The Legacy of FLOSSIE: Evaluation of Wave Measurements Onboard a 6N NOMAD

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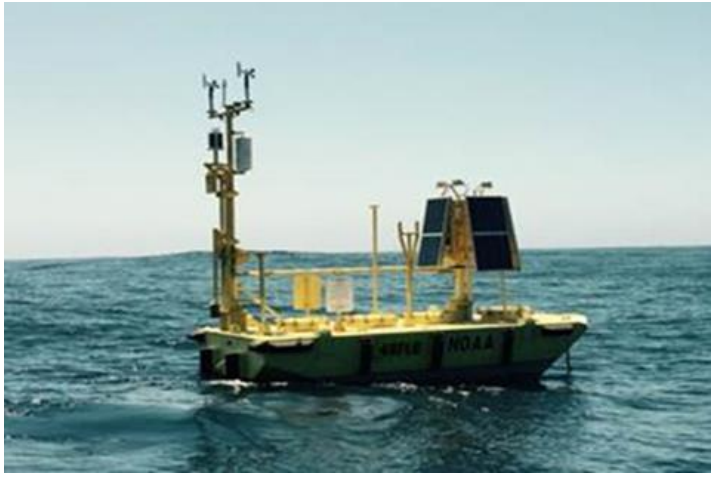
FLOSSIE: OUTLINE

- Introduction
  - Background
  - Study Area
  - Buoy Characteristics
- Analysis-Results
  - Bulk Parameters / Statistics
  - Frequency Spectra
- Observations
- Conclusions
- Vision Forward



Jensen, R.E., Swail, V. and R.H. Bouchard, (2021). Quantifying wave measurement differences in historical and present wave buoy systems, *Ocean Dynamics,* **71,** 731-755, https://doi.org/10.1007/s10236-021-01461-0.

FLOSSIE: MOTIVATION

- Test and Evaluation of Wave Measurement Systems:
  - Critical to NWP's to evaluate wave forecasts
  - Assimilation into NWP forecasts
  - Used to improve wind-wave modeling technologies
  - Drive nearshore wave models
  - Track spatial / temporal variations in wave climate
  - Altimeter algorithms
  - Tracking wave climate trends
- Differences exist between wave measurement systems
  - Will differences affect the outcome of their usage?
  - Scale of the differences vs. application

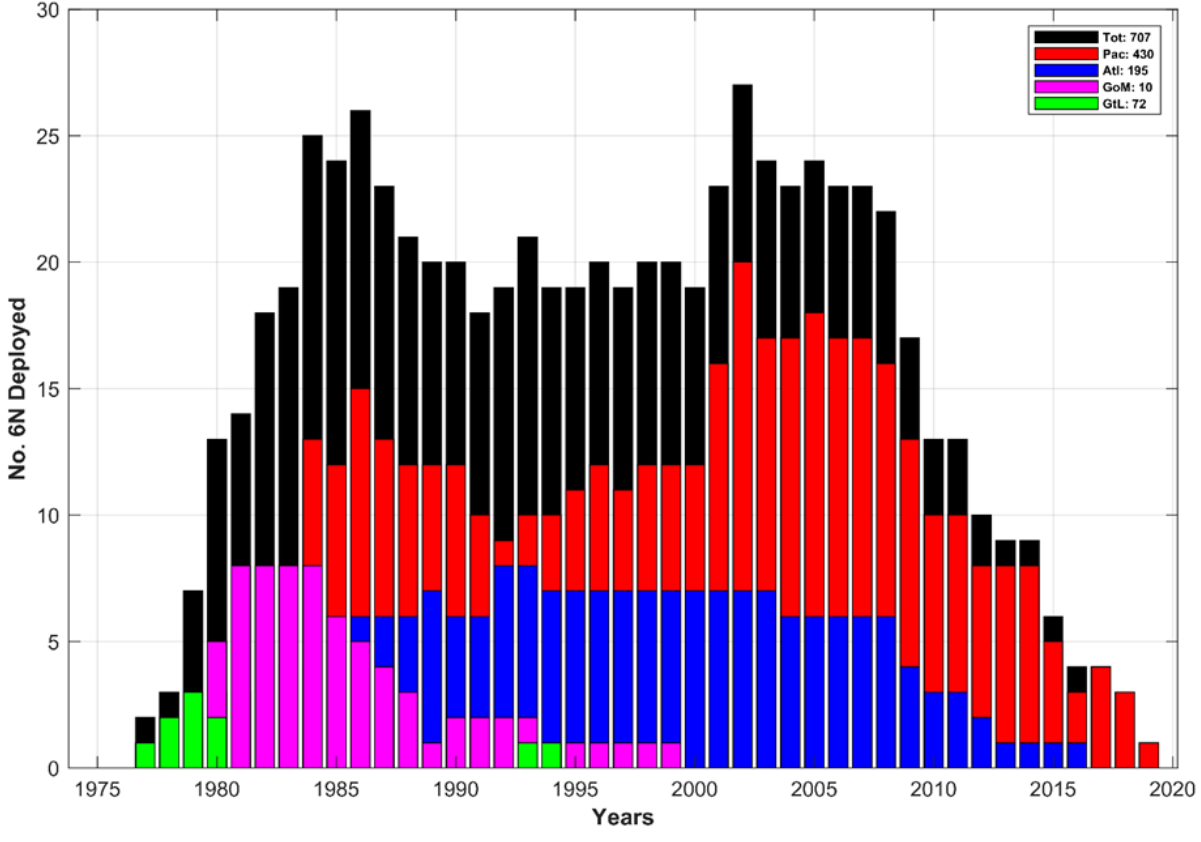
DBCP: Task Team on Wave Measurements

FLOSSIE: MOTIVATION

- Focus: 6N NOMAD Buoy and their data
- Used by NOAA-NDBC and ECCC over 4 decades
- Limited evaluations
  - Steele et al. (1978) / Murphy (1979): GoM (198 samples)
  - Skey et al. (1998) SWS-1: Pacific (Winter 94 - 95)
  - Taylor et al. (2005) SWS-2: Atlantic (Oct 1997 - Mar 1998)
  - Jensen et al. (2011) 44255: Atlantic (Jul 2010- Feb 2011)
  - Collins et al. (2014) ITOP: Pacific (4 months)
- NOAA-NDBC: 0 (all decommissioned 2019)
- ECCC: 0 (all decommissioned ~2020)
- Time is running out to evaluate 6N buoys

FLOSSIE: MOTIVATION

Historical account of NDBC 6N buoys
Total number of ‘buoy years’ = 707



FLOSSIE COLLABORATION

- USACE: Coordination ($)
- NDBC:
  - Hull
  - Sensor/Payloads
    - Inclinometer
    - HIPPY-Magnetometer
    - 3DMG
- USCG: Deployment
- AXYS
  - TRIAXYS Next Wave II DWS/WM
- ECCC
  - Strapped Down Accelerometer
  - AXYS-Watchman
- MEDS
  - MEDS-Data Archive

US Army Corps of Engineers®

CDIP

National Data Buoy Center
Center of Excellence in Marine Technology

United States Coast Guard
U.S. Department of Homeland Security

AXYS Technologies Inc.

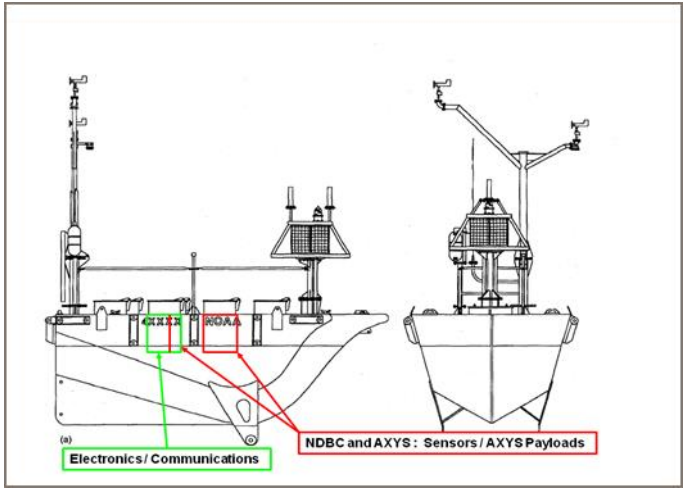
Environment and Climate Change Canada

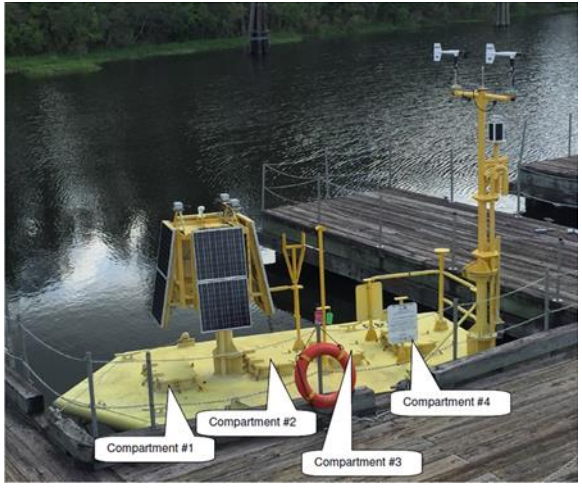
Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

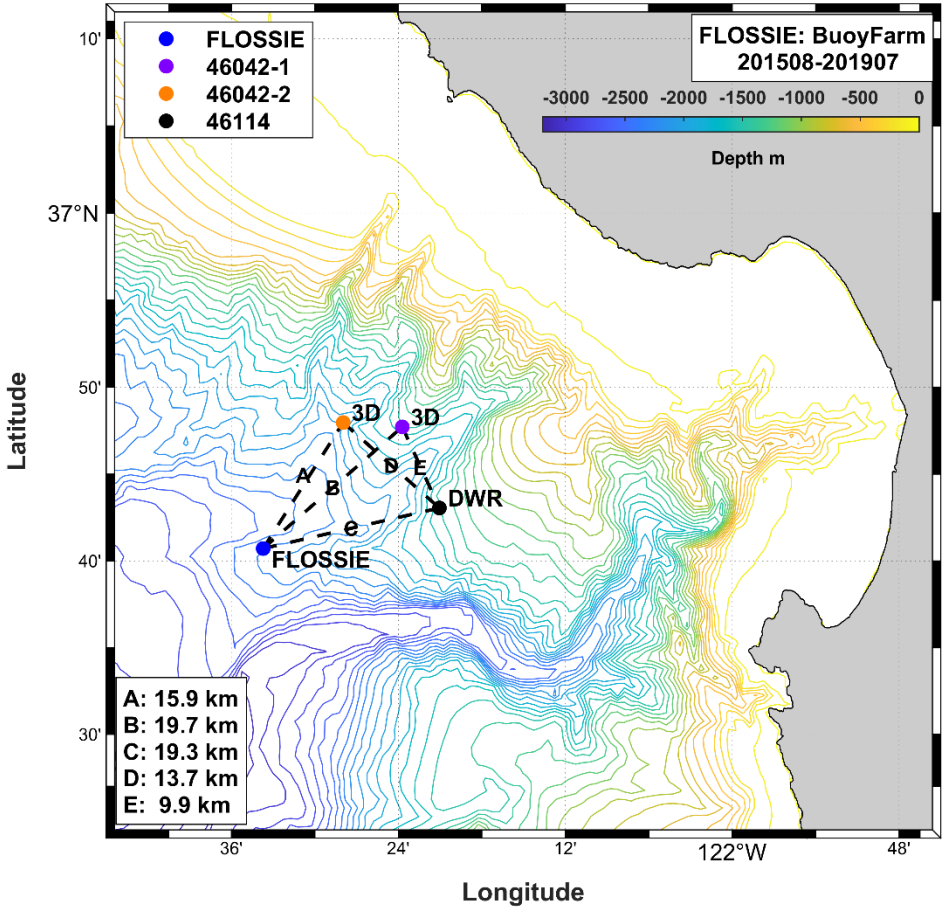
FLOSSIE: CONFIGURATION

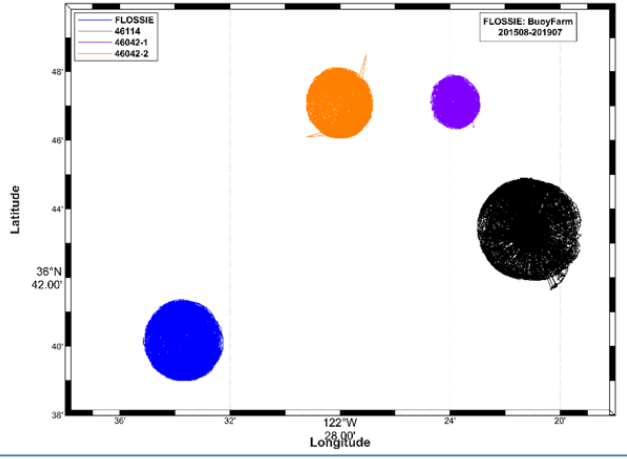
- FLOSSIE: 6N (NOMAD BUOY)
  - Aug 2015 – Oct 2019
  - 5 Sensors
    - NDBC: Inclinometer (Ndir)
    - NDBC: 3DMG (Dir)
    - NDBC: HIPPY (Dir)
    - ECCC: Watchman (Ndir)
    - AXYS: TRIAXYS Next Wave II DWS-WM (Dir)
- NDBC 3D (Aluminum)
  - NDBC: 3DMG (Dir)
  - NDBC: HIPPY (Dir)
- Datawell Directional WaveRider
  - *RELATIVE REFERENCE*



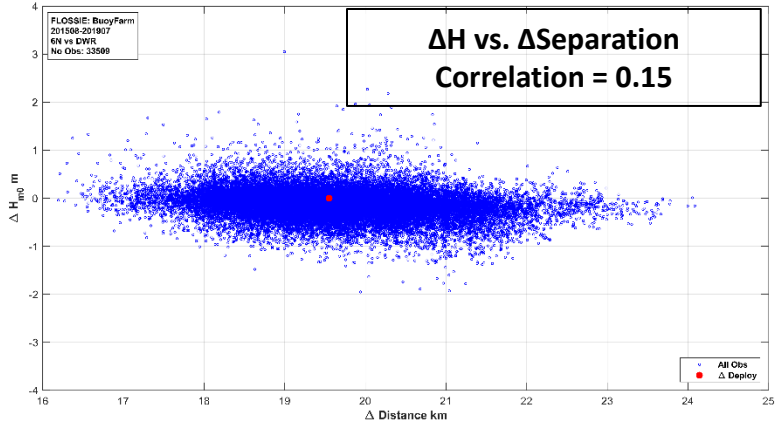


FLOSSIE: BUOY FARM DEPLOYMENT SITE





GPS Positioning Hourly Buoy movement



FLOSSIE: ANALYSIS

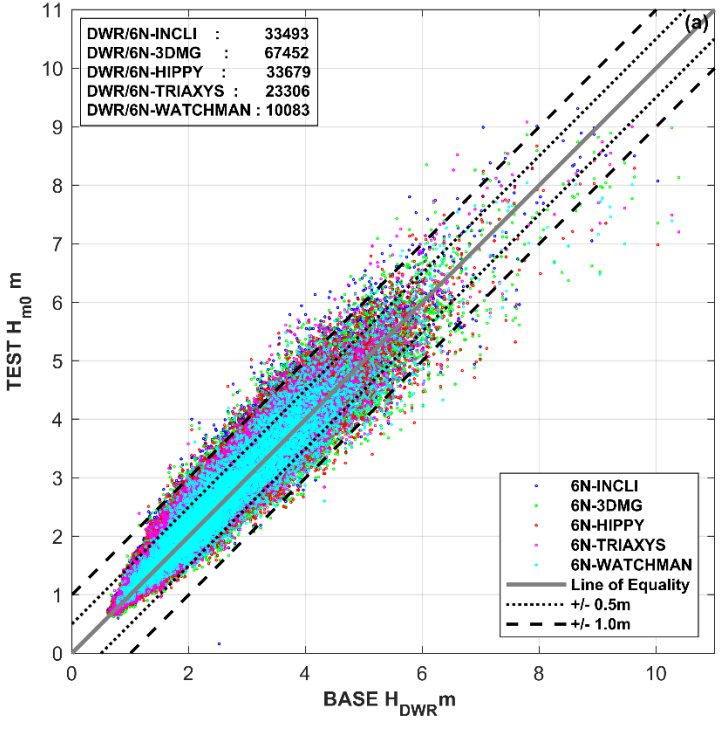
- Bulk Wave Properties
  - H_{mo}, T_{pp}, T_m, $\theta_{mean}(f_m)$, θ_{mean}, σ.
  - Quantile evaluations
  - Frequency spectral moments:
    - Spread, Peakedness, Steepness, Mean Square Slope

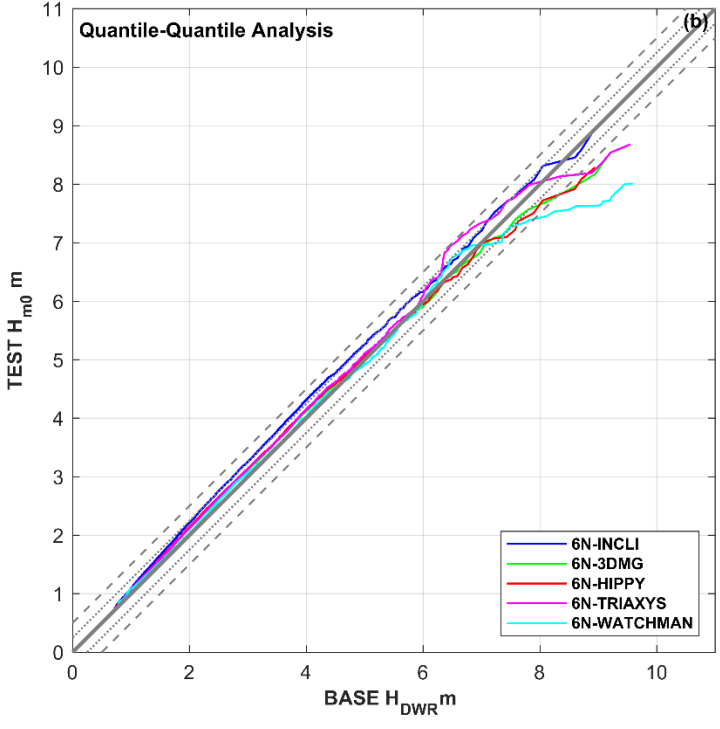
- Frequency Spectra
  - E(f), Steepness(f), Slope(f)

- D(f): Four Fourier Directional Parameters
  - Intent of FLOSSIE was <u>not</u> to determine if it could estimate wave directions
    - DDWM-3DMG / DWPM-HIPPY / AXYS-Triaxys WSII
    - On-board capability
  - Limit to: $\theta_{mean}(f_m)$, θ_{mean}, σ

FLOSSIE/ANALYSIS: BULK WAVE PARAMETERS

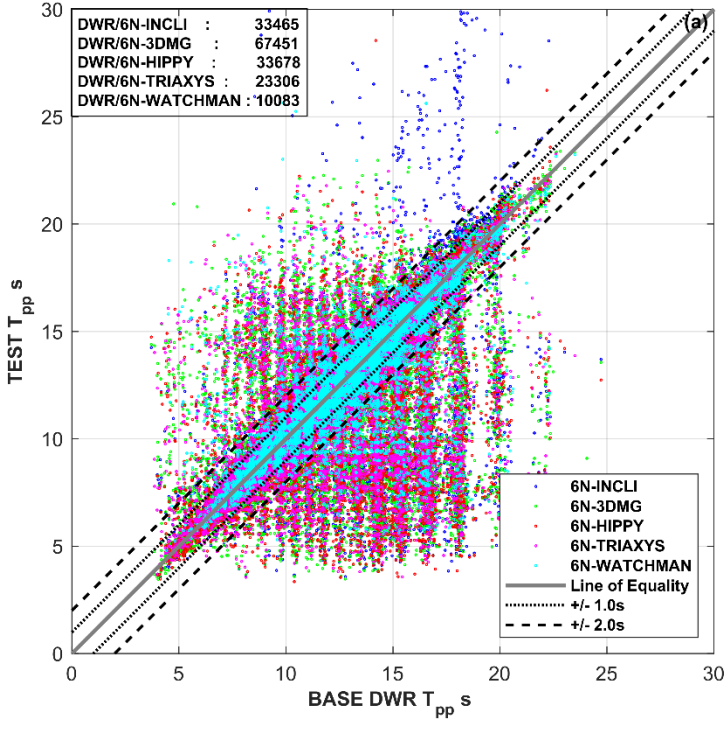
DWR: Base Data Set
Time paired to each Set

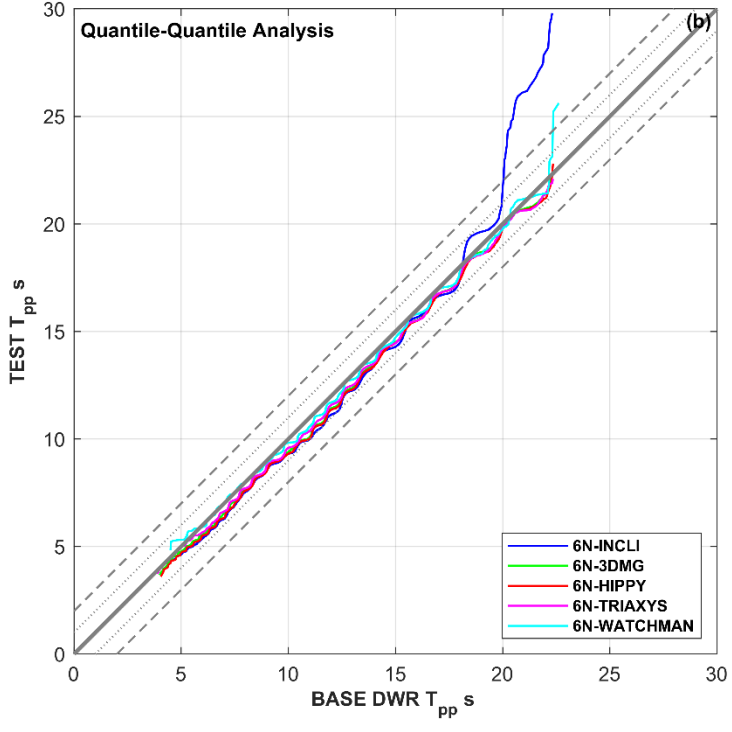




FLOSSIE/ANALYSIS: BULK WAVE PARAMETERS

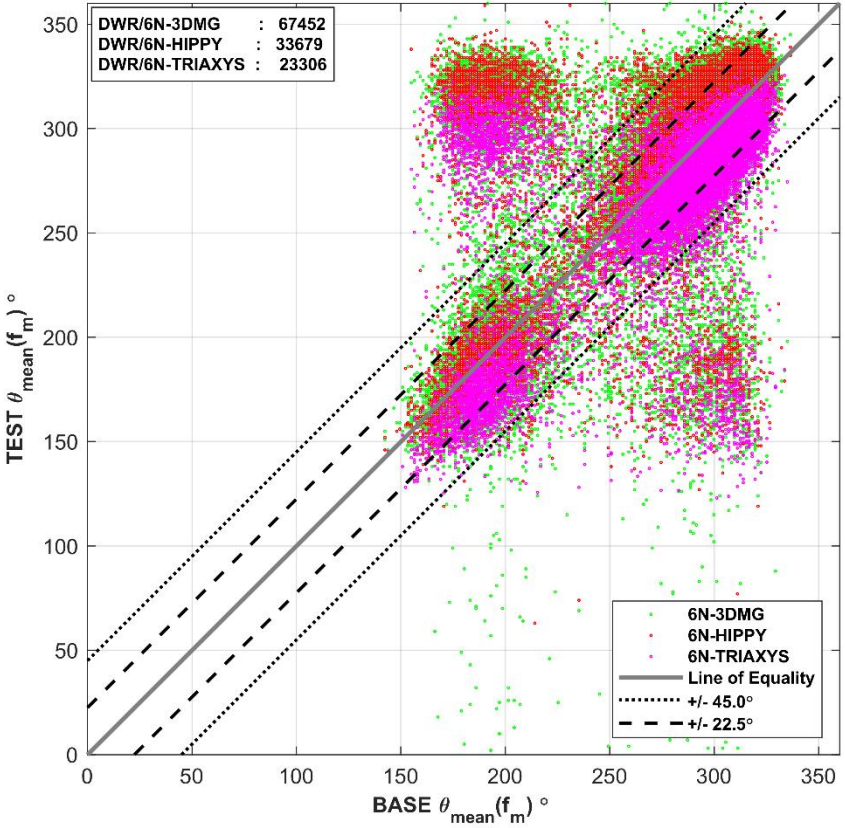
Differences around the Spectral Peak
Existence of Multiple Wave Systems



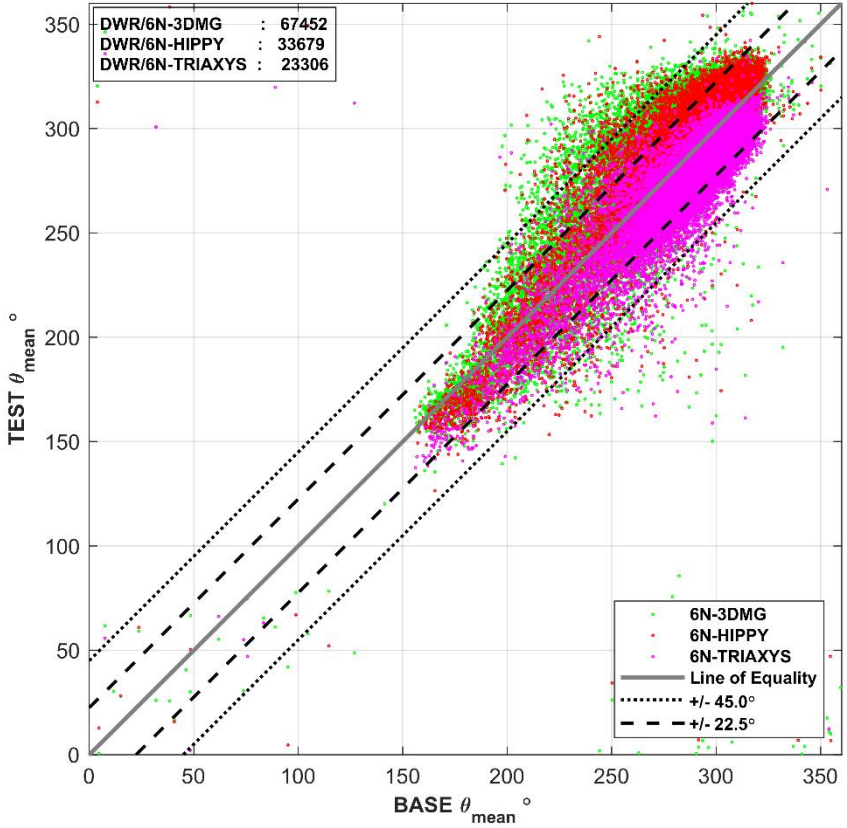


FLOSSIE/ANALYSIS: BULK WAVE PARAMETERS

Vector Mean Wave Direction at spectral peak
Pure Measurement



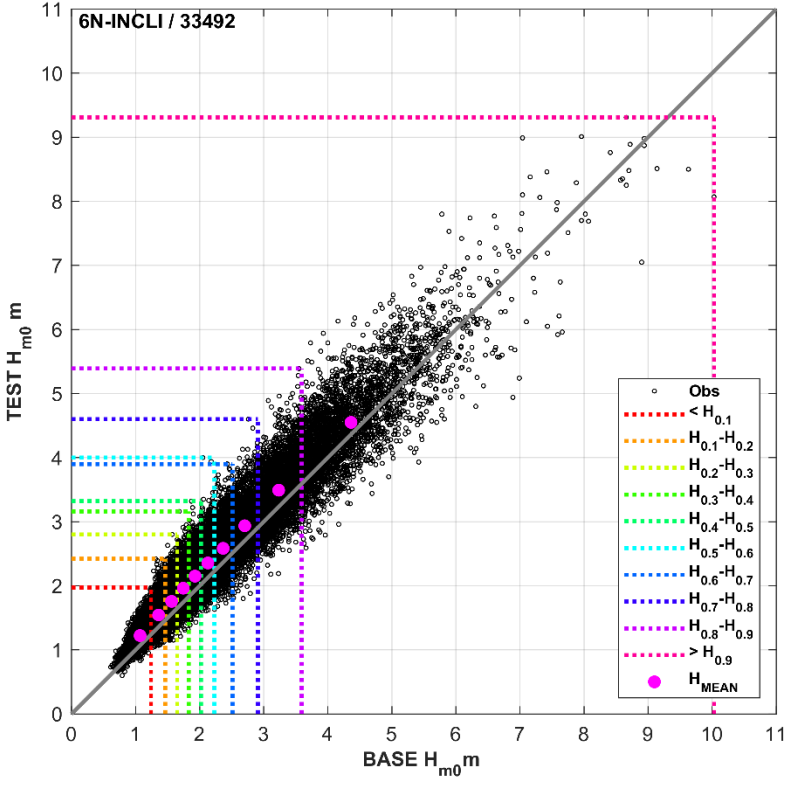
Overall Vector Mean Wave Direction
Estimate using a_1,a_2,b_1,b_2 and MEM



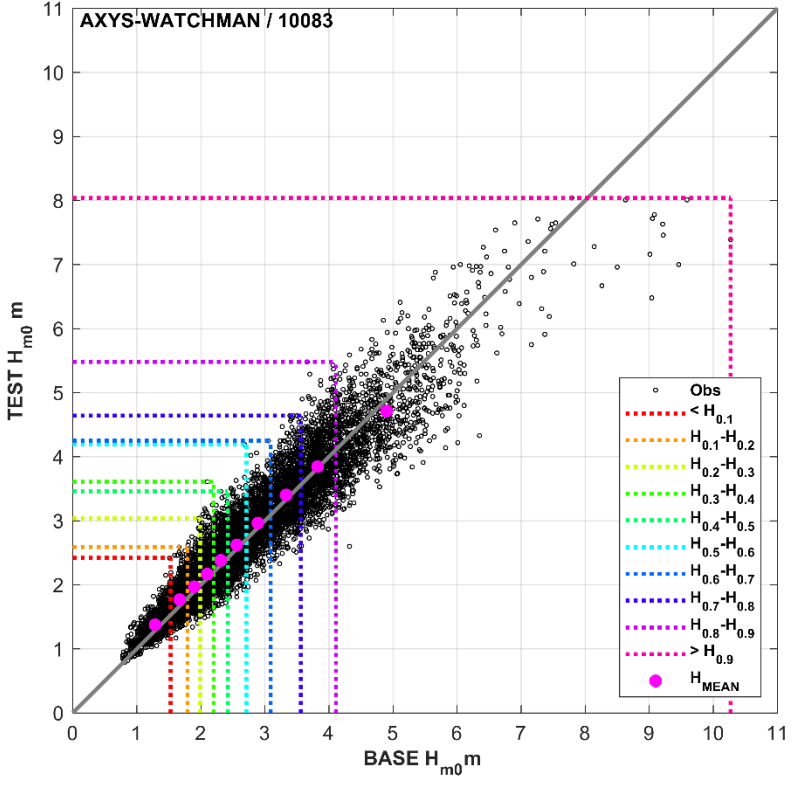
FLOSSIE/ANALYSIS: QUANTILES H_{m0}

What is the variation in statistics over set quantiles?

DWR vs Inclinometer

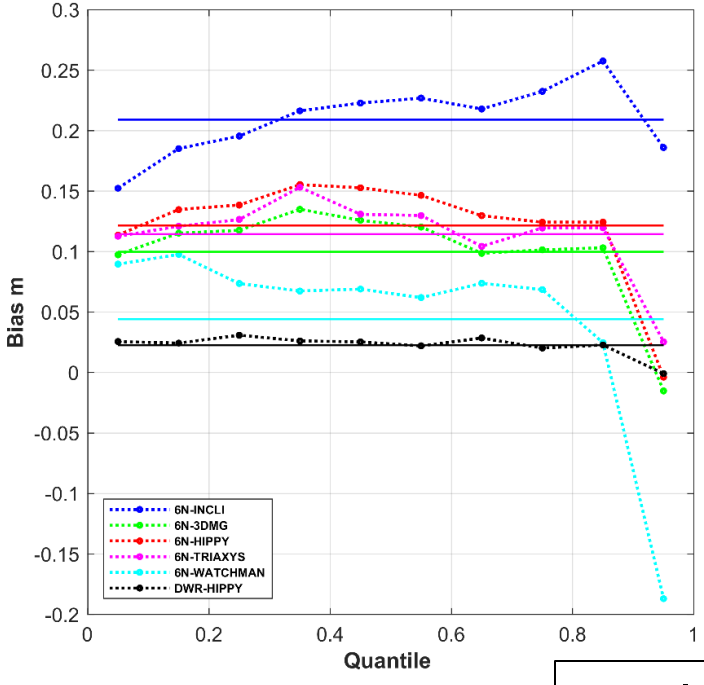


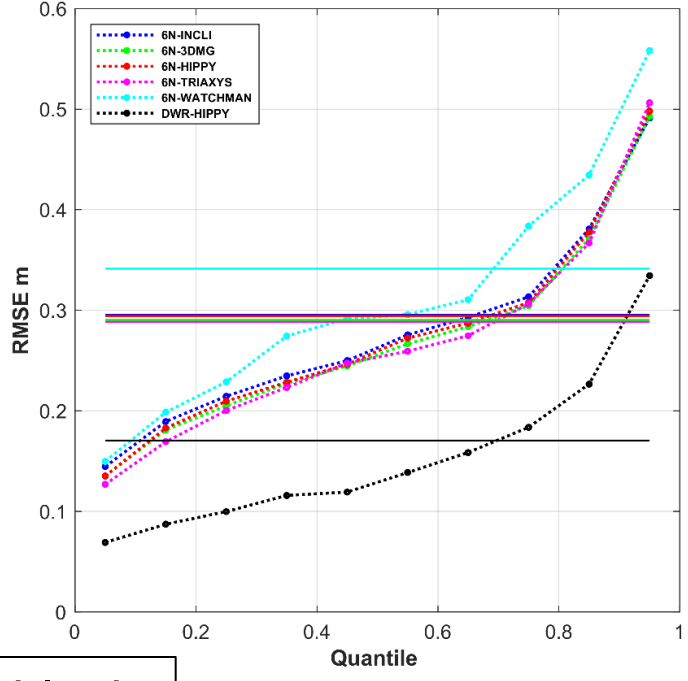
DWR vs Watchman



FLOSSIE/ANALYSIS: QUANTILES H_{m0}

Is one statistical value sufficient as a metric marker?
Solid line: Mean / Dashed line: Quantiles

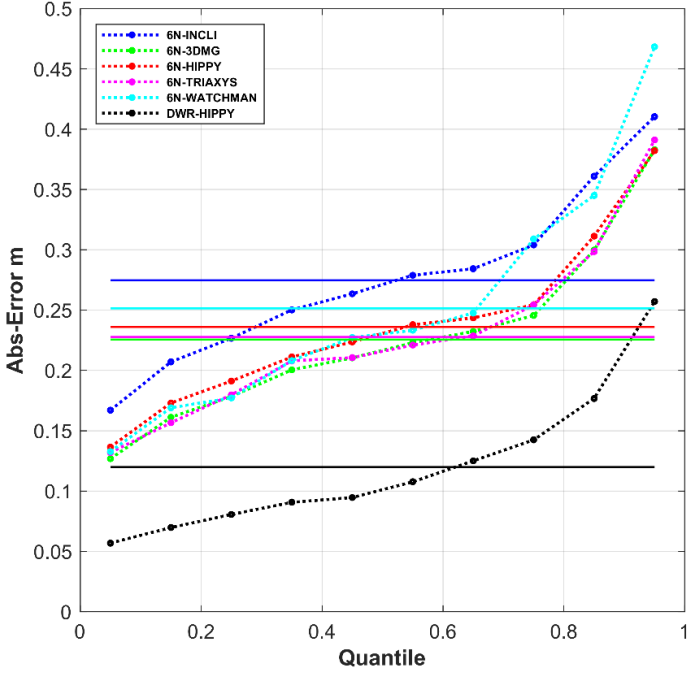


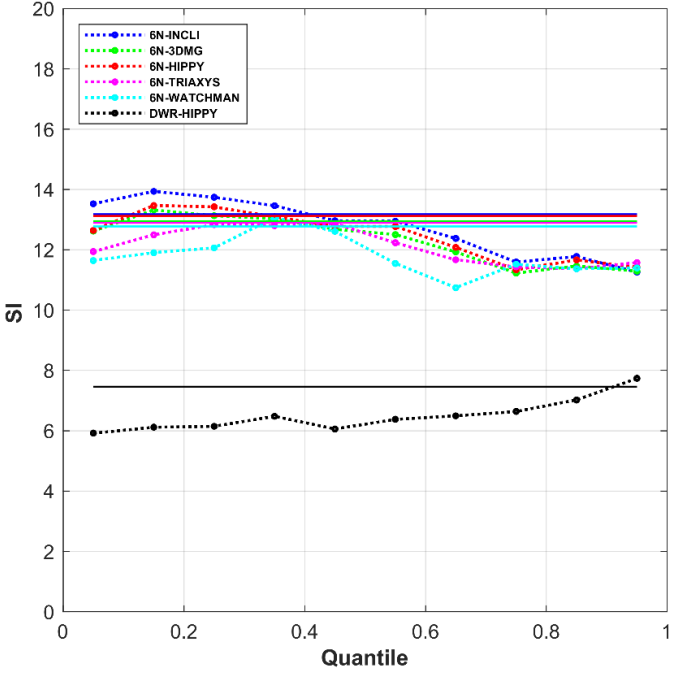


Co-located DWR's in black
Gold Standard for metric?
Harvest Platform 2015-2017

FLOSSIE/ANALYSIS: QUANTILES H_{m0}

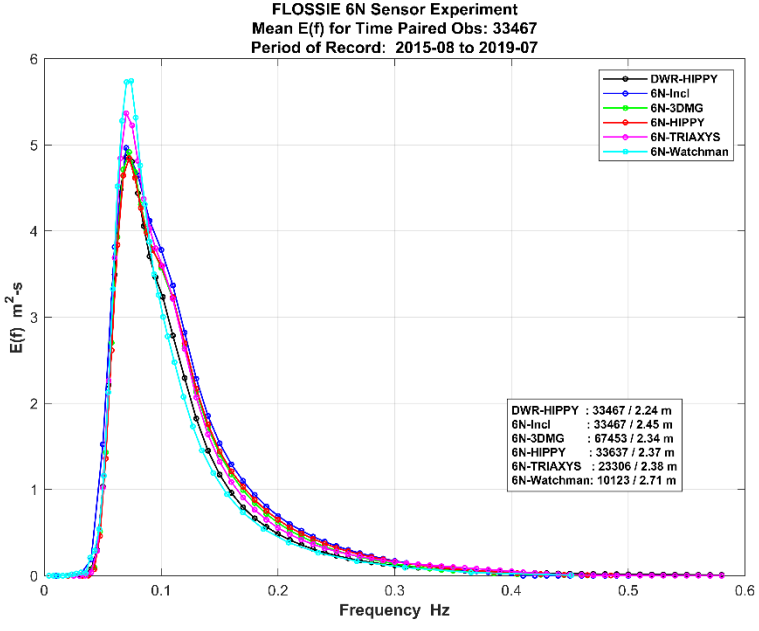
Is one statistical value sufficient as a metric marker?
Solid line: All data / Dashed line: Quantiles

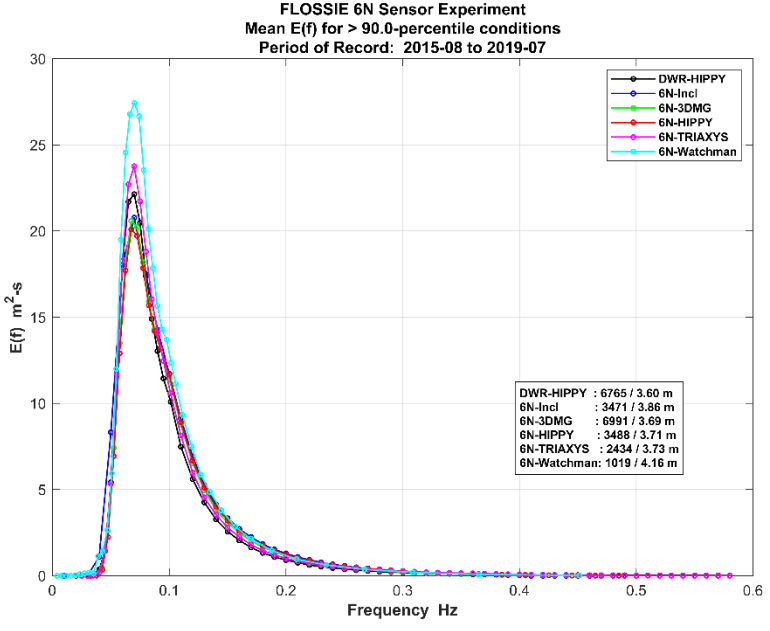




FLOSSIE/ANALYSIS: FREQUENCY SPECTRA

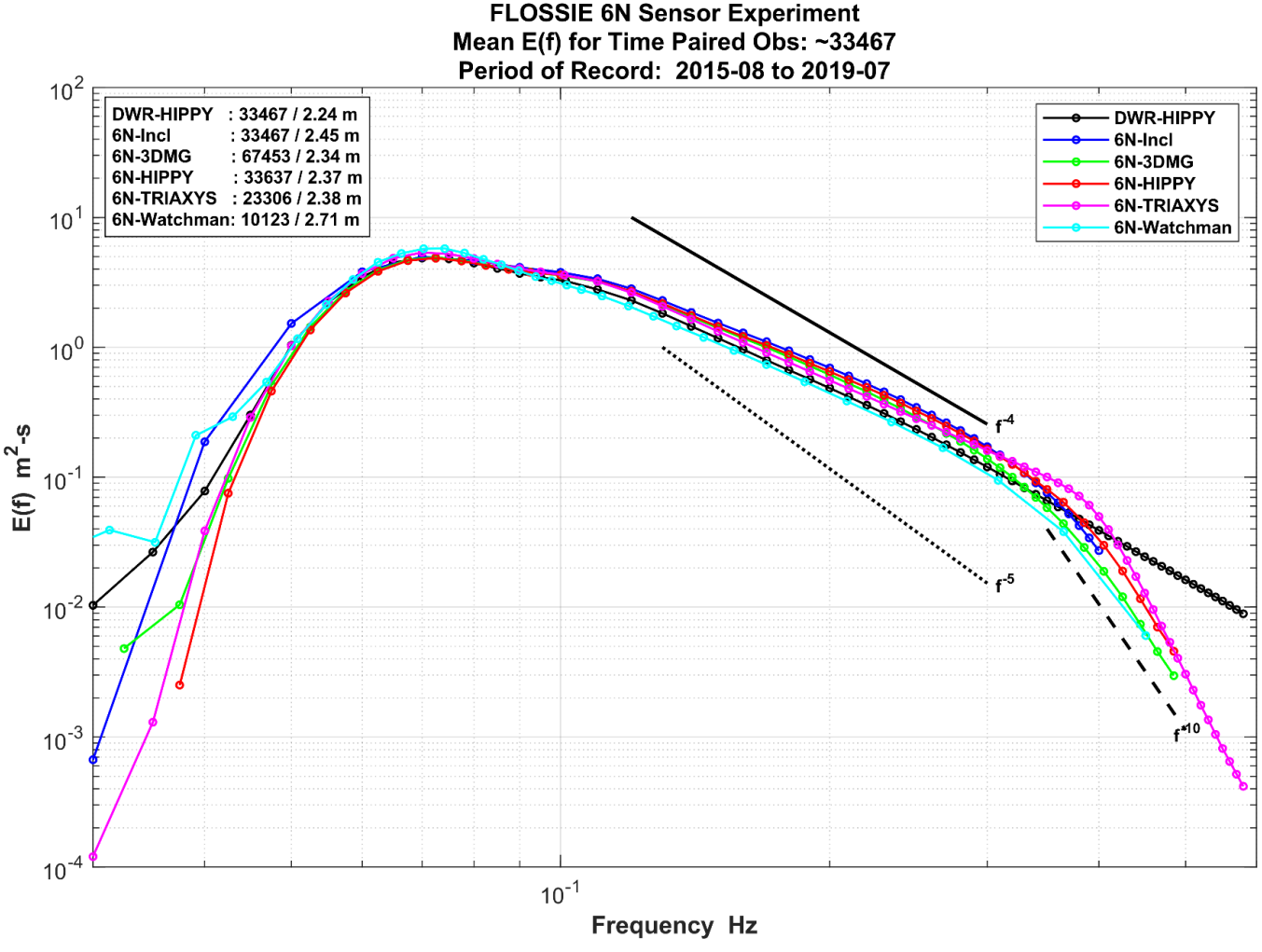
Over the mean shapes similar for All vs 90th Percentile



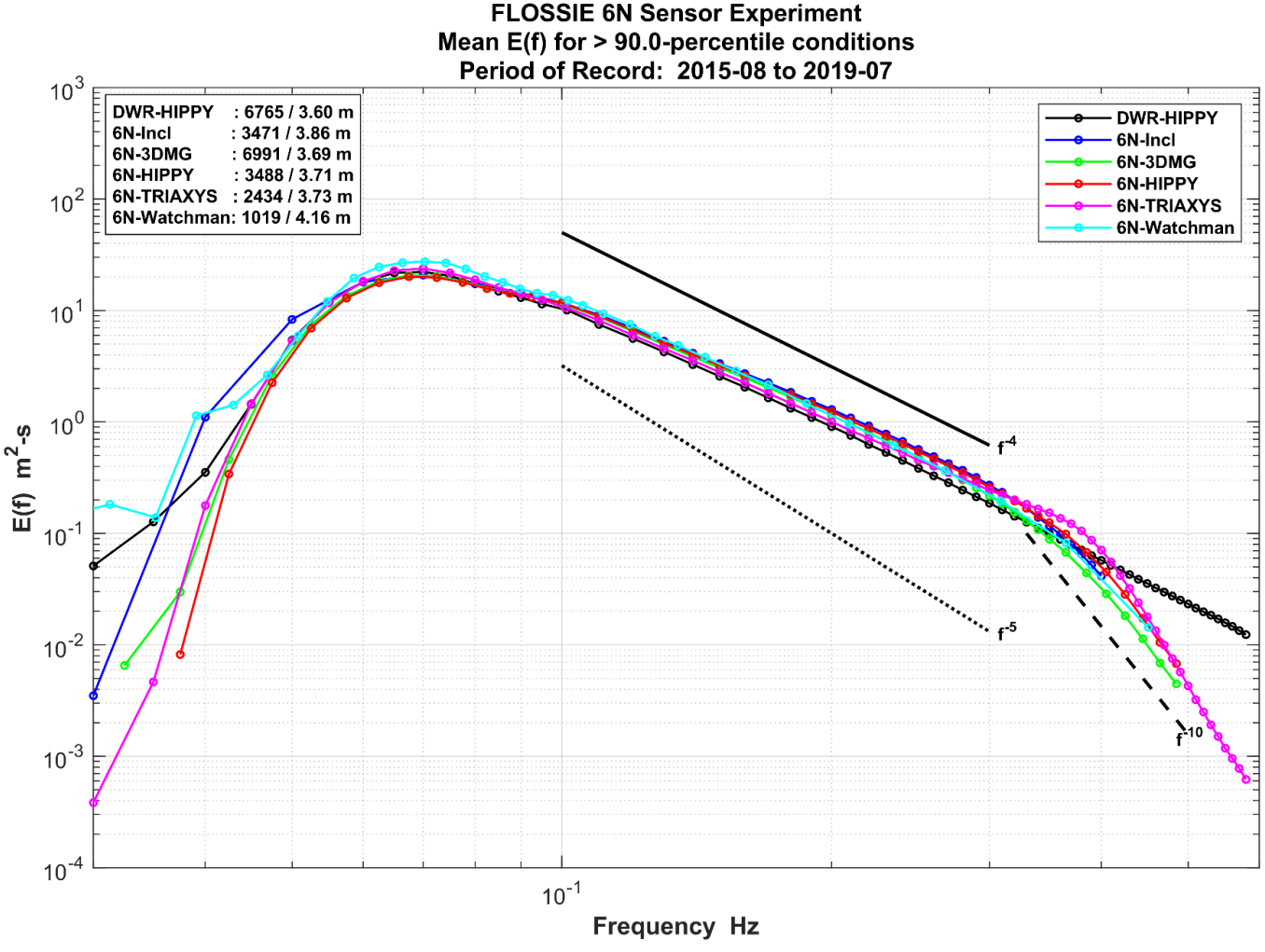


Watchman results affected by smaller population size

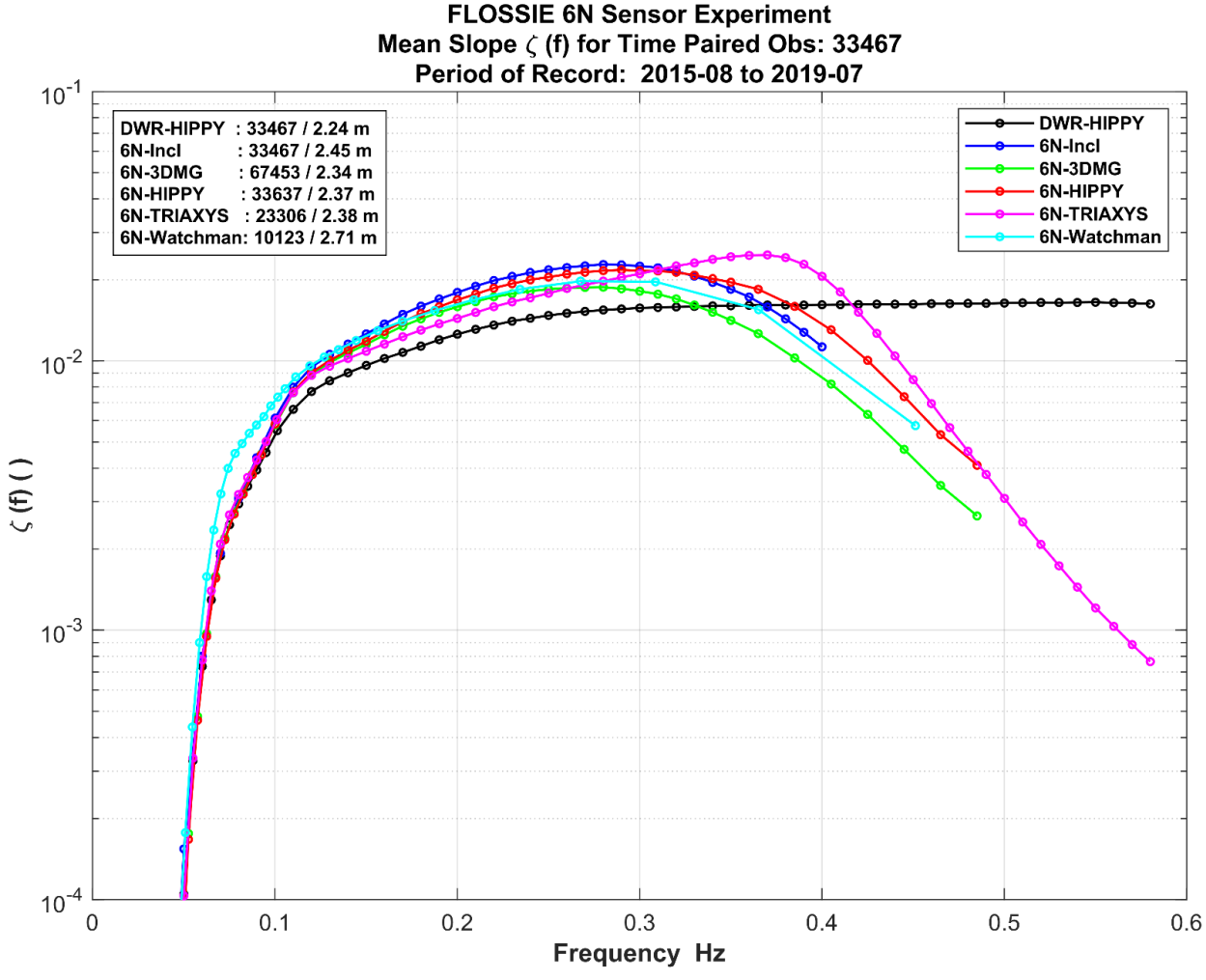
FLOSSIE/ANALYSIS: FREQUENCY SPECTRA



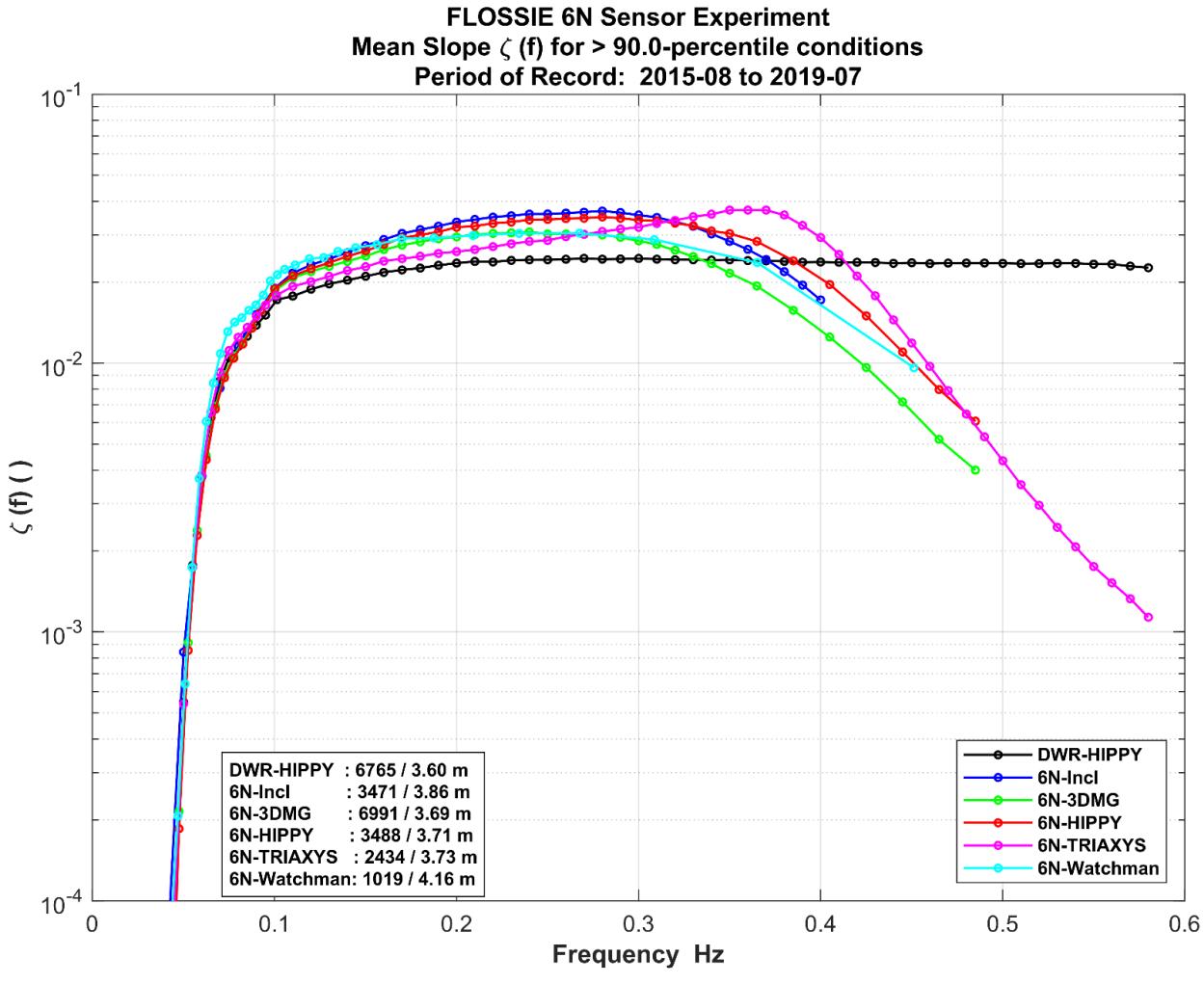
FLOSSIE/ANALYSIS: FREQUENCY SPECTRA



FLOSSIE/ANALYSIS: SLOPE SPECTRA



FLOSSIE/ANALYSIS: SLOPE SPECTRA



FLOSSIE: OBSERVATIONS

- Wave measurement systems have their own specific attributes that can impact the data
- Intra-measurement evaluations must go beyond bulk wave parameters and defined by a single statistical value
- Despite the QA-QC measures, wave data delivered contains embedded errors that must be corrected especially in the frequency spectra
- Co-location intra-measurement investigations are subject to spatial and temporal variations in the wave climate measured that may go beyond geophysical variability
- Despite original thoughts regarding directional wave measurements from non-symmetric buoys they appear to be accurate
- If raw spectra (no filtering / modifications by a RAO) are available, errors can be corrected
- Despite a successful 4-yr campaign, results from FLOSSIE may only be applicable to the wave climate measured in the eastern Pacific

FLOSSIE: CONCLUSIONS

- NDBC-Inclinometer
  - Compares better to DWR than all sensors in H_{m0} for full range of wave conditions
  - Has elevated T_{pp} estimates
  - Energy tails off rapidly > 0.4Hz
  - Slope spectral estimates run high in mid-range / does not approach constant (as in DWR).

- NDBC-3DMG and HIPPY
  - Performed well up to ~6m then showed an increasing under-estimate compared to DWR H_{m0}
  - Follows T_{pp} estimates well through range
  - Slope spectra fall off at > 0.35Hz (worse than Inclinometer)

FLOSSIE: CONCLUSIONS

- AXYS-Triaxys WSII
  - Over estimates in H_{m0} range from 6-7m, then under estimates by 1m
  - Has consistent T_{pp} estimates
  - Energy tails off rapidly > 0.4Hz (most severe of all)
  - Slope spectral estimates run high and continues in mid-range / does not approach constant (as in DWR).

- ECCC-Watchman
  - Performed well up to ~7m then showed an increasing under-estimate (most severe of all) compared to DWR H_{m0}
  - Follows T_{pp} estimates well but elevated in the +20s.
  - Slope spectra fall off at > 0.4Hz and similar to all other sensors
  - Note that analysis was constrained by the limited population size

FLOSSIE: CONCLUSIONS

- Co-located intra-measurements are extremely useful but there are caveats that need to be considered
  - Spatial (separation distances)
  - Temporal (sampling interval) variabilities
- One statistical value for a specific parameter does not define the deviations found in the data
- Frequency spectra needs to be included in evaluations
- Steepness (not shown here) and Slope spectra should comply with theory
- If we consider a 10% error in the H_{mo} measurements are we willing to accept a $\pm$1m difference in 10m?

OR IN OTHER WORDS, HOW CLOSE IS CLOSE ENOUGH TO DEFINE ACCURACY IN WAVE MEASUREMENT?

VISION FORWARD

- Continued Test and Evaluation
- New buoy configurations
- New sensor packages to be evaluated
  - NDBC: OWL-Ocean Wave Linux (Replaces 3DMG)
    - Meteorological
      - Rm-Young and secondary: Sonic anemometer
      - Elevation change from standard 5m

QUESTIONS?

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