

Are Wave Measurements Actually Ground Truth ?

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US Army Corps
of Engineers®





How is your wave measurement?



“My waves are 10% higher than your waves.”

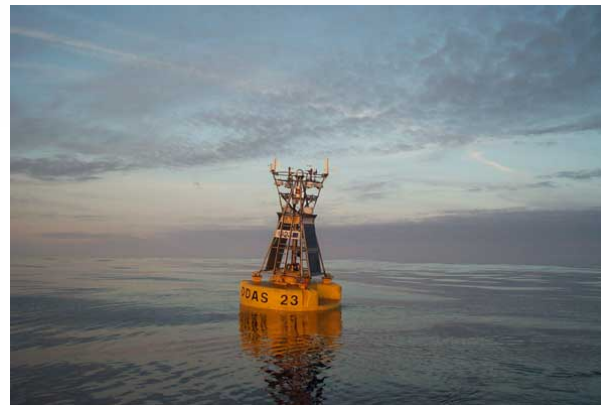


“10%? That’s a lot!”

Are Wave Measurements Ground Truth?

- Outline:

- Background
- Historical Perspective
- Discrepancies in Data
- Evaluation Methodology
- Analysis
- Conclusions and Recommendations



OBSERVATION REQUIREMENTS FOR WIND WAVES

(developed by the JCOMM Expert Team on
Wind Waves and Storm Surges)

Applications:

- Assimilation into offshore wave forecast models
- Validation of wave forecast models (and hindcast and reanalysis)
- Calibration / validation of satellite wave sensors
- Ocean wave climate and variability
- Role of waves in coupling
- Coastal zone modelling – erosion, sediment transport, inundation etc.
- Wave Energy Resource Assessment

Reference:

- *OceanObs09 paper Swail et al.*
- *OceanObs99 paper Swail et al.*
- *DBCP-22 Meeting Report October 2006*
- *ETWS-II Meeting Report March 2007*
- *CBS/OPAG-IOS/ET-EGOC-3 Doc. 7.2.6*

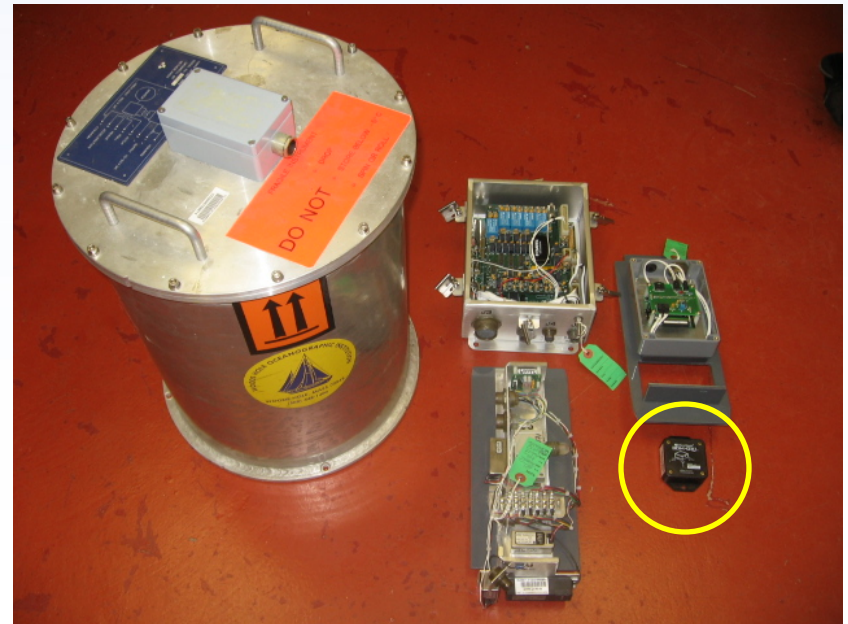
Background

- Measurements of surface gravity waves are **estimates**
 - From accelerations (double integrated)
 - From pressure response (invert to free surface)
 - From x,y velocities (invert to free surface)
- Only direct measurement of waves:
 - From capacitance or resistance gauges
 - From photo analysis
- **Signal to noise:**
 - Contamination of wave records

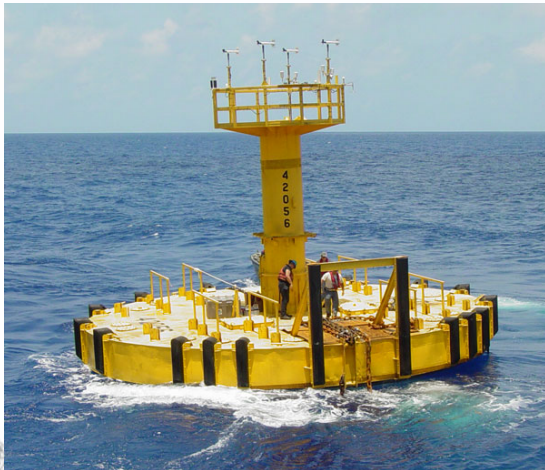
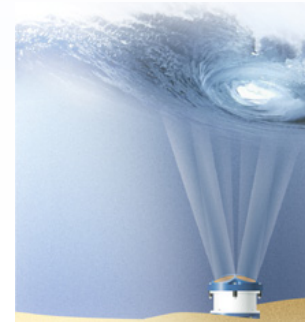
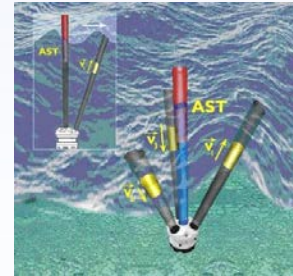
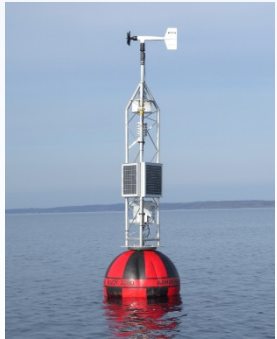


Historical Perspective

- Sensors (NDBC)
 - Pre-1990: HIPPIY Sensors dominated
 - Post-1990
 - Tri-axial accelerometers
 - Angular Rate Sensors
 - Magnetometers
 - Motion Sensors
 - GPS
 - Why?
 - Economics
 - Power consumption
 - Weight / Size
 - New harsh environments



How to “ground truth” the “ground truth” ?

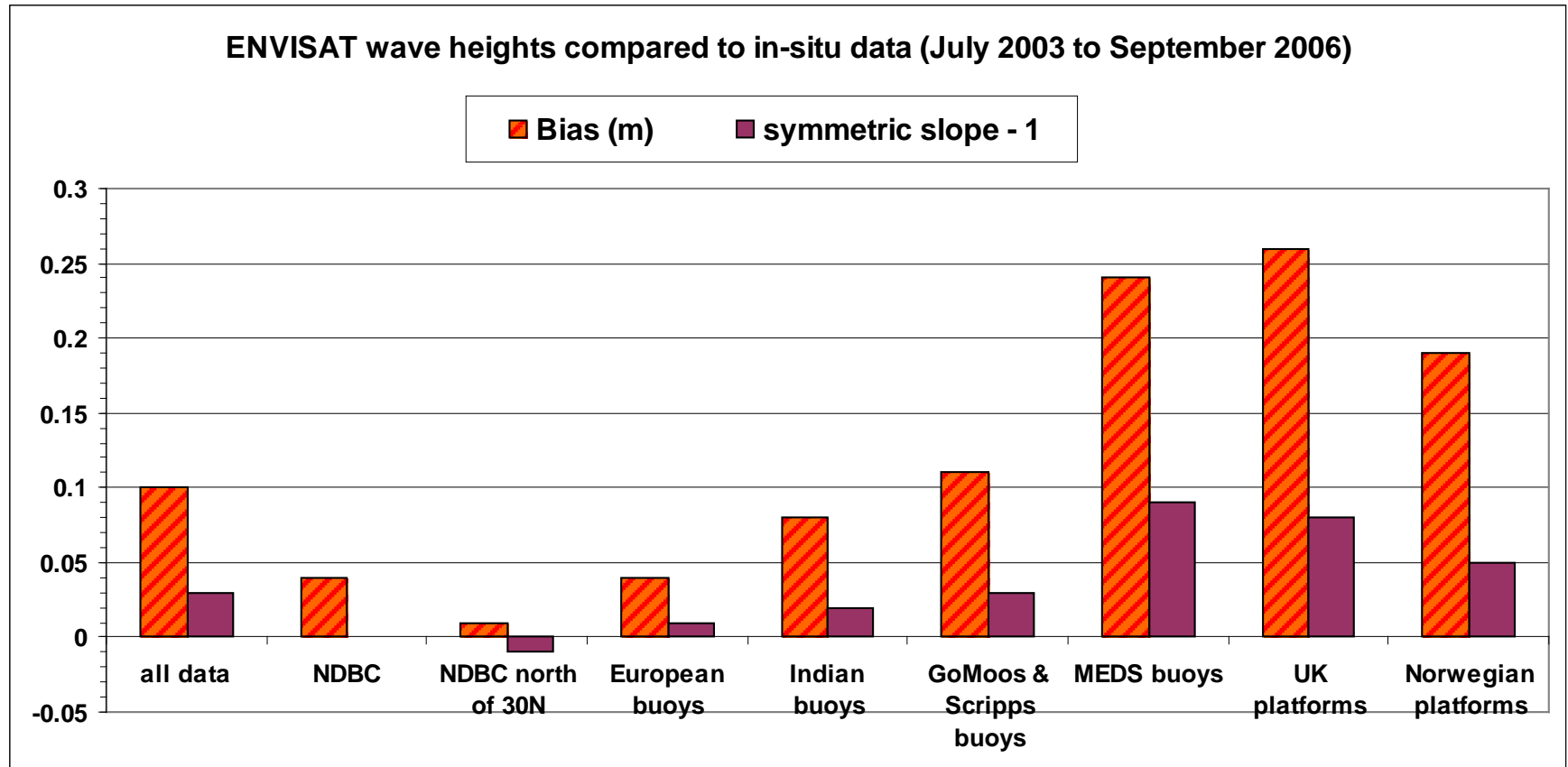


Wave height: White, green or blue water?



Courtesy A.K. Magnusson

Why Do We Need to Test and Evaluate

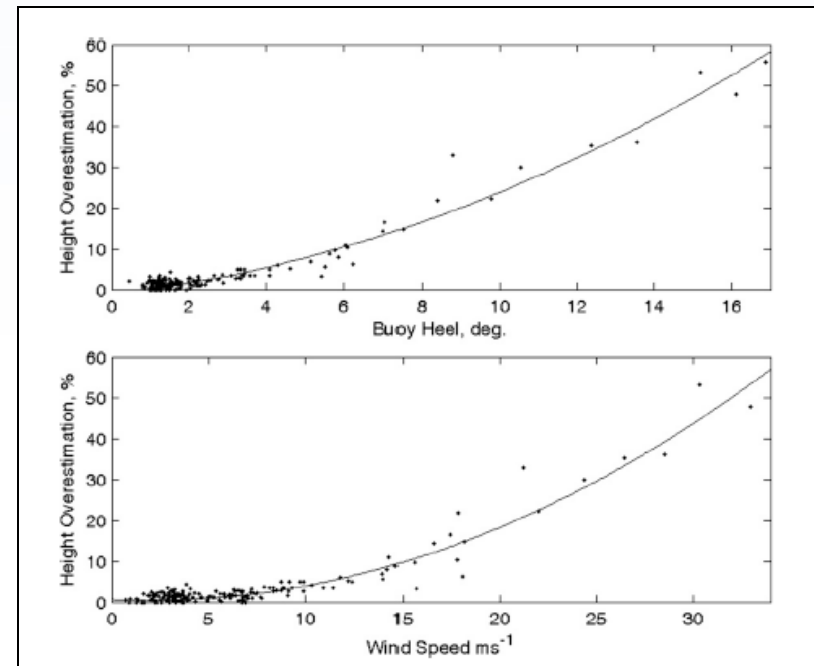
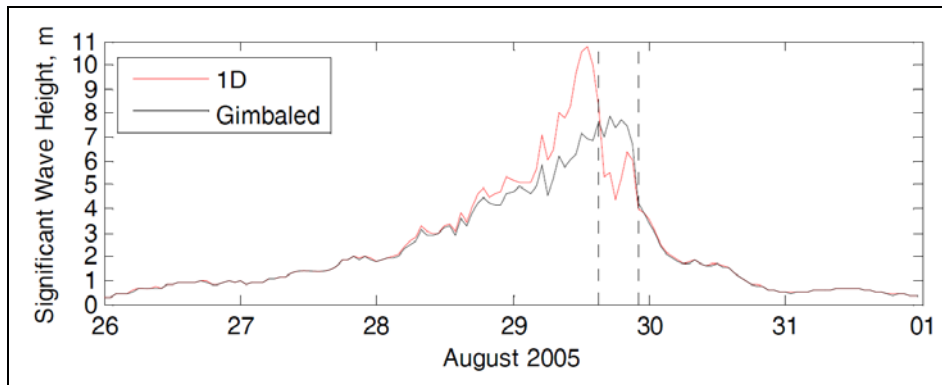


Bias: altimeter Hs – in-situ Hs

Symmetric slope: ratio of variance altimeter to variance in-situ

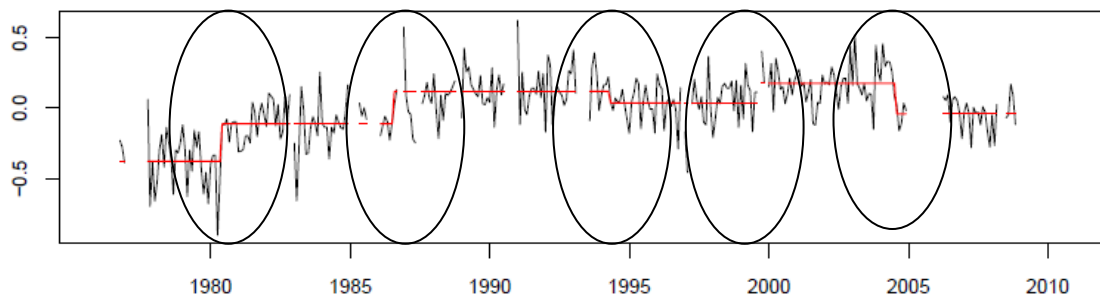
Why Do We Need to Test and Evaluate

- Bender et al. (2010)
 - Strapped Down 1D accelerometers
 - ~3-m over-estimation in H_{mo}
 - Buoy Heel
 - Payload correctable
- Test (3 Sites / NDBC 3D buoys)

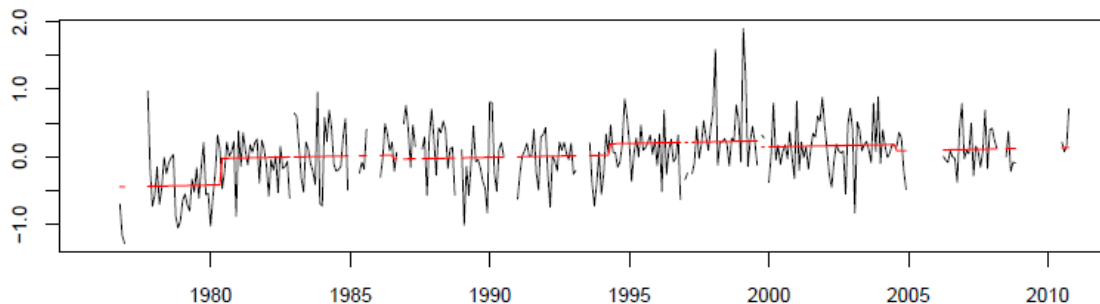


Documented Step Changes in Waves at 46005 - Washington

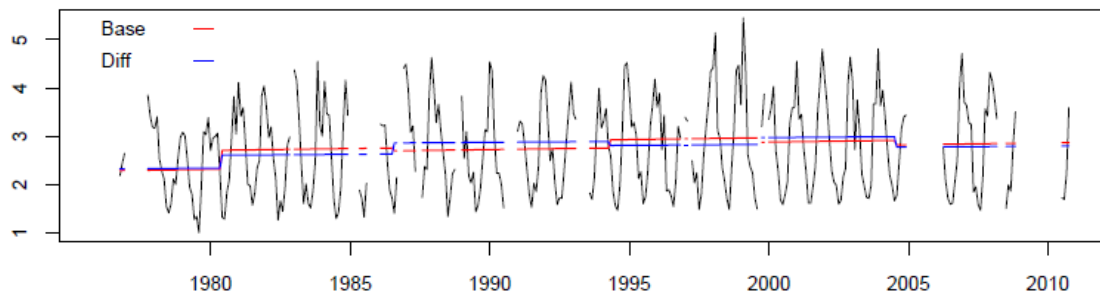
a. Base-minus-reference series



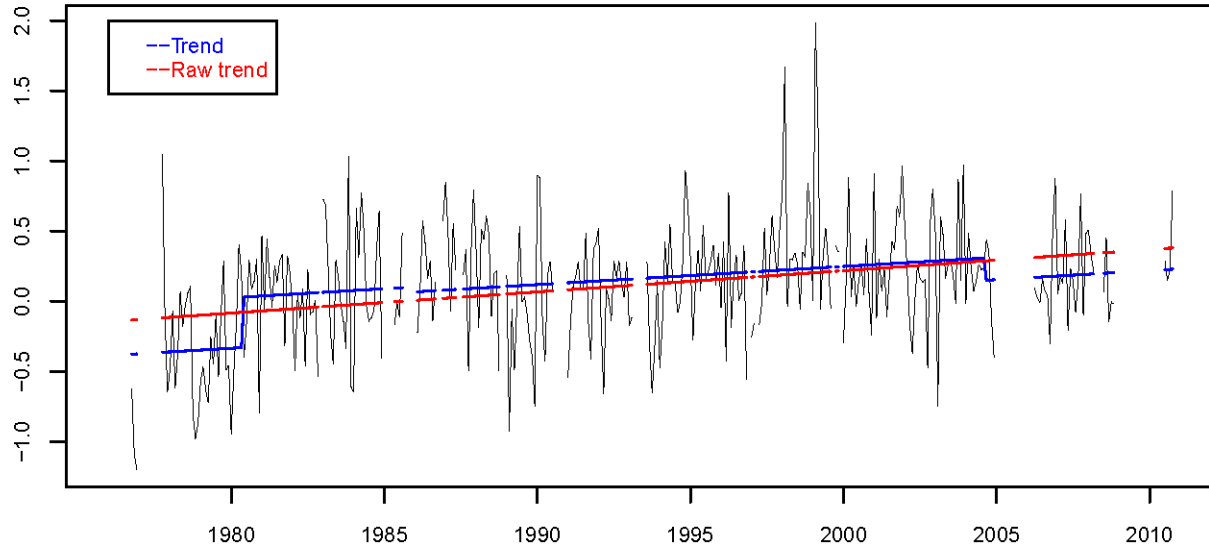
b. De-seasonalized base series



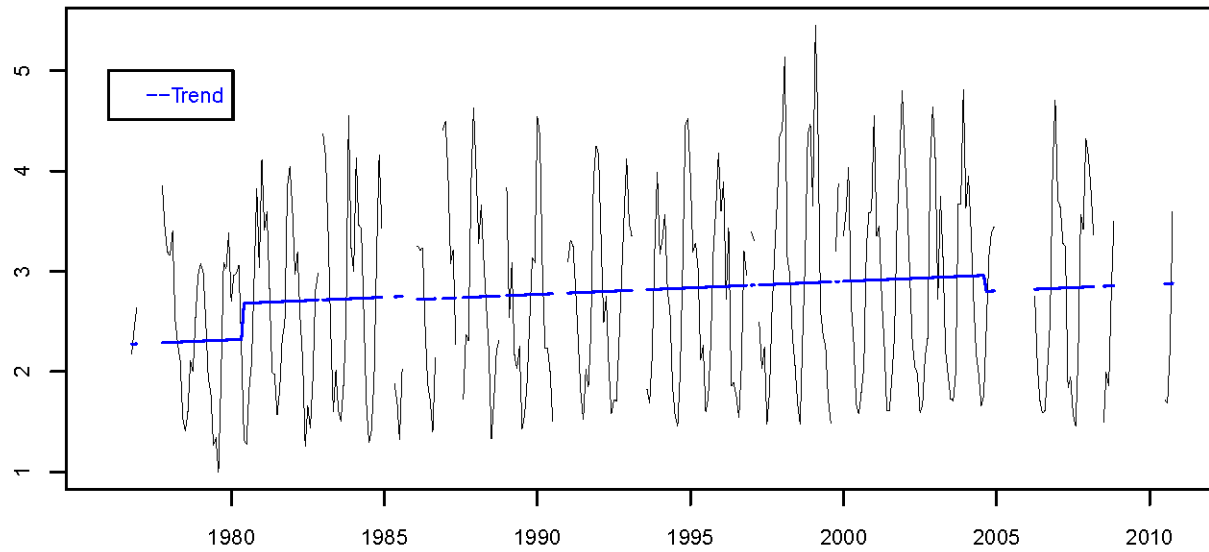
c. Base series



De-seasonalized buoy series

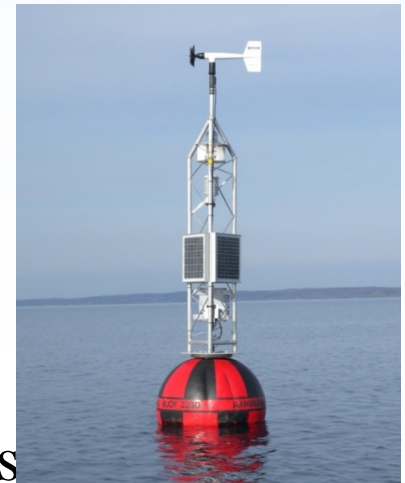


Original buoy series



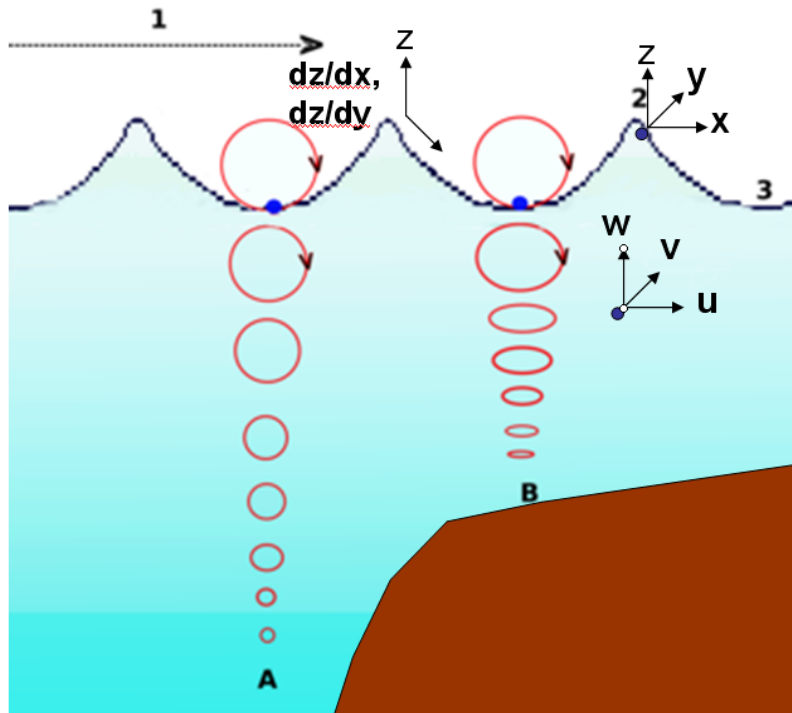
Evaluation Procedure

- Co-Located Procedure
 - Period of record consistent
 - Time consistency between devices
 - Similar geographic/hydrographic
- Alternatives
 - Co-deployments in one location
 - Buoy Farm – multiple deployments
 - Multiple sensors in one buoy
- Analysis based on First-5 principles
 - Does not preclude non-directional measurements



Background

The Basics: Estimating the Motion of a Sea Surface Particle



The Big 3

X, Y, Z

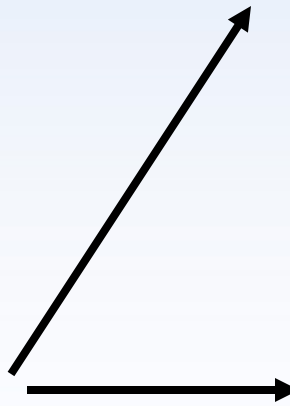
- Pressure Sensors
- Accelerometers
- Tilt sensors
- Angular Rate Sensors
- Acoustic Sensors
- GPS

The Outcome and Minimum Requirements for Directional Observations

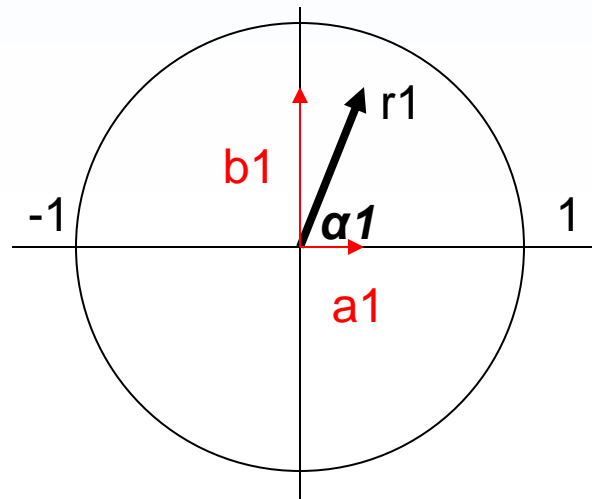
- mean direction
- directional spread
- skewness
- kurtosis

or, in NDBC format

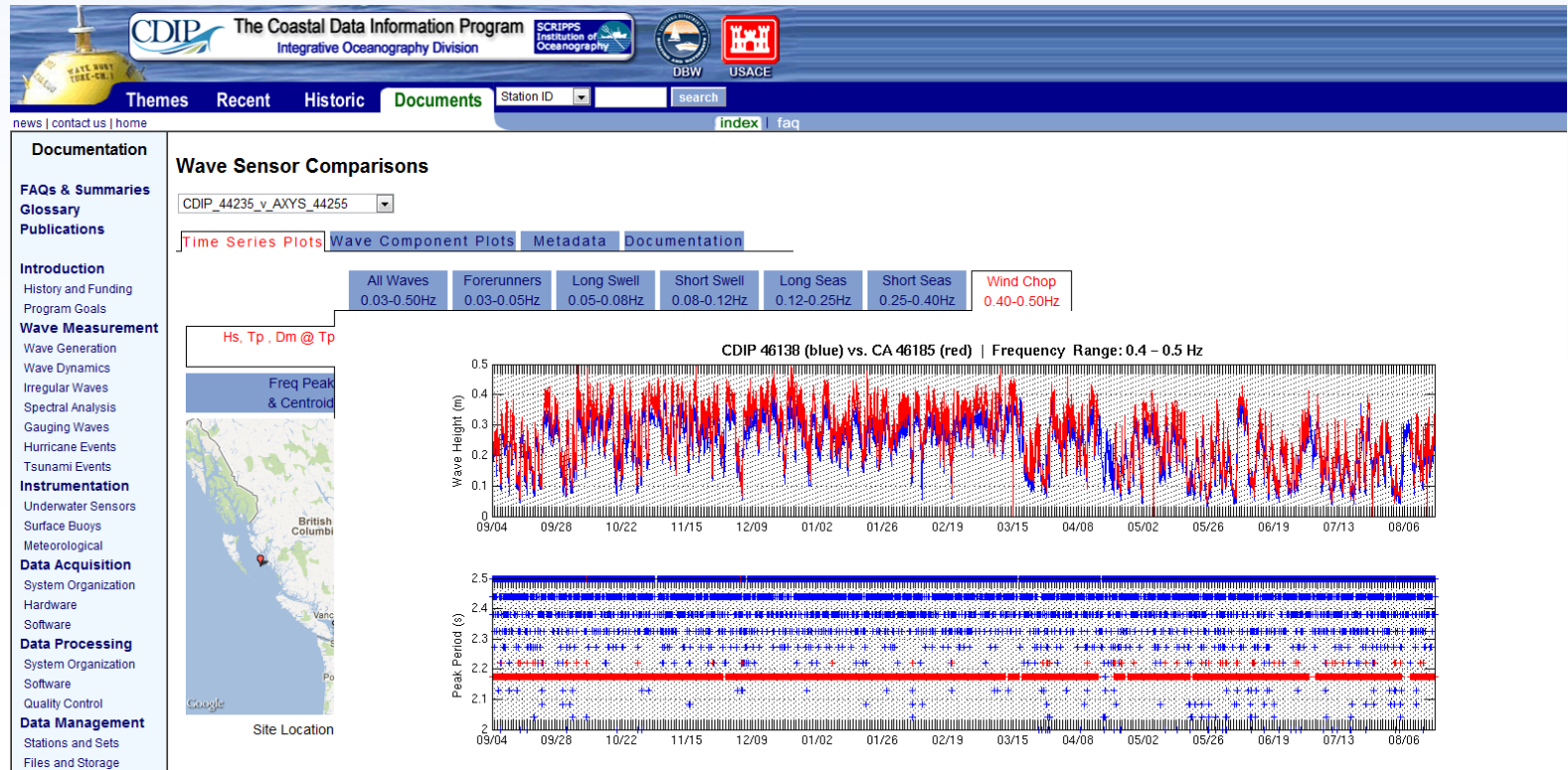
a_1, b_1, a_2, b_2



- first-moment mean direction (α_1)
- first-moment spread parameter (r_1)
- second-moment mean direction (α_2)
- second-moment spread parameter (r_2)

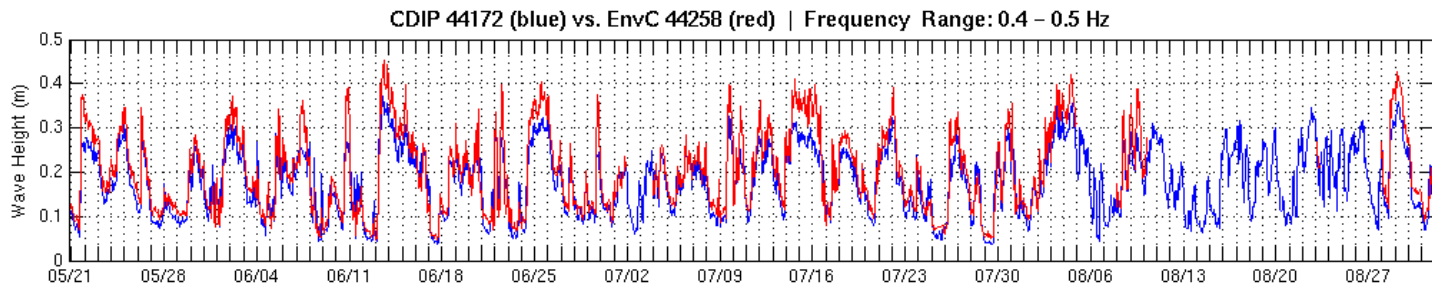
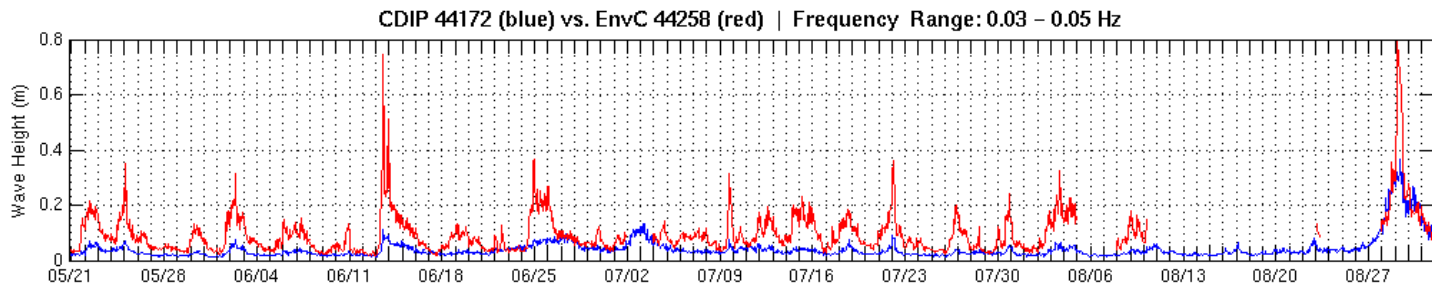
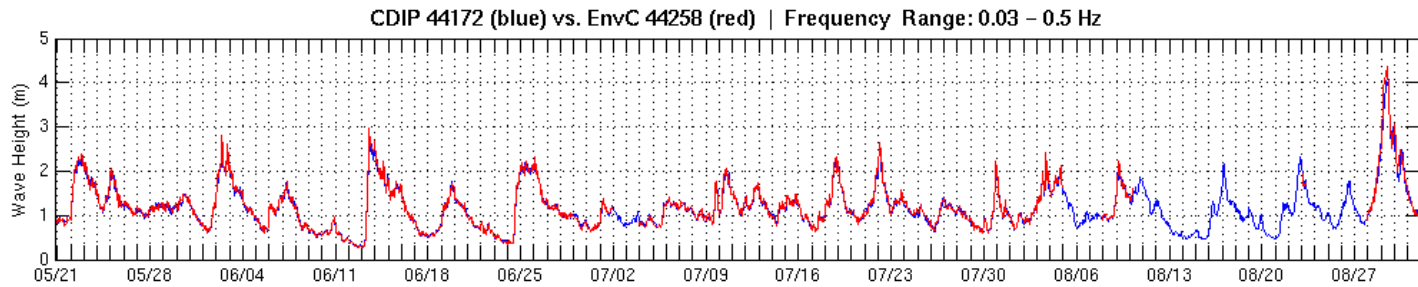


- Datawell Mark III ***RELATIVE REFERENCE***
- ***WAVEVALtool*** selected as the evaluation tool



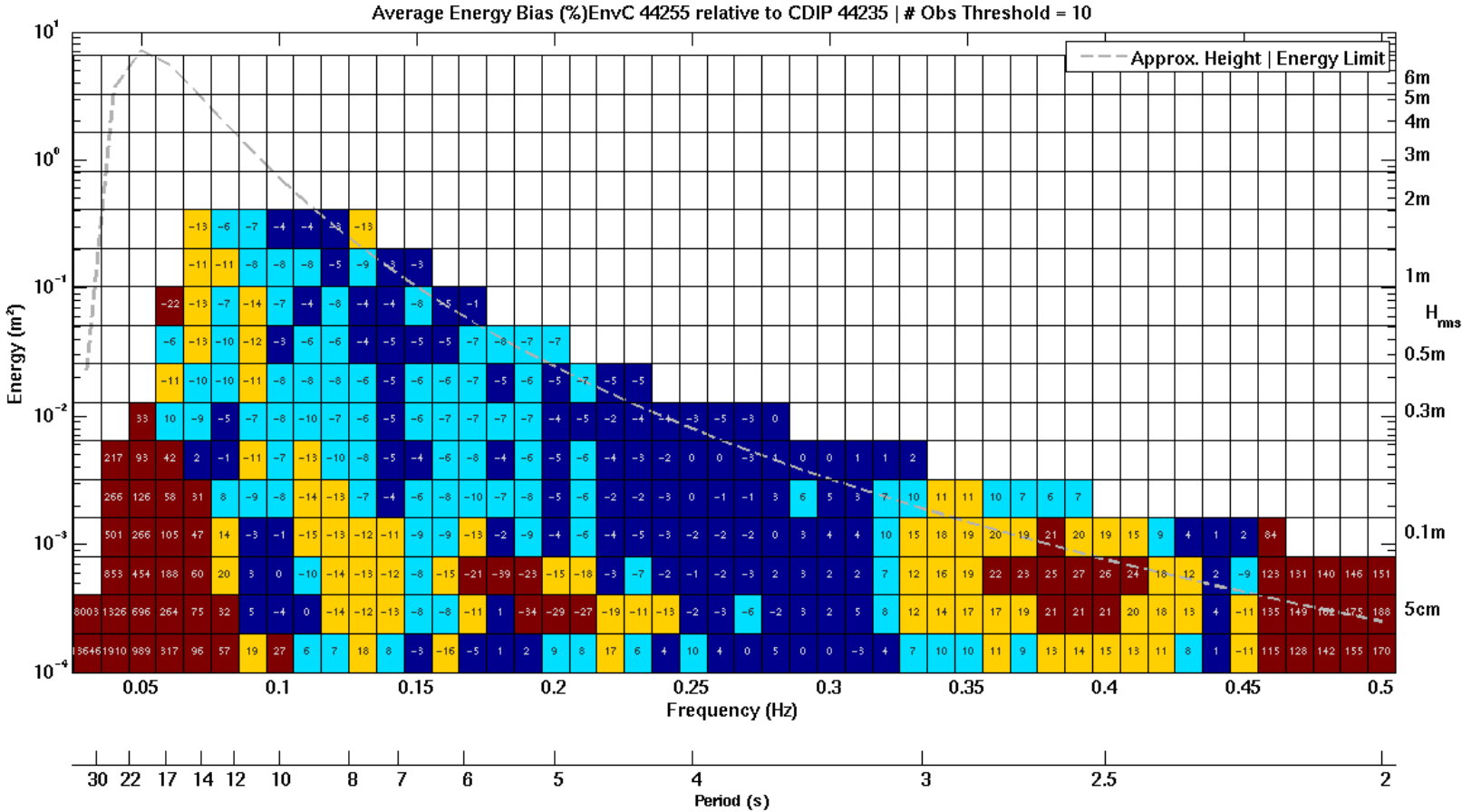
Evaluation Procedure: Co-located

Time Series Analysis for specific differences



Halifax 44258: 3D / AXYS

Method of Analysis



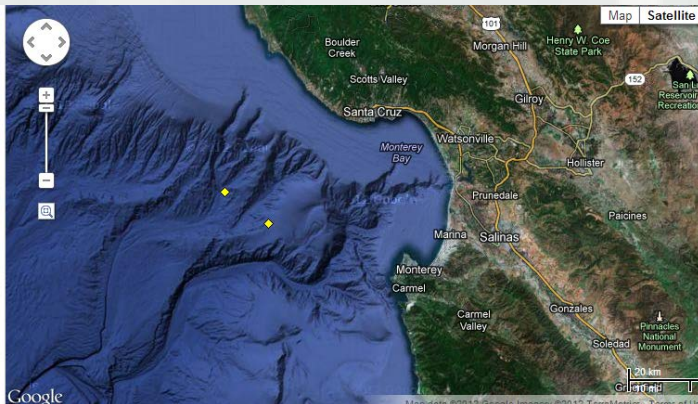
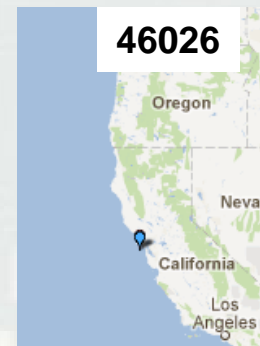
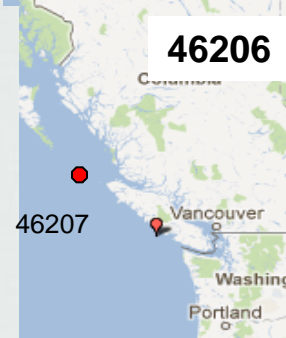
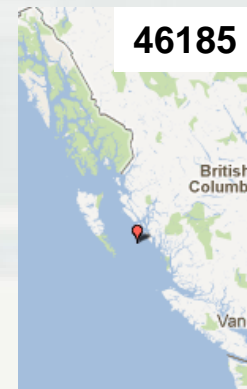
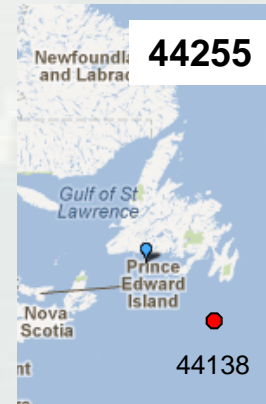
Intercomparison Locations

Co-Located Evaluation

- ▶ Atlantic (44255: 6N / MSC & AXYS)
- ▶ Atlantic (44258: 3D / MSC & AXYS)
- ▶ Atlantic (44138: 6N / MSC & AXYS) *planned*
- ▶ Pacific (46185: 3D / MSC & AXYS)
- ▶ Pacific (46206: 3D / MSC & AXYS*)
- ▶ Pacific (46026: 3D / 3DMG)

Dual Sensor Single Hull

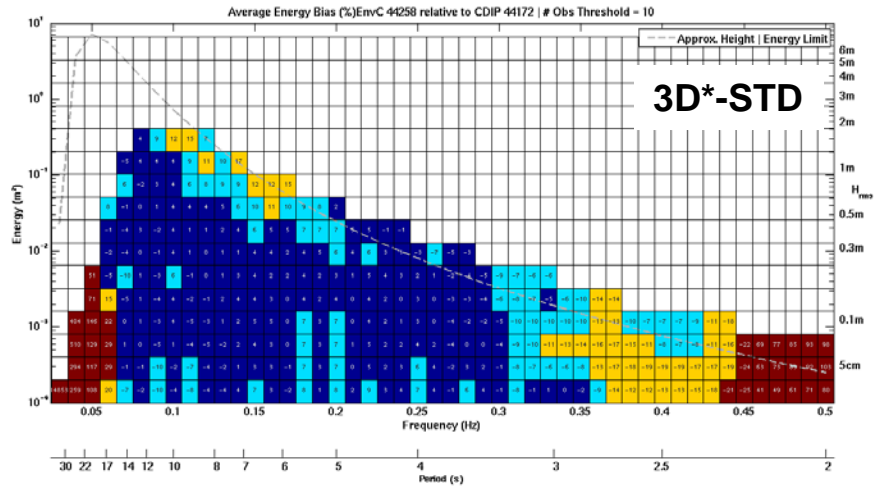
- ▶ Pacific 46207: (3D/MSC & AXYS, GPS)
- ▶ Pacific 46029 (3D HIPPIY and 3DMG+)
- ▶ Pacific 46042* (3D HIPPIY and 3DMG+)
- ▶ Atlantic 44014 (3D HIPPIY and 3DMG+)



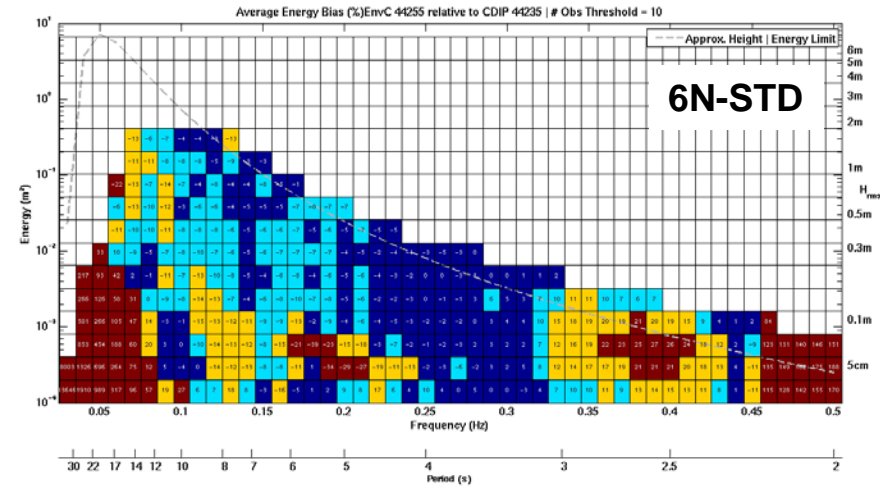
BUOY FARM
 46042: 3D
 46114: DWR
 2.3-m DISCUS
 6N: TBD

Evaluation Procedure: Co-located

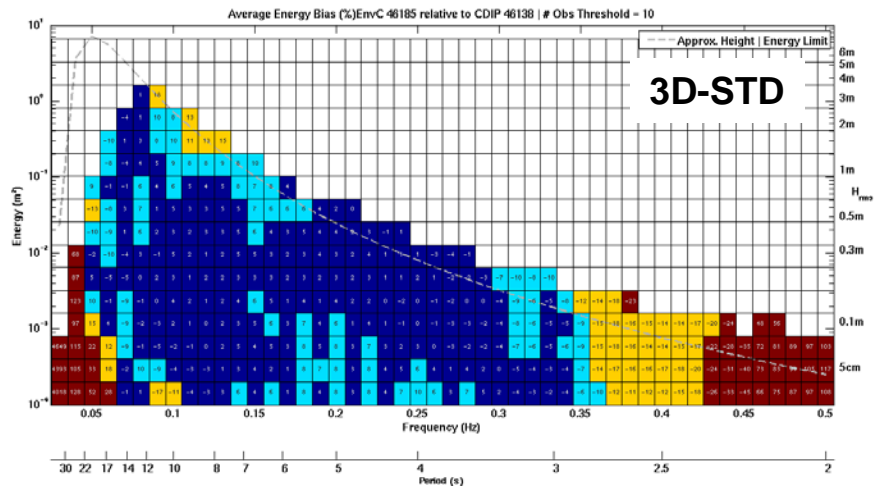
Bias in Energy: Sensor / Hull / Payload Package



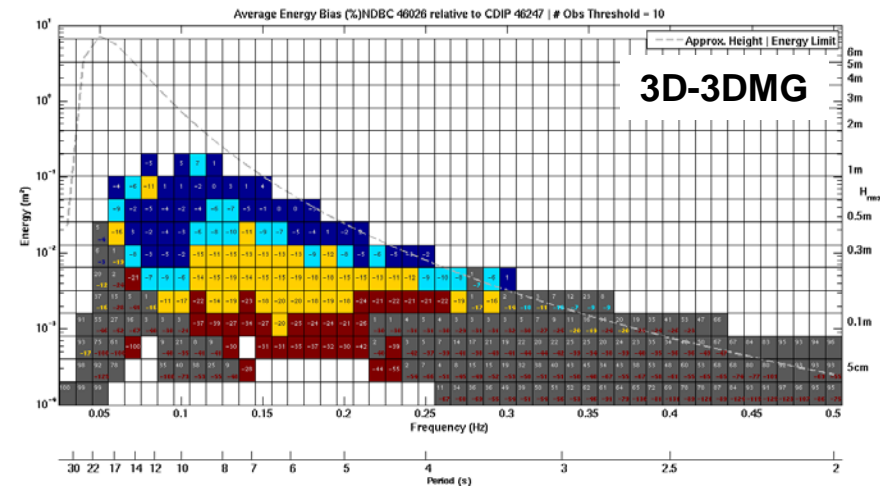
Wave Spectra Comparison Tool, Version 2.0



Wave Spectra Comparison Tool, Version 2.0



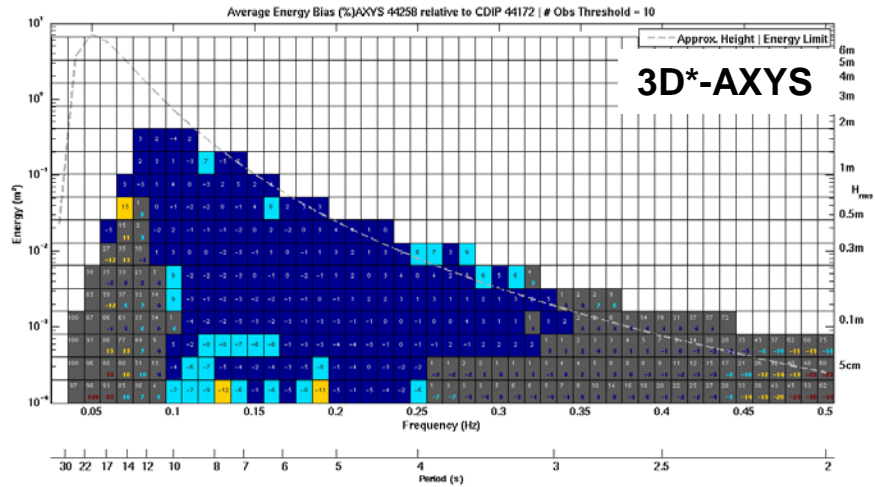
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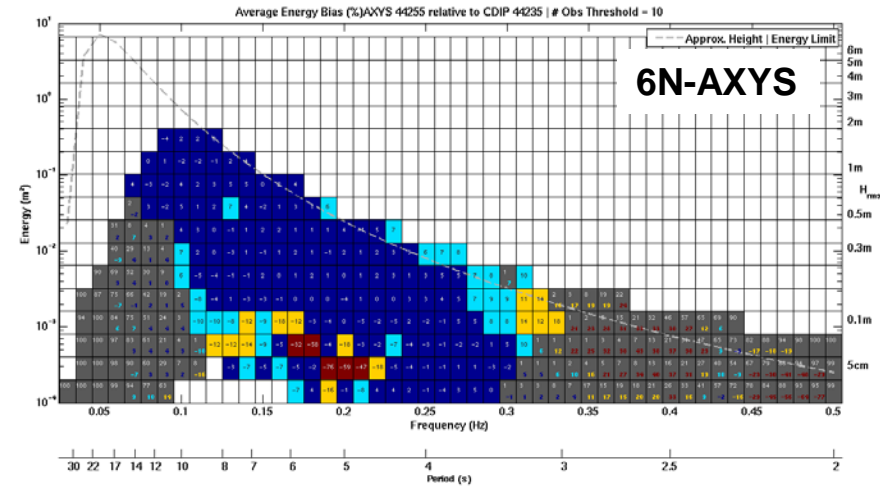
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Evaluation Procedure: Co-located

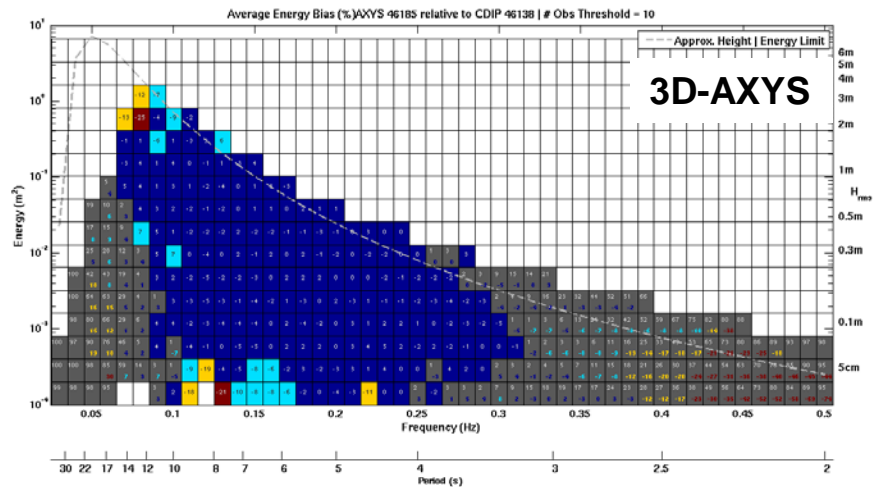
Bias in Energy: Sensor / Hull / Payload Package



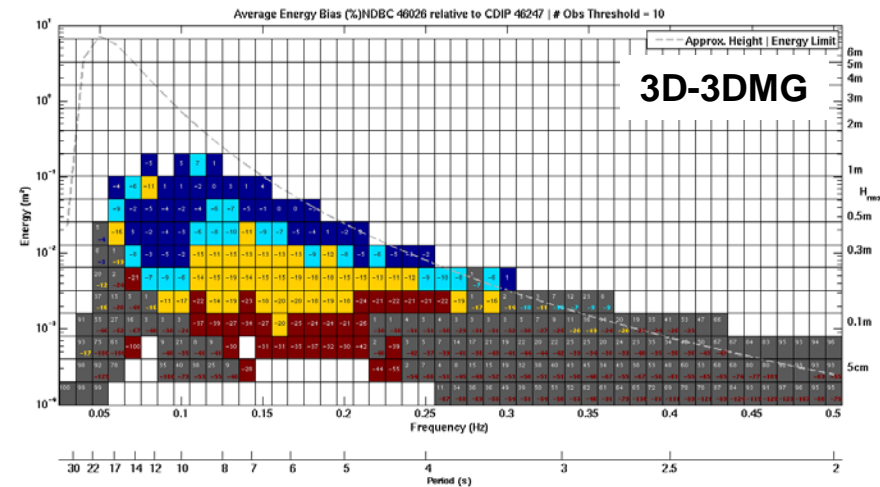
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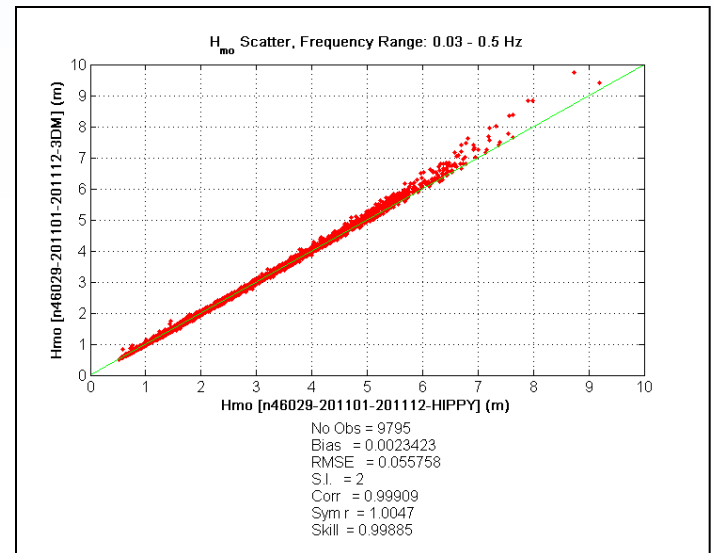
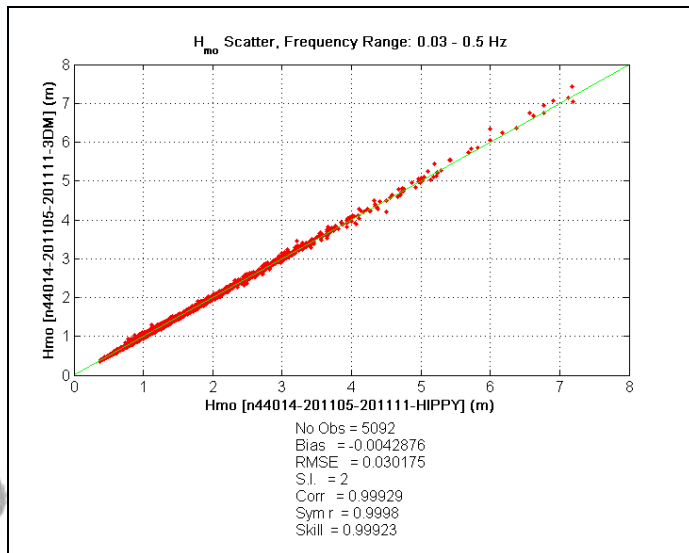
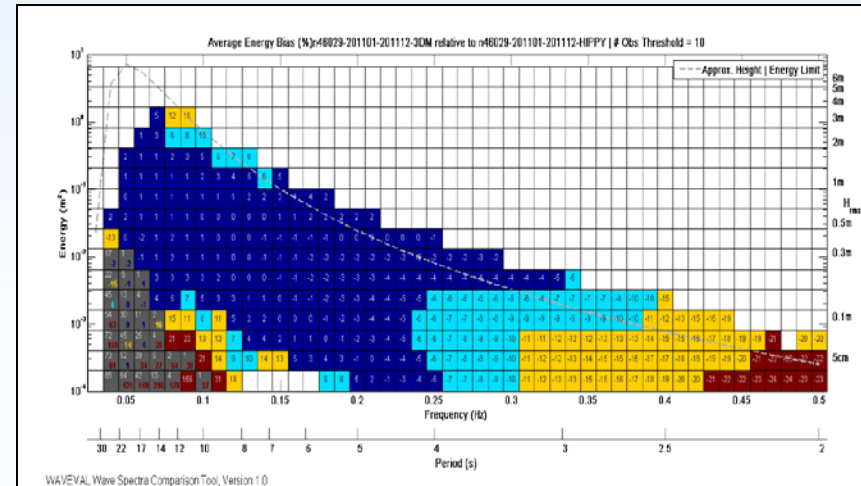
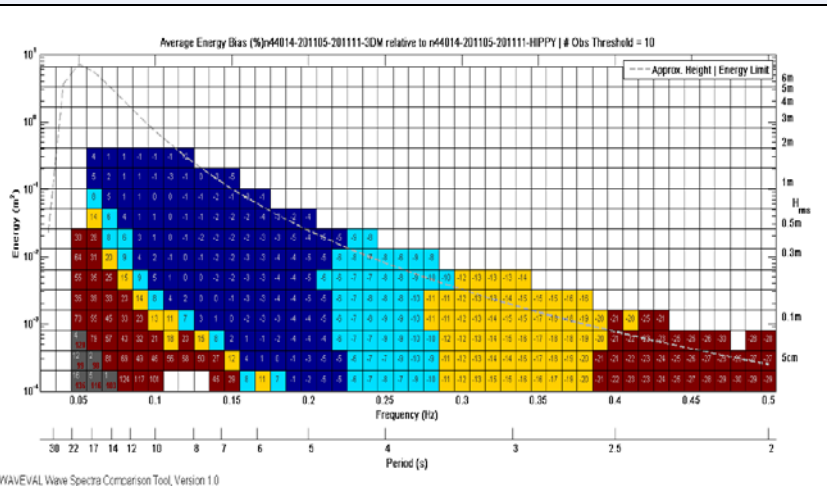
Wave Spectra Comparison Tool, Version 2.0



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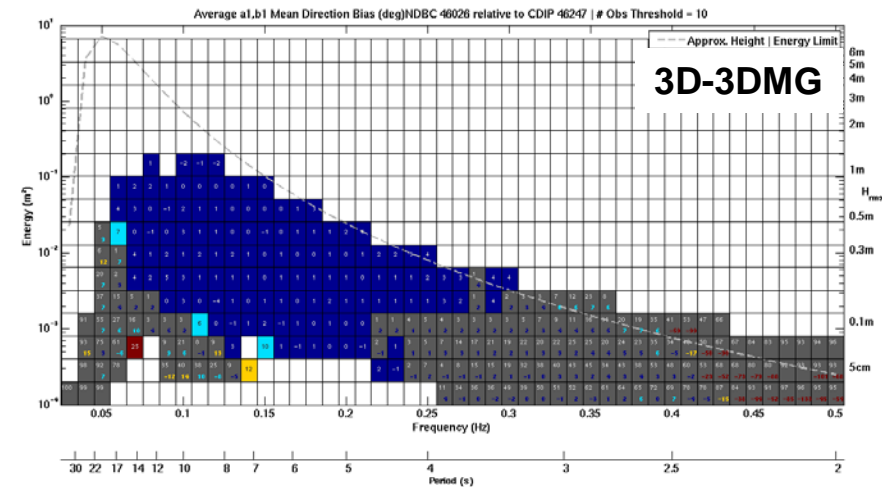
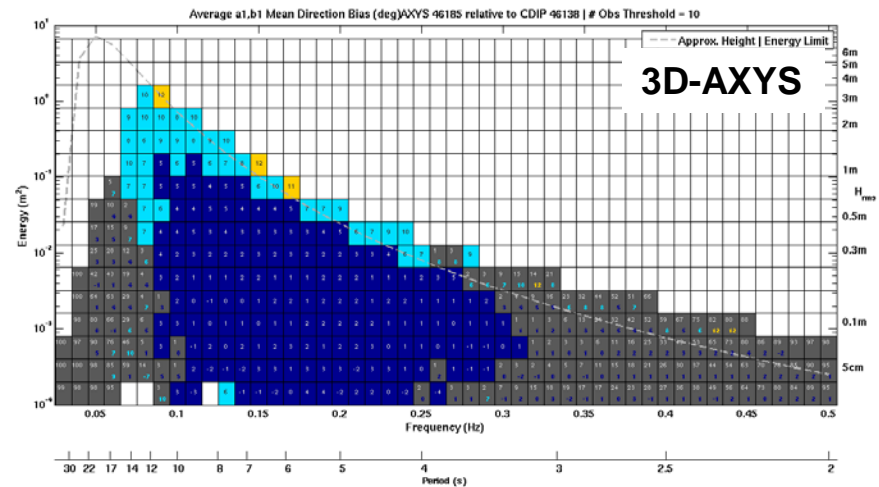
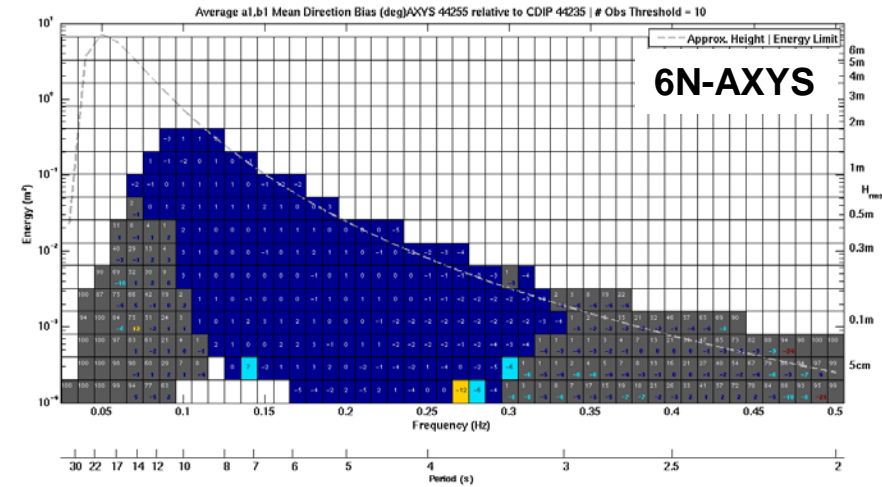
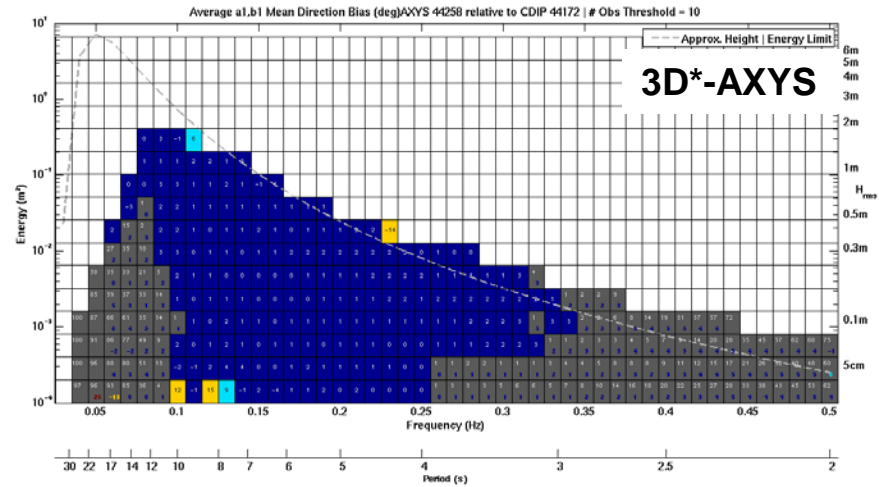
Evaluation Procedure: Co-located

Bias in Energy Dual Sensor: 3DMG+ and HIPPY



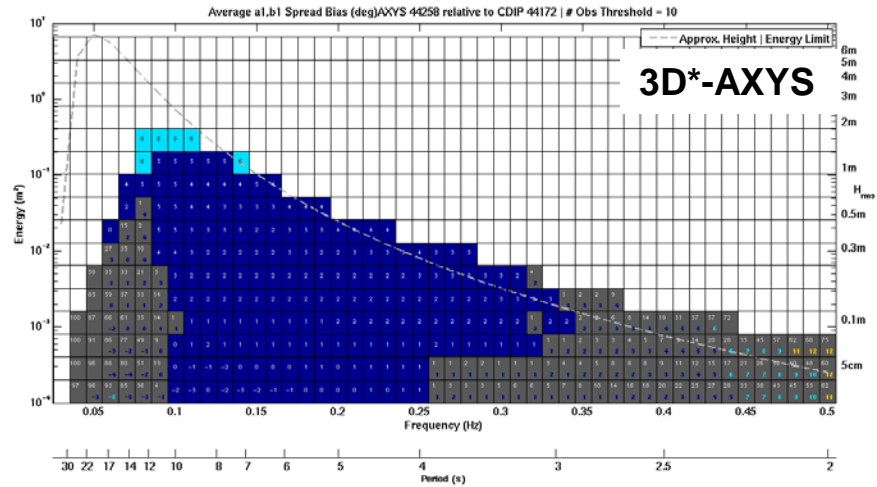
Evaluation Procedure: Co-located

Bias in Direction: Sensor / Hull / Payload Package

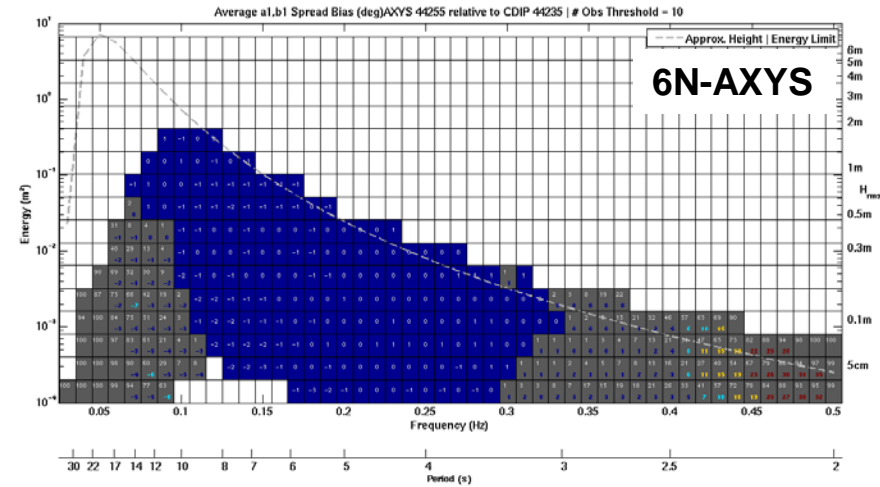


Evaluation Procedure: Co-located

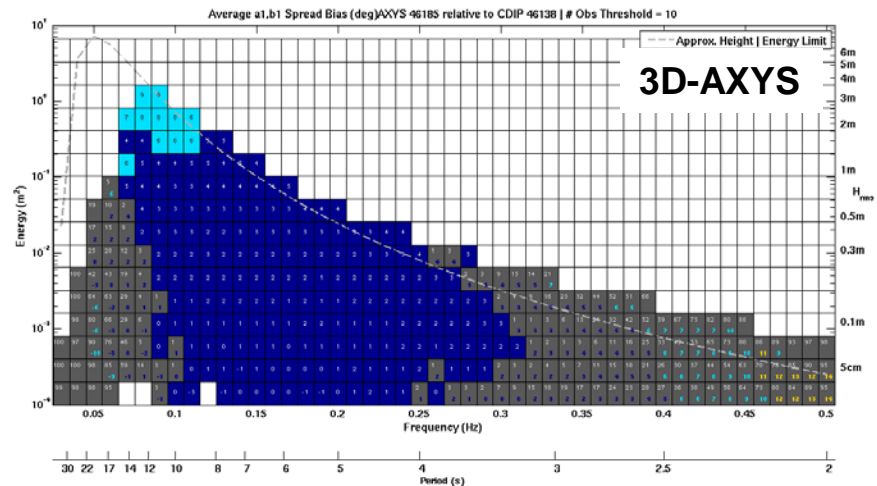
Bias in Directional Spread: Sensor / Hull / Payload Package



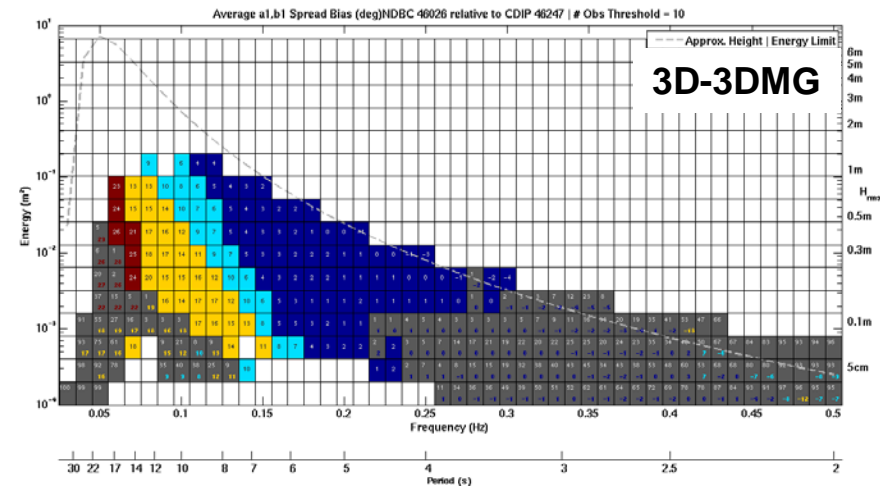
Wave Spectra Comparison Tool, Version 2.0



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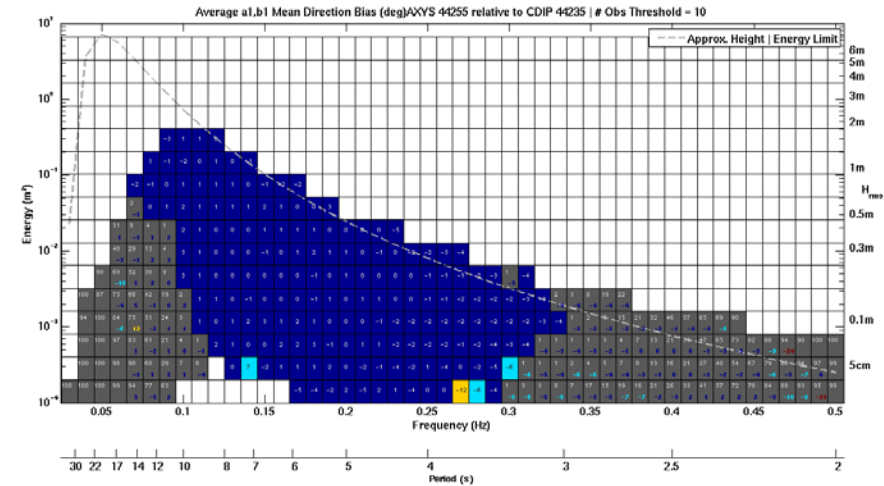


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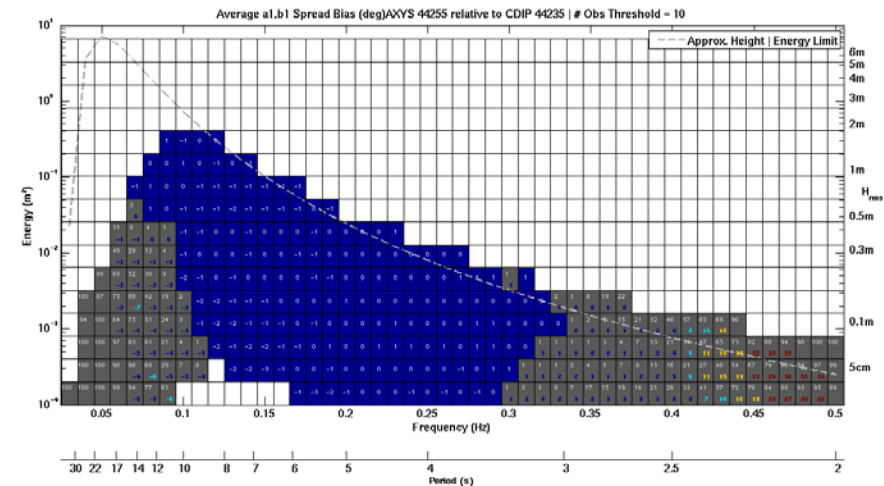
Method of Analysis

Analysis of: Directional Estimates from NOMAD

6M / Tri-AXYS/ AXYS



Wave Spectra Comparison Tool, Version 2.0

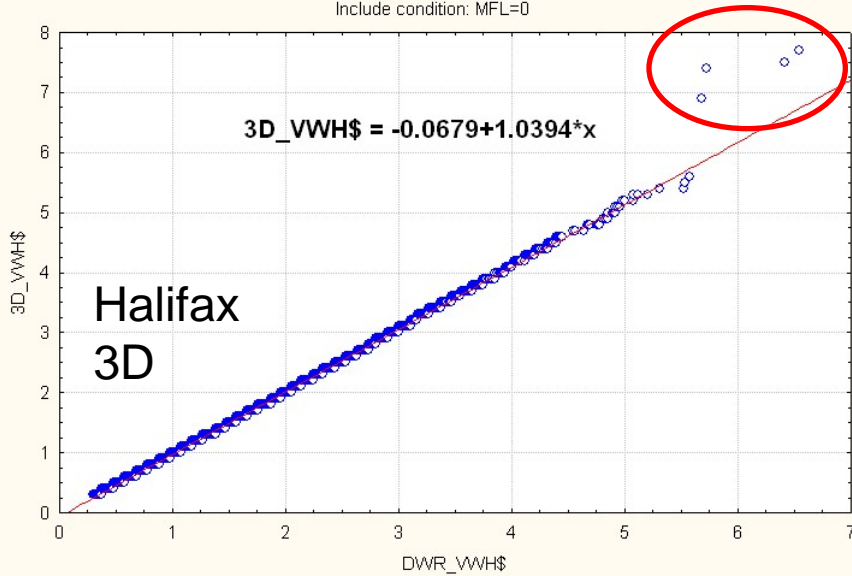


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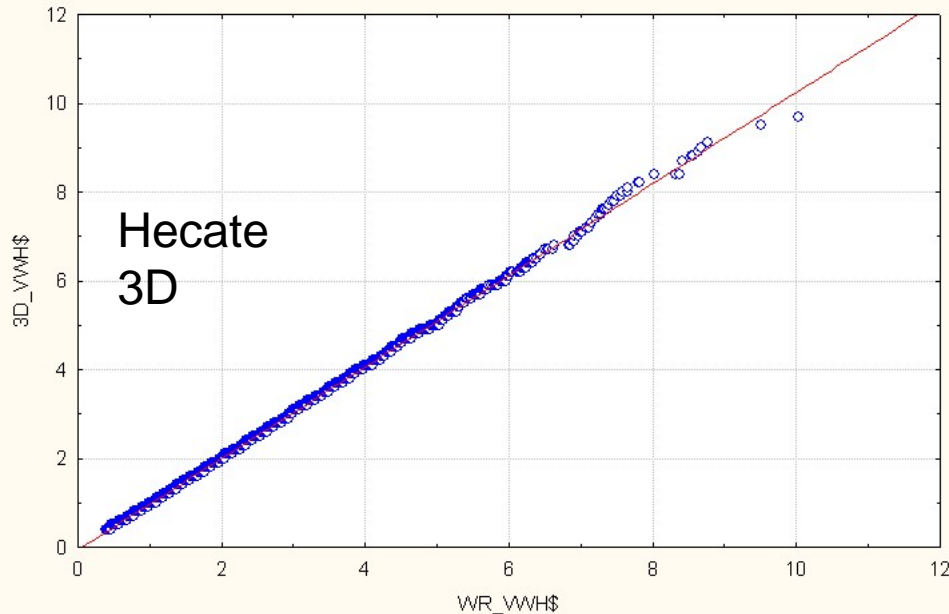
H_s Comparison

- NOMAD H_s ~ 6% low compared to WR H_s
- 3D H_s ~ 3% > WR H_s (both)
- Treat results with caution! – not First-5.

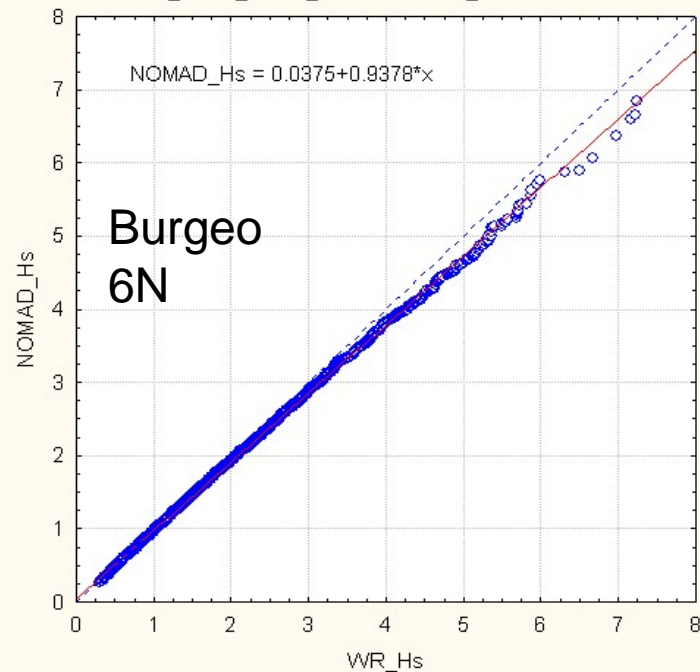
Quantile-quantile scatterplot of 3D_VWH\$ against DWR_VWH\$
 c44172_c44258_MergeDateMinNrst30.sta 59v*17975c
 Include condition: MFL=0



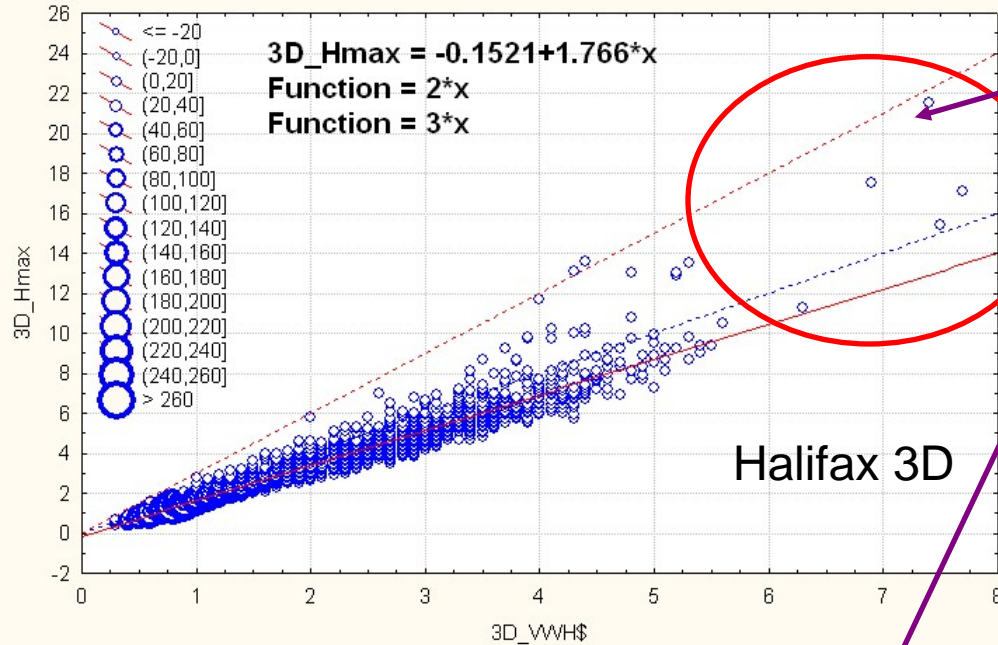
Quantile-quantile scatterplot of 3D_VWH\$ against WR_VWH\$
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 $3D_VWH\$ = -0.0633 + 1.0307 * x$



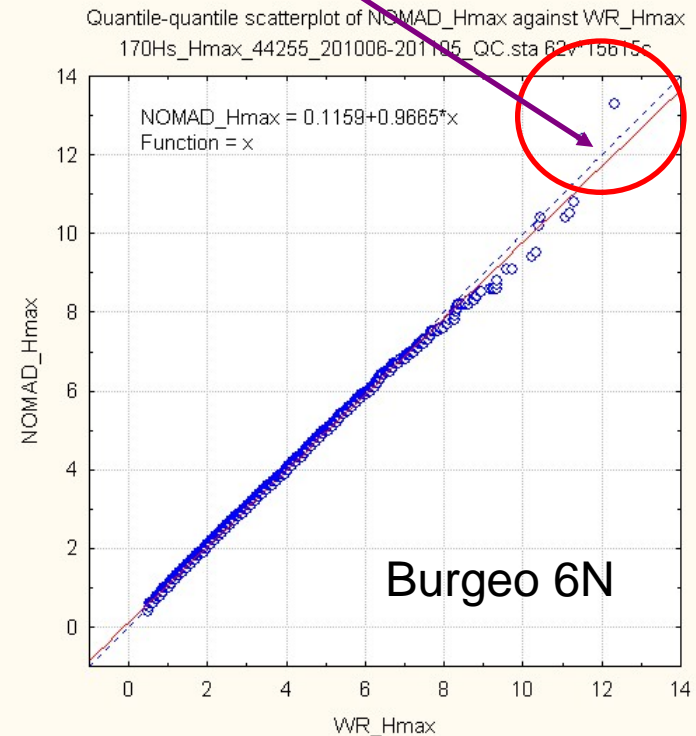
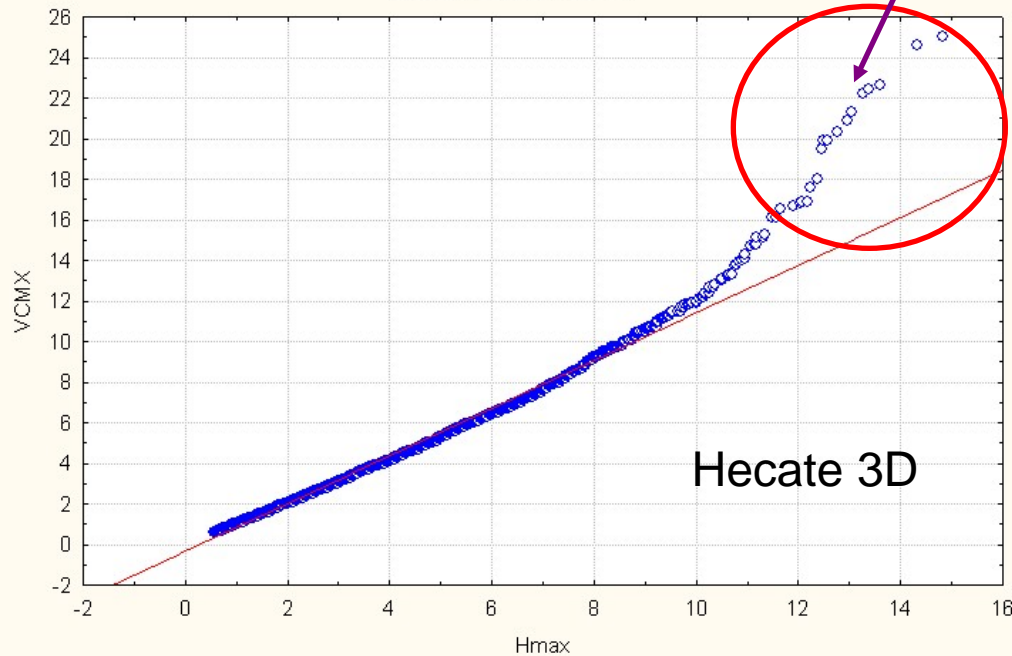
Quantile-quantile scatterplot of NOMAD_Hs against WR_Hs
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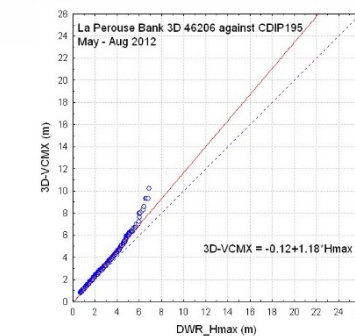
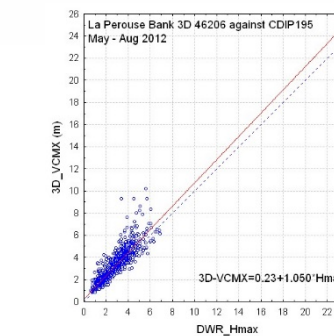
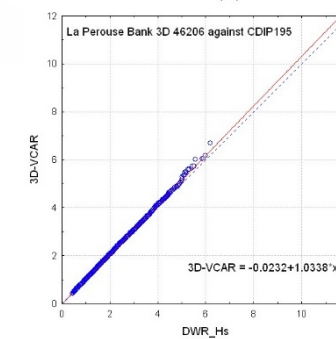
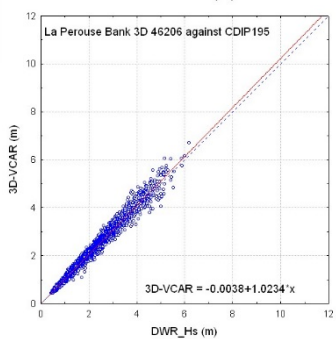
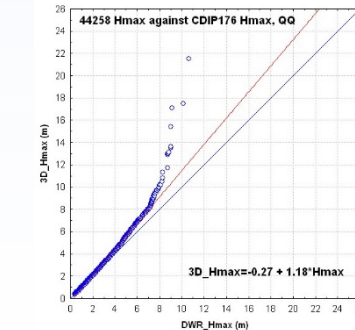
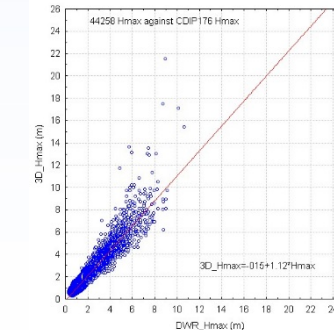
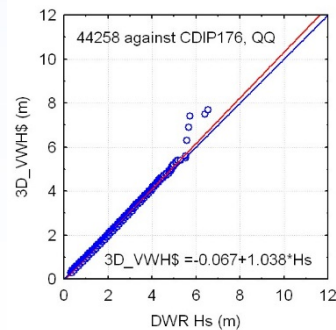
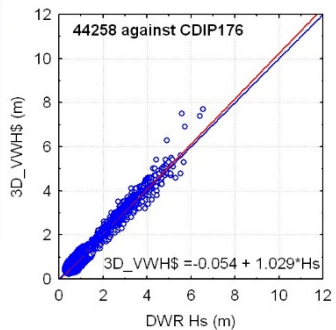
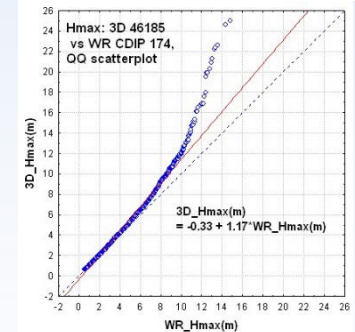
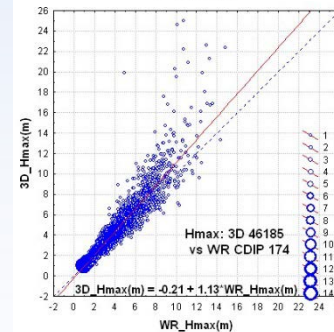
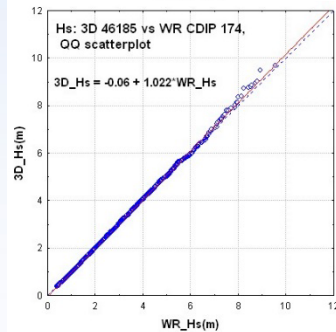
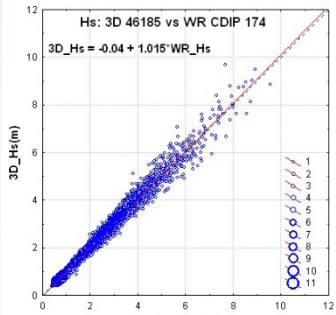
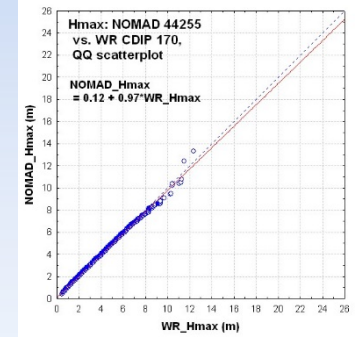
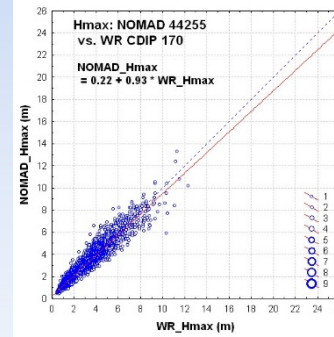
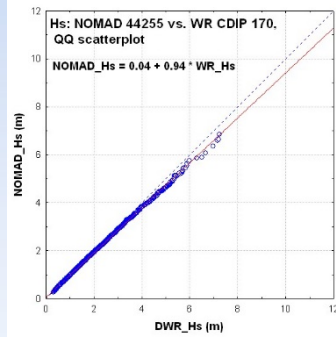
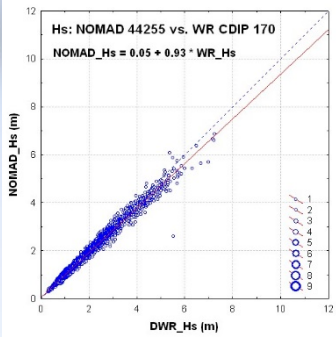


H_{max} Comparison

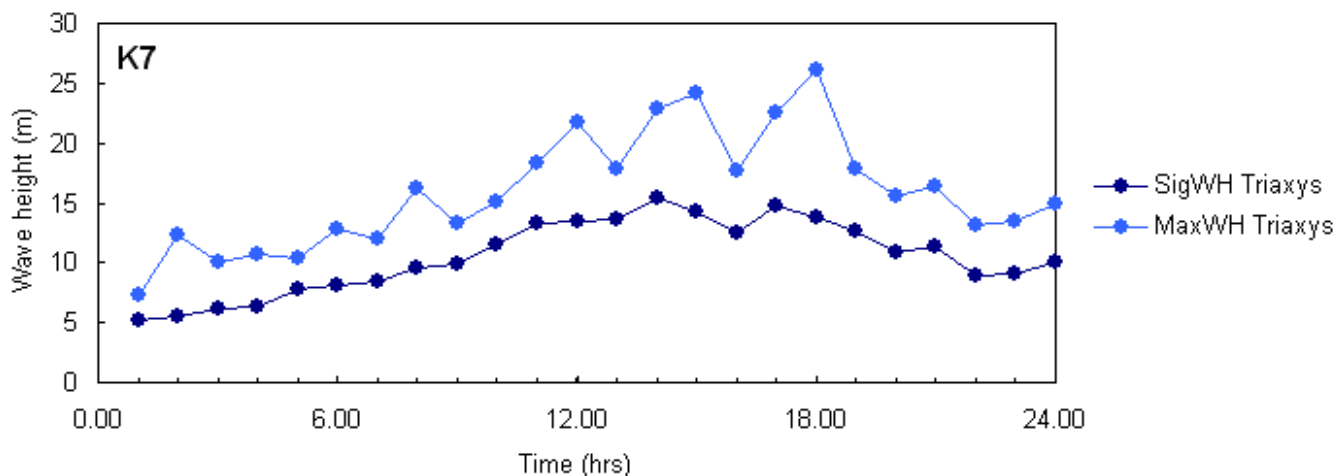
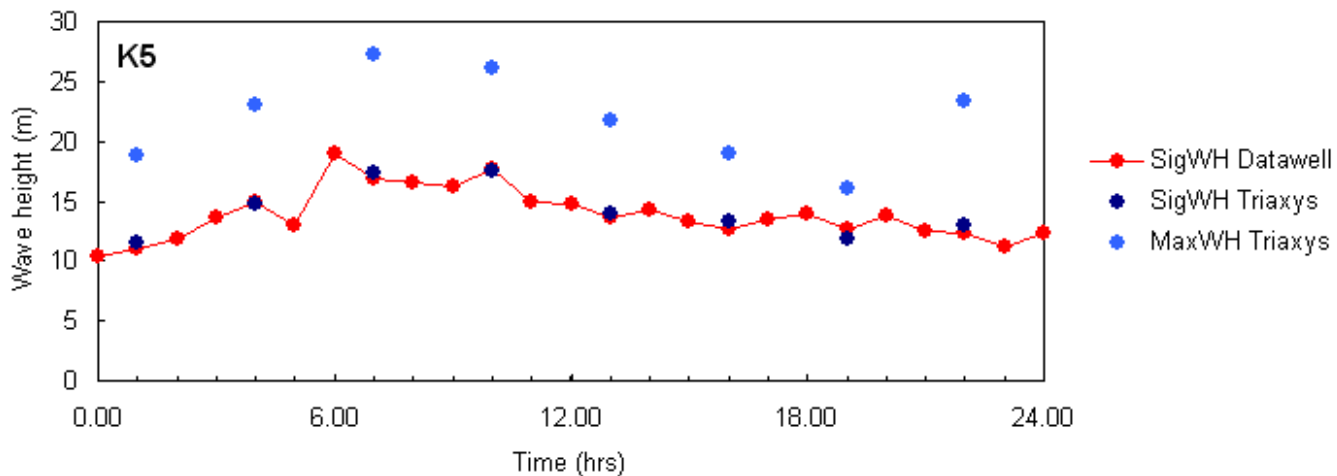


- Hmax/Hs ratio frequently 2-3 at Halifax 3D
- 3D spuriously high values of Hmax compared to WR
- NOMAD_Hmax = 3% < WR_Hmax
- a few high outliers (NOMAD_Hmax > WR_Hmax)





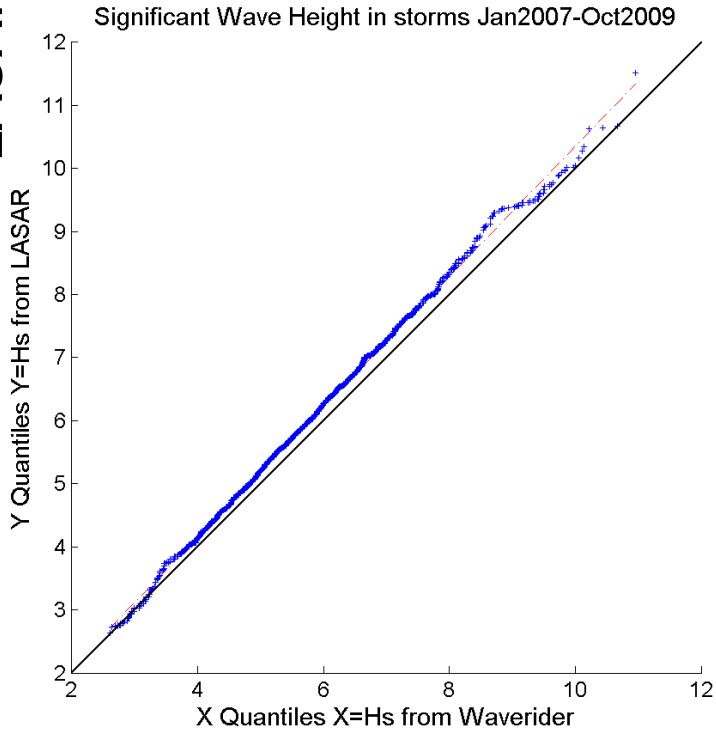
Wave measurements from K5 and K7 buoys on 4th February 2013



Comparison of Hs in 20 storms jan2007-oct2009 qq-plot

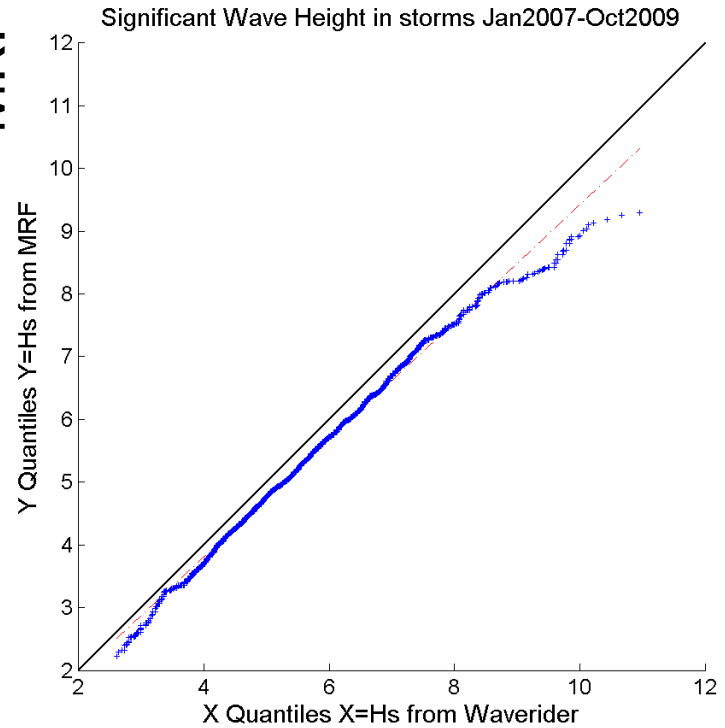


LASAR



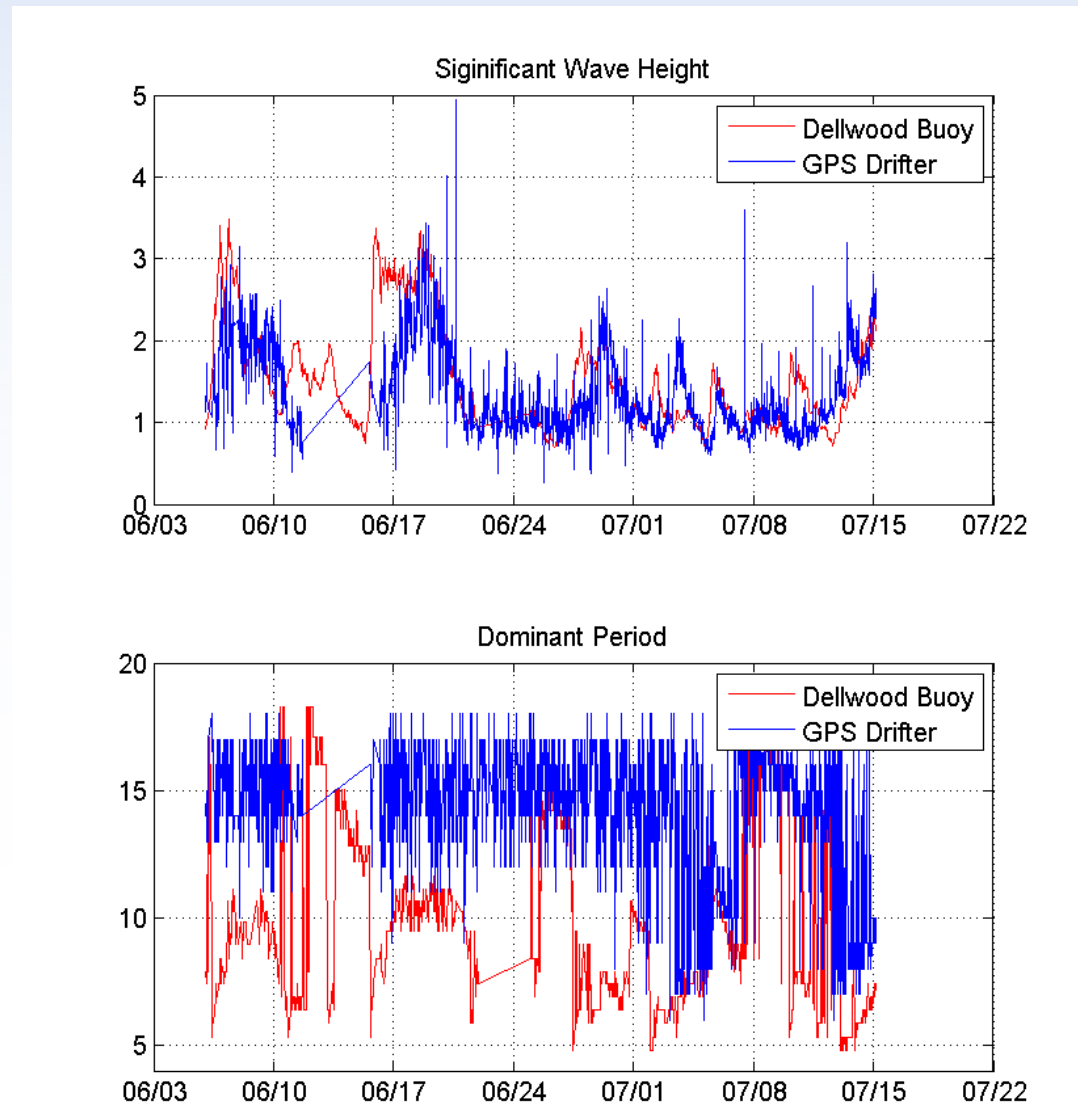
Waverider

MRF



Waverider

Comparison of drifter mounted GPS wave sensor with MSC East Dellwood weather buoy



- Clear differences in NOMAD component plots between DWR and MSC; smaller differences in 3D/DWR
- The AXYS system replicates DWG data
 - Still some biases (low and high frequency ranges)
 - Directional estimates thru 2nd and 3rd moments consistent
 - Co-located positions were “controlled” tests
 - Directional windows small < 90-deg
- No evidence of Bender effect except in Hmax and shallow water
- EC-NOMAD’s capability to estimate directions
- Need more comparisons at higher Hs

Preliminary Results - Canadian Deployments

- All 3D buoys H_s agree fairly well with DWR (3D ~3% higher); few cases where 3D H_s is anomalously high
- All 3D buoys show a tendency for increasingly large, spurious H_{max} in comparison to the DWR H_{max} as wave heights increase
- H_{max} from 3D buoys in shallower water start showing unexpectedly large values at lower wave heights than the 3D in deep water
- 6N shows generally consistent agreement in H_s and H_{max} with DWR, albeit ~6% lower

Preliminary Results - US Deployments

- NDBC's 3DMG motion sensor contains biases
 - Compared to DWG and HIPPY (dual sensor package)
- Initial wave drifter comparison encouraging
- Main conclusion – need more US comparisons!

Preliminary Results - UK Deployments

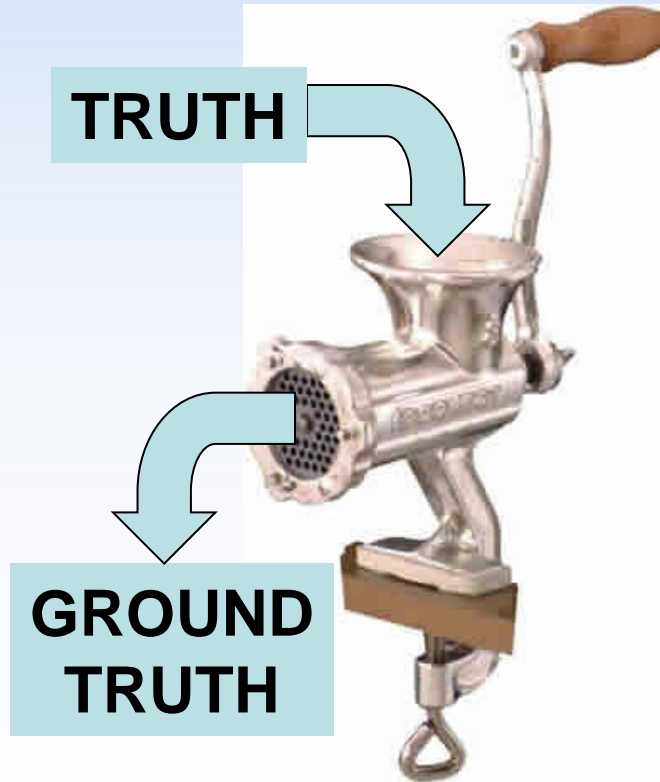
- Triaxys spectral wave systems on K5, Brittany and Gascogne compared well with co-located Datawell heave sensors in non-First-5 comparisons up to 19 m Hs
- Light vessels underestimate H_s and overestimate T_z relative to K-series buoys (also confirmed by comparison with Hastings Datawell waverider 2011).
- No evidence of Bender effect

Immediate Priorities for PP-WET

- Compare an existing NDBC 6N buoy containing all historical sensor and payload packages, a HIPPIE and 3DMG – Monterey buoy farm
- Evaluate additional wave drifters, including dual-sensor comparison of GPS sensor in 3D or 6N hull
- Operate the DWR alongside a regular UK buoy (e.g. K-5)
- Co-locate DWR with the LASAR array at Ekofisk
- Continue Canadian co-locations including another 6N
- More directional spectral intercomparisons
- Further investigate “Bender effect”

Immediate Priorities for PP-WET

- Need to quantify component results – address the “10% difference” – how to do this
- Need to look at individual spectra
- Bench Test analysis packages (IEEE, time series, etc)
- Need comparisons in higher wave conditions



Thank you!