from fitting a wave spectrum model (Pierson-Moskowitz cardioid in direction).

What are strengths and limitations?

Strengths:

1. Non-invasive remote sensor.
2. Provides wave height, period, and direction.
3. Uses existing surface current measurement HFR National Network.

Limitations:

1. When ocean wavelength exceeds limit for the radar frequency, the Doppler spectrum becomes unusable since the 1st-, 2nd-, and 3rd-order spectra merge. This saturation threshold in terms of significant wave height (SWH) is
$$h_{saturation} \approx \frac{2}{k_{transmitter}}$$
Examples: $h_{saturation}(f = 13\ \text{MHz}) = 7.4\ \text{m}$
$h_{saturation}(f = 5\ \text{MHz}) = 20\ \text{m}$
2. Somewhat large spatial and temporal averaging.
3. Wave fetch limits offshore wave detection.
4. Background noise floor greatest at lower frequencies.

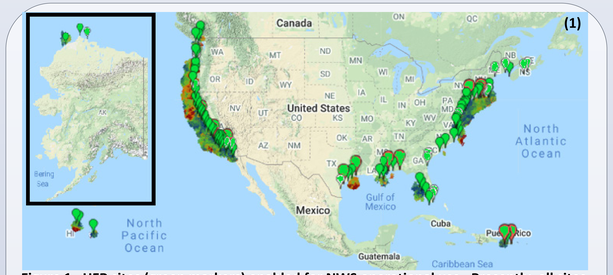

Figure 1. HFR sites (green markers) enabled for NWS operational use. Presently, all sites measure surface current velocity hourly and this effort will add the wave data product at those locations where ocean conditions are determined to fall within HFR limitations.

Key NWS Data Requirements & Standards

Program	Requirements	
MARINE	NWS requires wave period, direction, and height globally	• Every 5 km, height ±0.1 m, hourly, direction ±10°, period ±0.1 s
	In polar regions	• As above but every 0.5 km.
	Wave height, period, direction	• Every 25 km (1 km inside tropical cyclone) • height ±0.25 m, hourly, wave direction ±10°, period ±0.1 s
MODELING	Similar to the Marine	• Must have a reference to calibrate model.
	Unbiased data	• Research has shown consistency between buoy and HFR wave data.

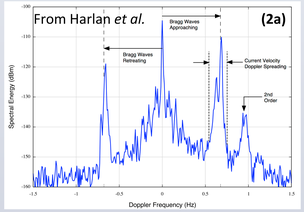

Figure 2. (a) Doppler Spectrum w/ 2nd-order and (b) transmit/receive antenna.

Validation Results

Table 1. List of HFR sites and National Data Buoy Center (NDBC) buoys used, along with the corresponding IOOS region and WFO that evaluated the wave data.

IOOS Region	WFO Location	HFR Site Code	HFR Frequency (MHz)	NDBC Buoy
Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS)	Mt. Holly, New Jersey	SEAB	13.45–13.55	44065
		BRNT	13.45–13.55	44091
		SPRK	13.45–13.55	44091
Caribbean Coastal Ocean Observing System (CARICOOS)	San Juan, Puerto Rico	FURA	13.45–13.55	41115
		MABO	4.438–4.488	42085
Central & Northern California Ocean Observing System (CeNCOOS)	Eureka, California	TRIN	4.438–4.488	46244
		SHEL	4.438–4.488	46213

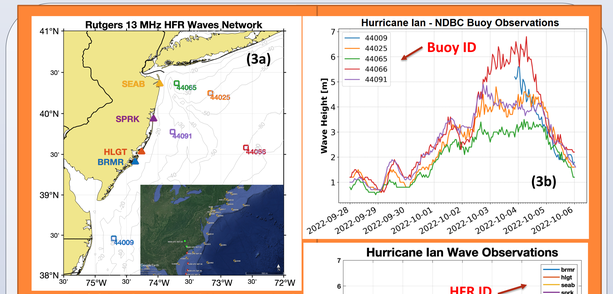

Figure 3. (a) Study area and Hurricane Ian's path (inset). (b) Wave heights from NDBC buoys only for September 28 – October 6, 2022. (c) Wave heights from HFR stations only for the same time period.

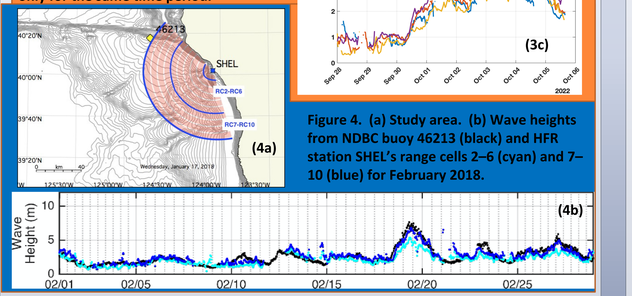

Figure 4. (a) Study area. (b) Wave heights from NDBC buoy 46213 (black) and HFR station SHEL's range cells 2–6 (cyan) and 7–10 (blue) for February 2018.

- There were no HFR wave data closer to hurricane Ian's landfall in 2022.
- The buoy data themselves have variance compared to other buoys. Wave heights become weaker closer to shore, and these match better with HFR-derived waves in this instance, since the centroid of the HFRs' measurement ranges were likewise closer to shore.
- Up to 0.9 correlation index in wave height demonstrated in study off Spain.

Research to Operations (R2O) Way

- Over 60 NOAA products use sea wave variables.
- Meet R2O requirements through validation and verification.
- Ensure data format is operationally useable.
- Test data impact with experimental model runs.
- Use HFR wave data to calibrate existing NOAA forecast models.
- Create new NOAA forecast models that assimilate wave data in near real-time.

Use of HFR wave data in NOAA models

- This will be explored with a graduate student through the Student Scholarship Internship Opportunity (SSIO) and NOAA Experiential Research & Training Opportunities (NERTO) at the NWS National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) to assess:
  - HFR wave data, buoy observations, and numerical model outputs;
  - Data quality control requirements.
- HFR data will be utilized for validation and verification of the operational modeling systems at NOAA including the Global Forecast System (GFS), Global Ensemble Forecast System (GEFS), and Nearshore Wave Prediction System (NWPS).
- HFR wave data will be used in the design of next generations of the aforementioned operational systems.
- HFR wave data will fill the gap between offshore NDBC buoy networks, satellite altimeters, and temporary nearshore observations (only available during severe events).
- HFR wave data could greatly extend current point-source and spatio-temporally variable satellite altimeter data for future Wave Data Assimilation in NOAA models.

Take-Away Messages

- NWS is moving toward leveraging HFR data from IOOS's Regional Associations (starting with CeNCOOS, MARACOOS, and CARICOOS).
- HFR wave data will become operationally available (expected Fiscal Year 2023).
- Validation and verification will compare HFR to existing buoy data.
- **HFR wave data are poised to become sea-truth or golden standard for coastal (~1–10s km offshore) wave measurements.**

References

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