Calibration and Field Evaluation of the National Data Buoy Center's New Wave Measurement System

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Photo of ship encountering waves courtesy of the Weather Forecast Office, Portland, OR, USA

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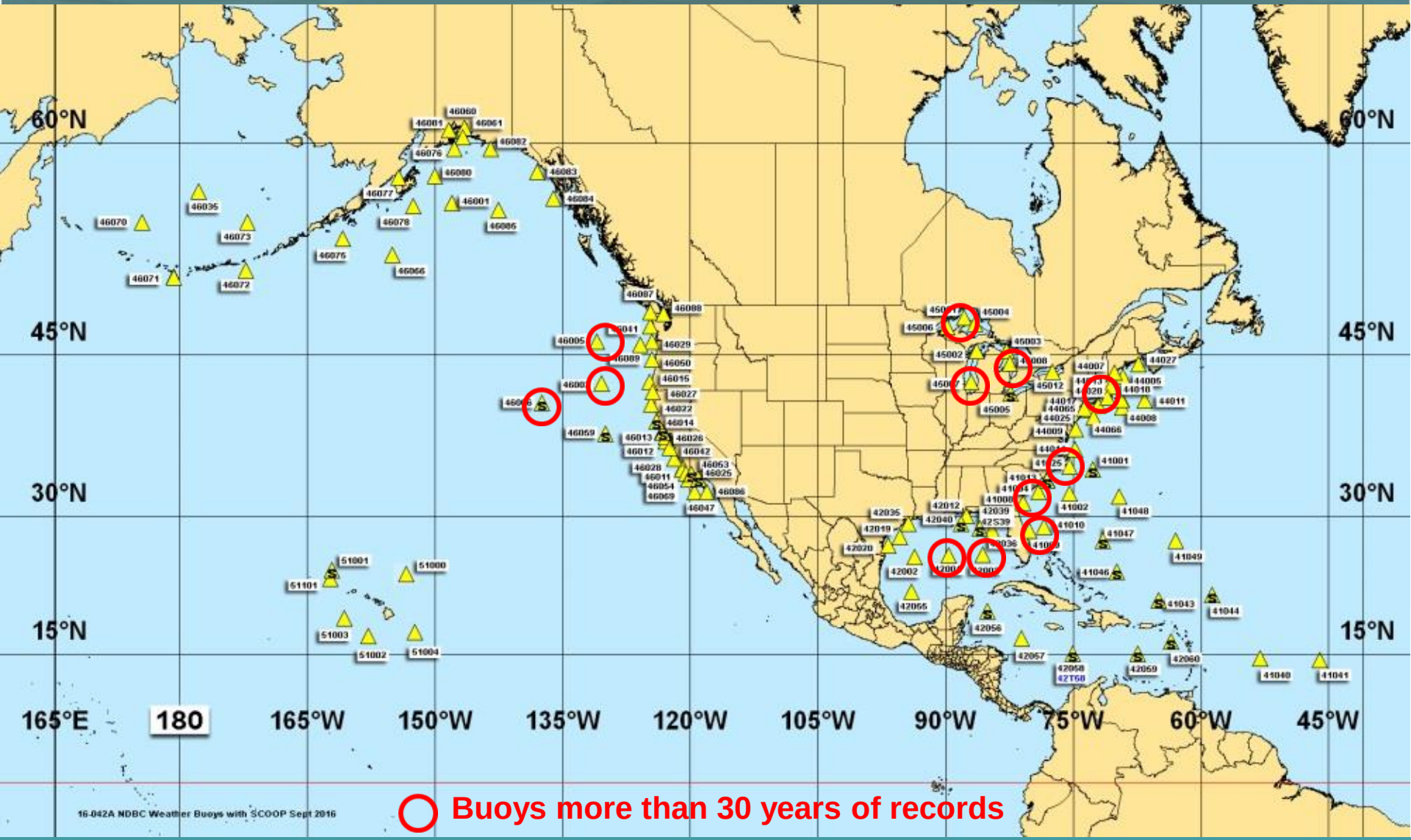
NOAA's National Data Buoy Center (NDBC) operates more than 100 buoys measuring wind, waves, temperatures



Used for Cal/Val in R2O of Marine Remote Sensing and Numerical Wave Models

Remote Sensing

Calibration/validation of an altimeter **wave** period model and application to **TOPEX/Poseidon** and Jason-1 altimeters
Y Quilfen, B Chapron, F Collard, M Serre - Marine Geodesy, 2004 - Taylor & Francis
... This fact, combined Page 9. An Altimeter **Wave** Period Model 543 FIGURE 3 Distribution of **buoy** (solid line) and altimeter (dashed line) **wave** period measurements (sec) for the different areas covered by **NDBC buoys** ...
☆ 99 Cited by 60 Related articles All 3 versions

Cross calibration of **TOPEX**, ERS-I, and Geosat **wave** heights
PD Cotton, DJT Carter - Journal of Geophysical Research ..., 1994 - Wiley Online Library
... We cannot expect **buoys** to provide **wave** height values iden- tical to altimeter values ... between satellites, to adopt the **buoy** data as "standard" and to calibrate the altimeters against measurements from the US National Data **Buoy** Center Network (**NDBC**) maintained by ...
☆ 99 Cited by 106 Related articles All 5 versions

Validation of *HY-2A* Remotely Sensed **Wave** Heights against **Buoy** Data and *Jason-2* Altimeter Measurements
H Zhang, Q Wu, G Chen - Journal of Atmospheric and Oceanic ..., 2015 - journals.ametsoc.org
... sensor with the main objectives of measuring sea surface height (SSH), significant **wave** height (SWH ... against the data from the South China Sea (SCS) field experiment, **NDBC buoys**, and Jason ... was found when comparing HY-2A (Jason-1/2) SWHs with **NDBC buoy** data using ...

[PDF] Technical Note - ESA Earth Online
https://earth.esa.int/documents/...v1.../be3875ab-dde1-41a9-8df9-994bd1db8a61
Validation for **CryoSat-2** Ocean Products. Technical Note for Daily and ... F. M. **Calafat**. 1.0. 06/05/2016. Check and First delivery to ESA. P. Cipollini. This Version. Version 1.0 – issued by National Oceanography Centre on 06/05/2016. Written by: ..... from the National Data **Buoy** Center (**NDBC**) at http://www.**ndbc**.noaa.gov.

Evaluation of algorithms for **wave** height measurements with high frequency radar
H Roarty, C Evans, S Glenn... - Current, **Waves** and ..., 2015 - ieeexplore.ieee.org
... Method **NDBC Buoy** Correlation ... This served as a backdrop for the comparisons between the radar measuremts and **buoy** measurements as the two were ... current product from the HF radar network is widely used and operational with the US Coast Guard for **search and rescue** ...

Wave Models

[HTML] Gulf of Mexico hurricane **wave** simulations using SWAN: Bulk formula-based drag coefficient sensitivity for Hurricane Ike
Y Huang, RH Weisberg, L Zheng... - Journal of Geophysical ..., 2013 - Wiley Online Library
... Red rectangles are positions of **NDBC** mooring **buoys** ... [6] Spectral **wave models** are categorized by their primary region of application, ie, deep water (DW) **models** such as **WAve** Modelling (WAM) [WAMDI Group, 1988] and WAVEWATCH-III [**Tolman**, 1991; Huang et al ...

Ocean surface **waves** in Hurricane Ike (2008) and Superstorm Sandy (2012): Coupled model predictions and observations
SS Chen, M Curcic - Ocean Modelling, 2016 - Elsevier
... location. It is imperative that we evaluate the coupled model results against the measurements from both the National Data **Buoy** Center's (**NDBC**) **buoys** and the **satellite** altimeter data from Jason-1 and Jason-2. We ...

An intercomparison of SWAN and WAVEWATCH III **models** with data from **NDBC**-NOAA **buoys** at oceanic scales
JC Ortiz-Royero, A Mercado-Irizarry - Coastal engineering journal, 2008 - World Scientific
... All the information referring to these experimental stations can be found at http://www.**ndbc**.noaa.gov, the National Data **Buoy** Center or **NDBC** ... 2.4 of the manual of WAVEWATCH III [**Tolman**, HL, 1999] ... 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 DATA **BUOY** SW A N ...

Modeling North Atlantic Nor'easters with Modern **Wave** Forecast Models
W Perrie, B Toulany, A Roland... - Journal of ..., 2017 - Wiley Online Library
... 2010. Model validation is based on **wave** data from **buoys** and **satellite** altimeters. Section 2 ... Winds and **waves** measured at **NDBC buoys** 44013 and 44008 (Figures 3 and 4) show the passage of this storm. The storm arrived at **buoy** ...

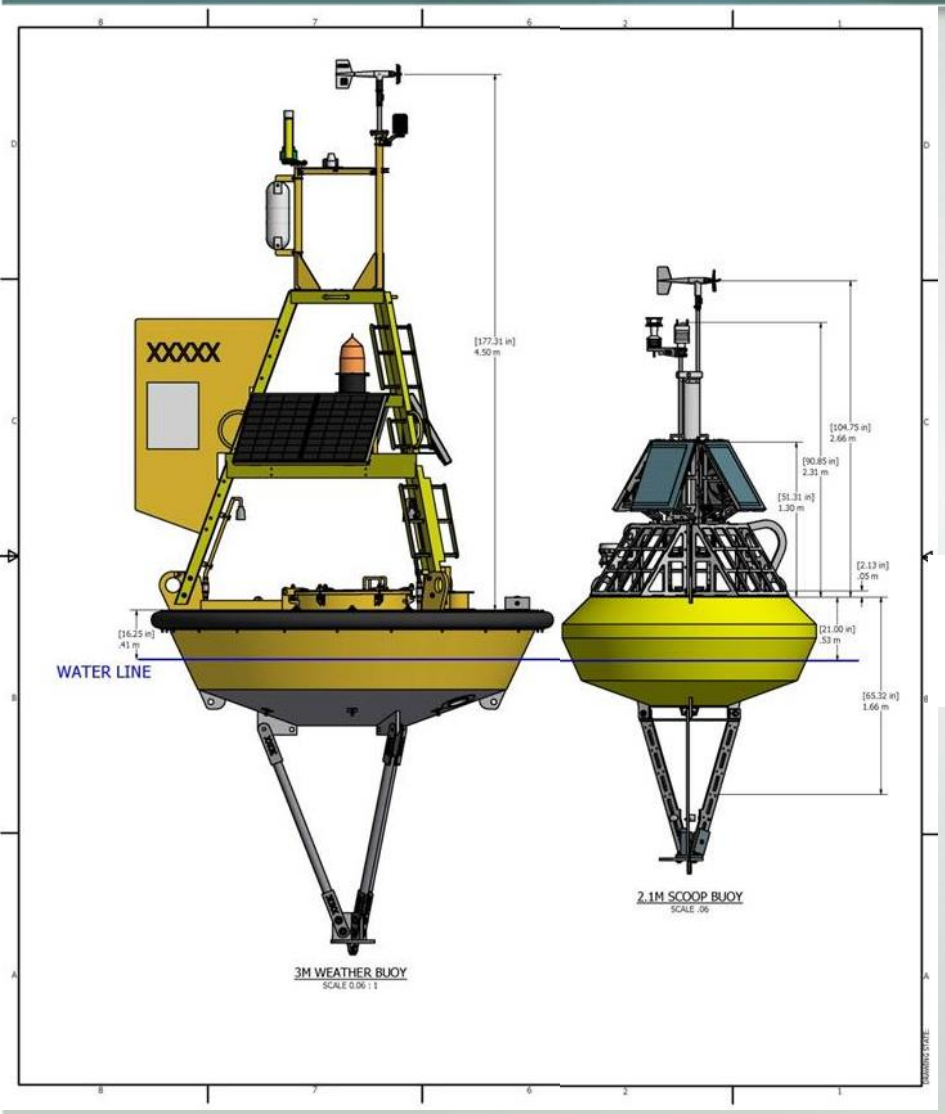
[PDF] **Evaluation** of **wave model** performance in a North Carolina Test Bed
EM Devaliere, JL Hanson... - ... 10th International **Wave** ..., 2007 - waveworkshop.org
... SEACOOS), the USACE Field Research Facility (FRF) and the National Data **Buoy** Center (**NDBC** ... Figure 9: July Storm **Wave** Height Scatters for **NDBC** 41036 and FRF Waverider Default Run ... Hanson, JL, BA Tracy, HL **Tolman** and RD Scott, (2006): Pacific Hindcast Performance ...

Directional validation of **wave** predictions
WE Rogers, DWC Wang - Journal of Atmospheric and ..., 2007 - journals.ametsoc.org
... Real-time and historical data from directional National Data **Buoy** Center (**NDBC**) **buoys** include estimates ... 1999) and WAVEWATCH-III (WW3; **Tolman** 1991, 2002) directly calculate actual two-dimensional spectra E(f), θ) and output-averaged θ 0 for frequencies f 1 –f 2 ...

NDBC Buoy Wave Cal/Val

- Hull Calibration: Make adjustments to the data processing to improve the measurements.
- Field Evaluation: Determine the accuracy of the new wave measurement system. Accuracy in terms of Root Mean Square Error (RMSE).
- Using a Datawell WaveRider MkIII (DWR) buoy as the accuracy and calibration standard
  - International Task Team on Wave Evaluation & Testing

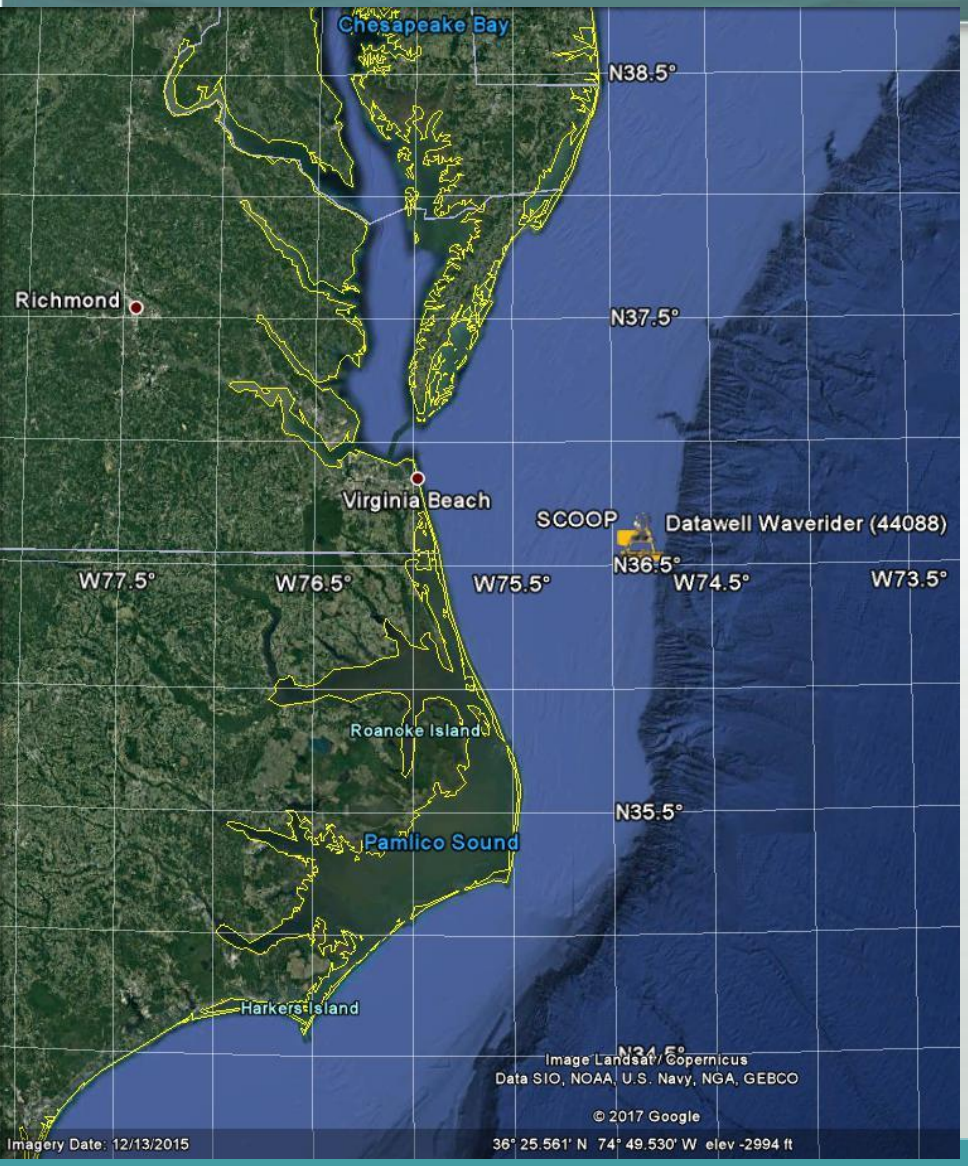
Cal/Val for new 2.1-m hull



- **NDBC 3-m diameter, aluminum discus, 1724 kg, +5 m height**
- **NDBC 2.1-m diameter, foam discus, 492 kg, +3.2 m**
- **DWR 0.9-m, stainless steel spherical, 225 kg, +0.5 m**

NDBC buoys do more than Waves!

Test Area: 110 km SE of Virginia Beach, VA
Buoys 800 m apart; Water Depth 45 m



Dataset

19 Apr – 15 Nov 2017

4966 Records

Maximum Wave Height: 7.1 m

Theory and Application of Calibration Techniques for an NDBC Directional Wave Measurements Buoy

KENNETH E. STEELE, JOSEPH CHI-KIN LAU, AND YUAN-HUANG L. HSU

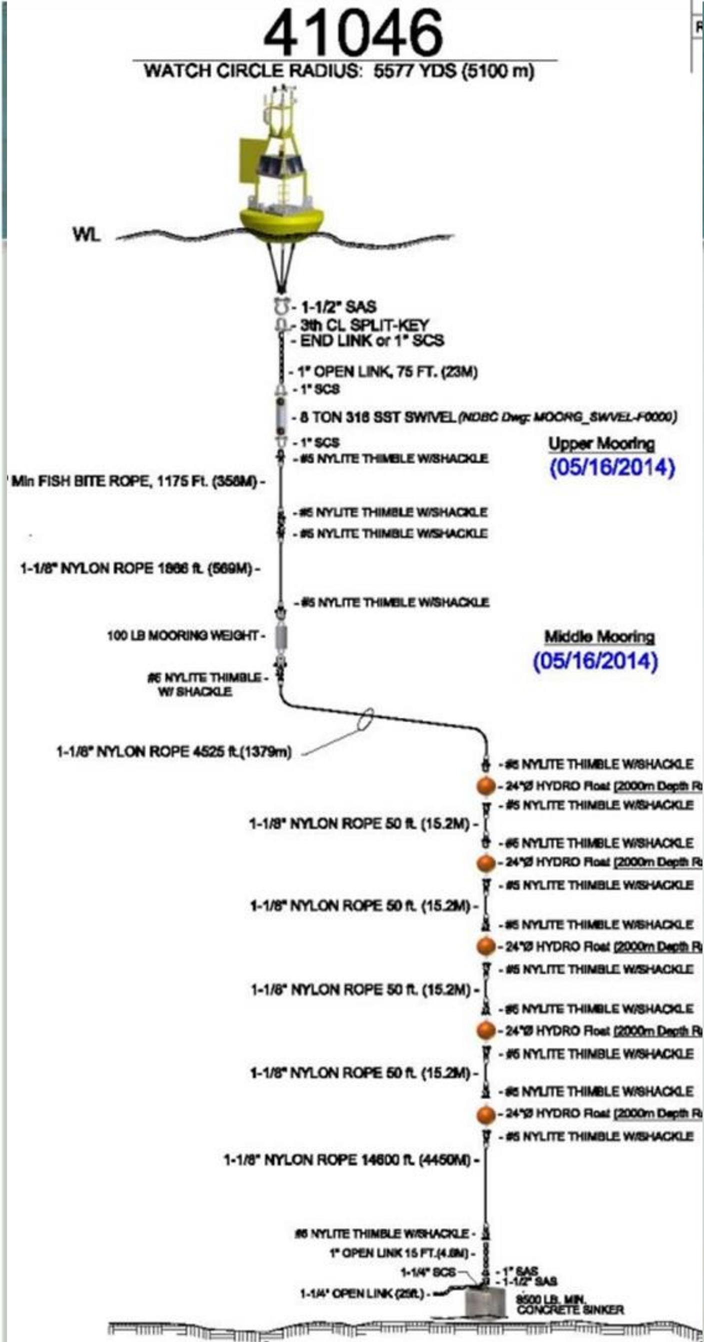
(*Invited Paper*)

- Although from 1985, NDBC still uses many of these techniques in fielding new Heave/Pitch/Roll buoy wave systems.
- Applied to Spectral Energy Densities
- Due to time constraints, will limit discussion to rthe effect on wave height
- Calibrations:

- Amplitude changes (*R*esponse) to vertical displacement (*H* - Heave) from hull (*h*) and mooring effects: (R^{hH})

- Low Frequency Noise Correction (NC)

Image of Steele *et al.,* 1985 title, author, and source used with the permission of the IEEE

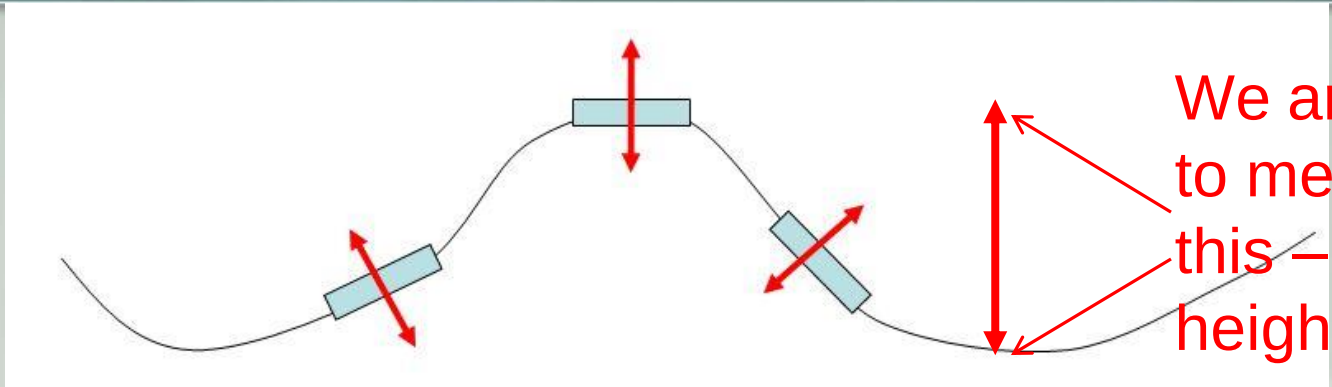


Hull/Mooring Response (R^{hH})

$$R^{hH}(\mathrm{f}) = \sqrt{\frac{C_{11}(\mathrm{f})(\text{large buoy})}{C_{11}(\mathrm{f})(\text{small buoy})}}$$

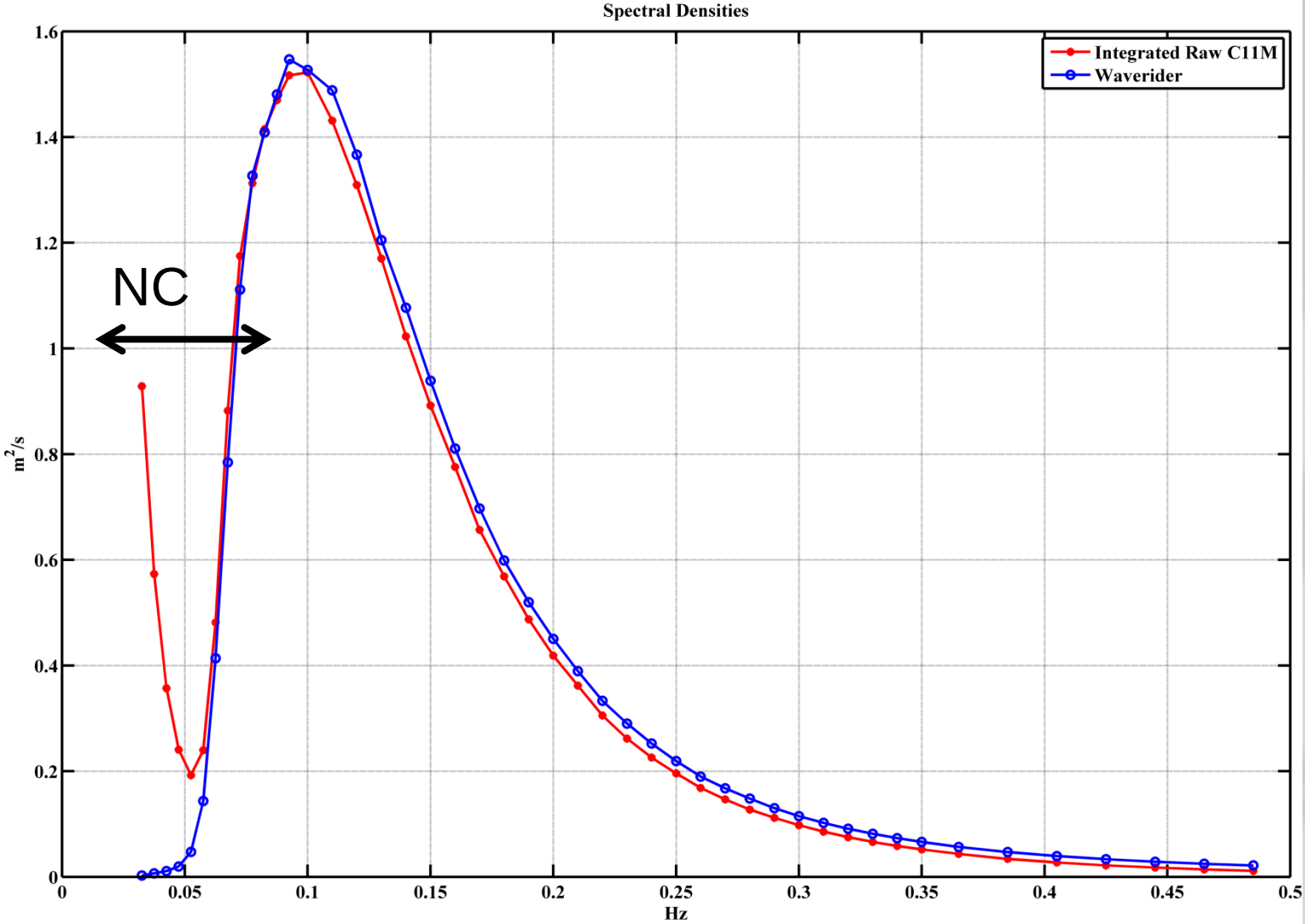
- C_{11}(f): Spectral Energy Densities
  - Time series AccelZ ->FFT->∫∫->C_{11}(f)
- Smaller buoy responds more closely to waves; Waverider MkIII = 0.9 m diameter
- Larger Buoys - affects higher frequencies/smaller wavelengths:
  - Can slice through crests, or
  - Not fully descend into trough if the hull diameter is more than twice the wavelength, and
- Any moored buoy does not perfectly respond to the wave changes beneath it

Empirical Noise Correction for Strapped-down Accelerometer

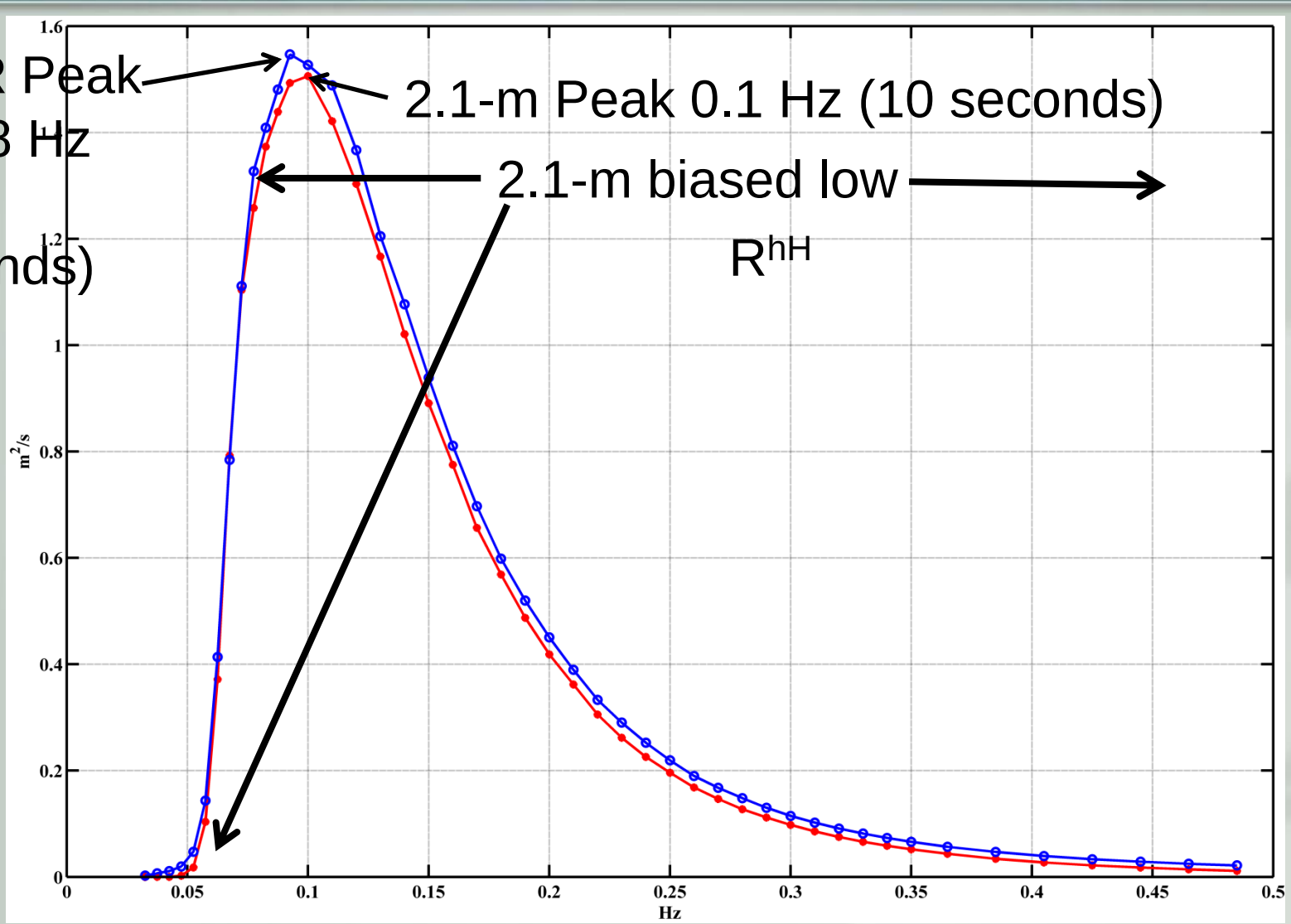


- NDBC measures vertical acceleration of the buoy hull using strapped-down accelerometer
- Accelerometer is not always vertical
  - Wave slopes
  - Tilt due to winds or currents
- Assume signal below 0.03 Hz is noise
- Correction is a function of the magnitude of that noise
- Linearly decreases with increasing frequency (Lang, 1987)
- Waverider MkIII: Vertically stabilized (Datawell, 2009)

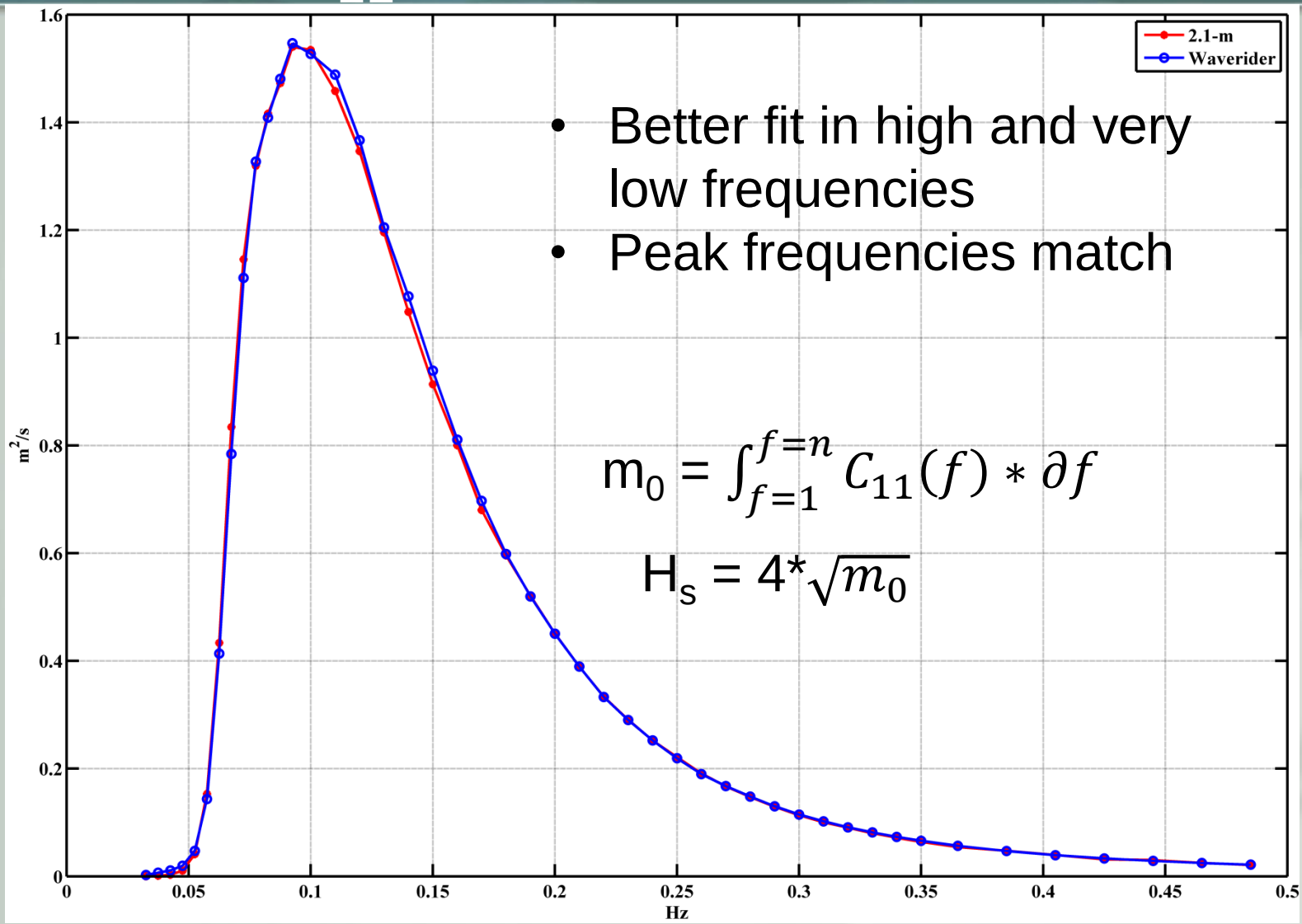
2.1-m Mean Uncalibrated Spectral Energy Densities (red) Waverider Mean Spectral Energy Densities (blue)



Mean Spectral Energy Densities
2.1-m with 3-m Noise Correction & R^{hH} = 1 (red)
Waverider (blue)



Mean Spectral Energy Densities ($C_{11}(f)$) after Calibration



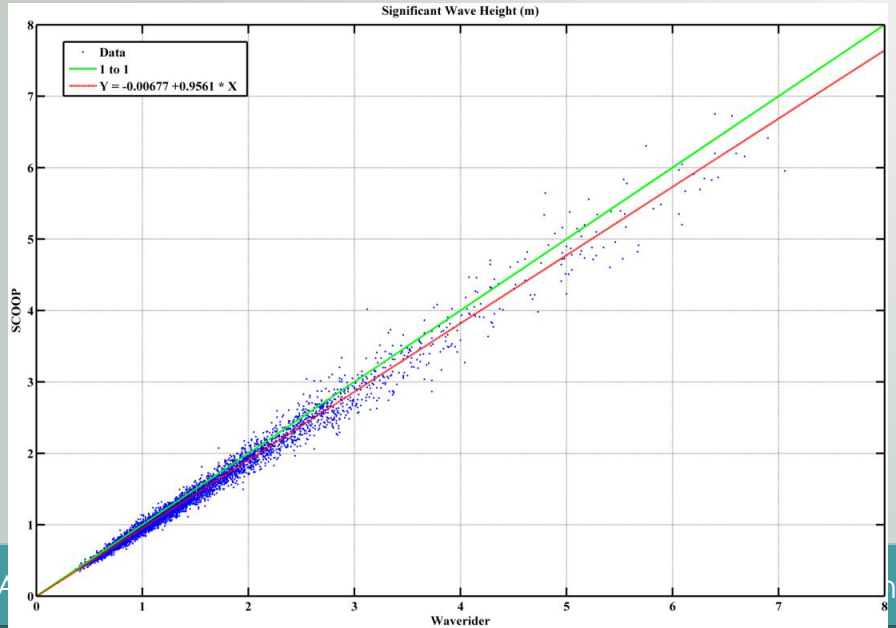
- Better fit in high and very low frequencies
- Peak frequencies match

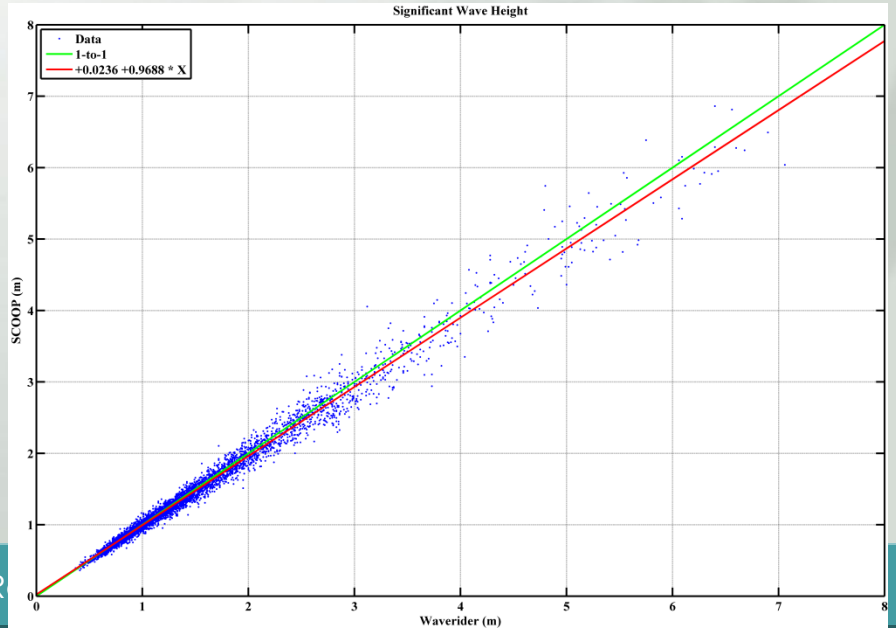
$$m_0 = \int_{f=1}^{f=n} C_{11}(f) * \partial f$$

$$H_s = 4^*\sqrt{m_0}$$

Significant Wave Height (m)

Statistic	With Old Calibration	With New Calibration
Bias	**-0.072**	**-0.023**
RMSE	**0.131**	**0.108**
Max |Error|	**1.1**	**1.0**
CorrCoef	**0.9926**	**0.9997**
Slope LSQ Fit	**+0.9561**	**+0.9688**
Y-intercept LSQ Fit	**-0.007**	**+0.024**
15-m Intercept LSQ Fit	**14.3**	**14.6**





Conclusions & Further Work

- **New Calibration improves mean spectra**
- **2.1-m accuracy with new calibration:**
  - Significant Wave Height: 0.11 m RMSE, N = 4966
- **Small bias (-0.02 m), most of the error is in the variance**
- **Constrained by present calibration, applies to a hull/mooring over all conditions**
  - Reduce variance by seeking different calibrations for specific conditions
  - New model for low-frequency noise correction
- **Investigate transportability of new calibrations to other test sites – West Coast and Great Lakes**

References

- Datawell, 2009: *Datawell Waverider Reference Manual*, Datawell BV, pp. 123 *[http://m.cdip.ucsd.edu/documents/index/gauge_docs/mk3.pdf]*

- Lang, N., 1987: The Empirical Determination of a Noise Function for NDBC Buoys with Strapped-Down Accelerometers, *Proc. MTS/IEEE OCEANS'87, Halifax, NS, Canada, 28 Sept.-1 Oct. 1987*, pp. 225-228. [http://ieeexplore.ieee.org/abstract/document/1160904/]

- NDBC, 1996*: NDBC Technical Document 96-01, Nondirectional and Directional Wave Data Analysis Procedures*, National Data Buoy Center, Stennis Space Center, MS, 43pp. [http://www.ndbc.noaa.gov/wavemeas.pdf]

- Steele, K.E., J.C-K. Lau, and H-H.L. Hsu, 1985: Theory and application of calibration techniques for an NDBC directional wave measurements buoy, *IEEE Journal of Oceanic Engineering*, OE-10(4), pp.382-396.

More Information

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(228) 688-3459

http://www.ndbc.noaa.gov/wavemeas.pdf
http://www.ndbc.noaa.gov/faq.shtml

Archive data:
https://www.nodc.noaa.gov/BUOY/, and
https://data.nodc.noaa.gov/thredds/catalog/ndbc/cmanwx/

Acknowledgements

Deployment and processing of Waverider funded by US Army Corps of Engineers, Coastal and Hydraulics Laboratory, Vicksburg, MS, USA, http://www.erdc.usace.army.mil/Locations/CHL/

Waverider data processing by Coastal Data Information Program (CDIP), Scripps Institution of Oceanography, La Jolla, CA USA, http://www.cdip.ucsd.edu/