Directional Wave Measurements: Answering the Question of *Ground Truth*

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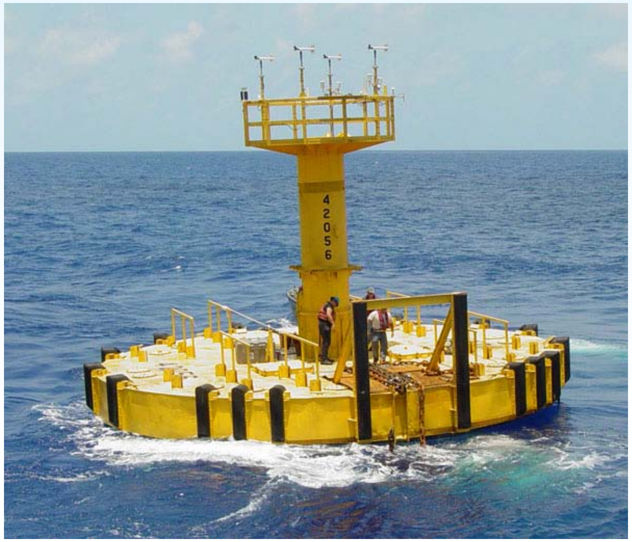
Outline

- What is Ground Truth?
- Historical Perspectives
  - Deepwater
  - Shallow-water
- First-5 Approach
- Evaluation Procedure
  - Co-located
  - Wave system evaluation
- Summary

Historical Perspective

- NDBC Monopoly
  - Add to existing MET platforms
  - HIPPY sensors
  - Focus on deepwater
- USACE
  - CDIP co-sponsored
  - Coastal sites
  - FRF
  - PUV / S_{xy}
- Changes in 1990-2000's
  - NDBC:
    - Alternate sensors
    - New buoy configurations
  - CDIP: Datawell's
  - IOOS: Regional Associations
    - New to wave measurements



Why Seek Ground Truth ?

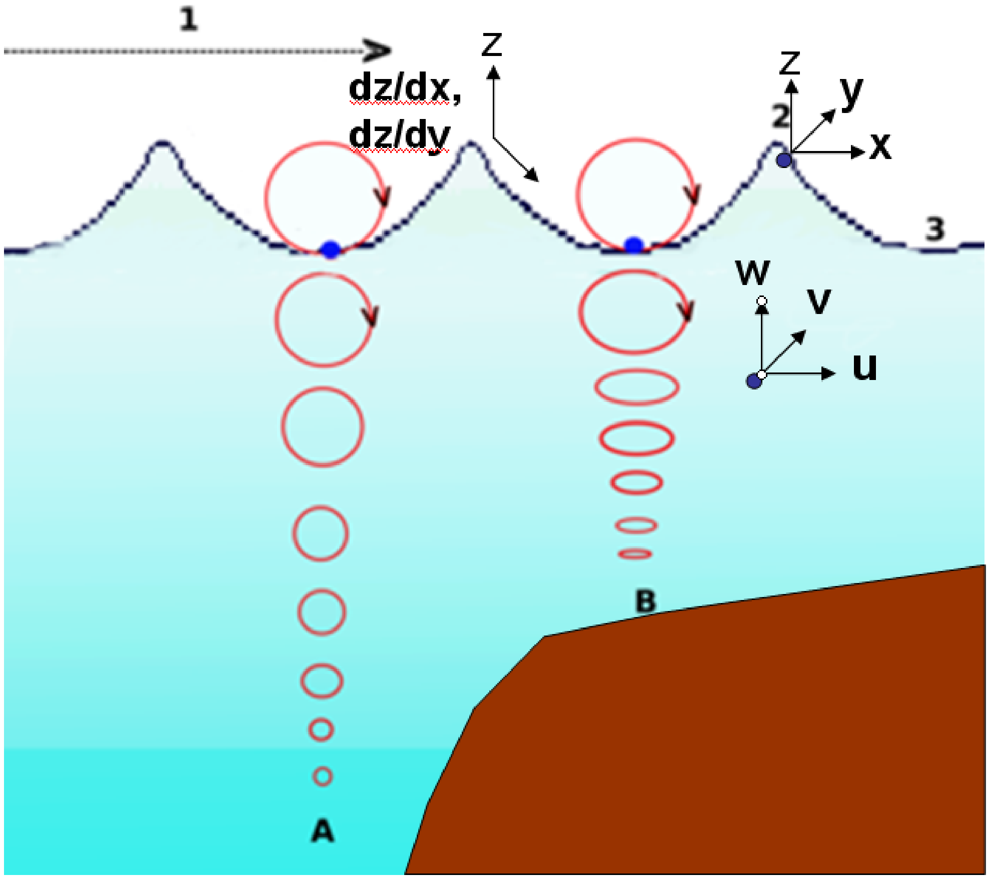
- Measurements of surface gravity waves are **estimates**
  - From accelerations (double integrated)
  - From pressure response (invert to free surface)
  - From x,y velocities (invert to free surface)

- Only direct measurement of waves:
  - From capacitance or resistance gauges
  - From photo analysis

- Signal to noise:
  - Contamination of wave records
  - Compliance for universal criteria
    - Reduces uncertainty in wave measurements
      - Provides consistency
      - Device to device
      - Underlying processes correctly evaluated

Seeking Ground Truth

The Basics: Estimating the Motion of a Sea Surface Particle



<u>The Big 3</u>

X, Y, Z

Pressure Sensors
Accelerometers
Tilt sensors
Angular Rate Sensors
Acoustic Sensors
GPS

Seeking Ground Truth: Deepwater

- Buoy motion ~ Free surface response = Waves

“Directional wave information is derived from buoy motions, the power transfer functions and phase responses associated with the buoy, mooring, and measurement systems play crucial roles in deriving wave data from buoys.”

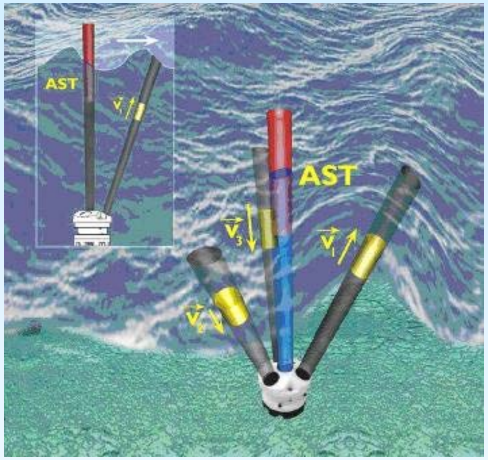
This dependence is particularly important at low energy levels and at both short and long wave periods where the wave signal being measured is weak and potential for added signal contamination increases.

Deepwater: Buoys

- Impact is universal and dependent on buoy/device:
  - Non-directional buoys
    - 10% differences between US and Canadian NOMAD buoys compared to altimeter records?
  - Directional buoys
    - Indicated in higher order moments
      - Mean wave direction
      - Directional spread
      - Skewness
      - Kurtosis

Shallow water

- Shallow water:
  - Pressure sensors + PUV's
  - Acoustic profilers (ADCP/AWAC)
  - Probes
  - Buoys



- Water depth acts as high pass filter
  - Deeper deployment reduction in high frequency response
  - Shallower deployment adds to nonlinearities
  - Surf zone introduces uncertainty in the free surface

Need for Compliance

US Existing Measurement Site Evaluation

2007

Table 1. Summary of Existing Wave Observation Platforms

Region	12 m & 10 m Discus	6-m NOMAD	3-m Discus: Hippy	3-m Discus: Angular Rate	3-m Discus: Magnetometer	3-m Discus: Strapped Down Accelerometer	Other Buoy Configurations: 2.0 m	Other Buoy Configurations: 1.8 m	Other Buoy Configurations: 1.7 m	Other Buoy Configurations: 1.1 m	Other Buoy Configurations: Waverider	Shallow: Pressure	Shallow: Acoustic
Atlantic Coast													
Non-Directional	2	10(1)				7	11					3	
Directional			2	6				5		2	4	1	7
Gulf of Mexico													
Non-Directional													
Directional	5			2	5			4			1		5
Pacific Coast													
Non-Directional	2	4(1)				6						1	
Directional			5	8		3					21		
Alaska													
Non-Directional	2	15(2)				2(3)							
Directional								3					
Pacific Islands													
Non-Directional		3											
Directional			2								4		1
Great Lakes													
Non-Directional						3(6)			(2)				
Directional				1	5								
Caribbean													
Non-directional		6											
Directional	2												
Total	13	38(4)	9	17	10	21(9)	11	12	(2)	2	30	5	13

Note: Number of Canadian sites is given in parentheses; these are not included in the totals

We are seeking a uniform evaluation procedure

First-5 Basics

- First-5 Basics
  - Three components (x,y,z or derivatives)
  - Time series analysis
  - Results in S(f), a1(f), b1(f), a2(f), b2(f)

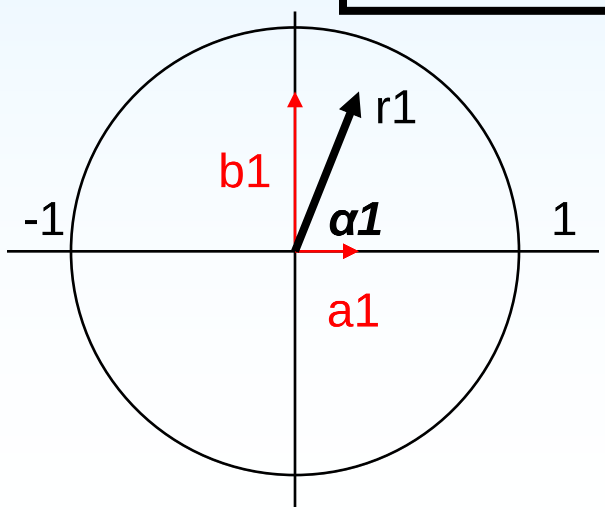
freq Hz	Band width	energy m*m/Hz	Dmean deg	a1	b1	a2	b2
0.0250	0.0050	0.0028	321	0.1920	-0.1567	-0.3925	-0.6345
0.0300	0.0050	0.0035	115	-0.1076	0.2259	-0.5132	-0.5796
0.0350	0.0050	0.0046	173	-0.2883	0.0348	-0.2973	-0.5084
0.0400	0.0050	0.0062	303	0.2602	-0.4085	-0.1606	-0.6449
0.0450	0.0050	0.0106	241	-0.0693	-0.1232	0.1890	-0.4245
0.0500	0.0050	0.0664	295	0.2434	-0.5111	-0.0182	-0.3324
0.0550	0.0050	0.4436	272	0.0230	-0.8426	-0.5614	-0.1069
0.0600	0.0050	2.4041	287	0.2594	-0.8467	-0.6409	-0.3178
0.0650	0.0050	4.6515	295	0.3985	-0.8367	-0.5535	-0.6727
0.0700	0.0050	5.2446	298	0.4468	-0.8304	-0.4730	-0.7269
0.0750	0.0050	1.9294	310	0.5513	-0.6680	-0.2944	-0.7509
0.0800	0.0050	1.4582	349	0.7292	-0.1430	0.2632	0.0403
0.0850	0.0050	2.5656	328	0.7689	-0.4840	0.2847	-0.6974
0.0900	0.0050	0.6455	352	0.7463	-0.1086	0.4258	-0.0207
0.0950	0.0050	0.6295	329	0.7213	-0.4297	0.2088	-0.6399
0.1013	0.0075	0.7499	0	0.6994	0.0019	0.2030	0.0206
0.1100	0.0100	0.5782	27	0.6616	0.3353	0.1029	0.4937
0.1200	0.0100	0.3596	23	0.7253	0.3028	0.2794	0.4324
0.1300	0.0100	0.1433	10	0.5246	0.0925	0.1332	-0.0804
0.1400	0.0100	0.0918	11	0.5567	0.1123	0.2326	0.1826
0.1500	0.0100	0.1041	17	0.6158	0.1886	0.2376	0.2832
0.1600	0.0100	0.0779	6	0.5846	0.0592	0.0527	0.2101
0.1700	0.0100	0.0458	11	0.4591	0.0926	-0.0412	0.1988

a1,b1,a2,b2

- mean direction
- directional spread
- skewness
- kurtosis

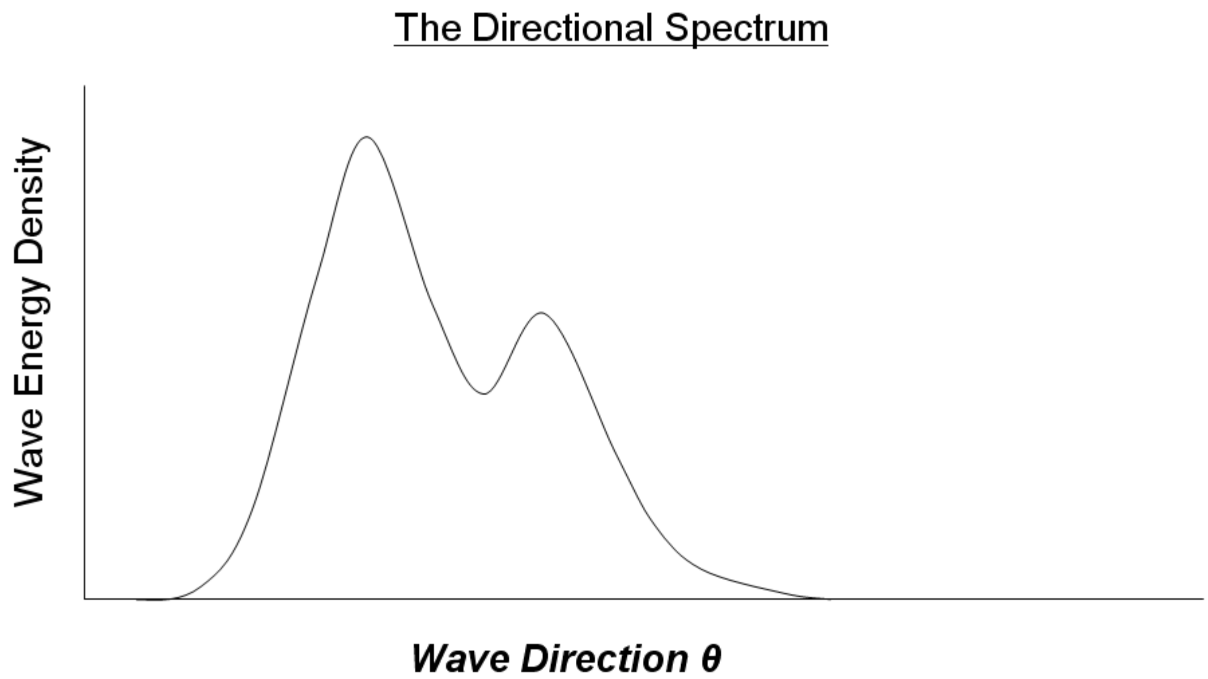
or, in NDBC format

- first-moment mean direction (α*1*)
- first-moment spread parameter (*r1)*
- second-moment mean direction (α*2*)
- second-moment spread parameter (*r2)*



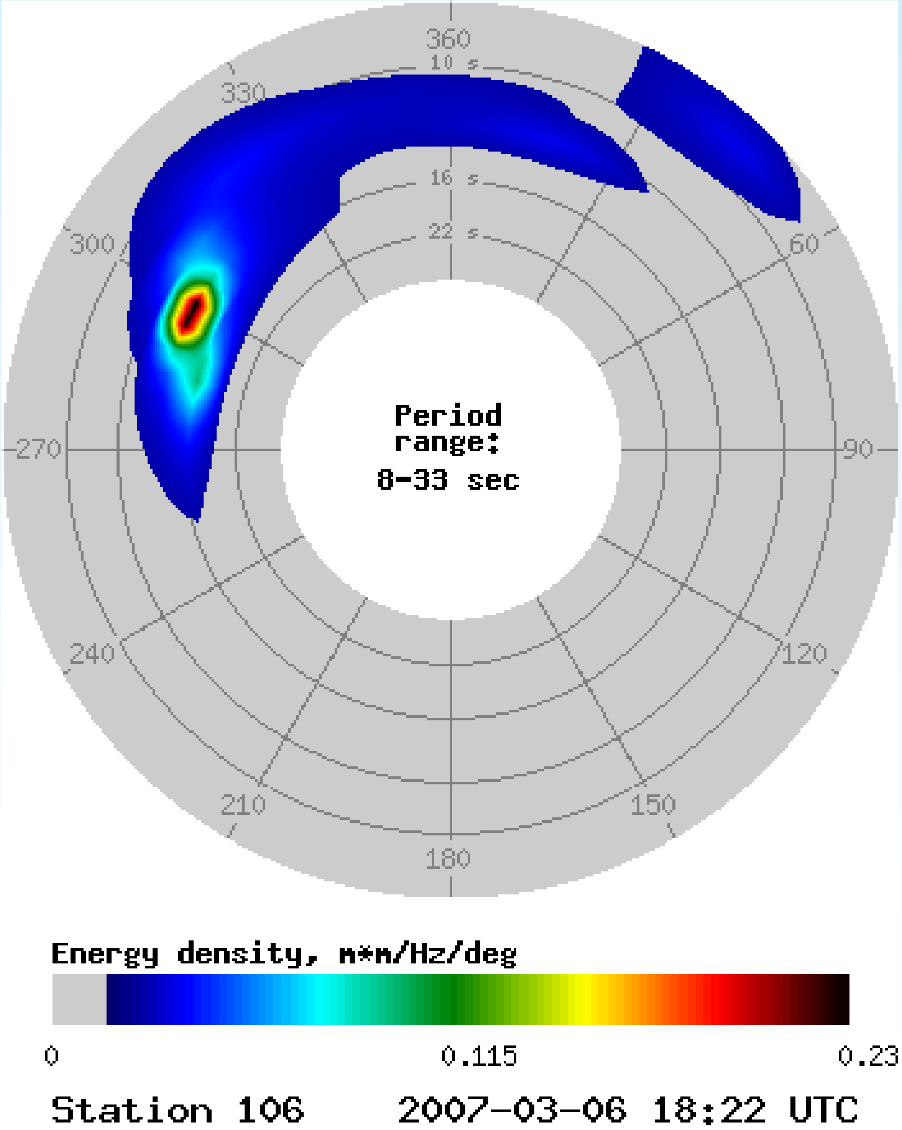
First-5 Basics

The Outcome and Minimum Requirements for Directional Observations



$$S(f.\theta)=S(f)[\mathbf{a1}\cdot\cos(\boldsymbol{\theta})+\mathbf{b1}\cdot\sin(\boldsymbol{\theta})+\mathbf{a2}\cdot\cos(\mathbf{2\theta})+\mathbf{b2}\cdot\sin(\mathbf{2\theta})+\mathbf{a3}\cdot\cos(\mathbf{3\theta})+\mathbf{b3}\cdot\sin(\mathbf{3\theta})+\mathbf{a4}\cdot\cos(\mathbf{4\theta})+\mathbf{b4}\cdot\sin(\mathbf{4\theta})+\ldots\ldots\ldots\ldots\ldots\ldots\text{infinity and beyond}]$$

First-5 Basics



Data Users & Measurement Accuracy

Dominant Wave Users

S(f),

θ_1 @ f-peaks

Generally tolerant of errors

Wave Component Users

First-5

Need a wave component approach to evaluating instrument performance.

Evaluation Procedure

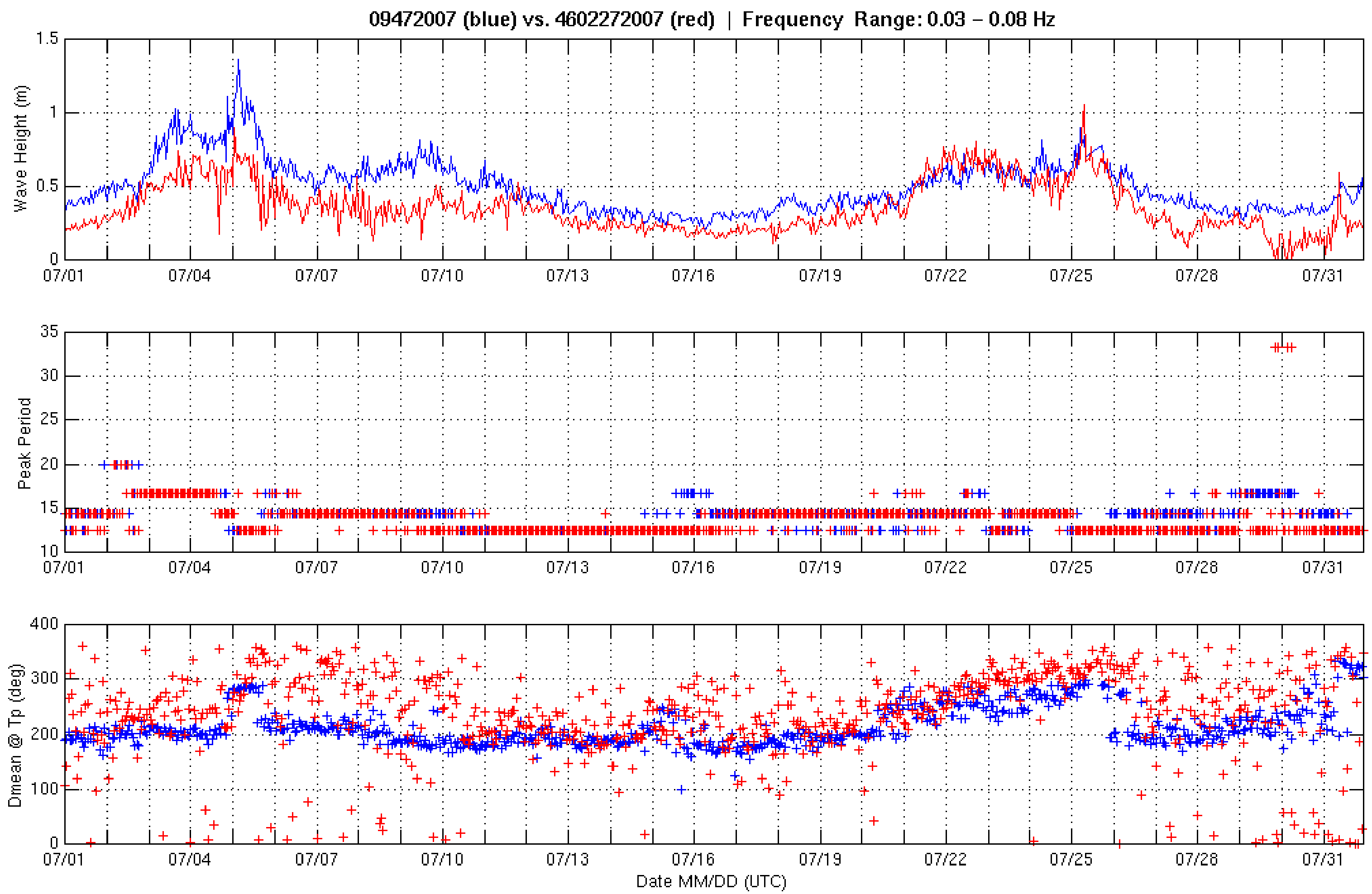
- Datawell Mark III as standard for analysis

  This does not mean all directional wave measurements are required to be derived from Datawell Mark III buoys

- Co-Located Procedure
  - Period of record consistent
    - Time consistency between devices
    - Similar geographic/hydrographic
  - Analysis based on First-5
    - NOTE: S(f) is 1st of 5

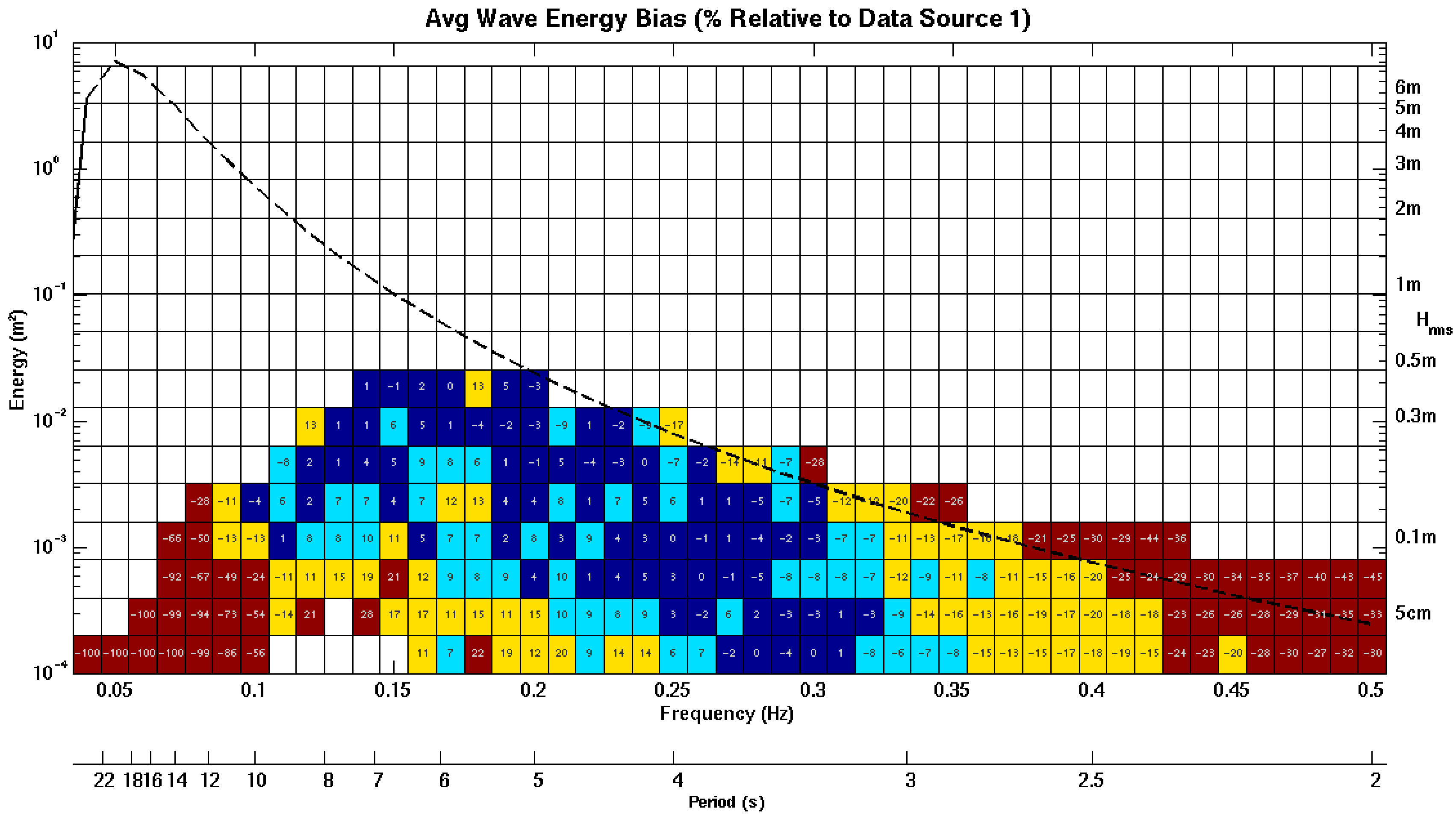
Evaluation Procedure: Co-located

Analysis in the time domain by frequency criteria



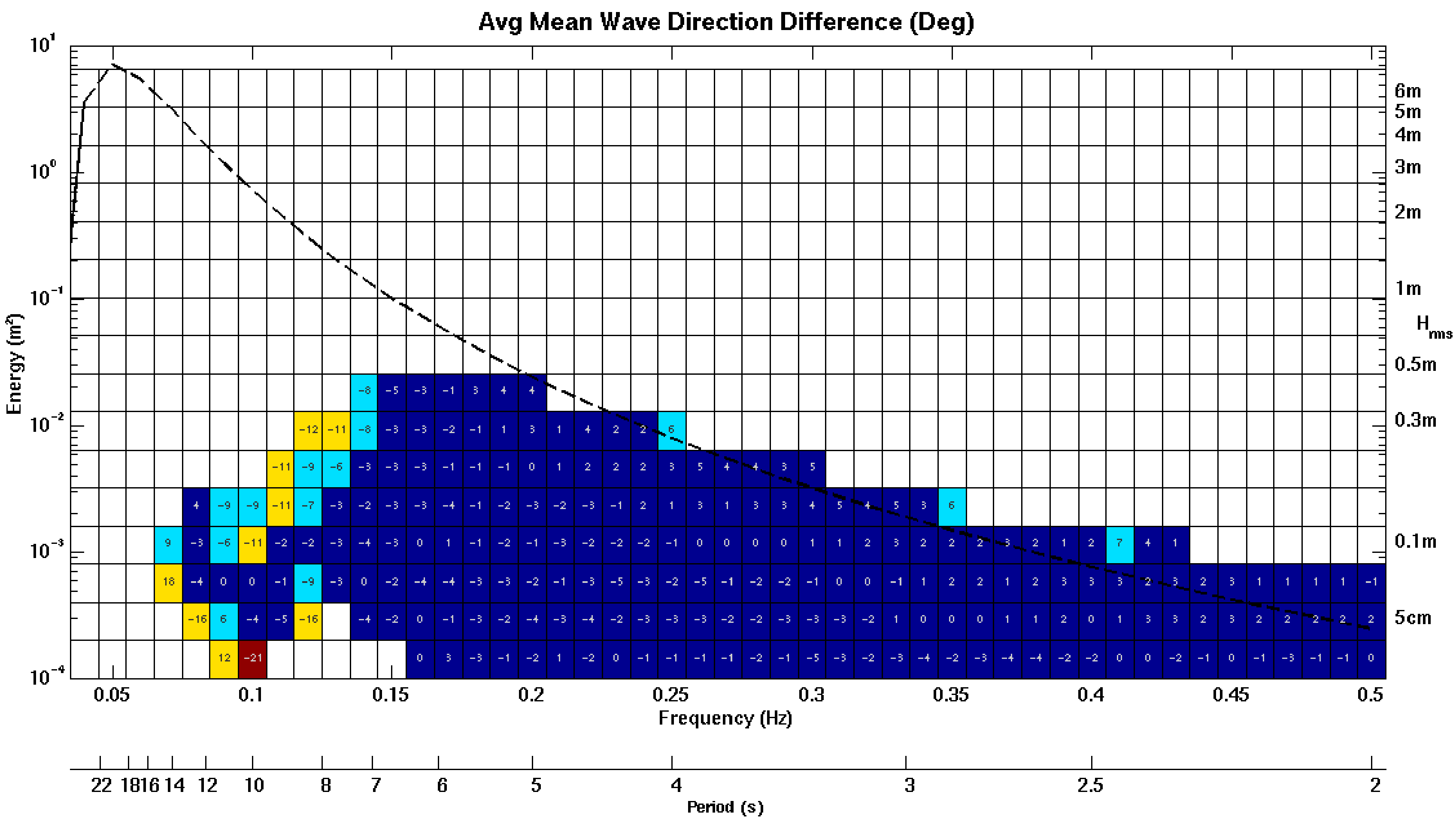
Evaluation Procedure: Co-located

Analysis in the frequency domain by moments



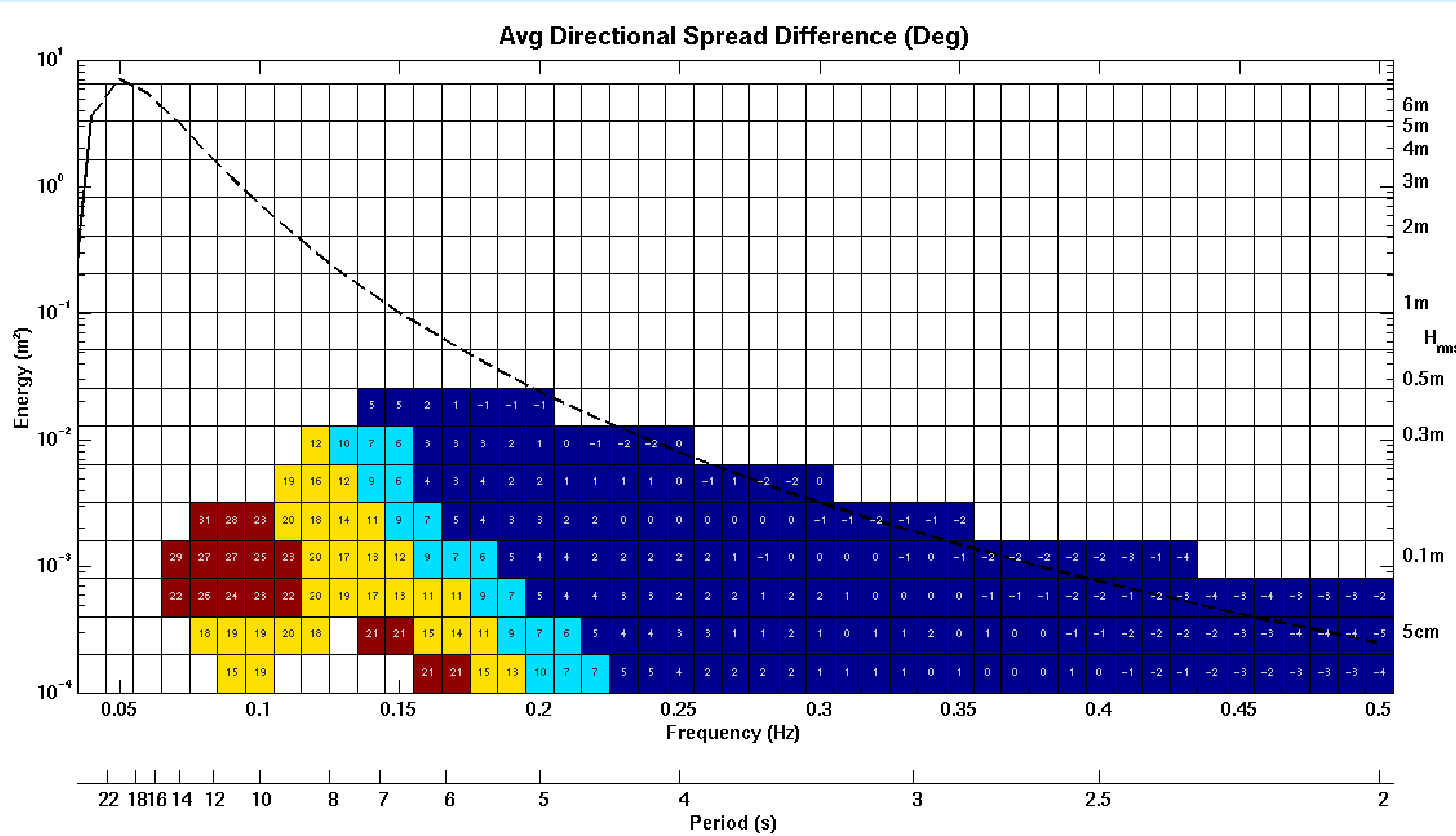
Evaluation Procedure: Co-located

Analysis in the frequency domain by moments



Evaluation Procedure: Co-located

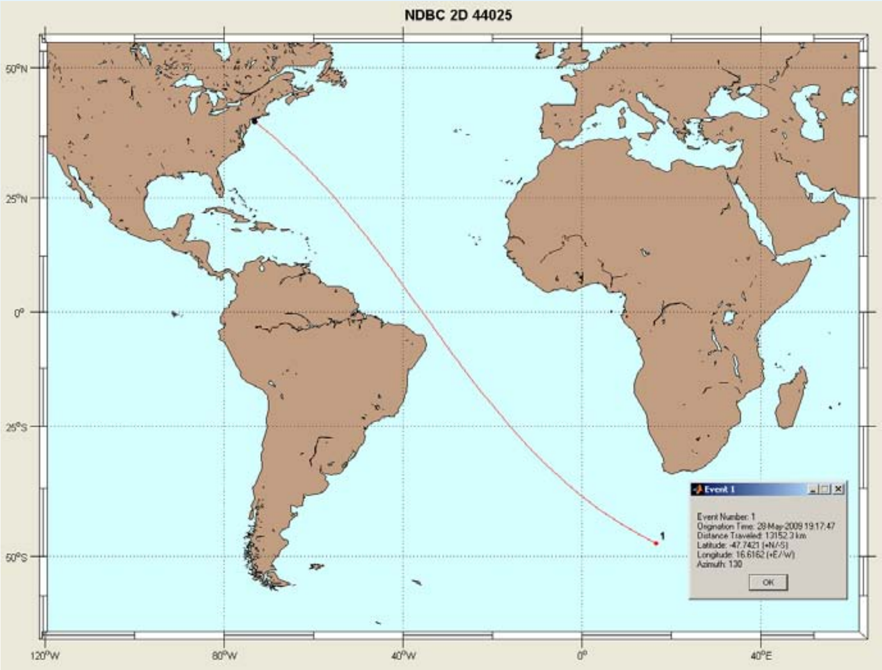
Analysis in the frequency domain by moments



Evaluation Procedure 2

FIND STORM

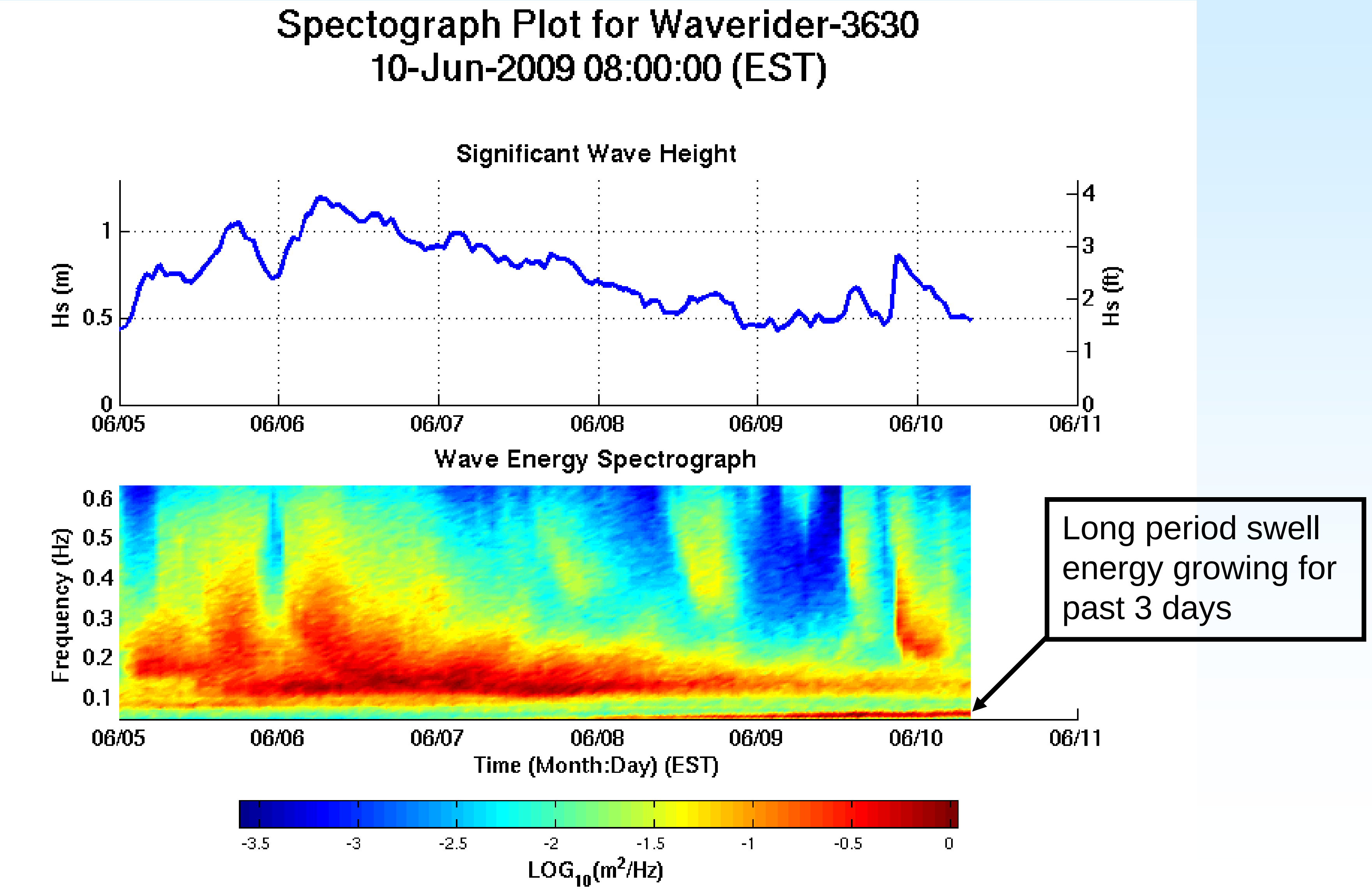
- Wave System Approach
  - Wave components
    - Analysis: frequency ranges for specific events
    - Looking for clean swell wave events
      - Hurricanes
      - Southern hemisphere storms
      - Decaying N'Easters
  - Period of record similar



Jeff Hanson/ERDC-CHL: IMEDS

Evaluation Procedure 2

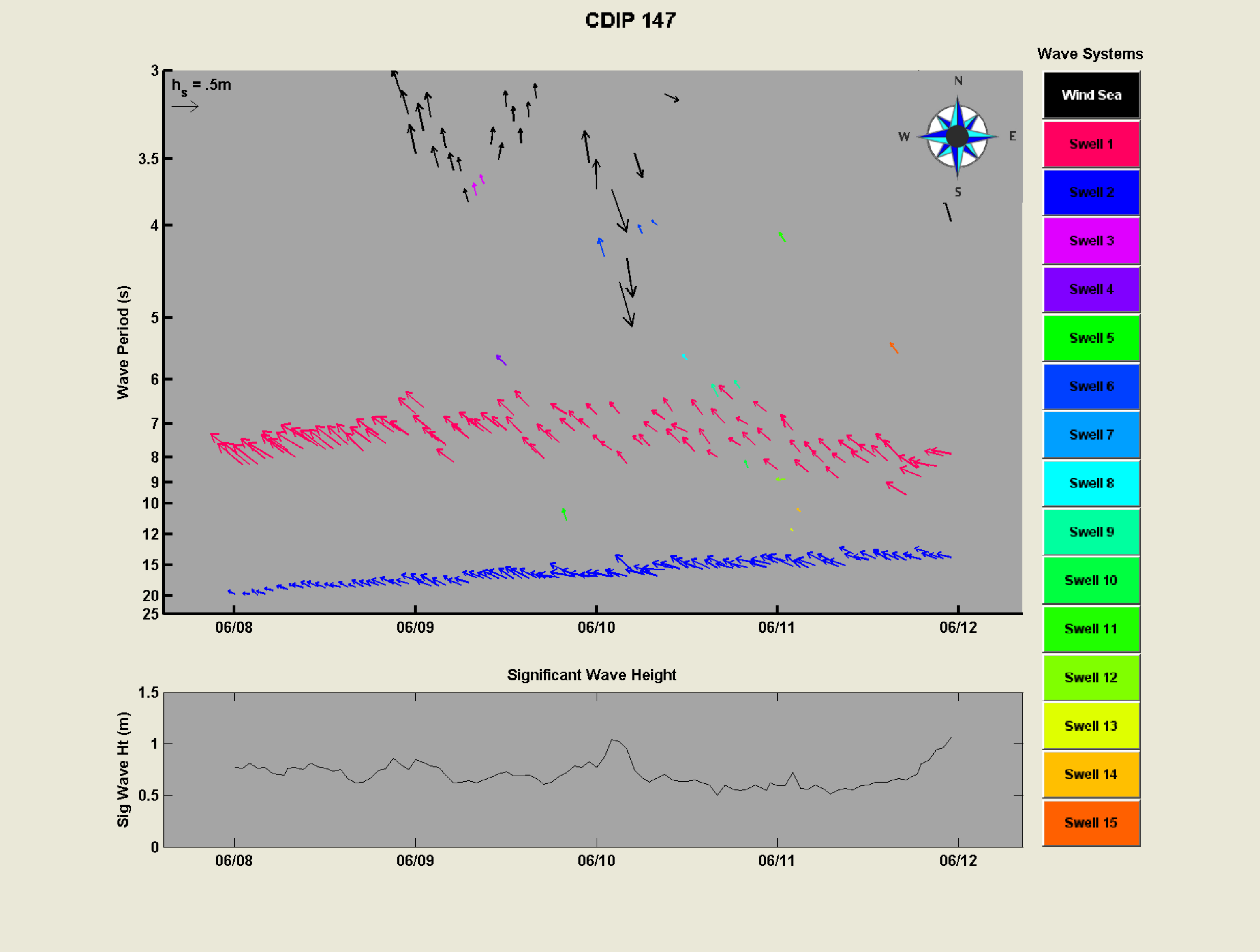
FIND RANGE



Evaluation Procedure 2

ANALYZE

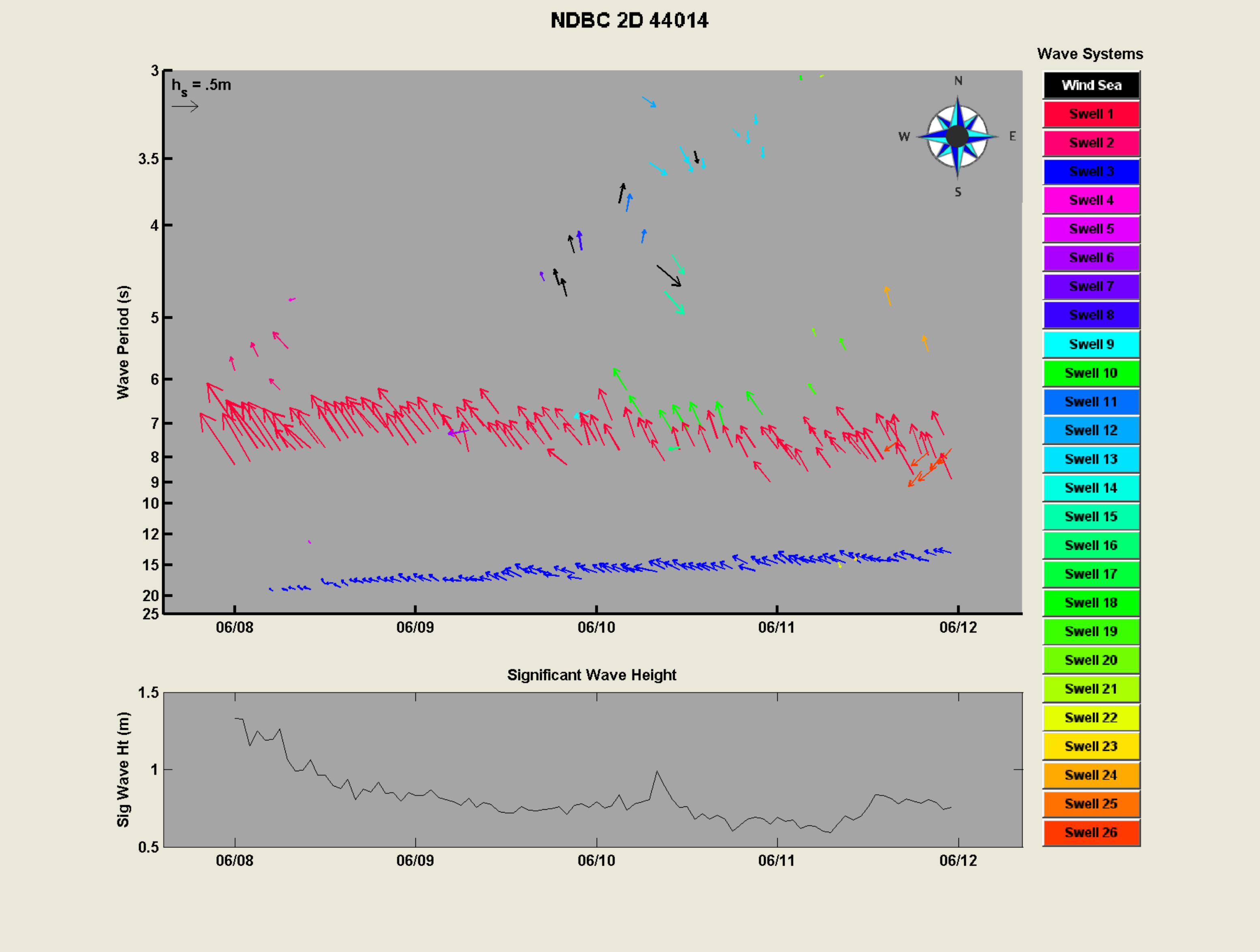
HIPPY



Evaluation Procedure 2

COMPARE

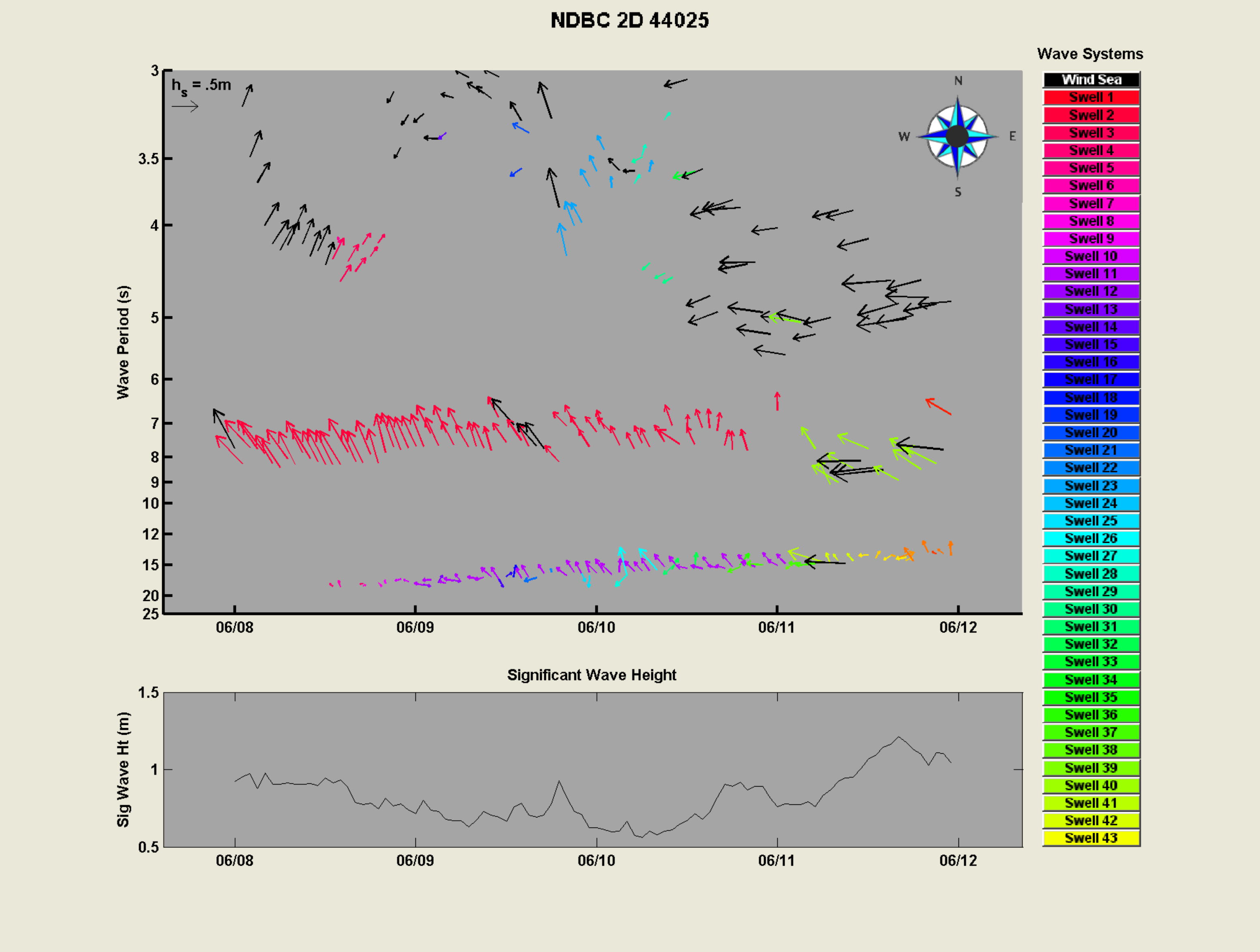
HIPPY



Evaluation Procedure 2

COMPARE

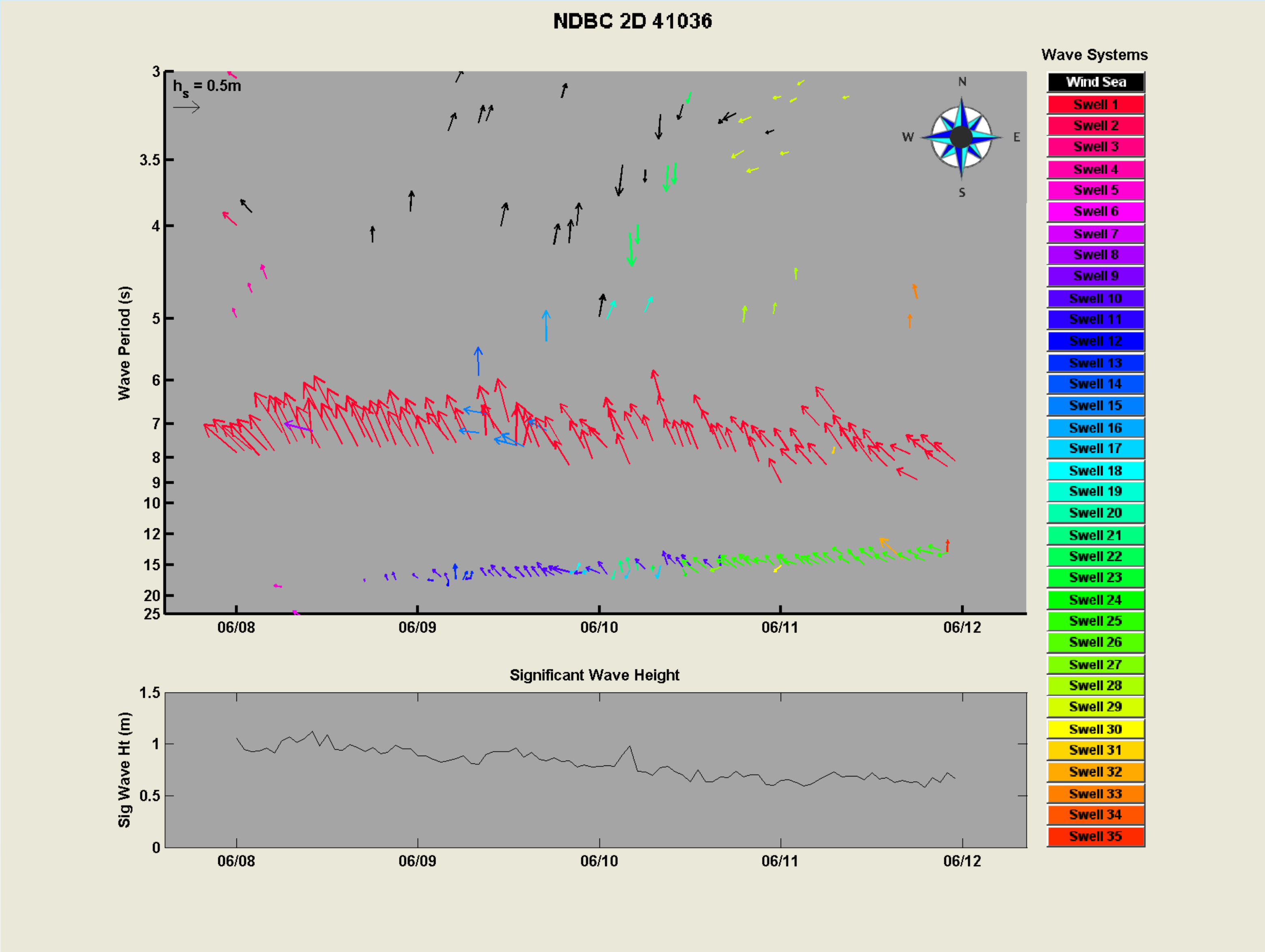
3DM



Evaluation Procedure 2

COMPARE

ARS



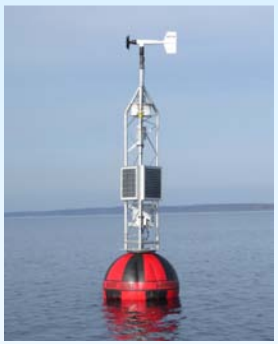
Summary

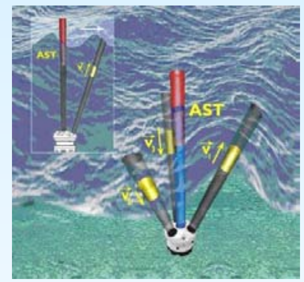
- There are a variety of wave measurement assets globally
  - Limited testing and evaluation performed to a baseline
  - Have limited performance metrics for directional measurements
- We need to test and evaluate based on one standard
  - Datawell Mark III Series
  - This does NOT mean all directional buoys need to be Datawell's

Summary

- Our goal is to evaluate based on First-5 principles
  - Endorsed by
    - NOAA-IOOS http://ioos.gov/program/wavesplan.html
    - USACE
    - AES: procured Datawell Directional Waveriders
    - JCOMM: PP-WET/DBCP
      - http://www.jcomm.info/index.php?option=com_content&task=view&id=62
    - OceanSITES: add directional wave measurements
    - NDBC: procured Datawell Directional Waveriders
  - Non-directional wave measurement evaluation included
  - Compliance for universal criteria
    - Reduces uncertainty in wave measurements
    - Provides consistency
    - Device to device
    - Underlying processes correctly evaluated

Questions ?





Bias in wave height measurements