The Legacy of FLOSSIE (Field Laboratory for Ocean Sea State Investigation and Experimentation) Evaluation of Wave Measurements Onboard a 6N NOMAD

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Melbourne, Australia

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

Environment and Climate Change Canada
Environnement et Changement climatique Canada

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

COASTAL & HYDRAULICS LABORATORY

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

JCOMM DBCP Task Team on Wave Measurements

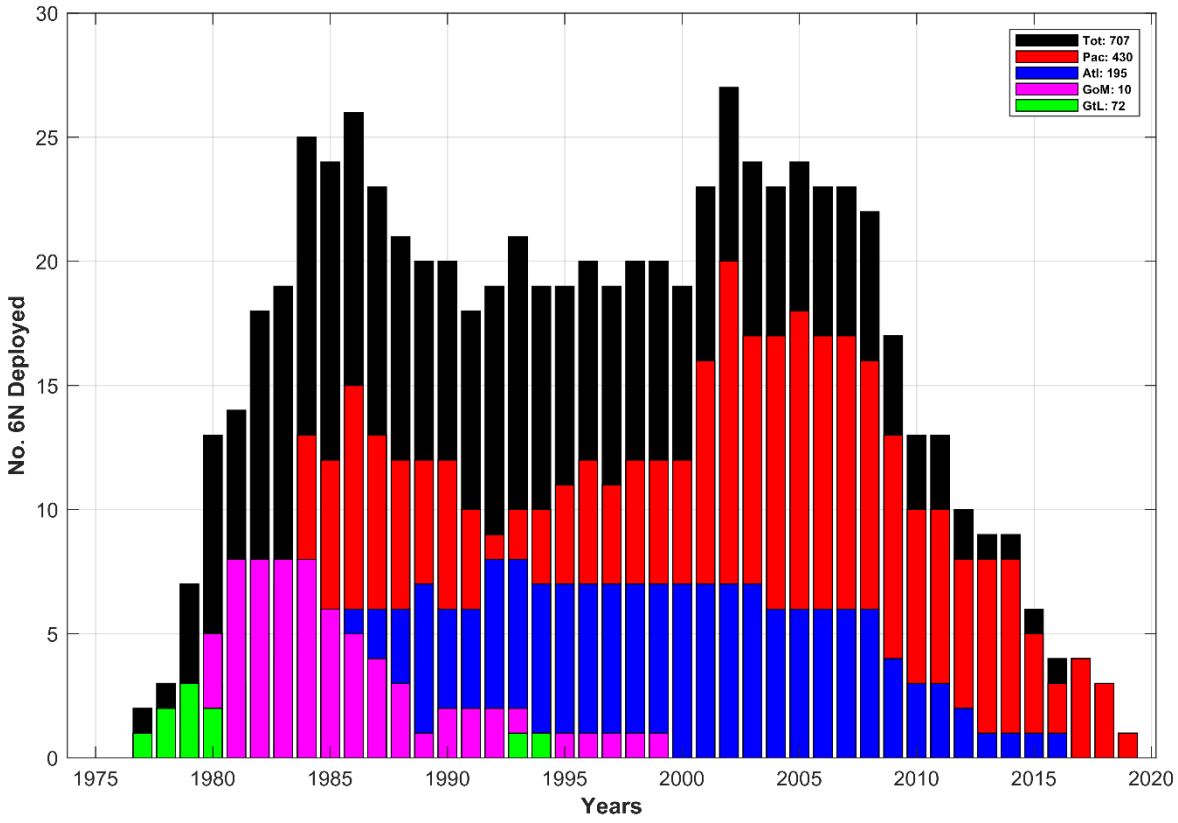
www.jcomm.info/WET

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)
  - Undocumented 44255: Atlantic (Jul 2010- Feb 2011)
  - Collins et al. (2014) ITOP: Pacific (4 months)
- NOAA-NDBC: 0 (all decommissioned 2019)
- ECCC: Operational 1
- Time is running out to evaluate 6N buoys

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
    With AXYS-Watchman processor

- 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

ERDC
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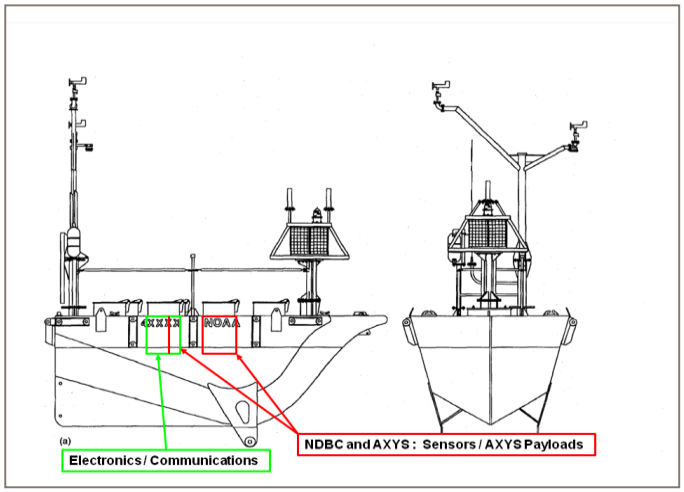
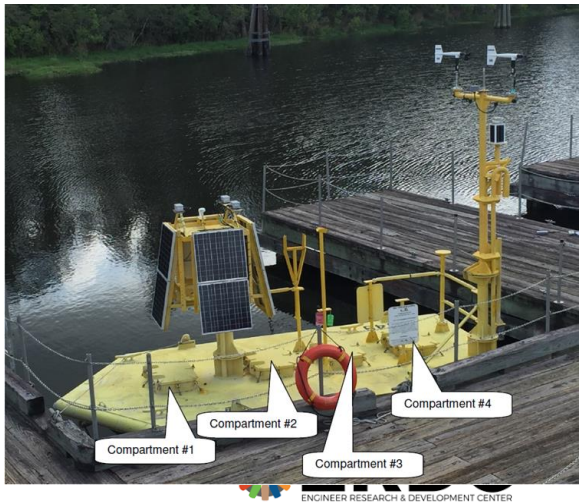
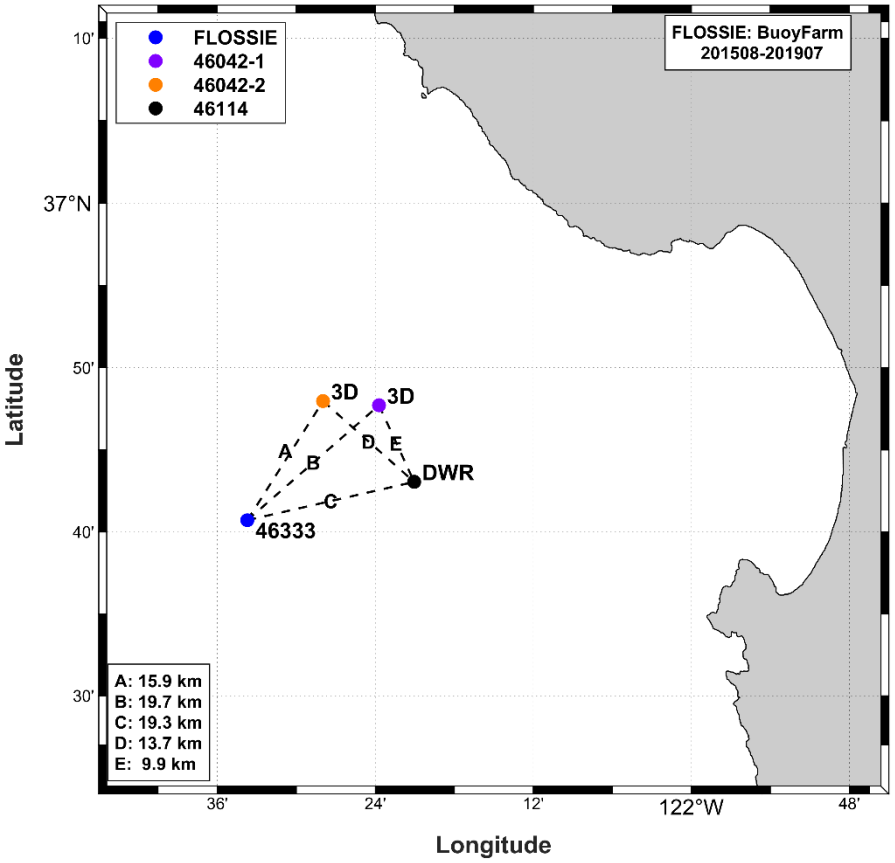
FLOSSIE CONFIGURATION

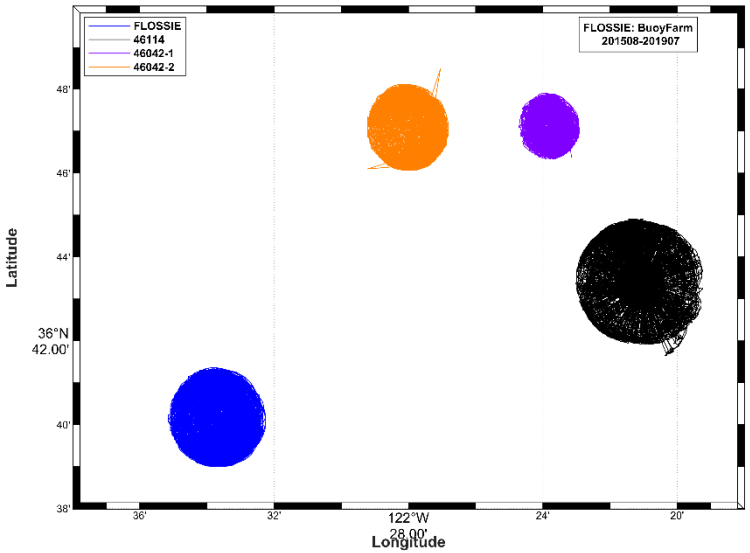
- FLOSSIE: 6N (NOMAD BUOY)
  - Aug 2015 – Oct 2019
  - 5 Sensors
    - NDBC: Inclinometer (Ndir)
    - NDBC: 3DMG (Dir)
    - NDBC: HIPPY (Dir)
    - ECCC: SDA Watchman (Ndir)
    - AXYS: TRIAXYS Next Wave II DWS-WM (Dir)
- NDBC 3D (Aluminum)
  - NDBC: 3DMG (Dir)
  - NDBC: HIPPY (Dir)
- Datawell Directional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





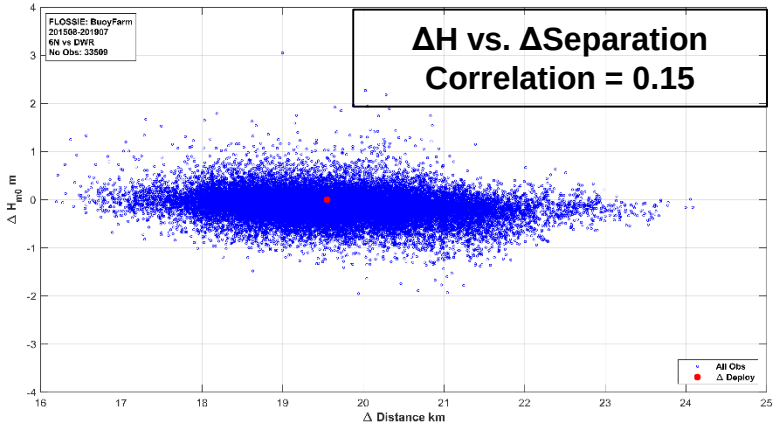
FLOSSIE-BUOY FARM DEPLOYMENT SITE





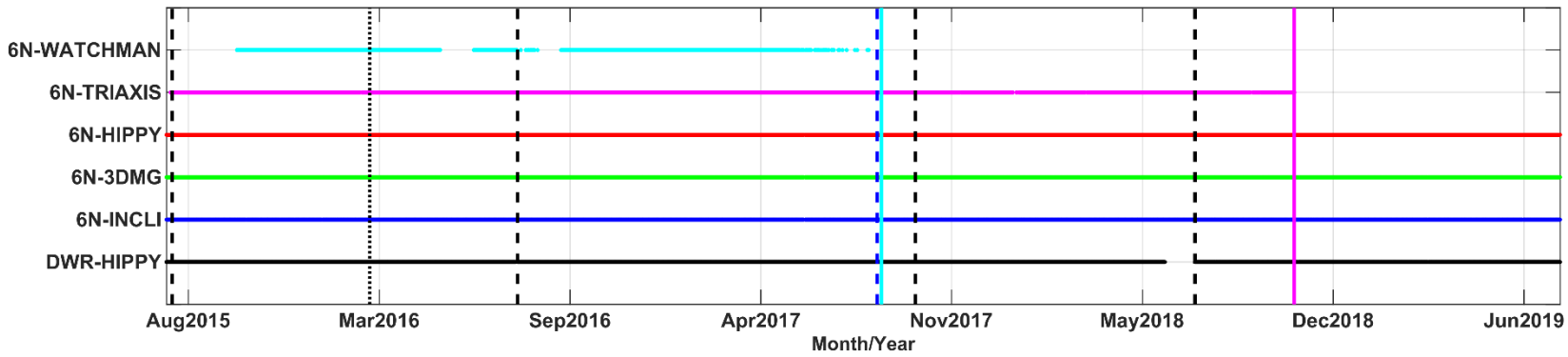
GPS Positioning Hourly Buoy movement

Depth: 1,500m



FLOSSIE DETAILS

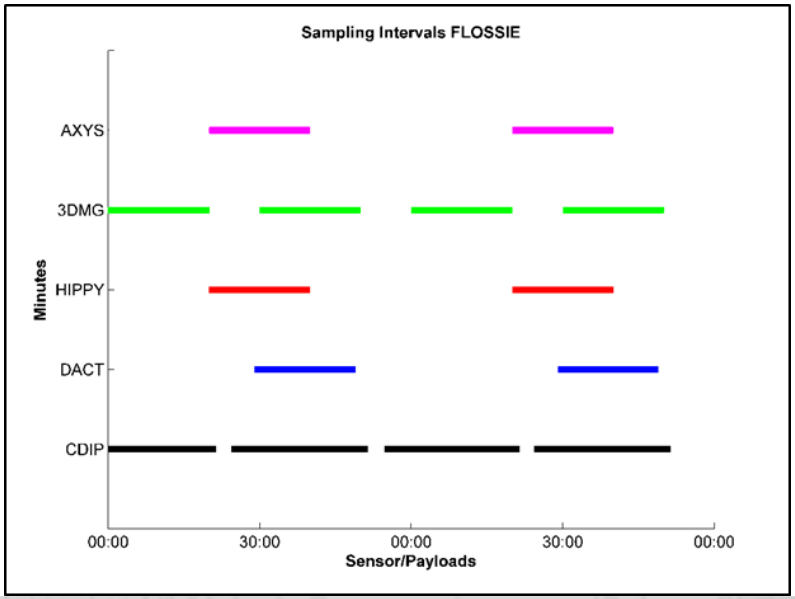
- FLOSSIE: 6N (NOMAD BUOY)
  - NDBC/CDIP: 95 ~100% return
  - Lost Watchman and TRIAXYS Signal: Antenna Failure
  - Evidence of biofouling on DWR



FLOSSIE DETAILS

	DWR	Inclinometer	DDWM (3DMG)	DWPM (HIPPY)	Watchman-SDA	AXYS-Triaxys
Sample Frequency (Hz)	1.28	2.0/SS-1.0	1.7066	1.7066	1.0	1.08
Sample Duration (s)	1600	1200	1200/600	1200/600	8*256	2220
Samples	2048	1200	2048/1024	2048/1024	2048	2048
# Frequency Bands	64	50	47	47	41	64
Frequency Min (Hz)	0.0250	0.0100	0.0200	0.0200	0.0039	0.0250
Frequency Max (Hz)	0.5800	0.5000	0.4850	0.4850	0.4512	0.5800
Output Interval (min)	30	60	30	60	60	60

Sampling Period
Overlap exists / Not perfect
May introduce some errors



FLOSSIE WINDS

Similar winds measured at 46FLO and 46042

	46FLO-Wind Speed	46042-Wind Speed	46FLO-Wind Direction	46042-Wind Direction	Wind Speed (m/s)	Wind Direction (deg)
Mean	6.3	6.0	323	321	-	-
StD	3.2	3.2	62	69	-	-
Max	20.9	21.1	-	-	-	-
Bias	-	-	-	-	-0.32	-3.2
RMSE	-	-	-	-	1.2	-6.0
SI	-	-	-	-	19	-
Correlation	-	-	-	-	0.93	-

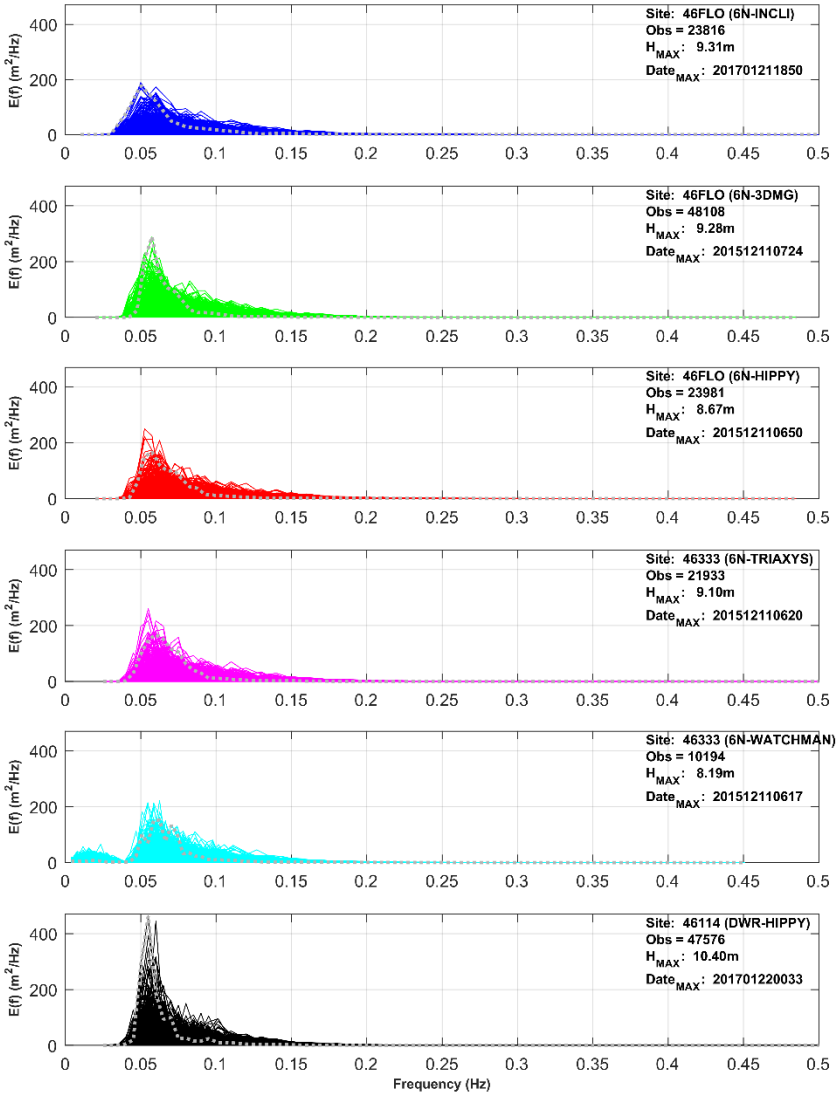
FLOSSIE WAVES

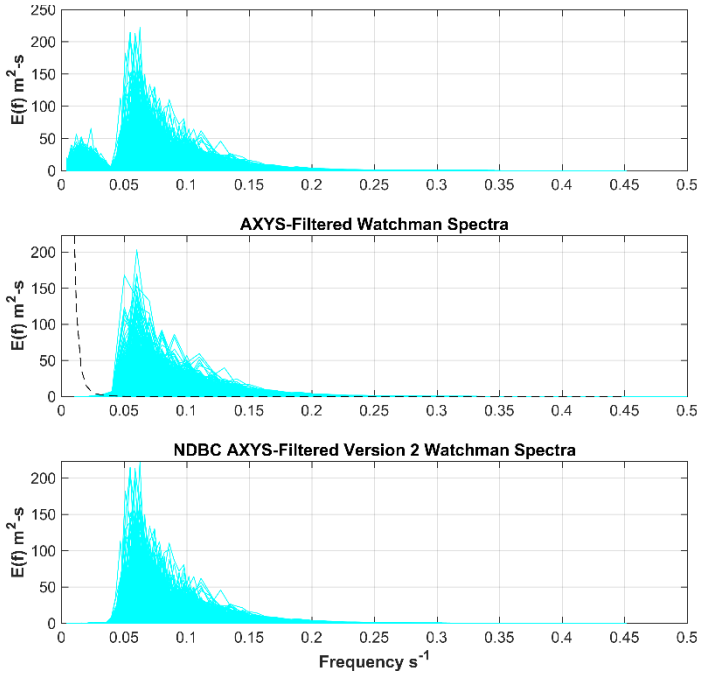
		DWR	46FLO-Inclinometer	46FLO-3DMG	46FLO-HIPPY	46FLO-TRIAXYS	46FLO-Watchman
H_{m0}	Mean (m)	2.24	2.44	2.24	2.36	2.35	2.71
	StD (m)	0.97	1.00	0.96	0.96	0.97	1.05
	Max (m)	10.39	9.31	8.98	8.67	9.08	8.04

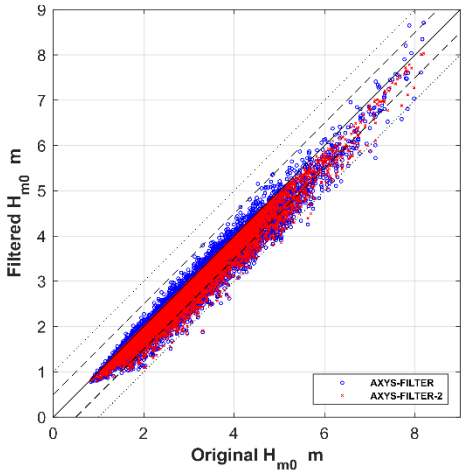
		DWR	46FLO-Inclinometer	46FLO-3DMG	46FLO-HIPPY	46FLO-TRIAXYS	46FLO-Watchman
T_{pp}	Mean (s)	12.1	11.6	11.6	11.6	11.7	12.8
	StD (s)	3.1	3.4	3.1	3.1	3.1	2.9
	Max (s)	24.7	29.9	31.3	34.3	23.4	25.6

		DWR	46FLO-Inclinometer	46FLO-3DMG	46FLO-HIPPY	46FLO-TRIAXYS	46FLO-Watchman
θ_{wave}	Mean (dir)	287	-	296	297	276	-
	StD (dir)	39	-	39	39	36	-
No. Obs		67650	33493	67452	33679	23306	10083

FLOSSIE FREQUENCY SPECTRA







ANALYSIS

- Based on deliverable data
  - Allender et al. (1989), Collins et al. (2014) intra-measurement evaluations
    - Used time-series from all data sources
    - Analysis based on same methodology
  - FLOSSIE: Only DWR delivers time series (X,Y,Z)
    - Restricting analysis to Deliverable Data
    - This is what is available to the waves community
- We understand
  - Two steps
    - On-board: They control/dependent on what is transferred
    - Shore-side: Filters, Response Amplitude Operators, Phase Operators
  - Each system uses different methods
    - Assume impact minor
  - All distribute the same thing: wave measurements

ANALYSIS

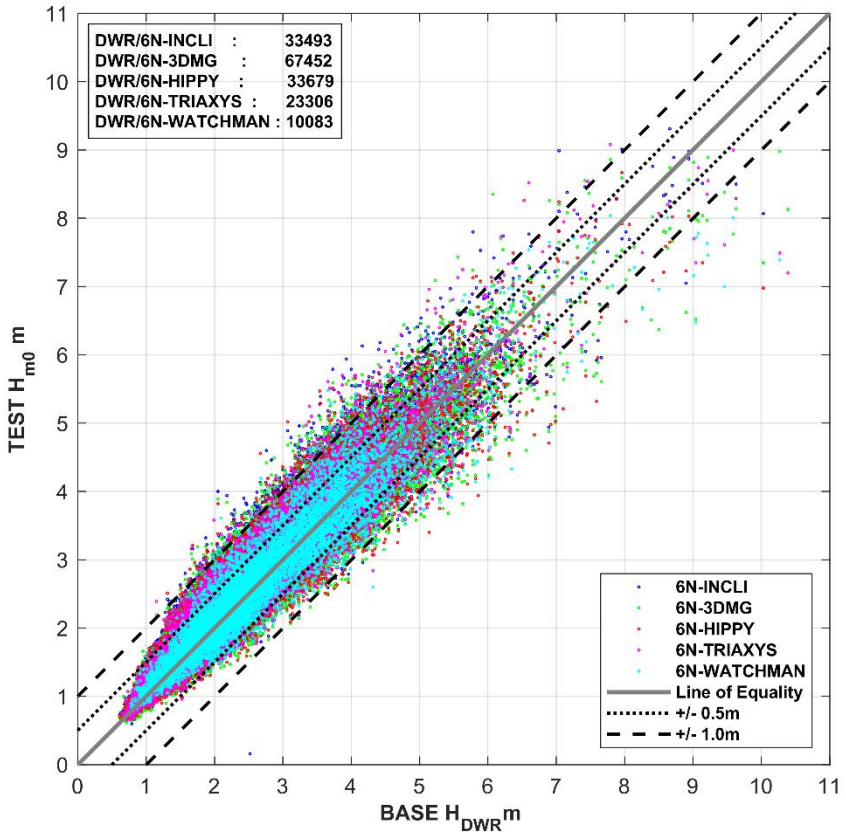
- Integral Wave Properties
  - H_{mo}, T_{pp}, T_m, $\theta_{mean}(f_m)$, θ_{mean}, σ.
  - Quantile evaluations
  - Frequency spectral moments:
    - Spread, Peakedness, Steepness, Mean Square Slope

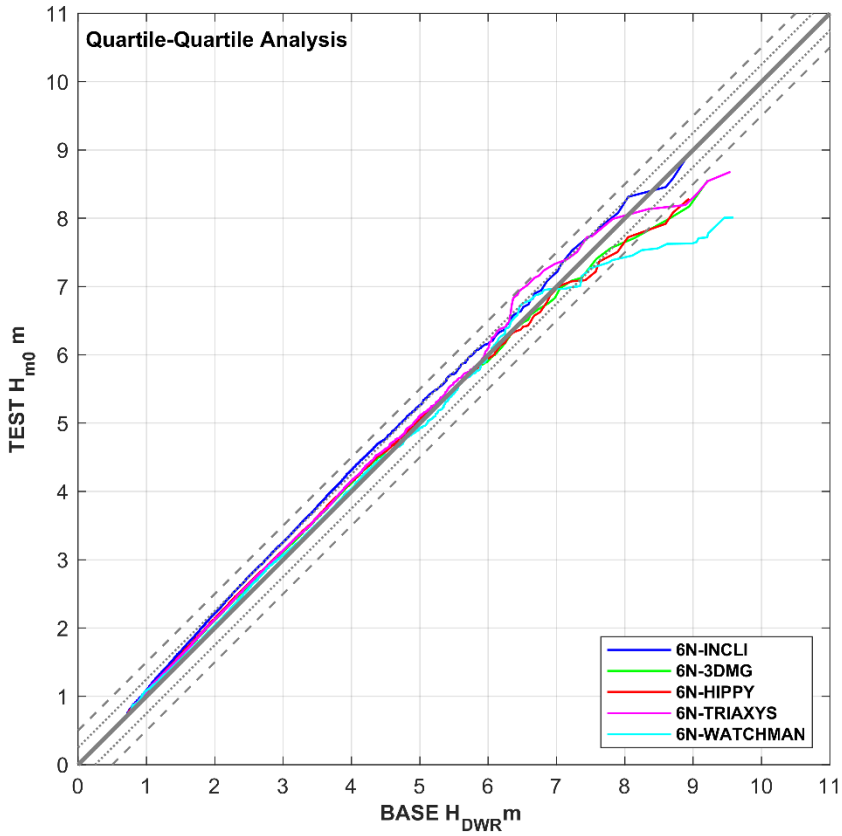
- Frequency Spectra
  - E(f), Steepness(f), Slope(f)

- 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

ANALYSIS: INTEGRAL WAVE PARAMETERS

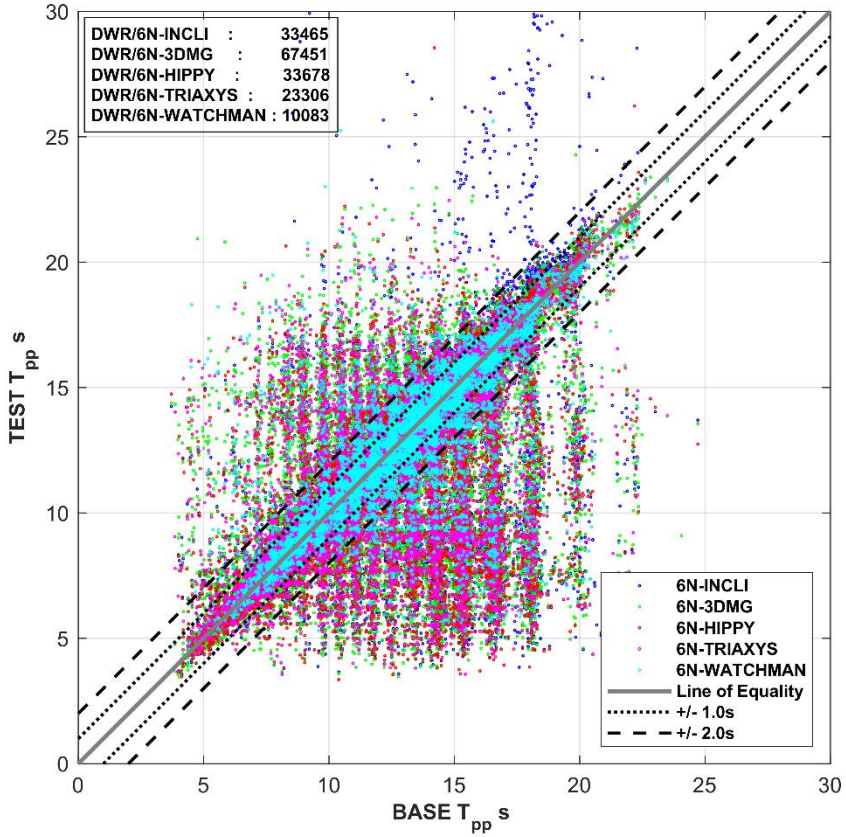
DWR: Base Data Set
Time paired to each Set

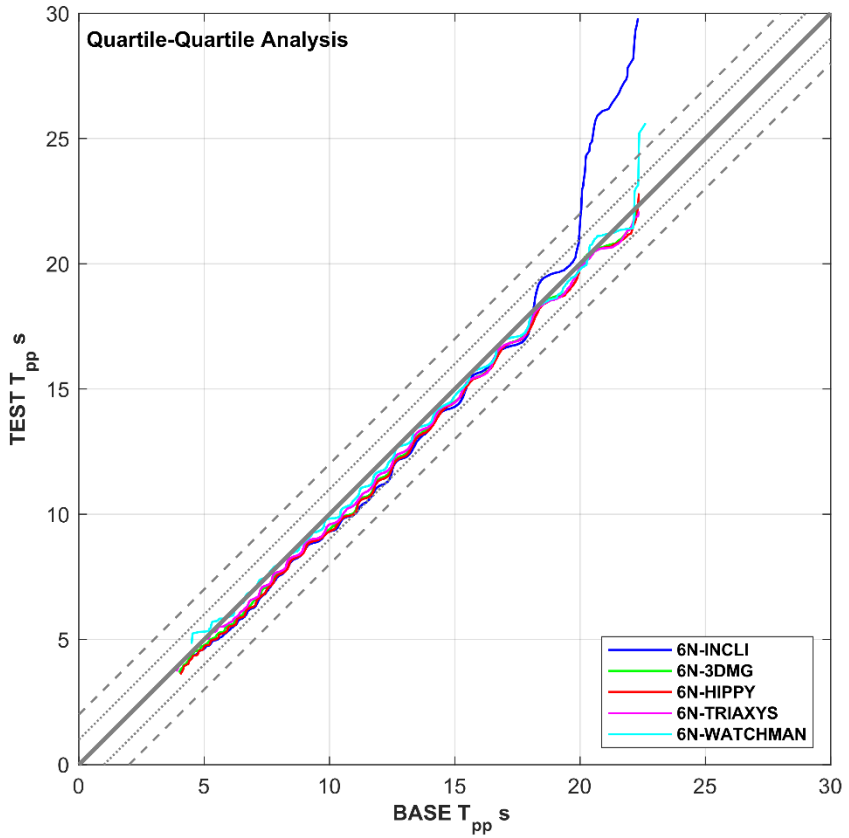




ANALYSIS: INTEGRAL WAVE PARAMETERS

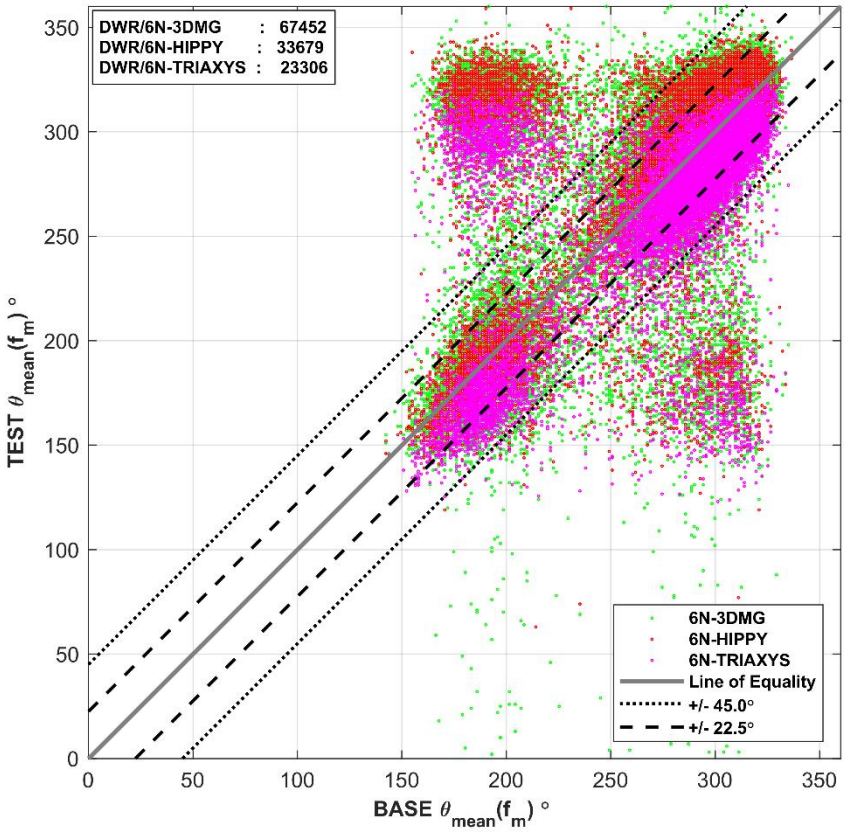
Differences around the Spectral Peak
Existence of Multiple Wave Systems



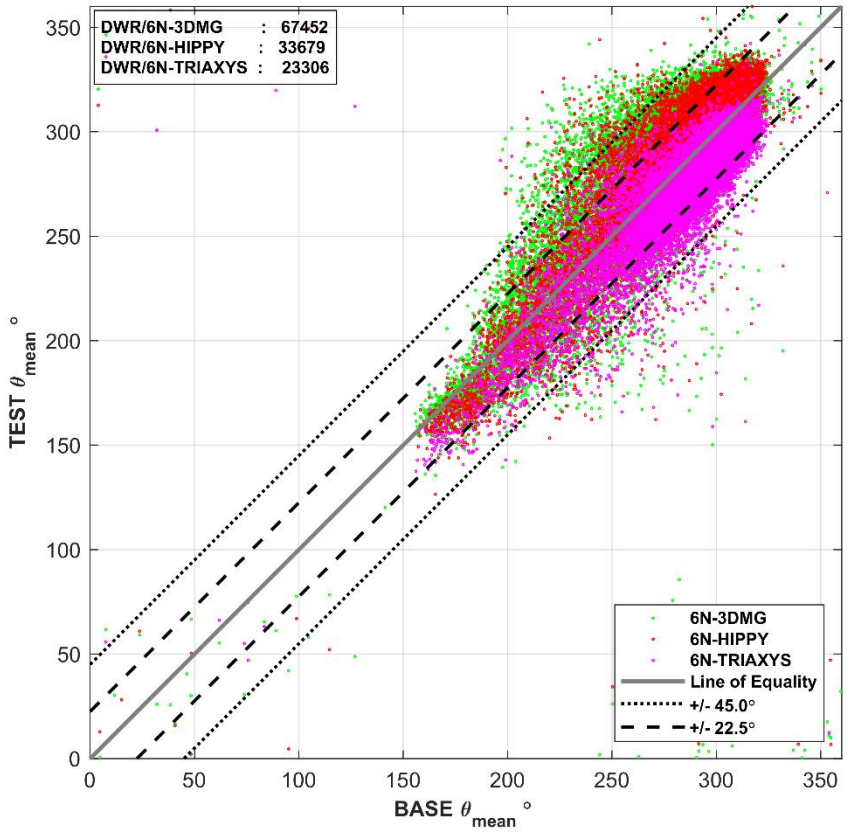


ANALYSIS: INTEGRAL WAVE PARAMETERS

Vector Mean Wave Direction
at spectral peak
Pure Measurement



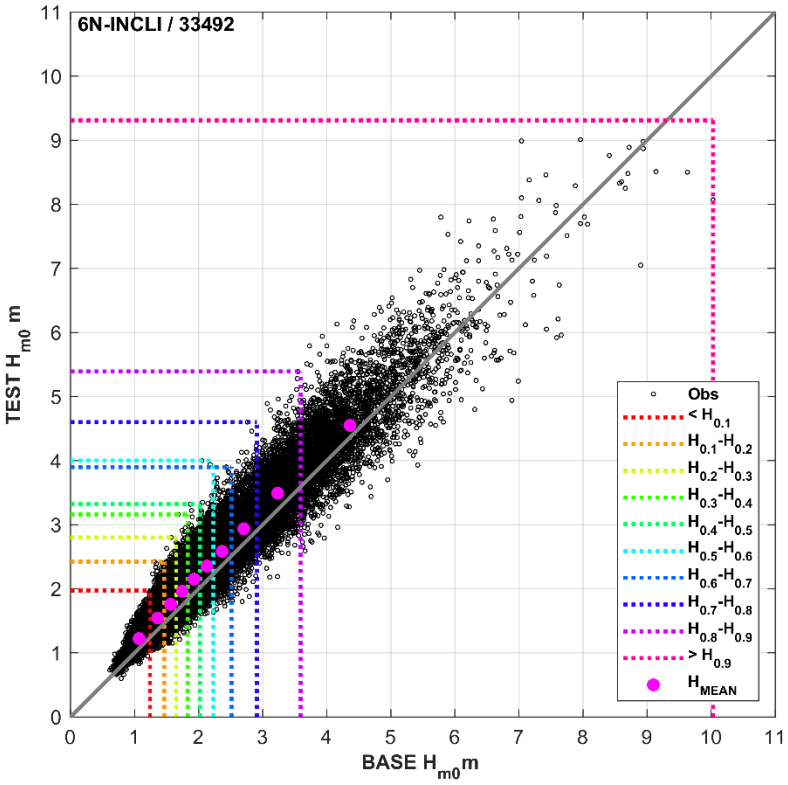
Overall Vector Mean Wave Direction
Estimate using a_1,a_2,b_1,b_2 and MEM



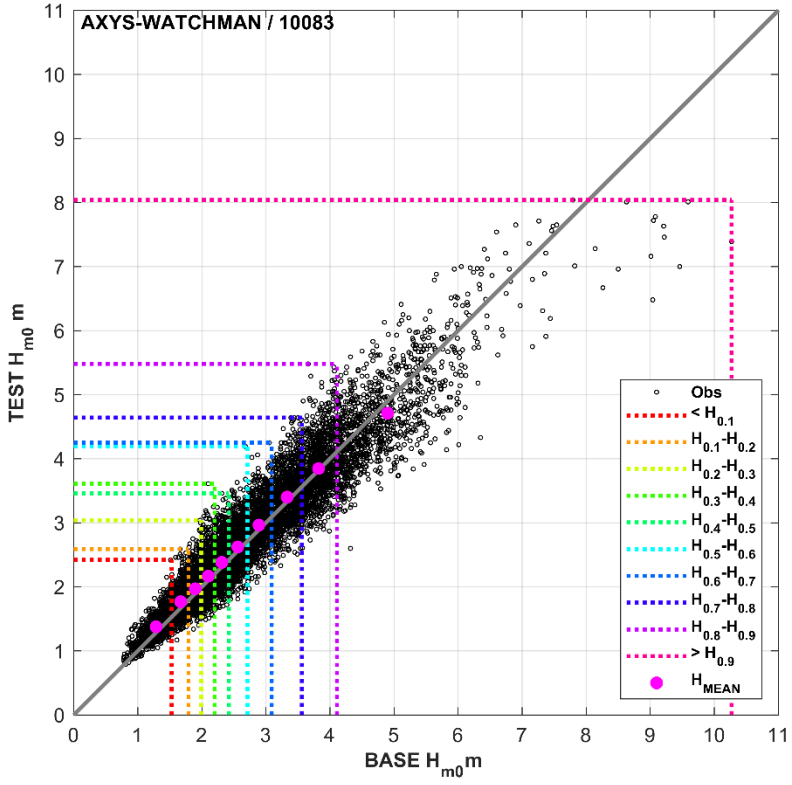
ANALYSIS: QUANTILES H_{m0}

What is the variation in statistics over set quantiles?

DWR vs Inclinometer

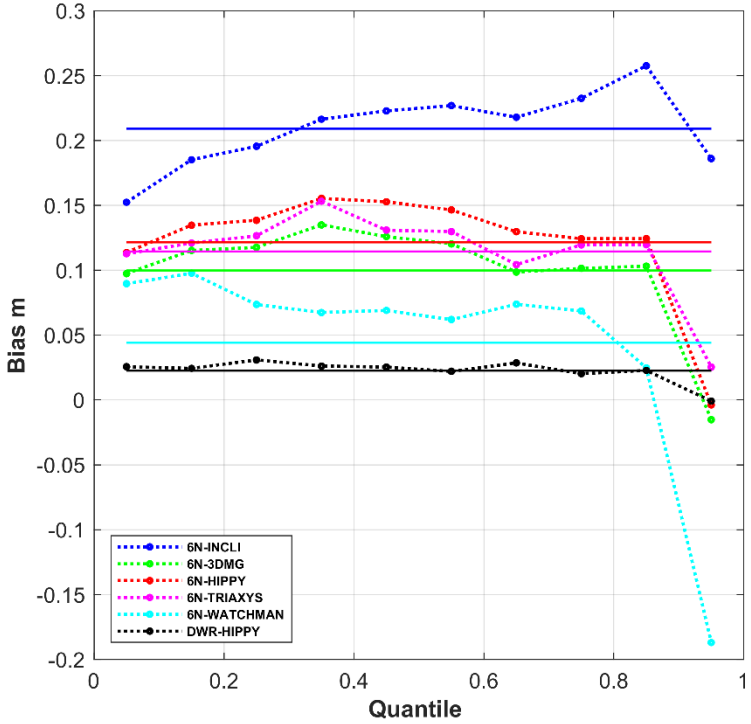


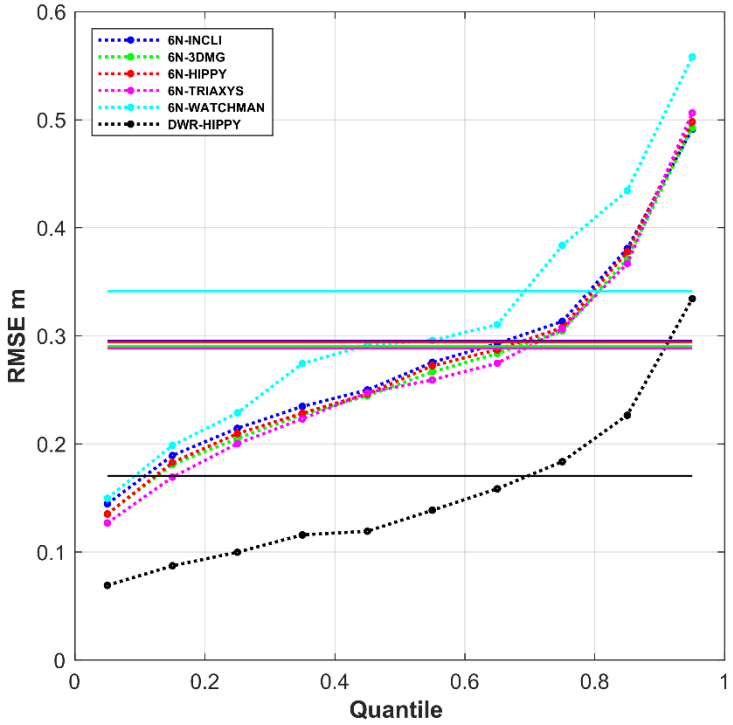
DWR vs Watchman



ANALYSIS: QUANTILES H_{m0}

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

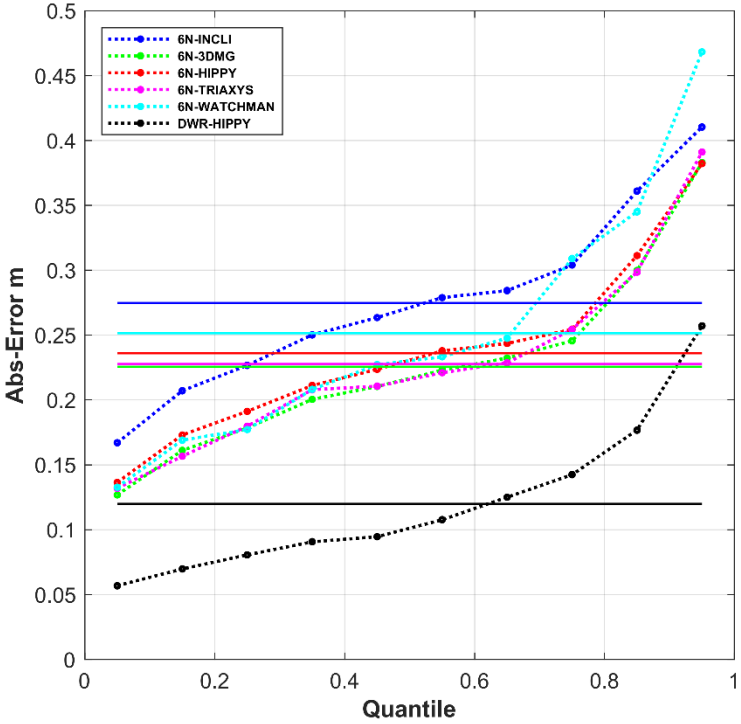


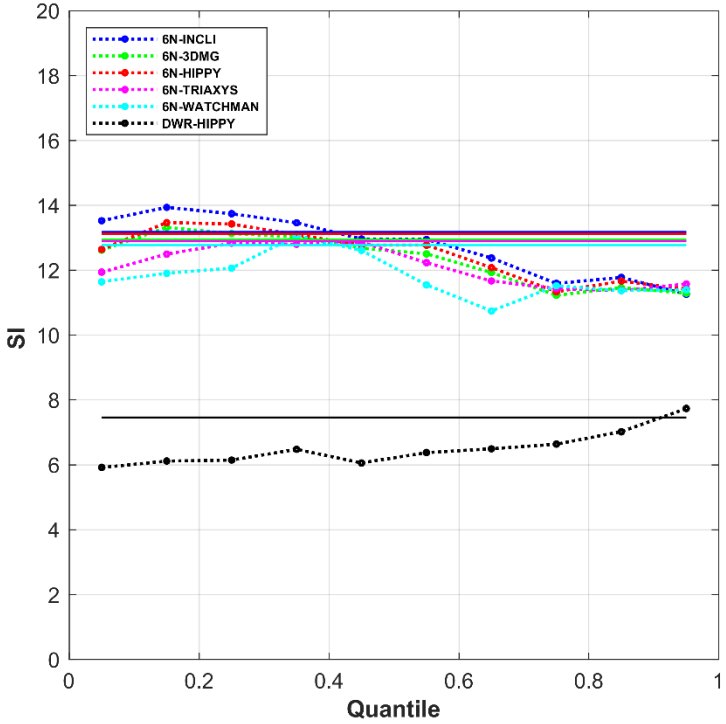


Co-located DWR's in black
Gold Standard for metric?
Harvest Platform 2015-2017

ANALYSIS: QUANTILES H_{m0}

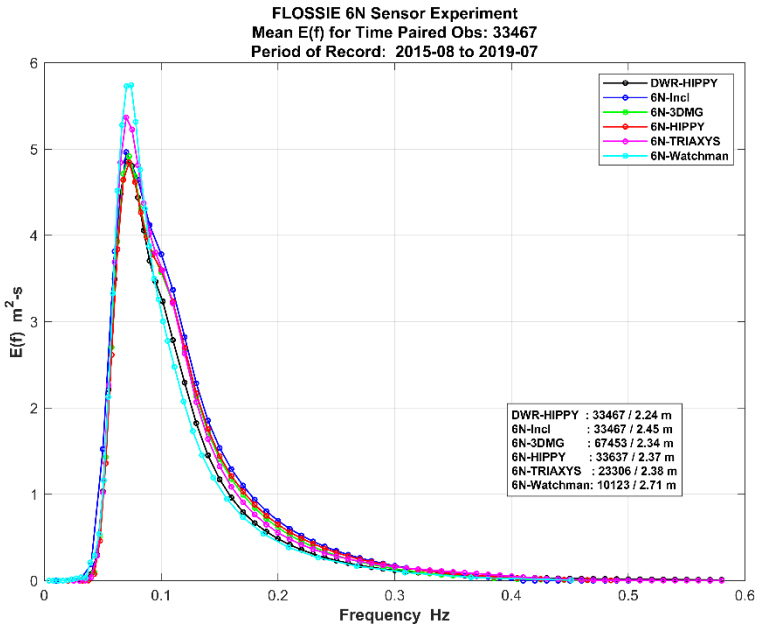
Is one statistical value sufficient as a metric marker?
Solid line: All data / Dashed line: Quantiles

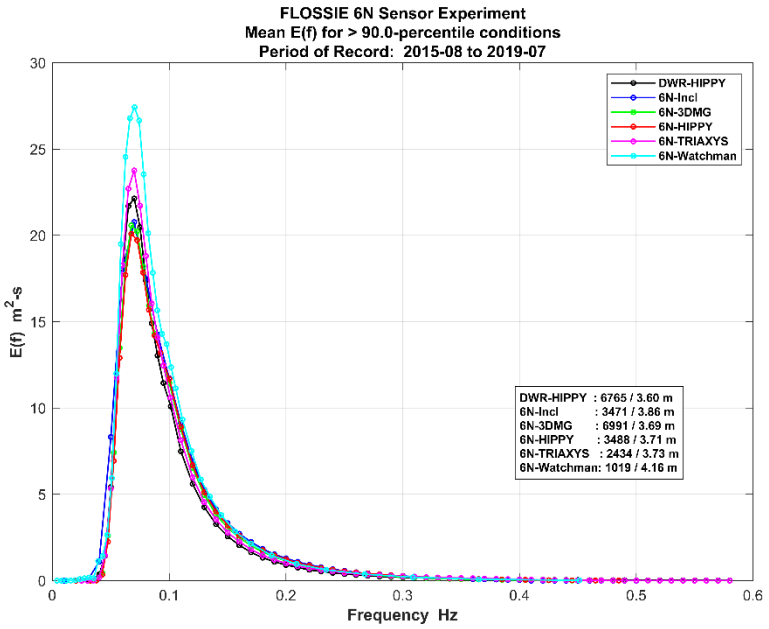




ANALYSIS: FREQUENCY SPECTRA

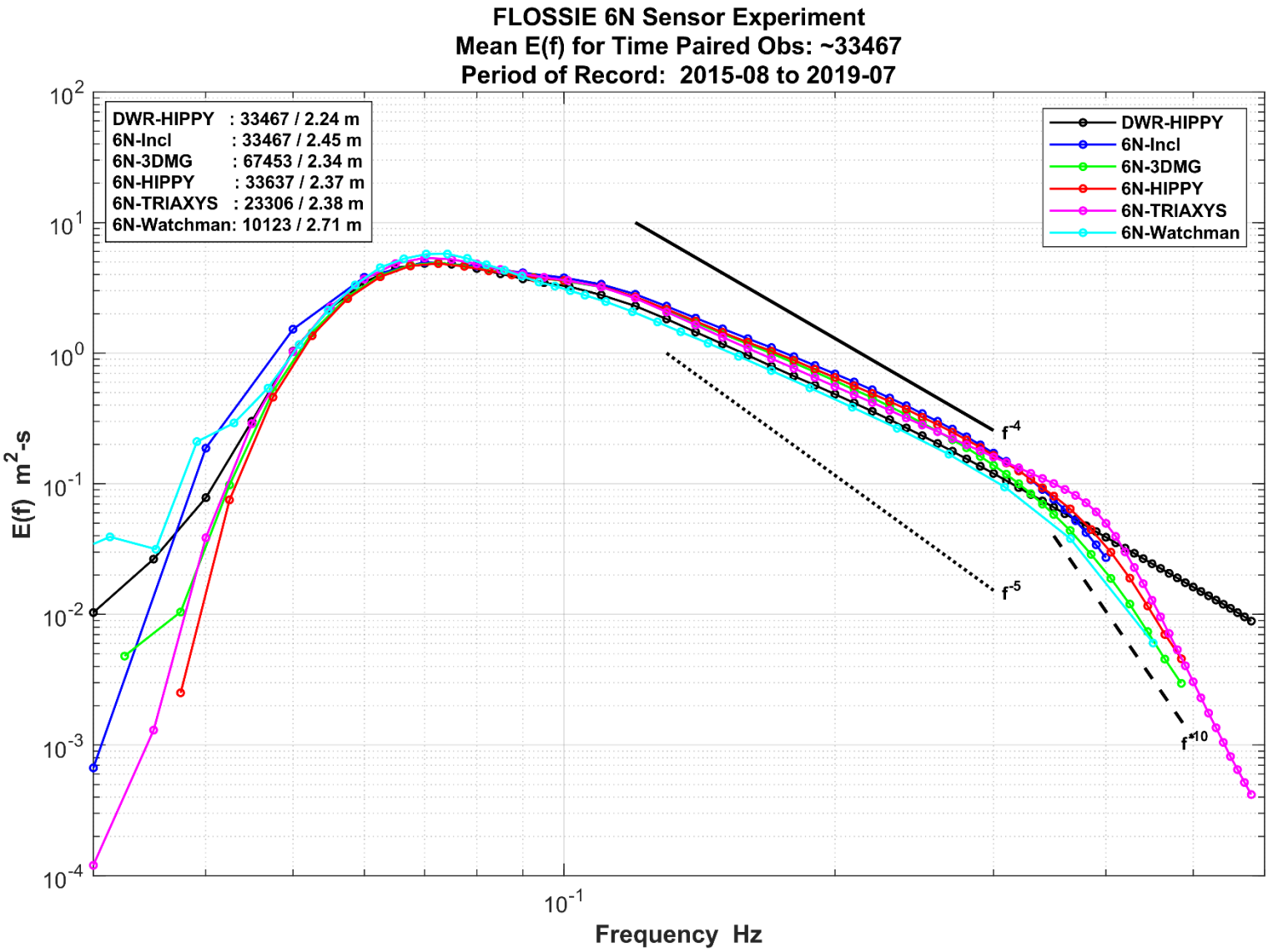
Over the mean shapes similar for All vs 90th Percentile



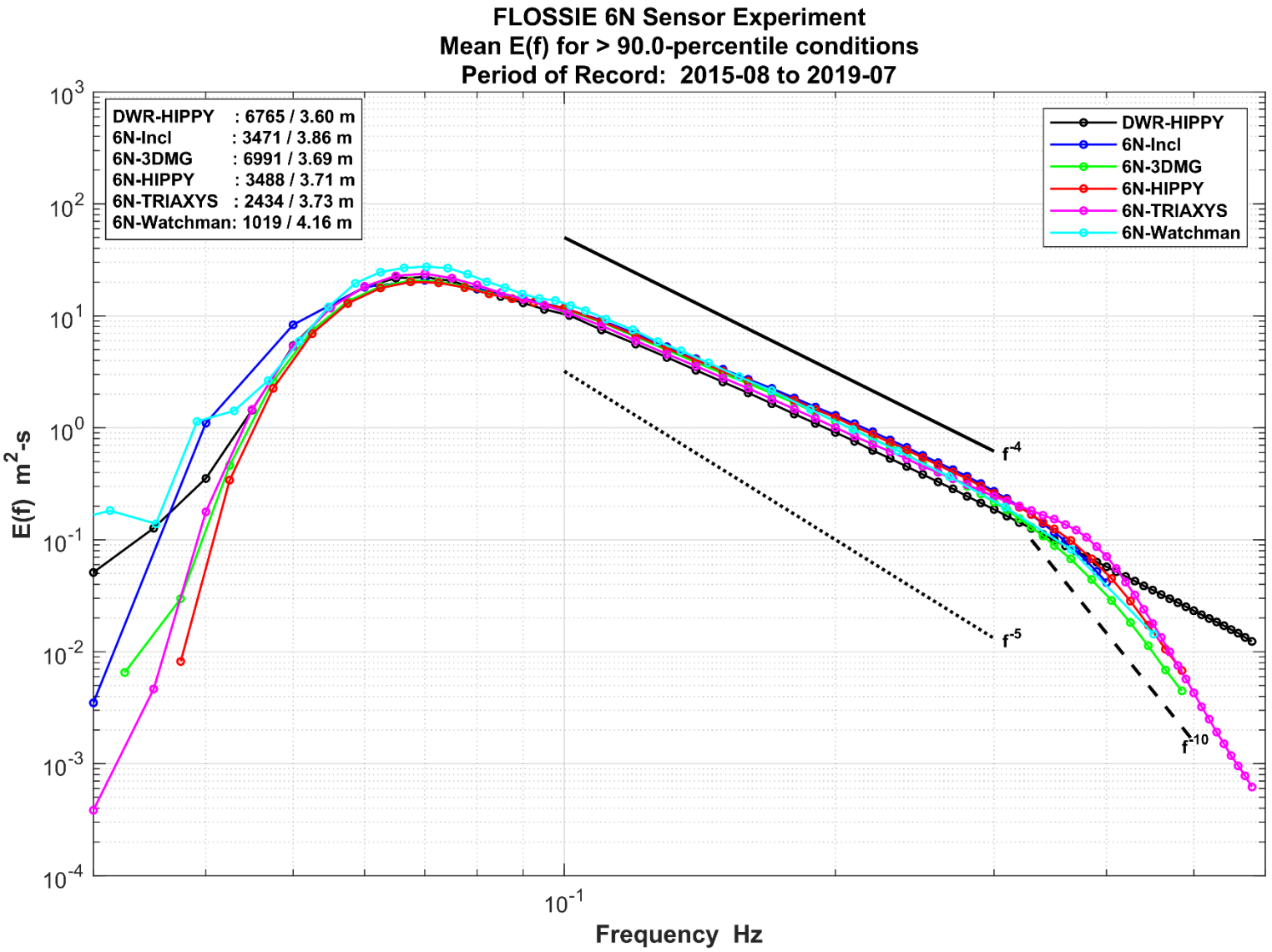


Watchman results affected by smaller population size

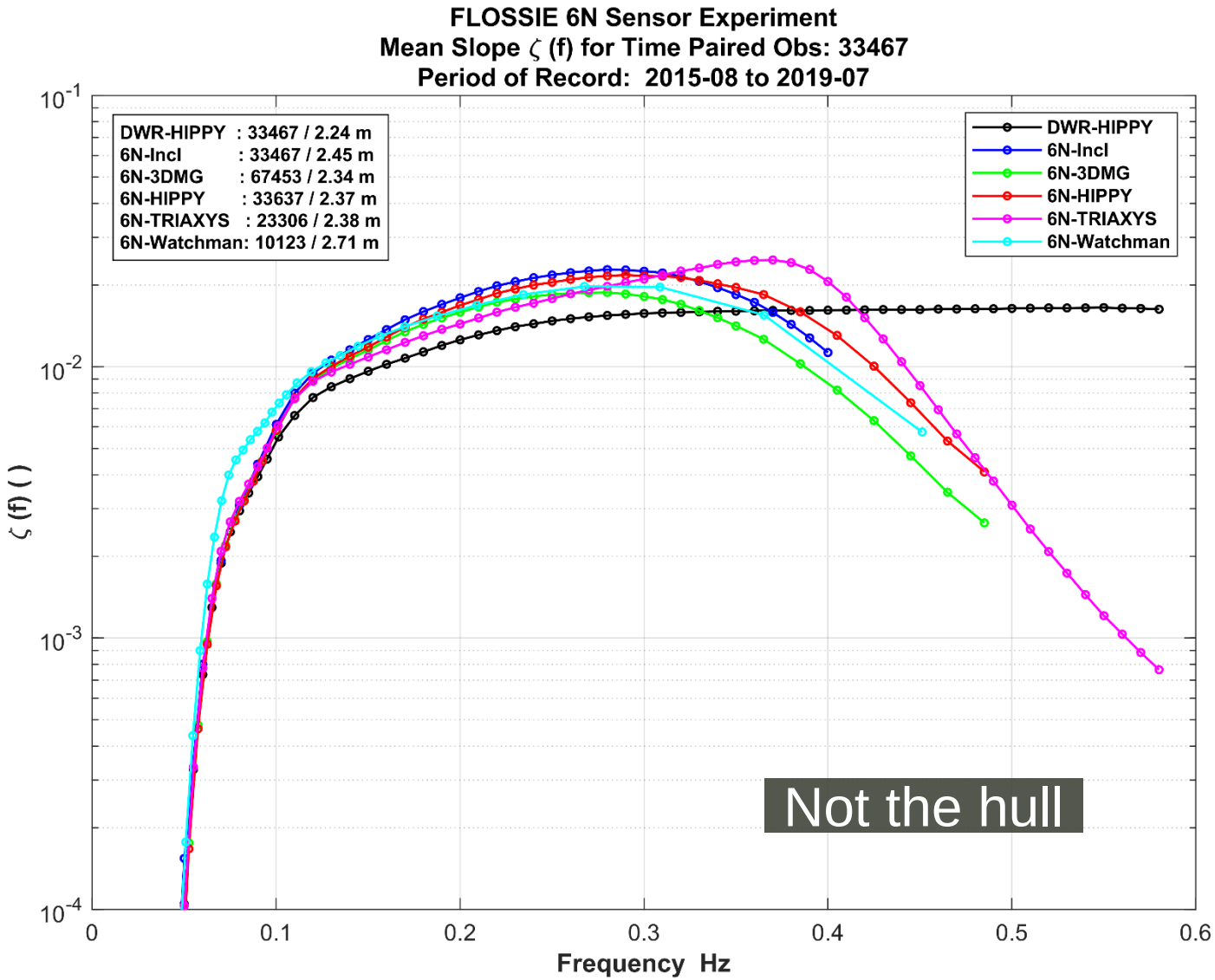
ANALYSIS: FREQUENCY SPECTRA



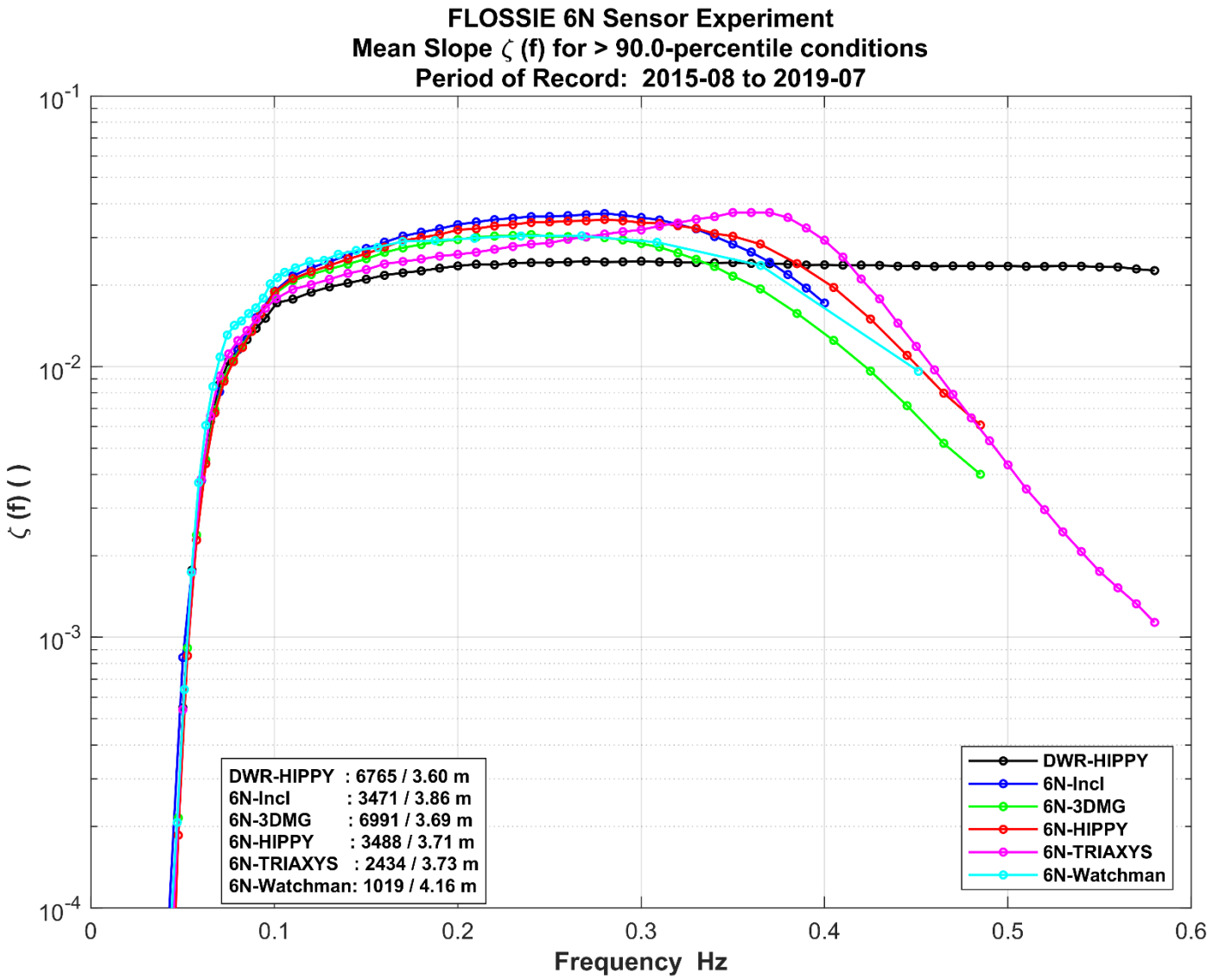
ANALYSIS: FREQUENCY SPECTRA



ANALYSIS: SLOPE SPECTRA



ANALYSIS: SLOPE SPECTRA



CONCLUSIONS (1/3)

- NDBC-Inclinometer
  - Compares better to DWR than all sensors in H_{m0} for full range of wave conditions
  - Has elevated T_p 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 Tp estimates well through range
  - Slope spectra fall off at > 0.35Hz (worse than Inclinometer)

CONCLUSIONS (2/3)

- AXYS-Triaxys WSII
  - Over estimates in H_{m0} range from 6-7m, then under estimates by 1m
  - Has consistent T_p 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-SDA Watchman
  - Performed well up to ~7m then showed an increasing under-estimate (most severe of all) compared to DWR H_{m0}
  - Follows Tp 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

CONCLUSIONS (3/3)

- 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 - mean squared slope used in altimeter algorithms generated from point-source measurements will produce bad data
- If we consider a 10% error in the H_{mo} measurements are we willing to accept a ±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
- Wave Measurement Workshop 2.0 (JCOMM/DBCP)
  - Initial workshop held in 2008
  - Second planned for 2020
  - Talk to Val Swail regarding your interest this week

THANK YOU