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Field Laboratory for Ocean Sea State Investigation and Experimentation: FLOSSIE Intra-Measurement Evaluation of 6N Wave Buoy Systems

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MARCDAT-IV
UK National
Oceanography Centre
Southampton UK
18-22 July 2016

US Army Corps
of Engineers ®
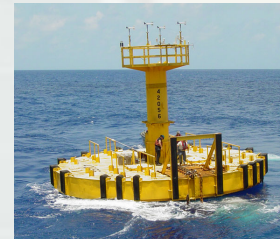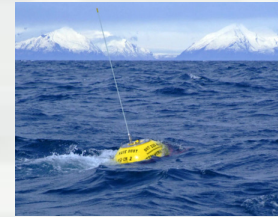
Outline

- **Motivation**
  - ▶ Point Source Measurements
    - • Climate
    - • Data Homogenization
- **Buoy Farm**
  - ▶ Configuration
  - ▶ FLOSSIE
    - • Sensor / Payload Packages
    - • Measurements Conducted
- **Method of Analysis: Results**
- **Findings and Conclusions**
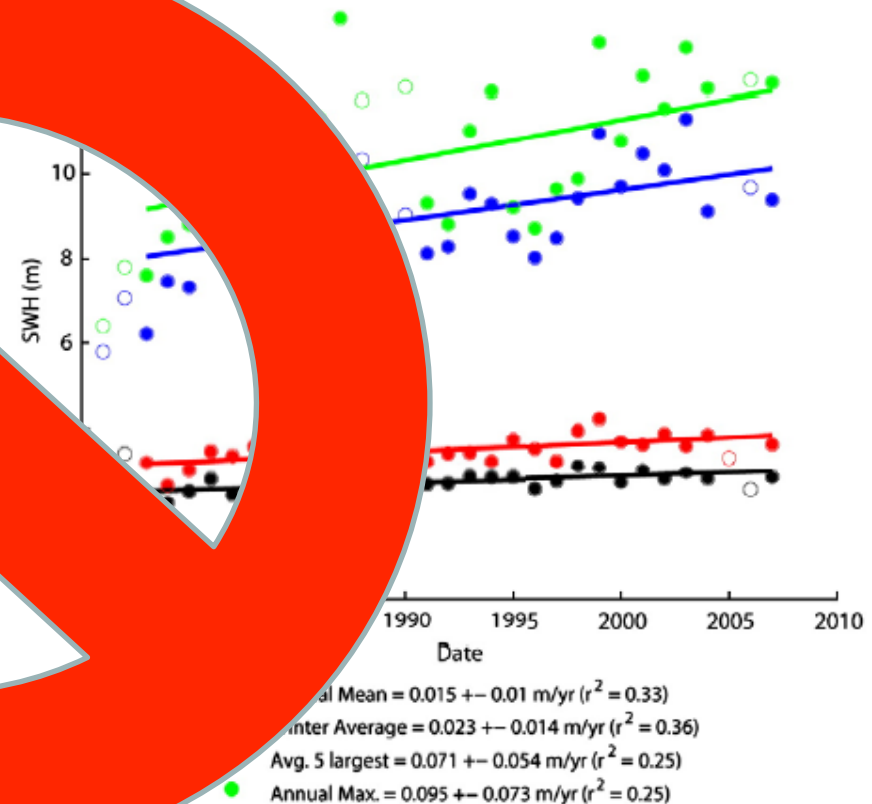- **Epilogue**

Climate: Point Source Measurements

- Data providers (mid-1970's)
  - ► Support weather
  - ► Provide timely measurements
  - ► QA/QC
  - ► Changes / Improvements
    - • Hardware (hulls / sensors / moorings)
    - • Software (payload packages)
    - • Record lengths / sampling intervals
  - ► Location
  - ► Metadata very limited pre-2011
  - ► Had no intention to support climate initiatives
- Researcher's use the data as if it were perfect

South Hecate Buoy off BC Coast – Fall 2009

Climate: Point Source Measurements

- Allan and Komar (2
  - ► East North Pac
  - ► NDBC Buoy
    - -0.004 to
    - Storm e
- Komar and (2
  - ► US East Hurrica
  - ► NDBC B a
    - + 0.017 .059 m/yr
    - Heights +3m
    - More freq
- Ruggiero et a
  - ► US Pacific Nort
  - ► NDBC Buoy data
    - Mean +0.015 m/yr (since mid 1970's)
    - Highest 0.071 m/yr

al Mean = 0.015 +− 0.01 m/yr (r² = 0.33)
nter Average = 0.023 +− 0.014 m/yr (r² = 0.36)
Avg. 5 largest = 0.071 +− 0.054 m/yr (r² = 0.25)
Annual Max. = 0.095 +− 0.073 m/yr (r² = 0.25)

Ruggiero et al., 2010

Point Source Measurements

- Gemmrich et al. (2011)
  - ► Brought reality to reported climate estimates
  - ► Buoy modification accounted for
    - Step changes 10 times greater than trend found in Ruggerio et al. (2010)
  - ► Indentified procedures to follow
  - ► Able to coalesce to one uniform time series
    - RHTestsV3 (Wang and Feng, 2009)
    - Homogeneity Tests on data
    - Define step-like features exist in long-term data

Gemmrich et al., 2011

46005
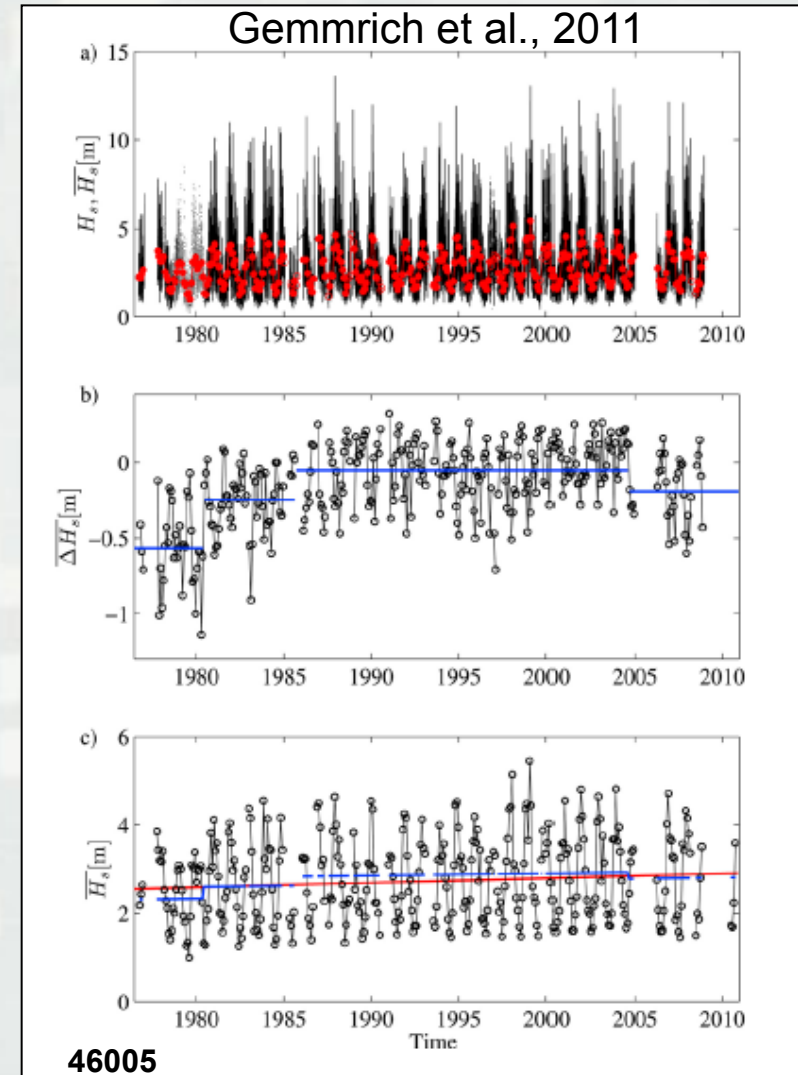
Point Source Measurements

- Livermont et al. (2016)
  - ▶ Alternate technique to account for
    - Hull / Payload
  - ▶ Criteria
    - US East Coast
    - Operational
    - 10-yr records
  - ▶ Analysis of Covariance
    - Tests hypothesis that means of several groups of data are equal
    - Based on hull type / payload
    - Spatial consistency?
  - ▶ Linear Models fit to wave records
    - Hardware corrected (5)
    - Payload corrected (8)
    - Corrected for both
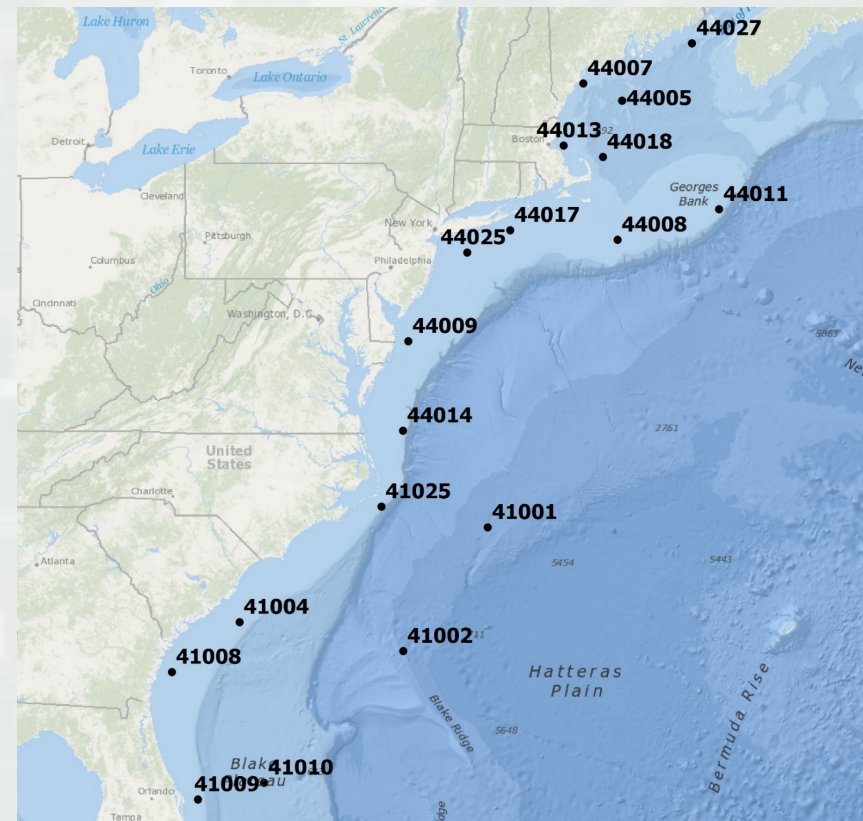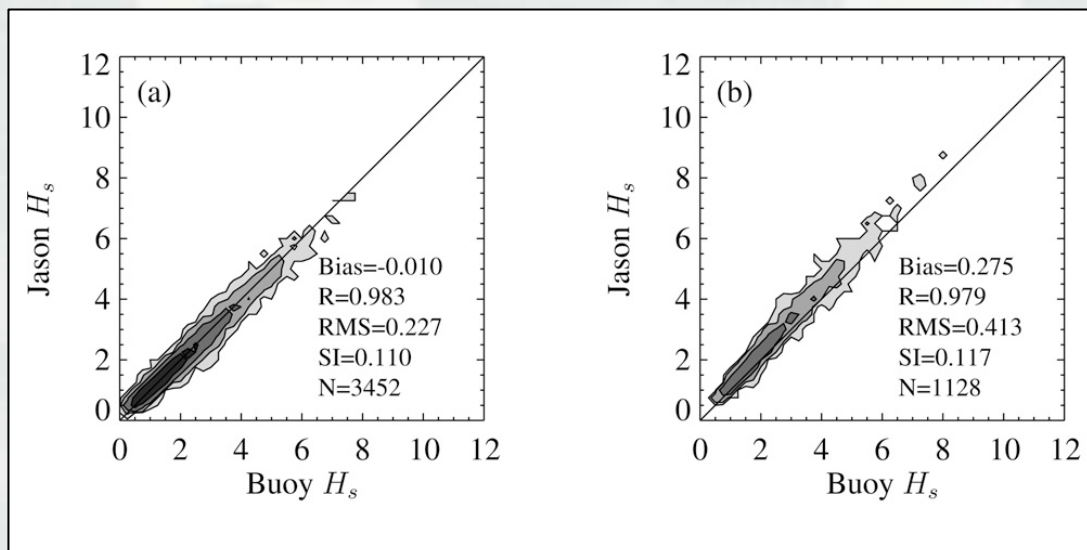
Point Source Measurements

Livermont et al., 2015

Buoy Number	Original Dataset Slope (mm/yr)	Corrected Slope (mm/yr)
Buoy 41001	3.027	-0.003
Buoy 41002	0.593	-0.264
Buoy 41004	-4.941	-1.709
Buoy 41008	-3.914	-1.691
Buoy 41009	4.123	-1.909
Buoy 41010	1.590	-1.932
Buoy 41012	3.009	-0.003
Buoy 41013	3.007	-0.003
Buoy 41025	3.009	-0.003
Buoy 44004	-2.625	-1.129

| Buoy Number	Original Dataset Slope (mm/yr)	Corrected Slope (mm/yr)
Buoy 44005	-8.582	-1.311
Buoy 44007	0.282	0.518
Buoy 44008	8.219	1.171
Buoy 44009	8.994	-0.921
Buoy 44011	2.824	1.582
Buoy 44013	14.581	0.115
Buoy 44014	2.640	0.231
Buoy 44017	3.008	-0.003
Buoy 44018	3.011	-0.003
Buoy 44025	7.526	1.052
Buoy 44027	3.008	-0.003

Discrepancies in Data

- Altimeter vs 6N Buoys (Durrant et al. 2008)
  - ▶ 10% difference Canadian & NDBC 6N
- Environment Canada (5 co-locations)
- NDBC no co-located sites
  - ▶ De-commissioning 6N Sites
  - ▶ USACE and FLOSSIE

**Altimeter Algorithms
Based on
Point Source Measurements**

Discrepancies in Data

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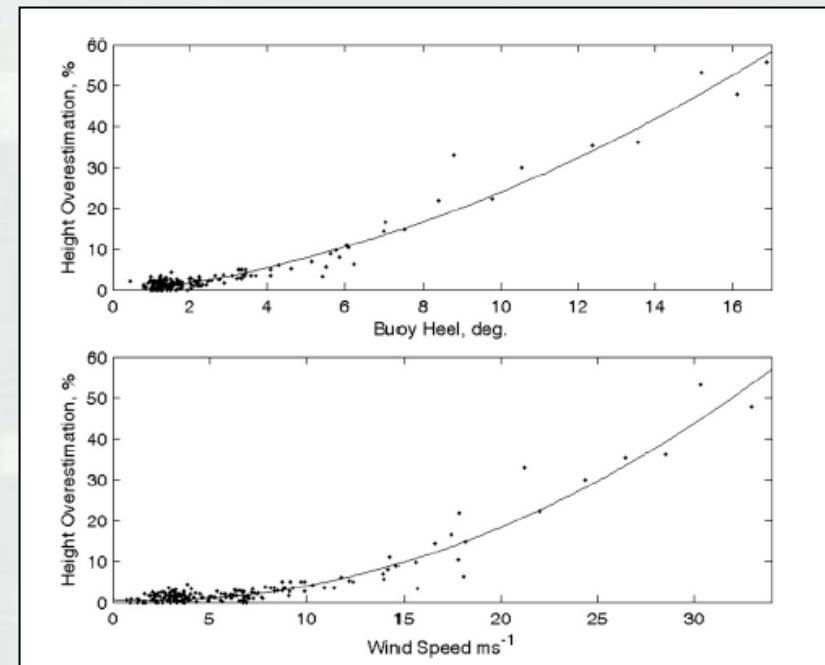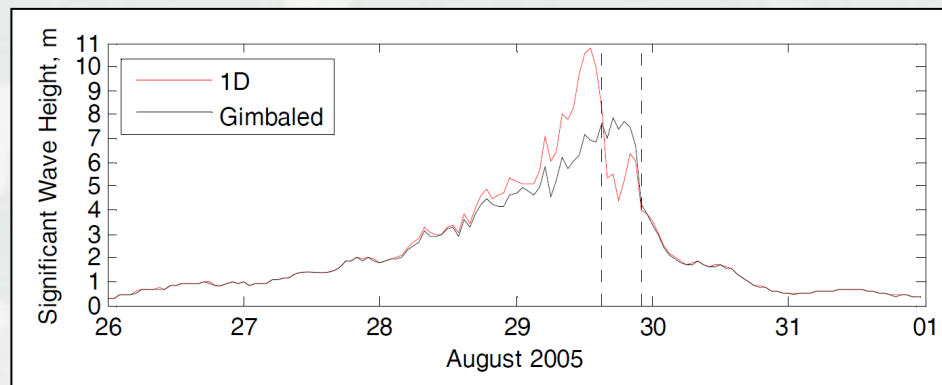
Method of Analysis

- Test and Evaluation: *First-5 Principles* (JCOMM / WMO)
 - ▶ Assumptions
    - Directional estimates: poorly defined
    - E(f): frequency spectra similar sensor to sensor
    - Analysis packages: did not introduce differences
    - Hull / Mooring: lower order contribution

  - ▶ Impact
    - Weather Prediction Center evaluation process
      - ▷ Integral wave parameters (H_{mo}, T_p, θ_{mean})
    - Wave Model Improvements
      - ▷ Still relying on integral wave parameters
      - ▷ Tolerances: 0.25 to 0.50-m
    - Climate Variation
      - ▷ Specification of extreme storm events


Example:RMSE for wave height at all buoys
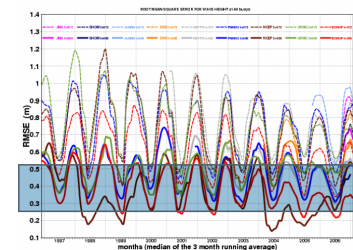
GlobWave KO, ESA ESRIN, Frascati Rome Italy
16th January 2009

Buoy Farm: Pacific / Monterey Canyon

- Buoy Farm
  - ► National Marine Sanctuaries
  - ► Water Depth 1500-2200m
  - ► Platforms
    - • NDBC 3D (HIPPY/3DMG+)
    - • Datawell Directional Waverider
    - • FLOSSIE
  - ► Altimeter Tracks

Altimeter Tracks (201306-201307)
Altimeters: CRYOSAT, SARAL, JASON1, JASON2

NATIONAL MARINE
SANCTUARIES
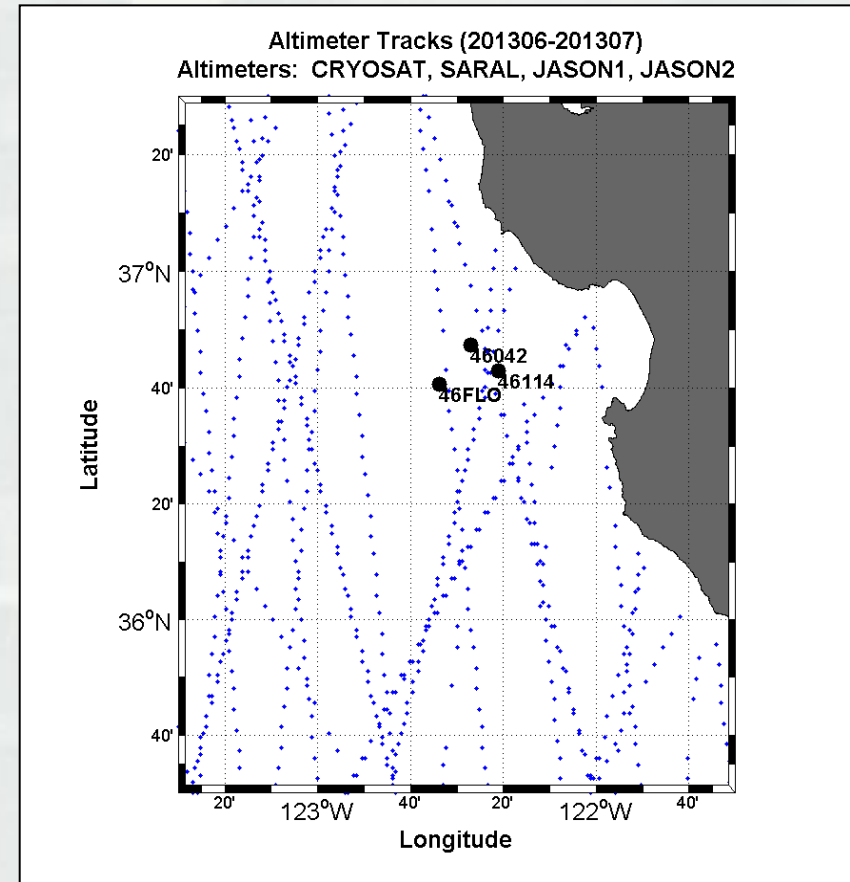
Buoy Farm: Pacific / Monterey Canyon

Collaboration / Contributions

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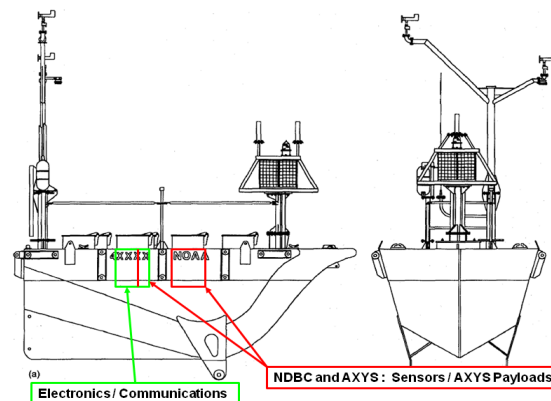 - ▶ AXYS-Watchman
  - ▶ MEDS-Data Archive

What FLOSSIE Will Measure

- Non-Directional Sensor / Payloads
  - ▶ NDBC: Inclinometer
  - ▶ NDBC: HIPPY/Magnetometer
  - ▶ EC : SDA / AXYS: Watchman
- Directional Sensor / Payloads
  - ▶ NDBC: HIPPY / Magnetometer (DWPM)
  - ▶ NDBC: 3DMG (DDWM)
  - ▶ AXYS: TRIAXYS Next Wave II DWS-WM
- Complete Suite of Met. Sensors
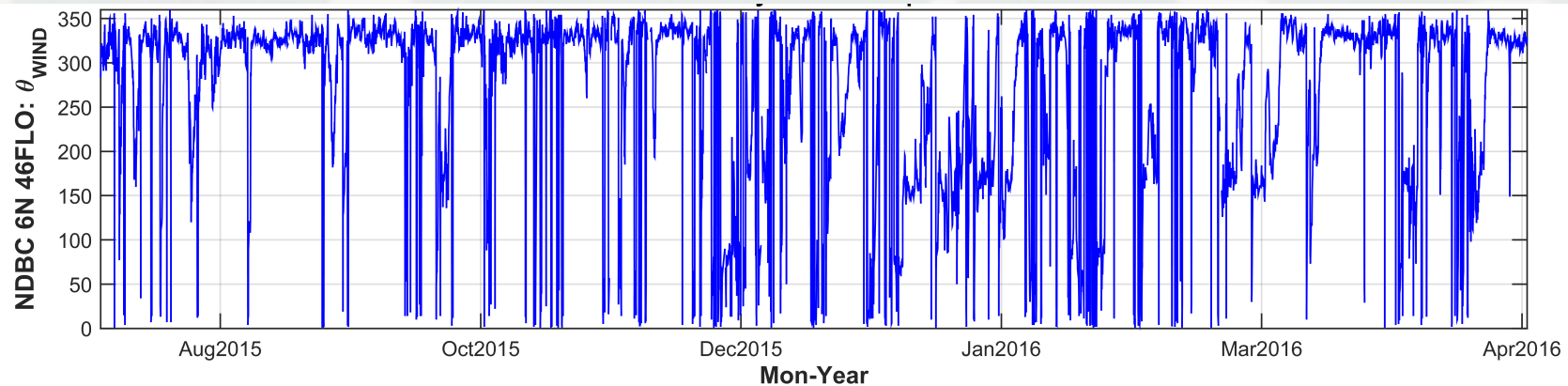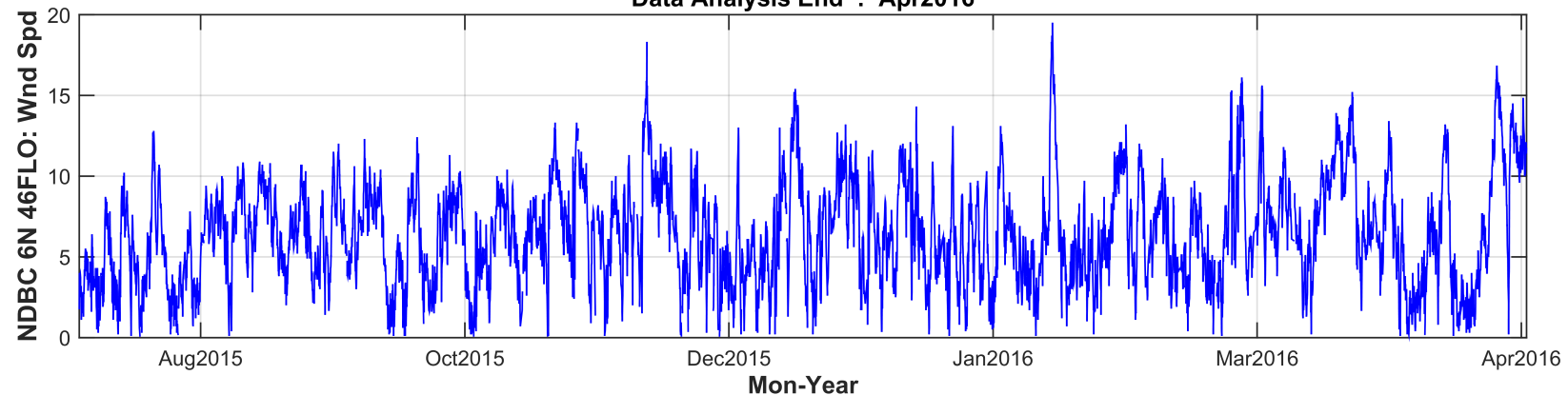- Data Transfer: IRIDIUM
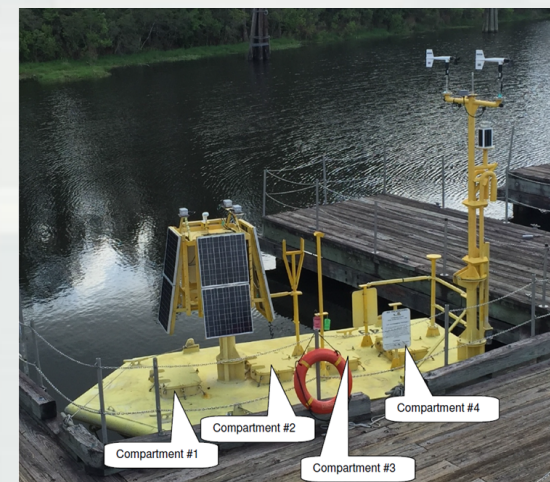
R. Riley & NDBC Techs

Method of Analysis

- Buoy Farm General Characteristics: Winds / Waves
- Winds at 5m elevation

FLOSSIE Study: NDBC 6N 46FLO
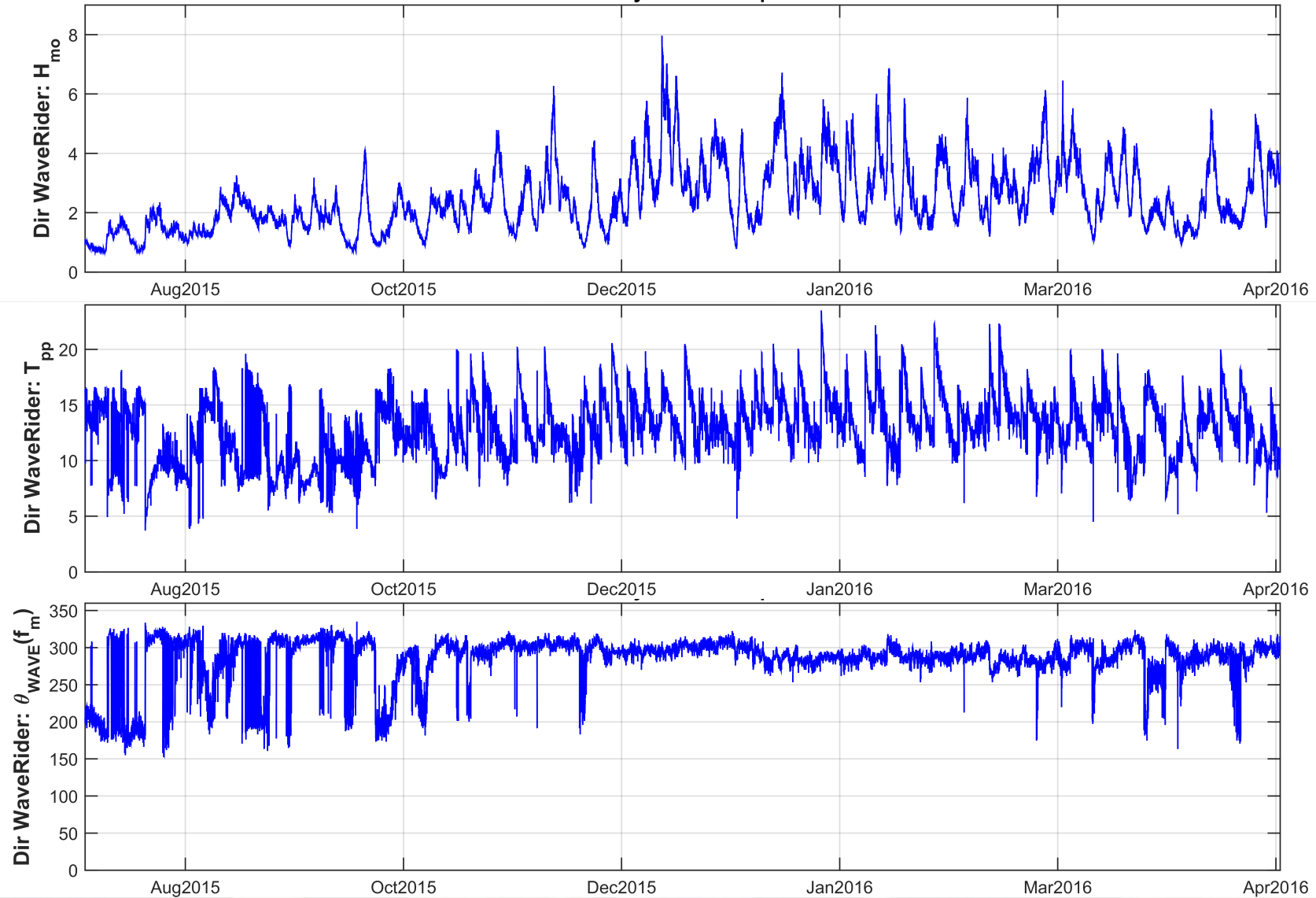Data Analysis Start: Aug2015
Data Analysis End : Apr2016

Method of Analysis

FLOSSIE Study: Directional WaveRider 46114
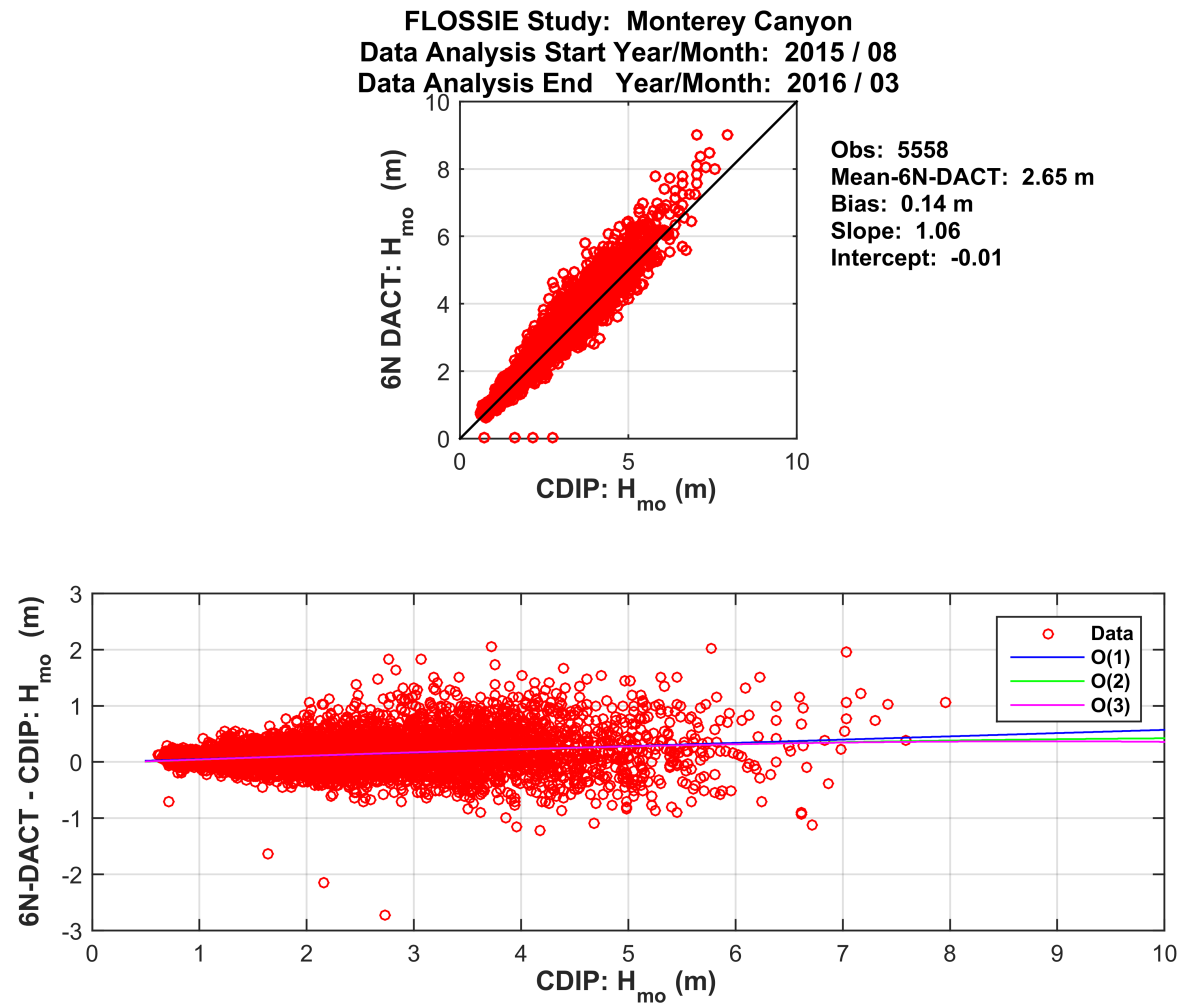Data Analysis Start: Aug2015
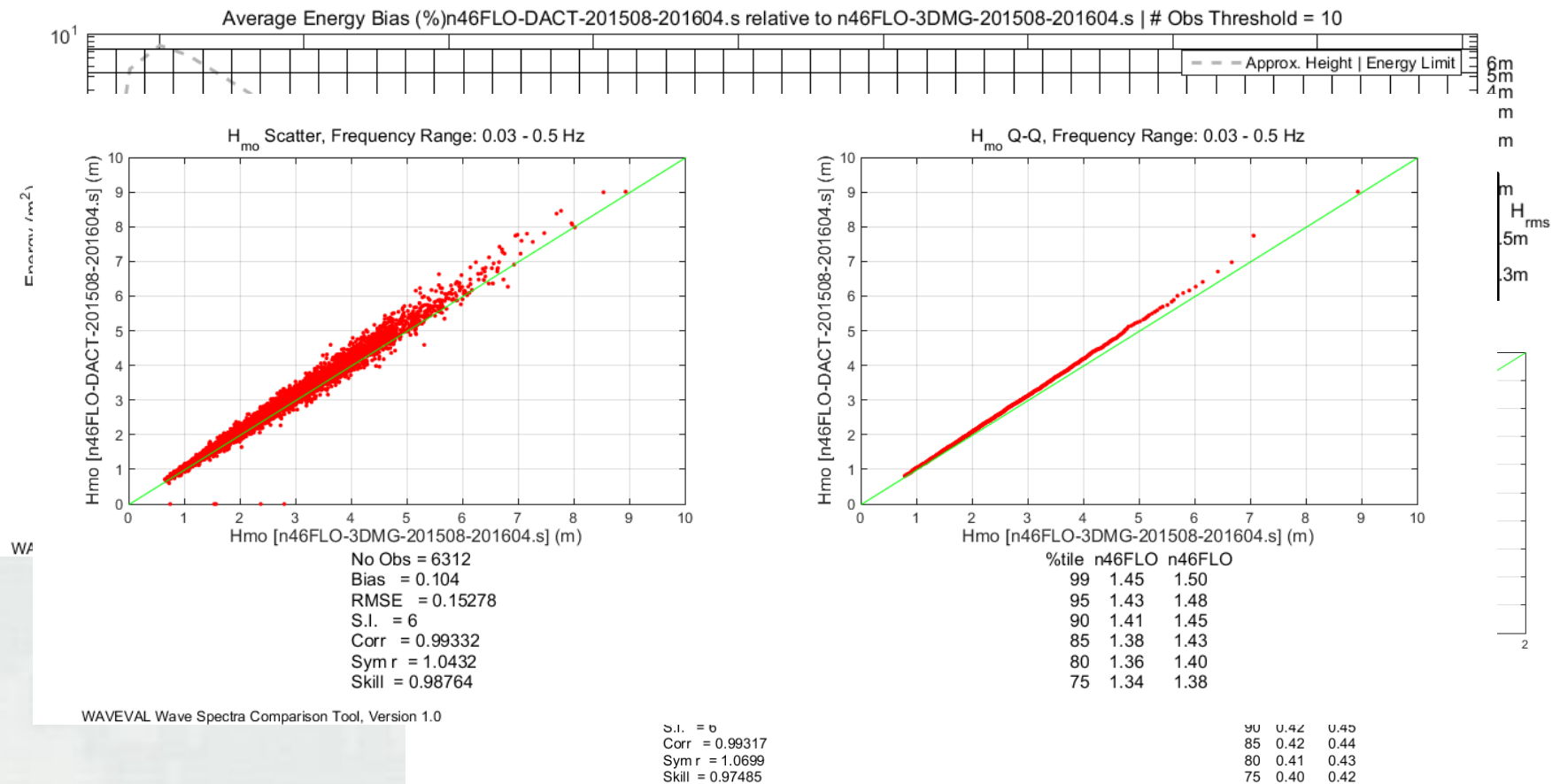Data Analysis End : Apr2016

Method of Analysis
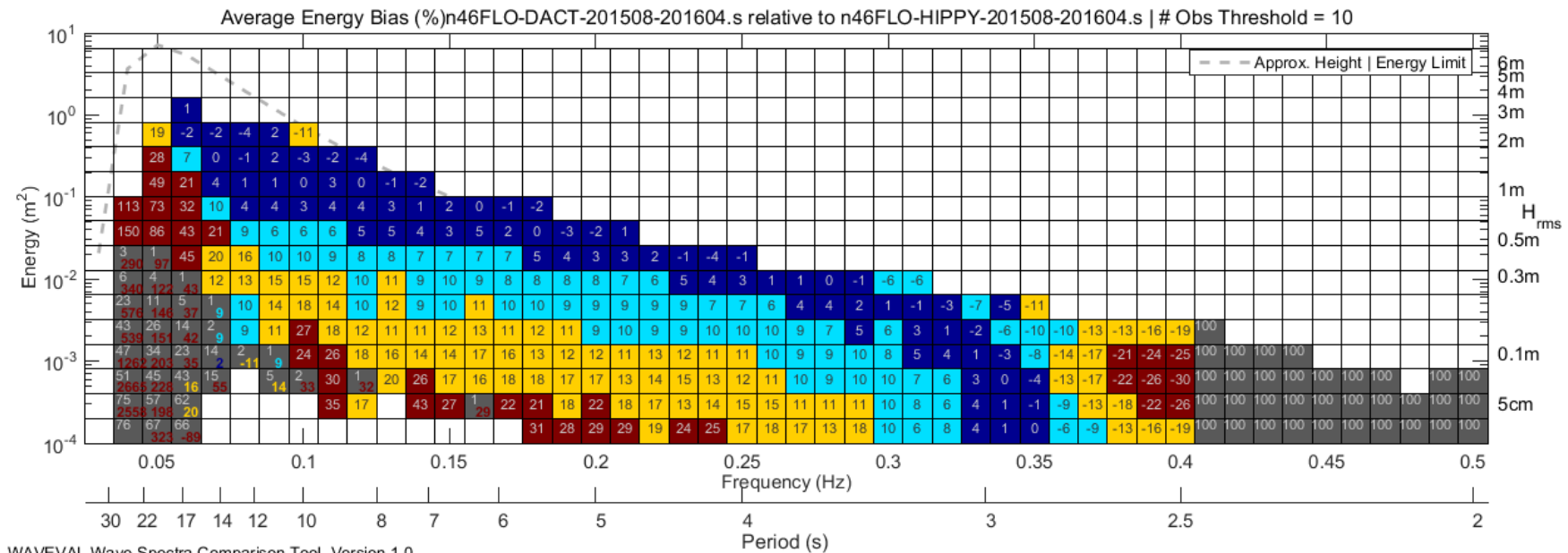
- Relative Reference Examination (WaveRider)

FLOSSIE Study: Monterey Canyon
Data Analysis Start Year/Month: 2015 / 08
Data Analysis End   Year/Month: 2016 / 03

Method of Analysis

- FLOSSIE 6N: Sensor Analysis

Average Energy Bias (%)n46FLO-DACT-201508-201604.s relative to n46FLO-3DMG-201508-201604.s | # Obs Threshold = 10

Method of Analysis

- FLOSSIE 6N: Sensor Analysis

Method of Analysis

- NDBC 3D 46042: Sensor Analysis
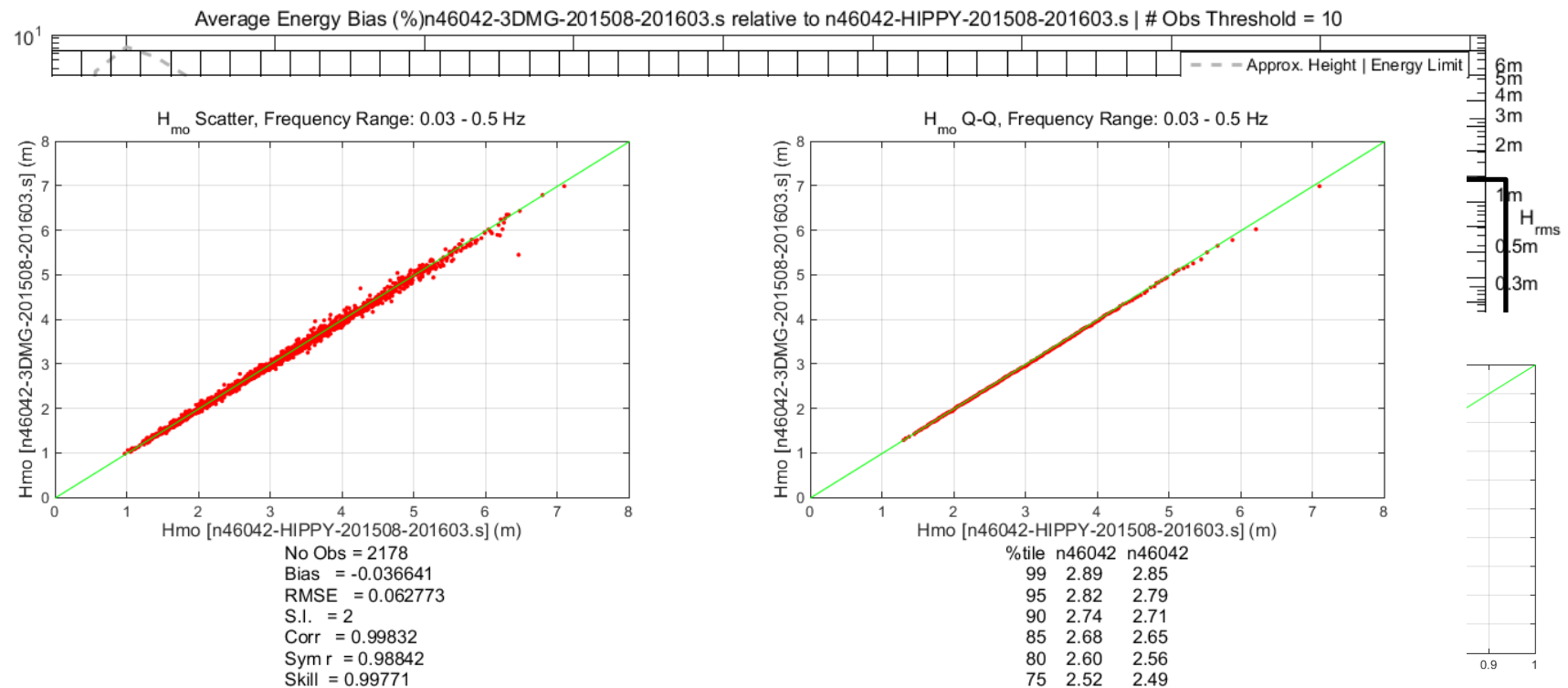
Findings and Conclusions

- Uses of wave measurements include
  - ▶ NWP forecast assessment
  - ▶ Hindcast assessment
  - ▶ Model development / modifications
  - ▶ Altimeter algorithms
  - ▶ Climate Analysis

- Quality of wave measurements varies
  - ▶ Hull size / composition
  - ▶ Super-Structure / Bridle / Mooring
  - ▶ Sensor
  - ▶ Payload / Analysis Packages
  - ▶ Changes in processing

- Cannot <u>overstress</u> the importance of
  - ▶ Continued Test and Evaluation of wave measurement systems
  - ▶ **Metadata are as important as the data itself !**

Findings and Conclusions

- **Buoy Farm created to investigate differences**
  - ► Contains majority of N America wave platform types
  - ► FLOSSIE: multiple sensor/payloads in one hull
  - ► Dual Sensor on NDBC Flagship 3D aluminum hull

- **Can we quantify those differences?**
  - ► Over the mean differences are small
  - ► Spread of +/- 1-2.0-m is a concern
  - ► Spread grows with increasing H_{mo}
  - ► Moments in direction?

- **Can we relate those differences to**
  - ► Sensor/payload type
  - ► Hulls, super-structure, mooring
  - ► Analysis package?

If so, this will lead to Improvements in Wave Climate Analyses

Epilogue

- NDBC Present-Future (106 Sites)
  - ► 10/12D: 0   (42040 replaced)
  - ► 6N: 9   (Decommissioning)
  - ► 3D: 55   (Aluminum *Flagship*)
  - ► 3DV: 33   (Foam / Little Testing)
  - ► 2.3DV*: 7   (Foam / Limited Testing)
  - ► 2.4DV*: 2   (Foam / Limited Testing)

*SCOOP Payload

Decommissioning

?

Thanks !