Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology

Wave Measurement Evaluation and Testing

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Scientific and Technical Workshop of the Data Buoy Cooperation Panel

28 September 2009

Paris, FRANCE

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Outline

- Motivation: Why Test?
- Historical Perspectives
  - Deepwater
  - Shallow-water
- First-5 Approach
- Evaluation Procedure
  - Co-located
  - Wave system evaluation
- Summary

Why Do We Need to Test and Evaluate

- 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

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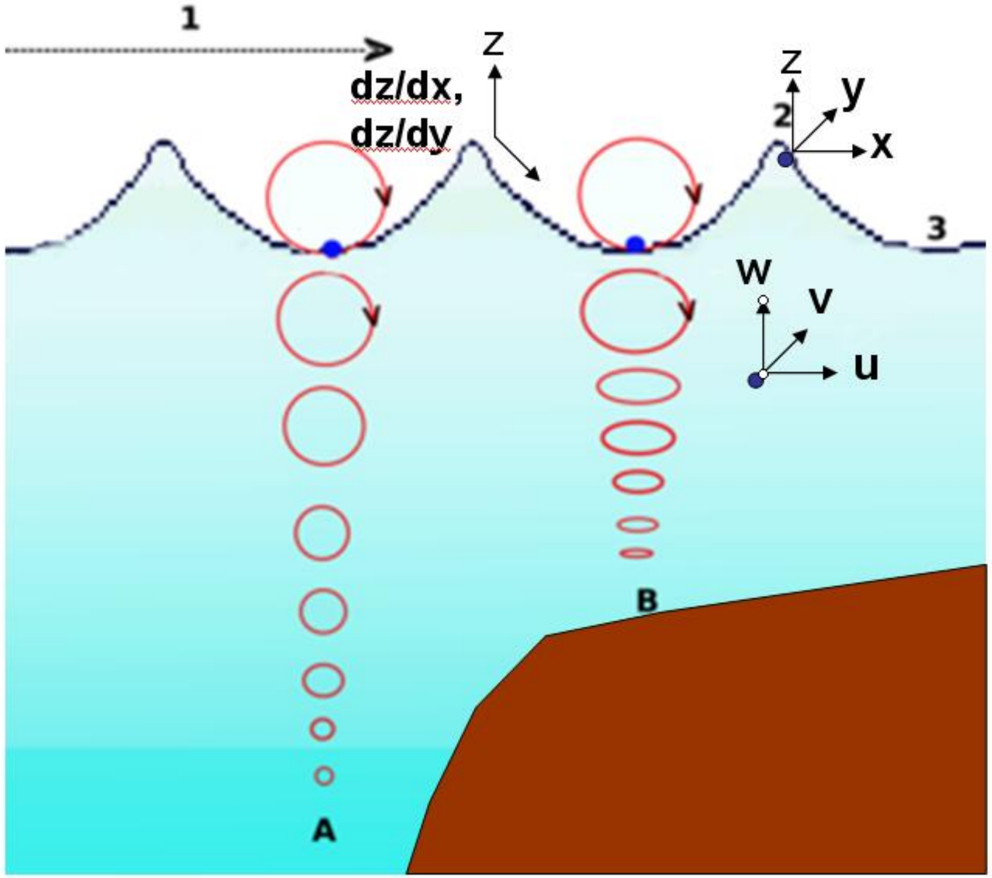
Why Do We Need to Test and Evaluate

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

Deepwater: Wave Buoys

- 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.

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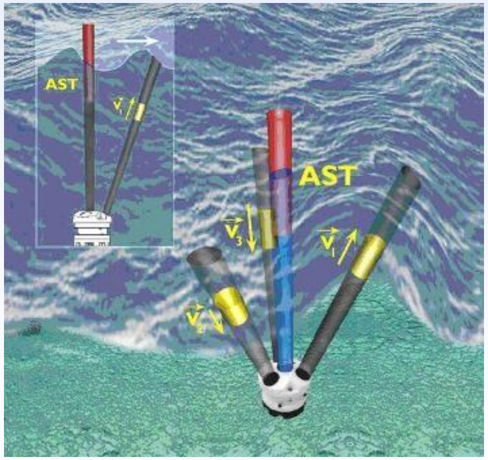
Deepwater: Wave Buoys

- 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

Table 1. Summary of Existing Wave Observation Platforms

Region	12 m & 10 m Discus	6-m NOMAD	3-m Discus				Other Buoy Configurations					Shallow	
			Hippy	Angular Rate	Magnetometer	Strapped Down Accelerometer	2.0 m	1.8 m	1.7 m	1.1 m	Waverider	Pressure	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

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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	-0.7309
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

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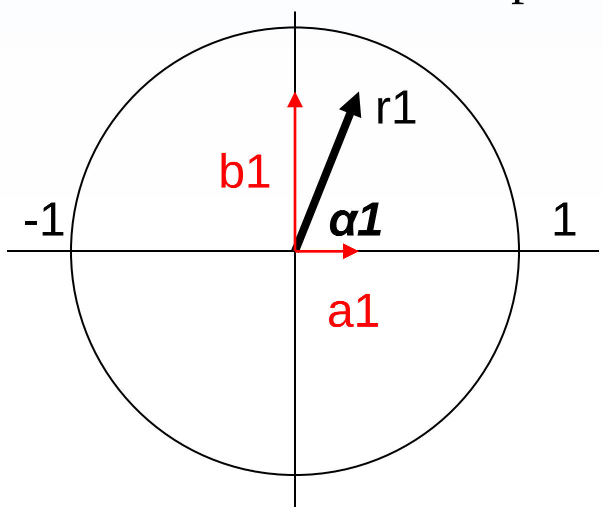
First-5 Basics

a1,b1,a2,b2

- mean direction
- directional spread
- skewness
- kurtosis

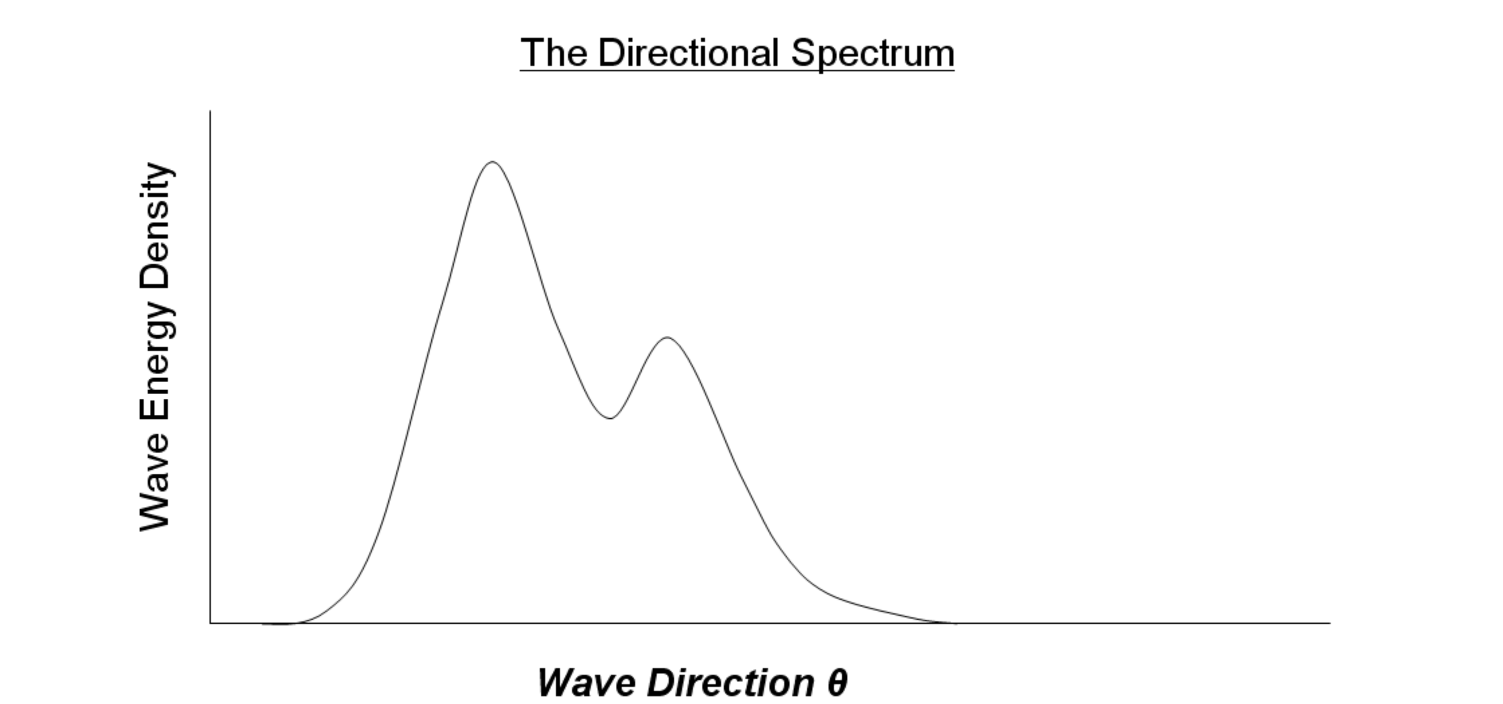
or, in NDBC format

- first-moment mean direction ($\alpha 1$)
- first-moment spread parameter (*r1*)
- second-moment mean direction ($\alpha 2$)
- second-moment spread parameter (*r2*)



First-5 Basics

The Outcome and Minimum Requirements for Directional Observations



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

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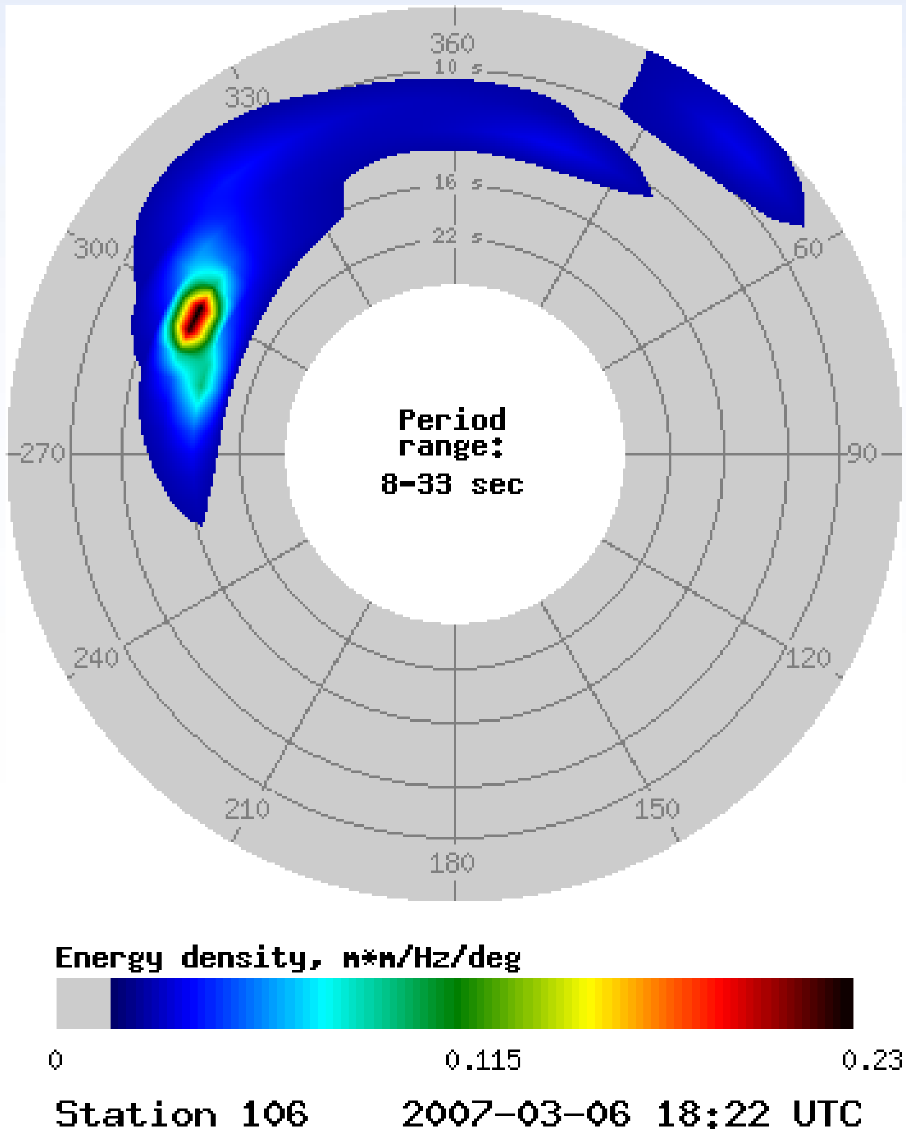
First-5 Basics



Data Users & Measurement Accuracy

Dominant Wave Users

S(f),
$\boldsymbol{\theta_1}$ @ f-peaks

Generally tolerant of errors

Wave Component Users

First-5

Need a wave component approach to evaluating instrument performance.

Evaluation Procedure

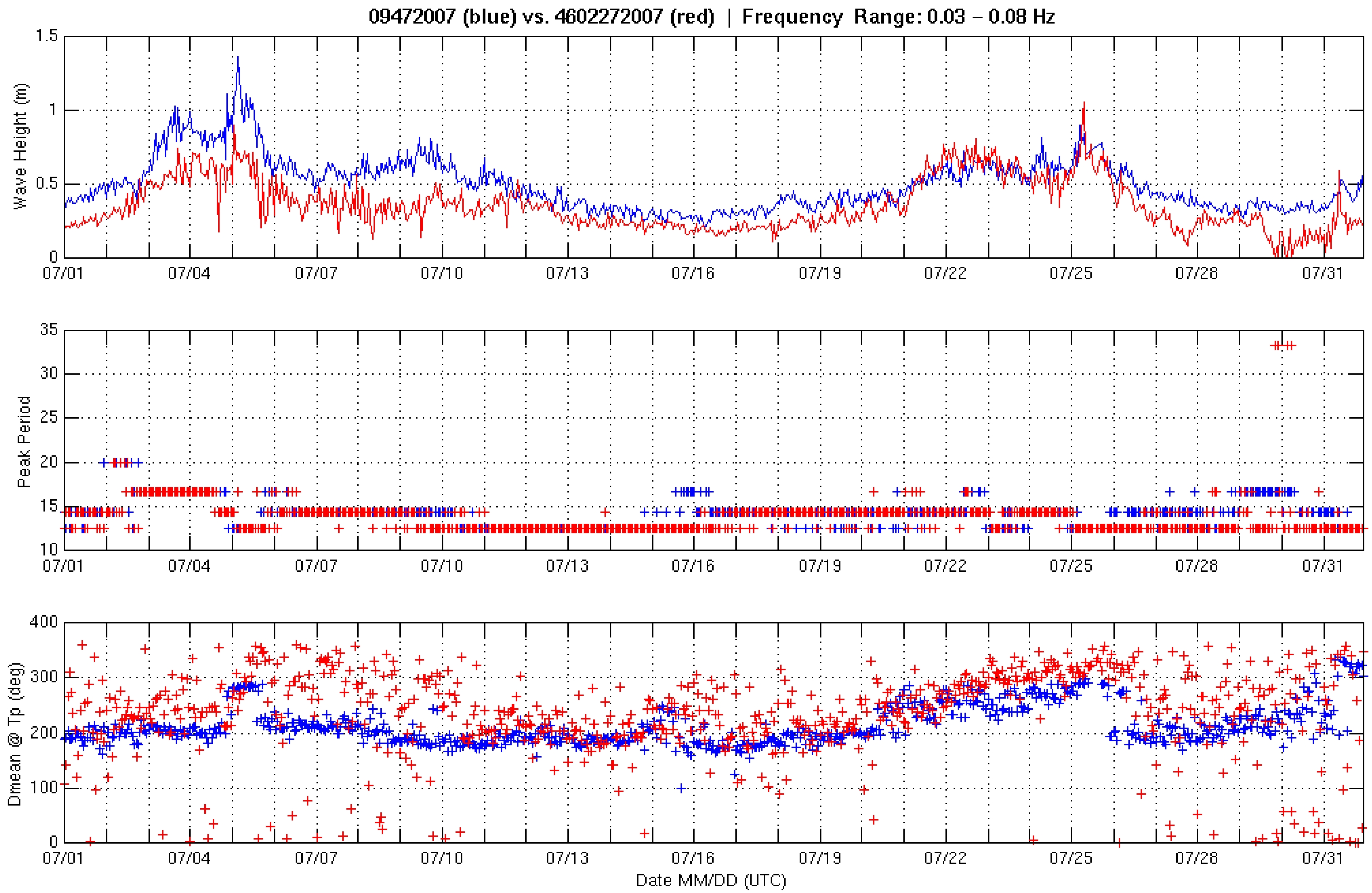
- Datawell Mark III as standard for analysis

  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

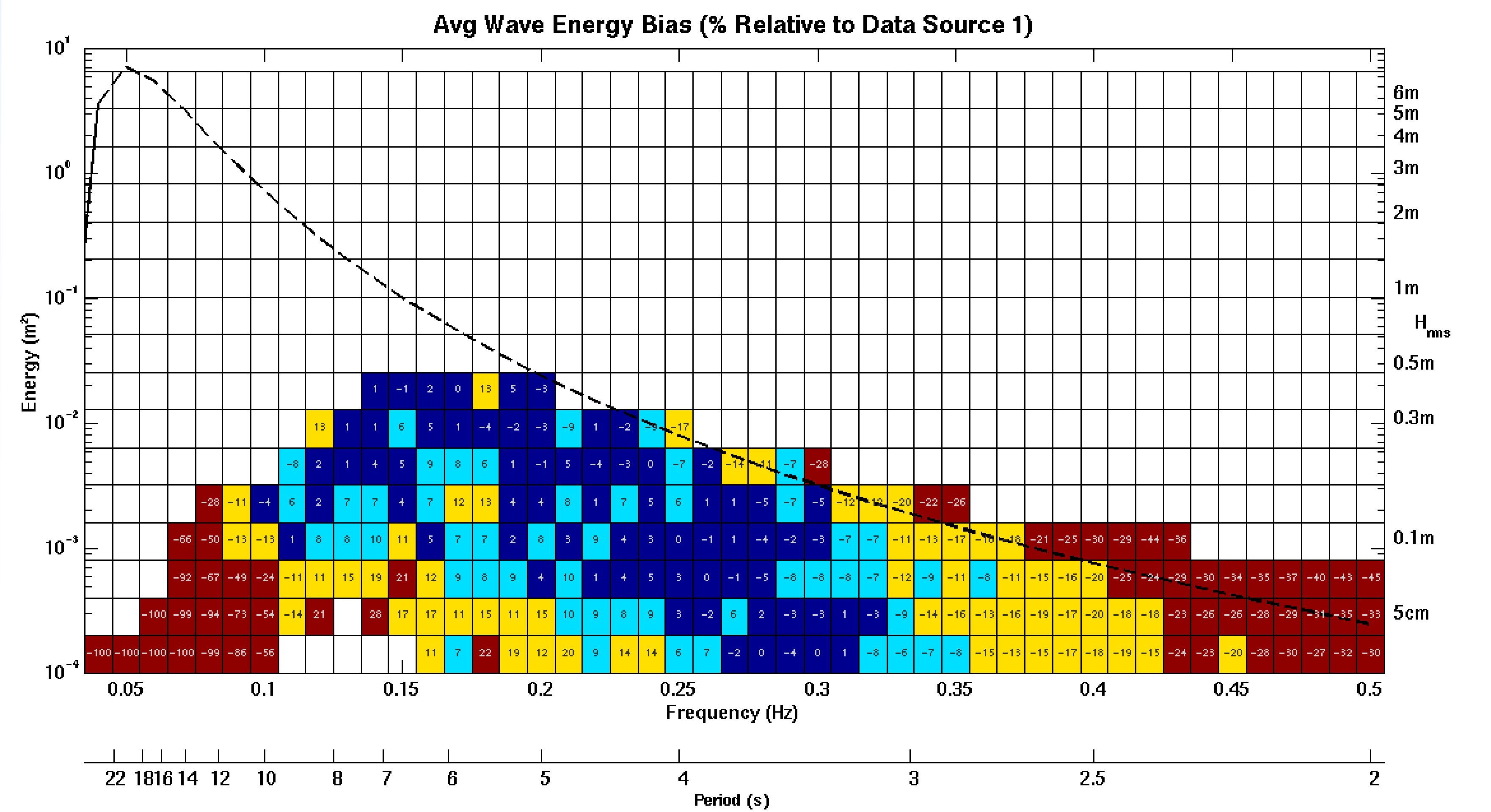
Evaluation Procedure: Co-located

Analysis in the time domain by frequency criteria



Evaluation Procedure: Co-located

Analysis in the frequency domain by moments



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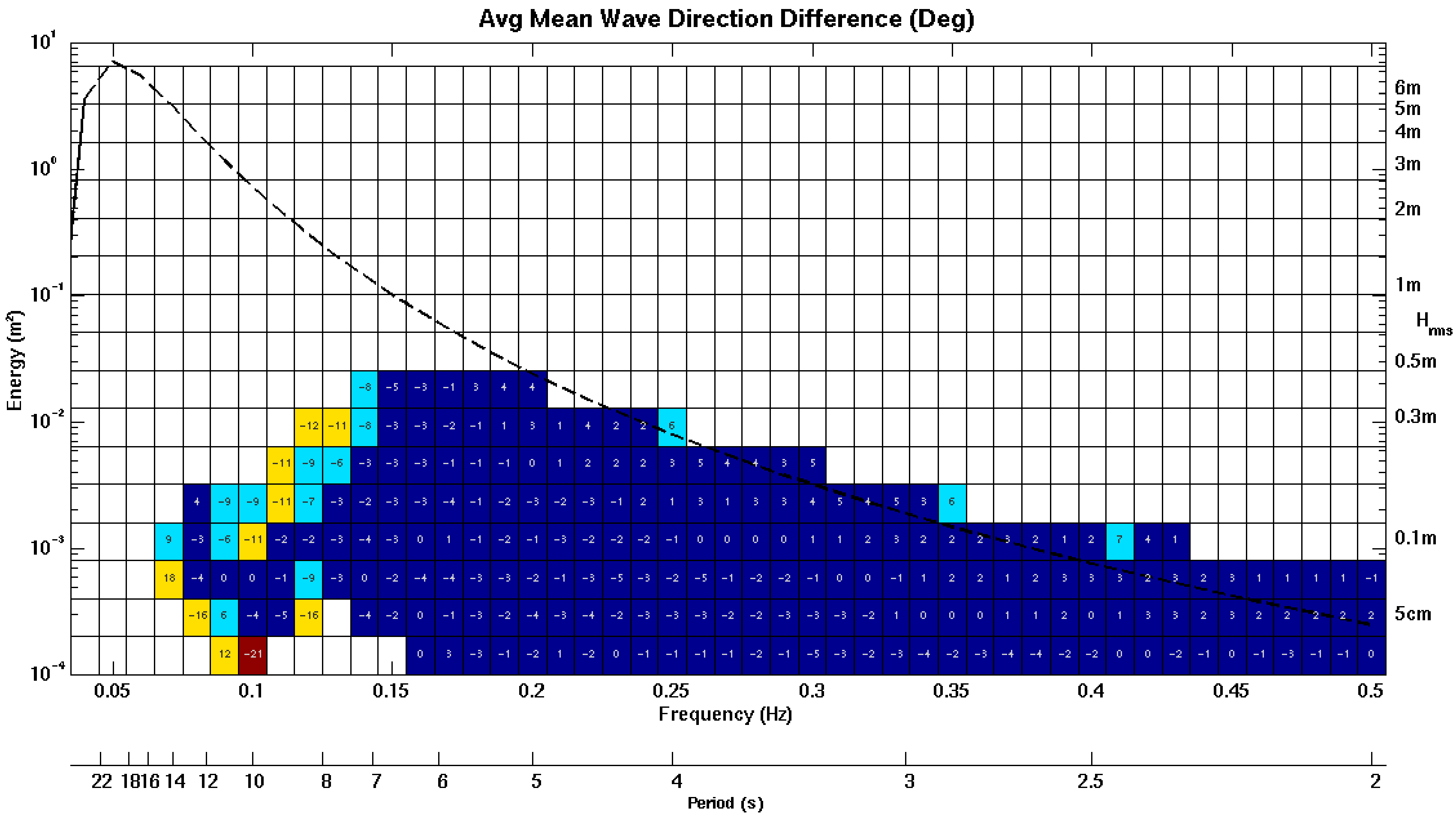
Evaluation Procedure: Co-located

Analysis in the frequency domain by moments



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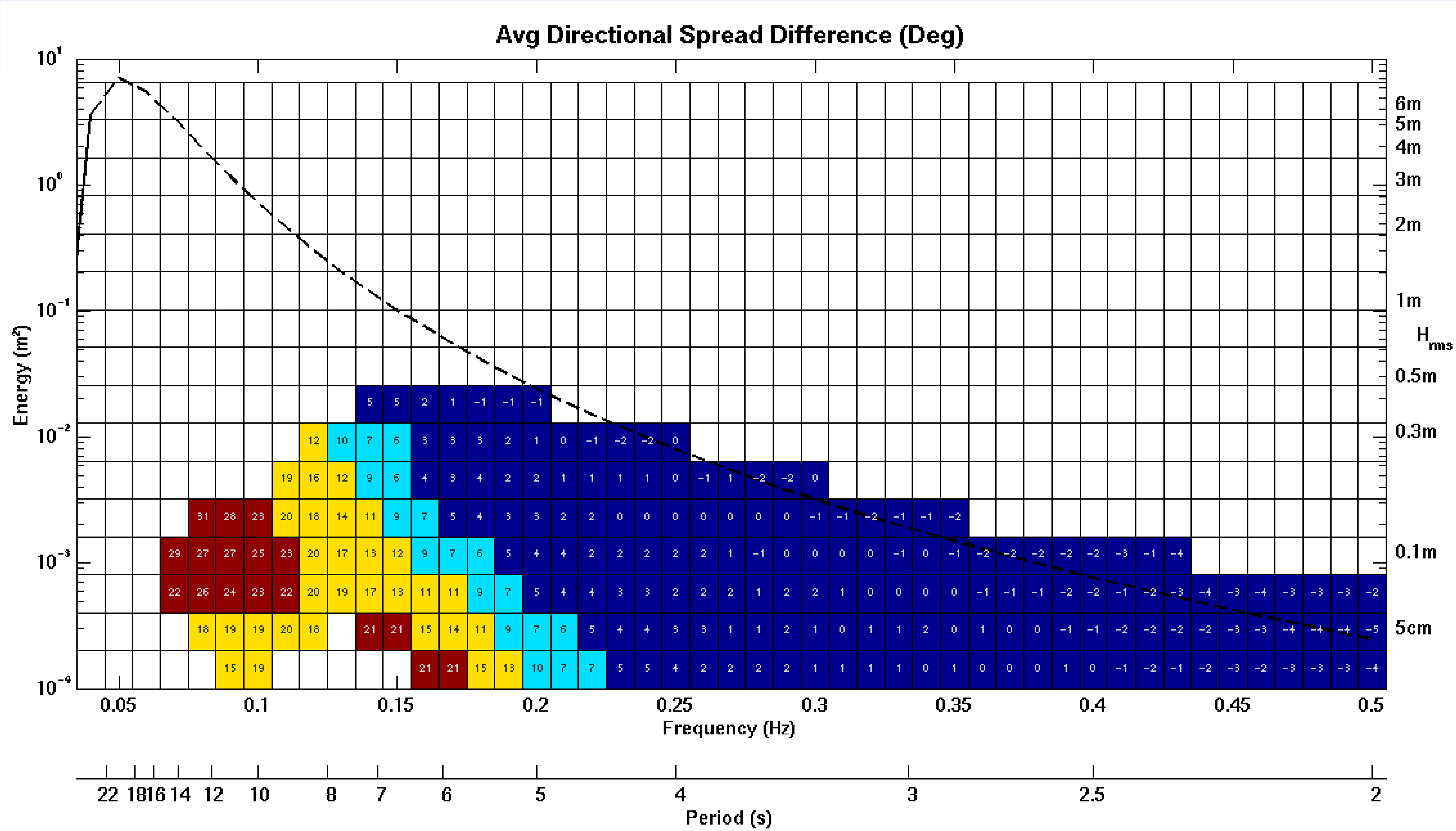
Evaluation Procedure: Co-located

Analysis in the frequency domain by moments



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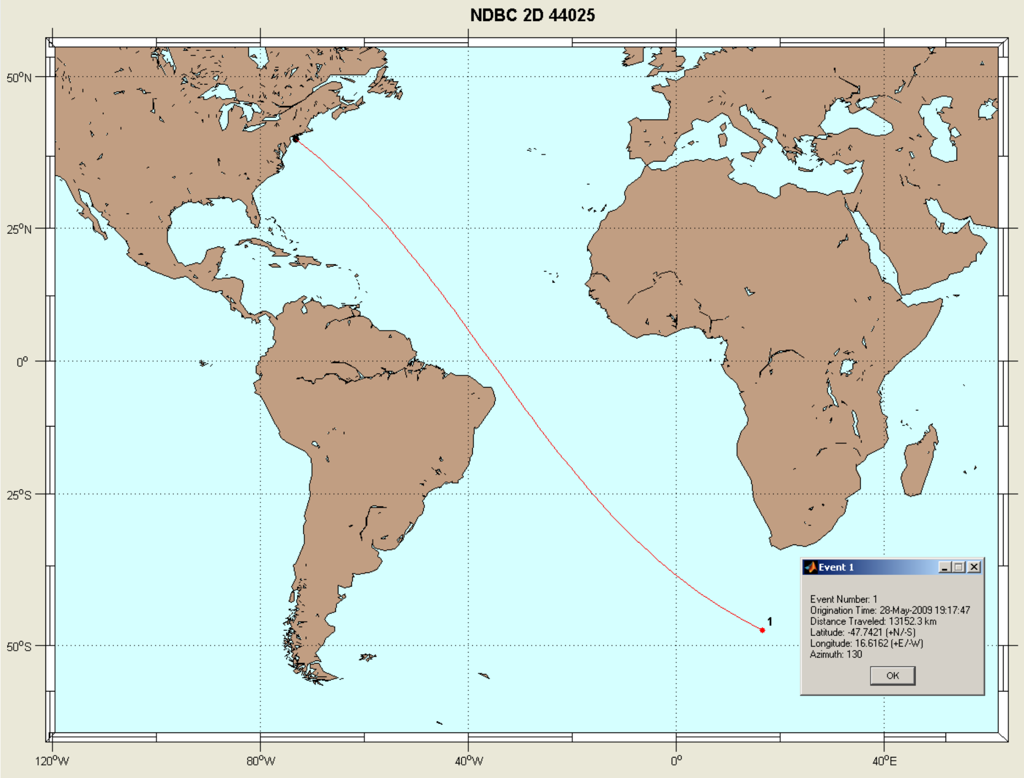
Evaluation Procedure 2

- Wave System Approach
  - Wave component similar
    - Analysis based on frequency ranges for specific events
  - Period of record approximate
  - Analysis based on First-5
    - NOTE: S(f) is 1st of 5



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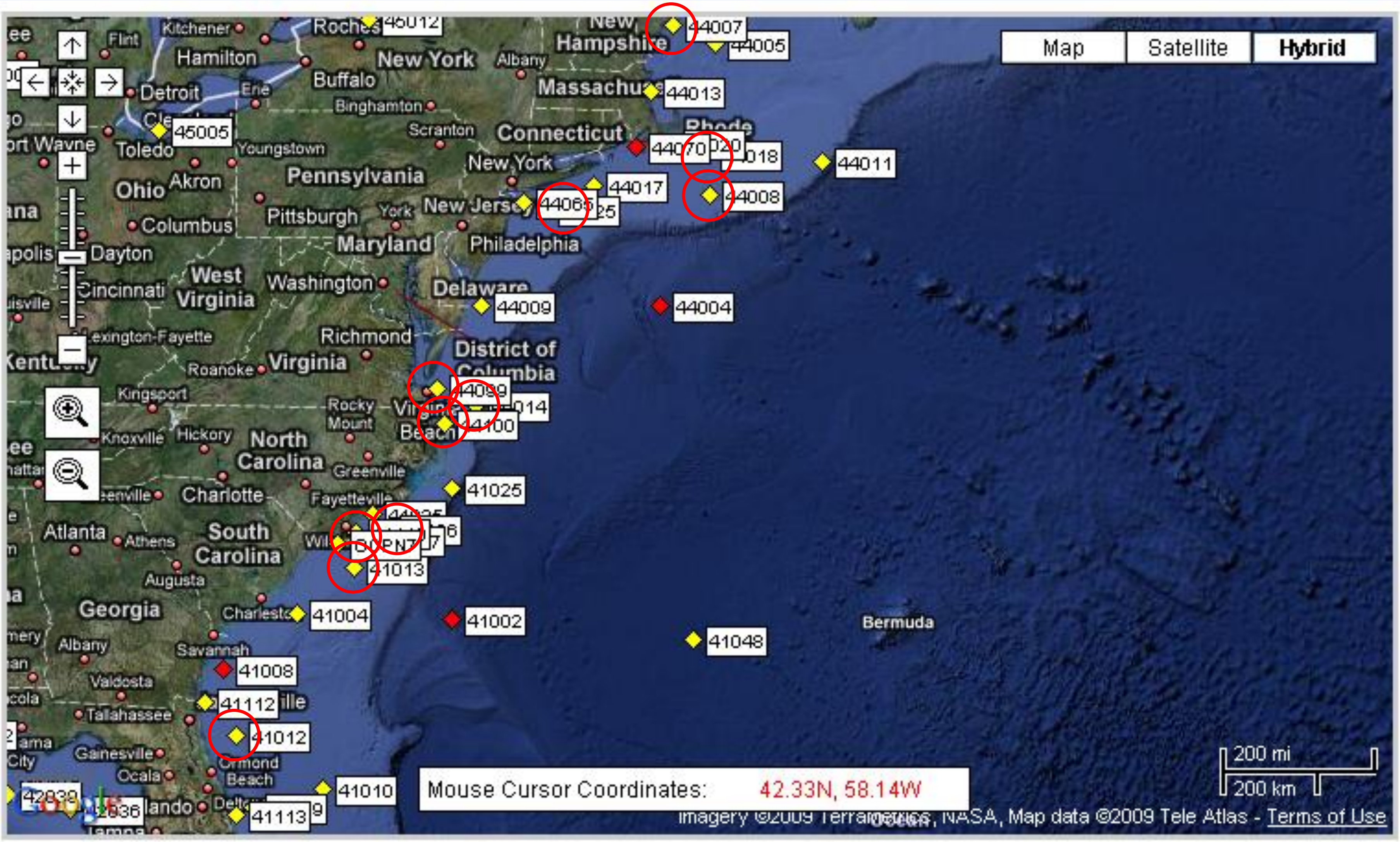
Evaluation Procedure 2



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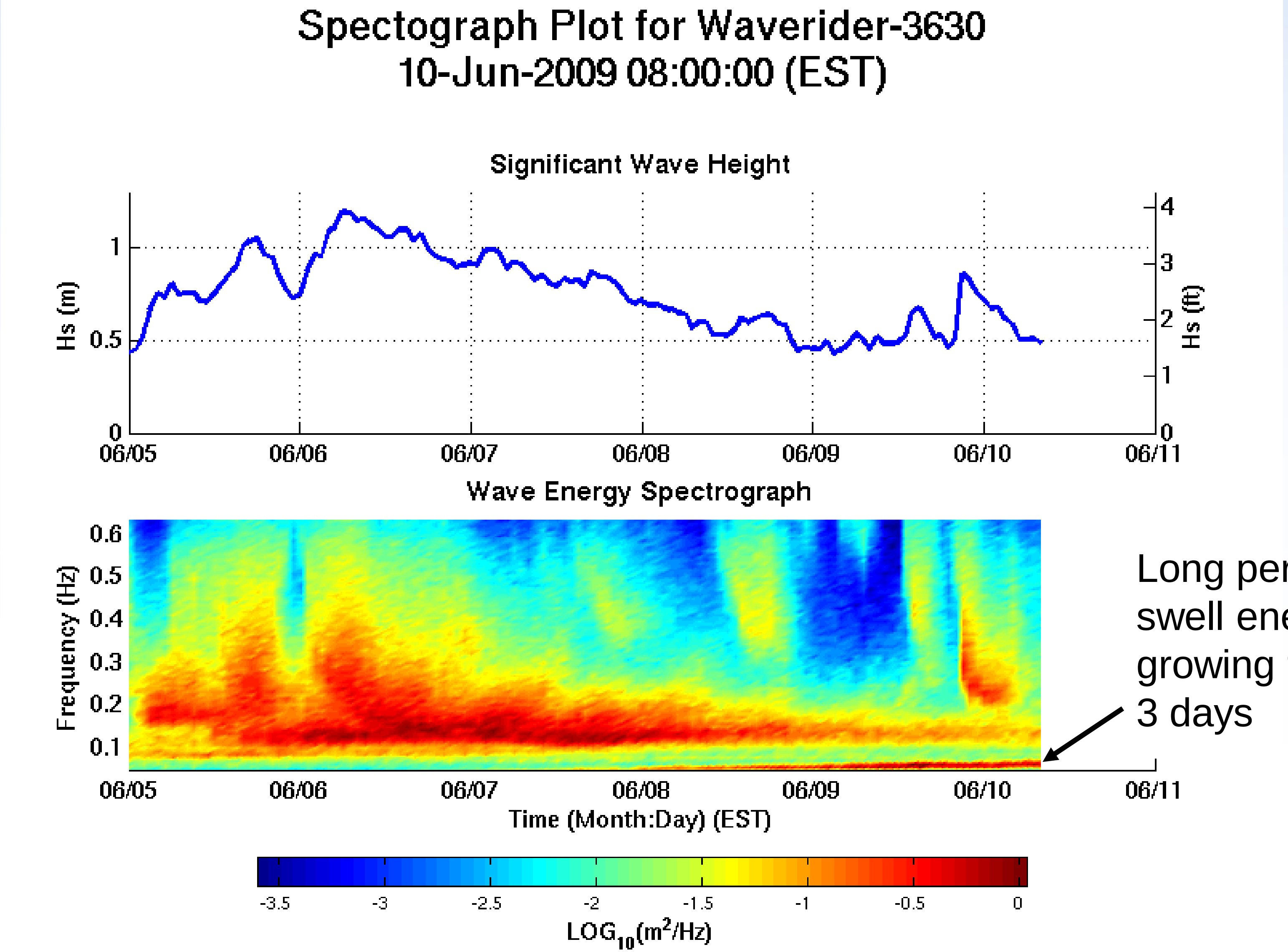
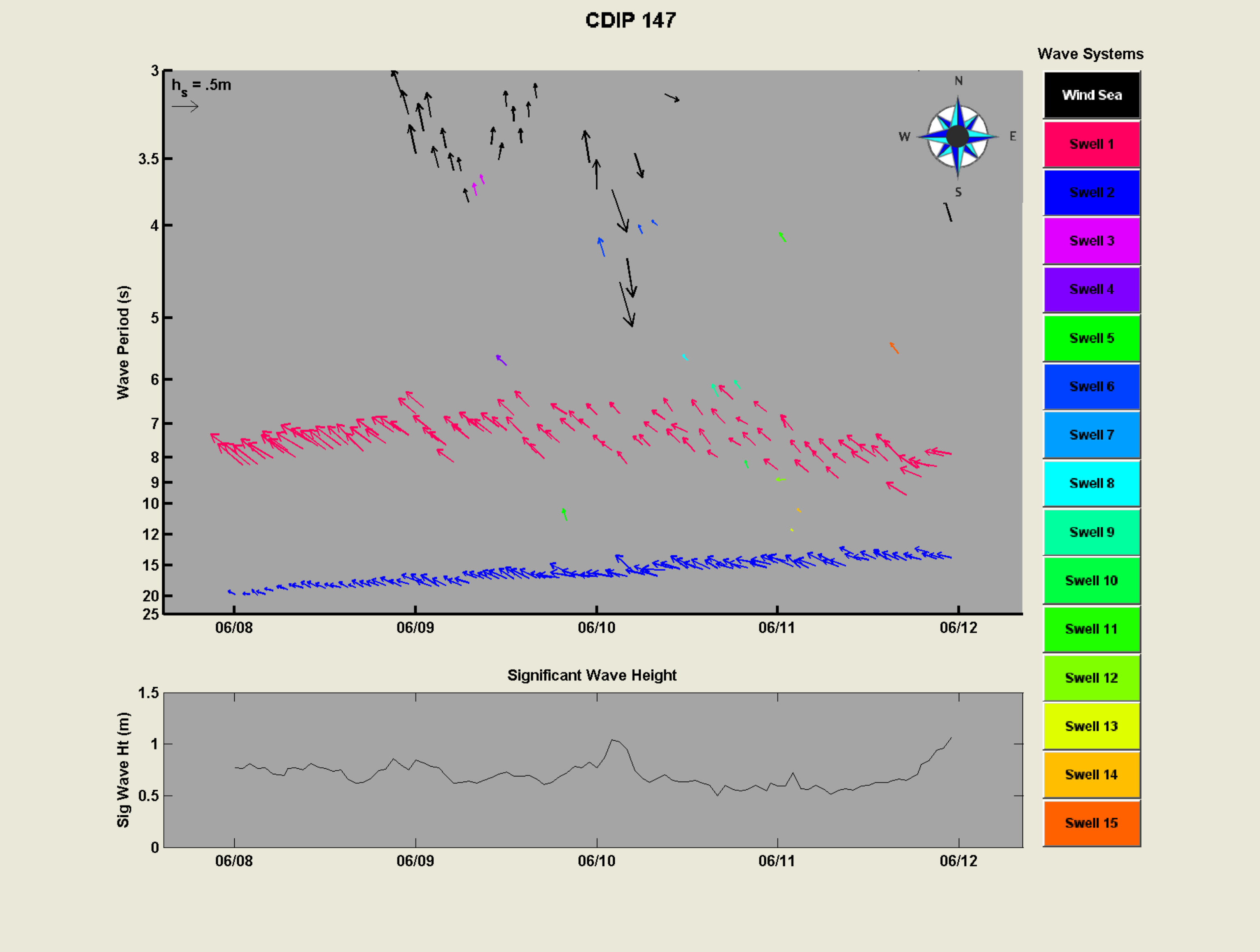
Evaluation Procedure 2



Long period swell energy growing for past 3 days

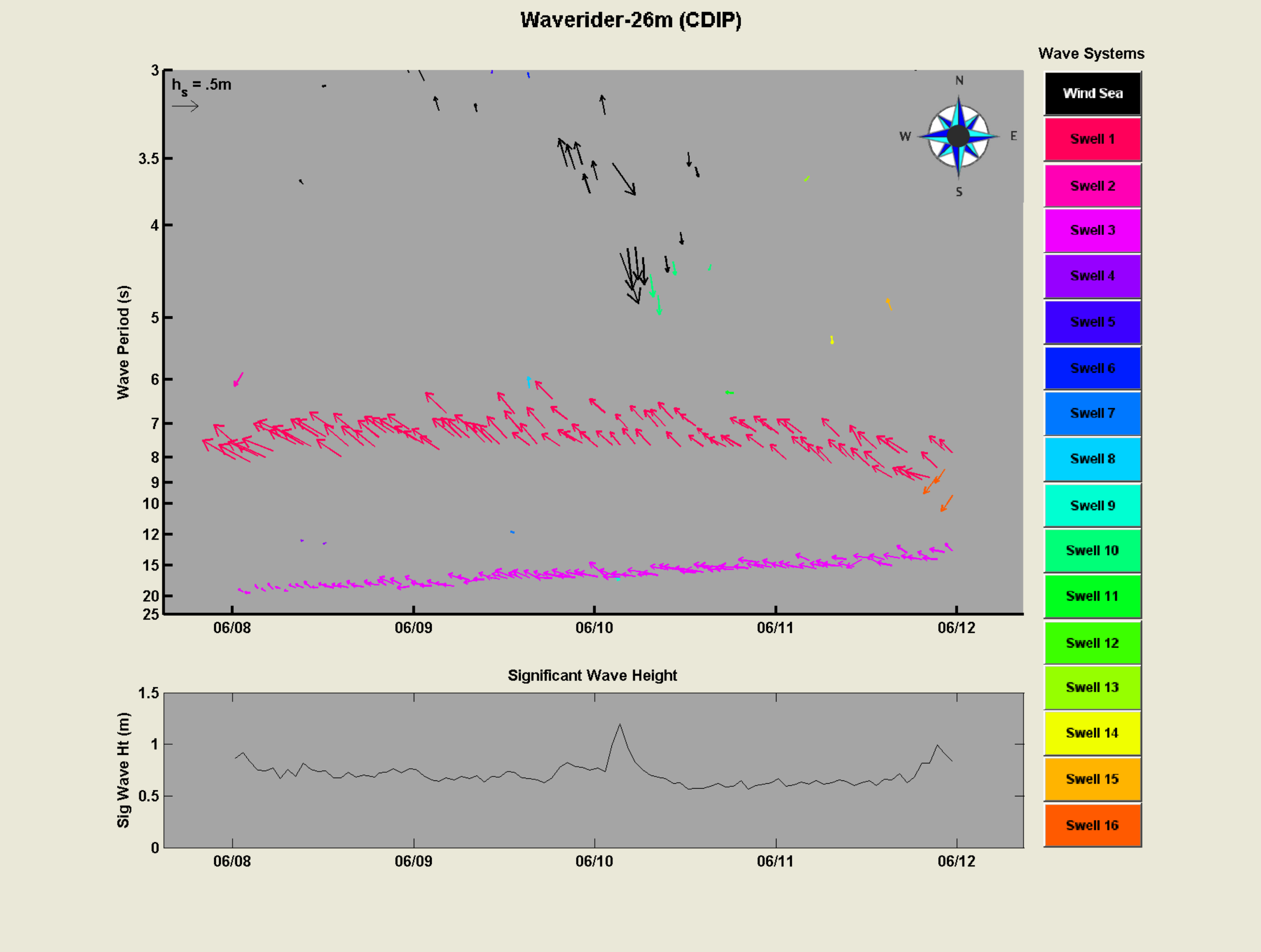
Evaluation Procedure 2

HIPPY



Evaluation Procedure 2

HIPPY



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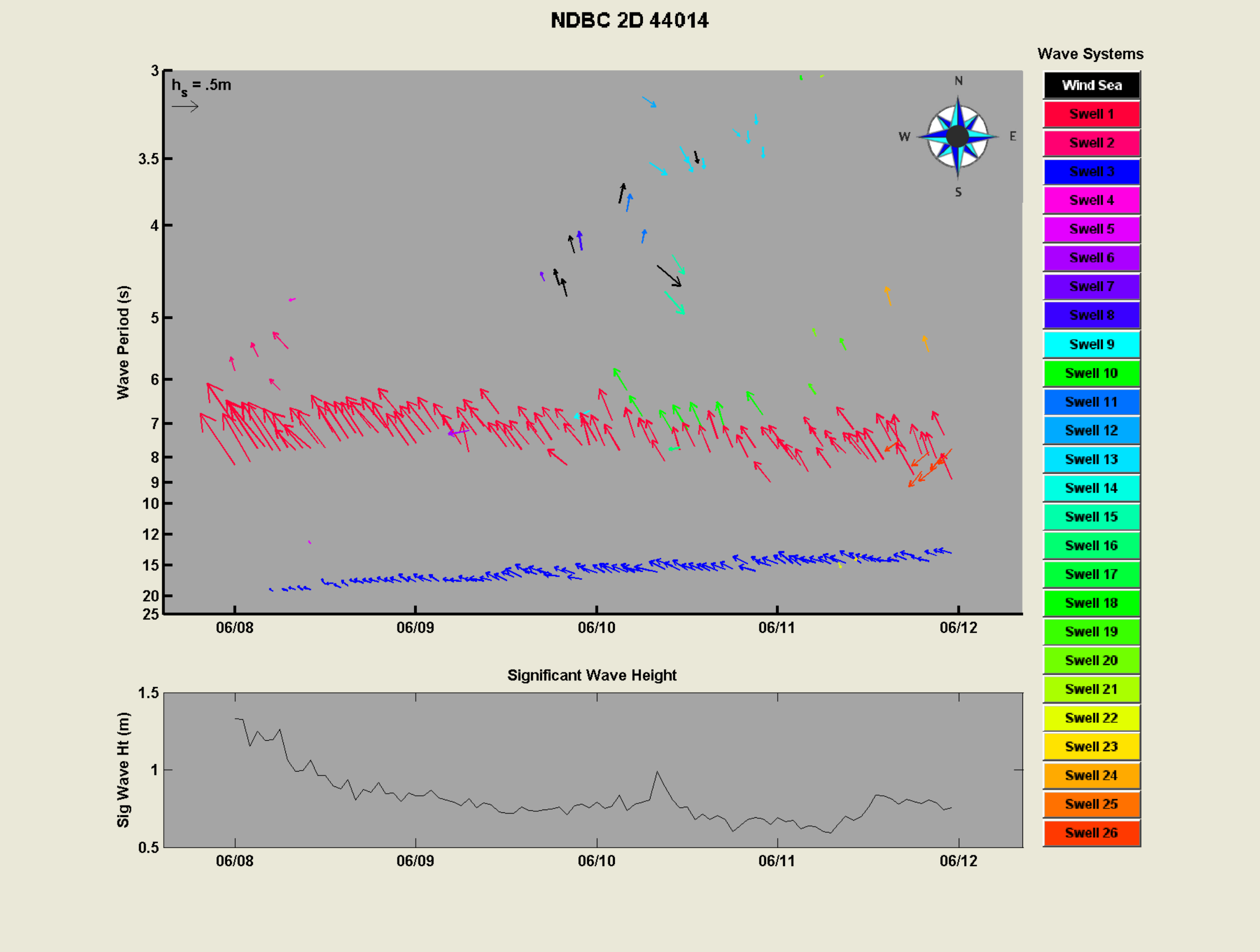

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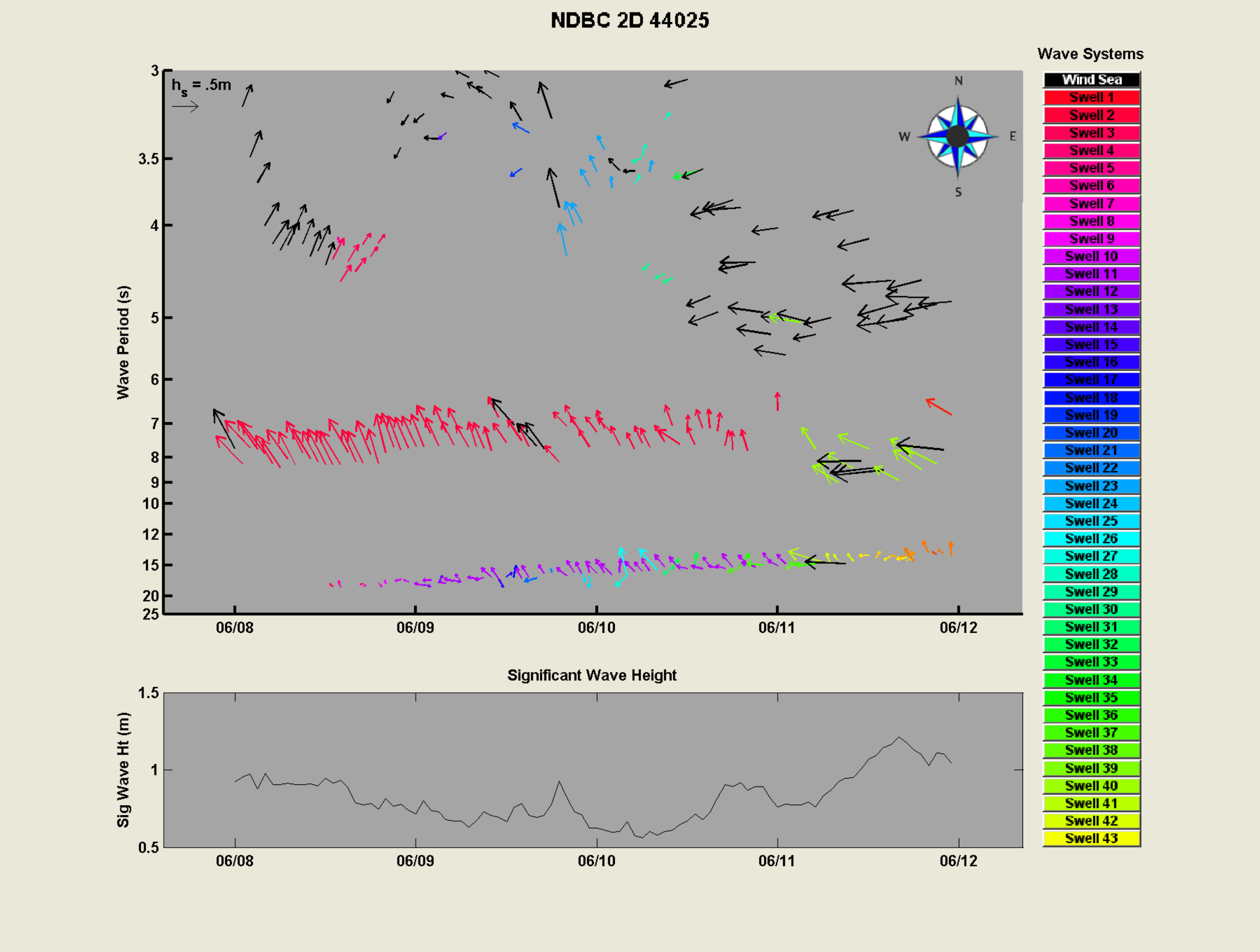
Evaluation Procedure 2

3DM



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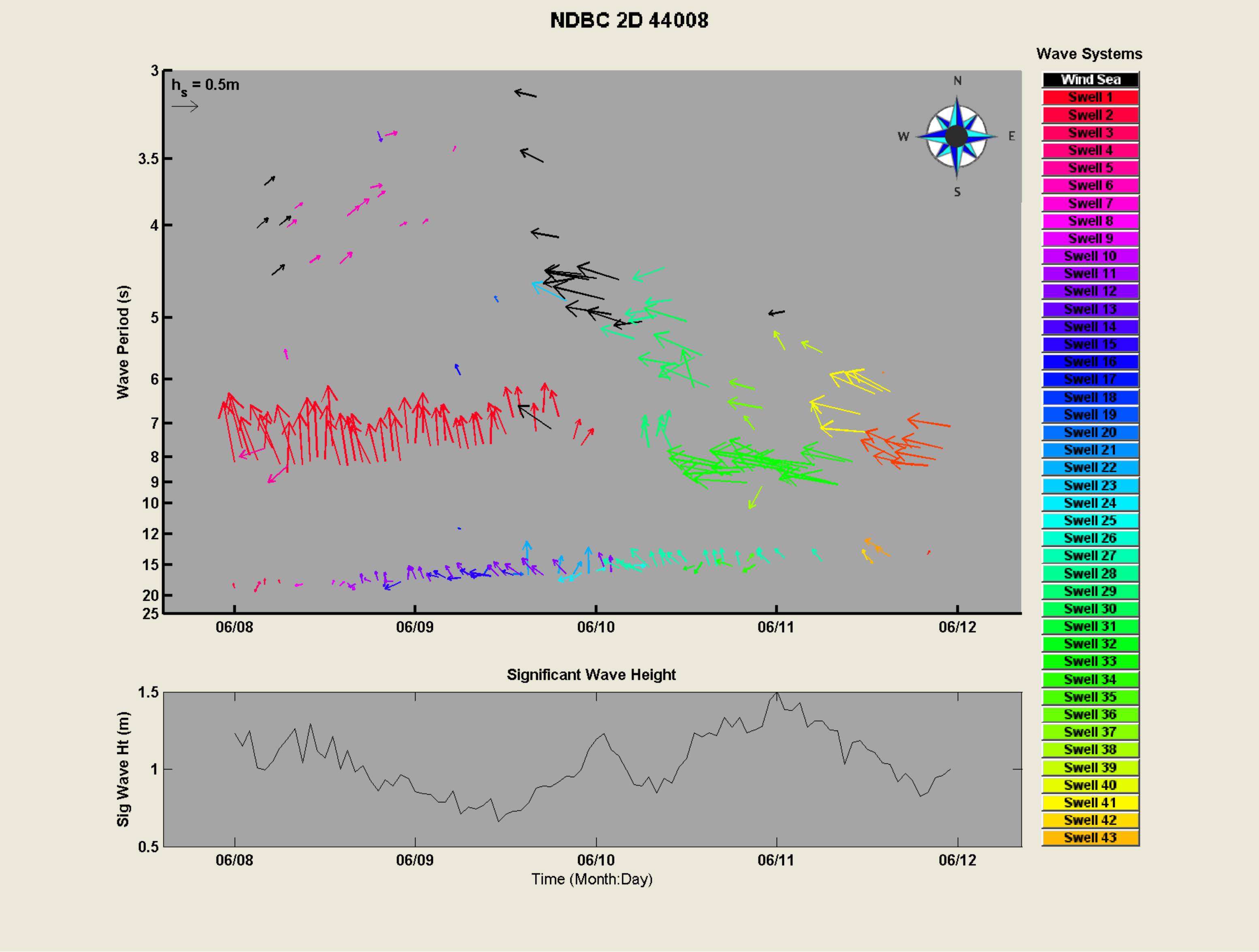
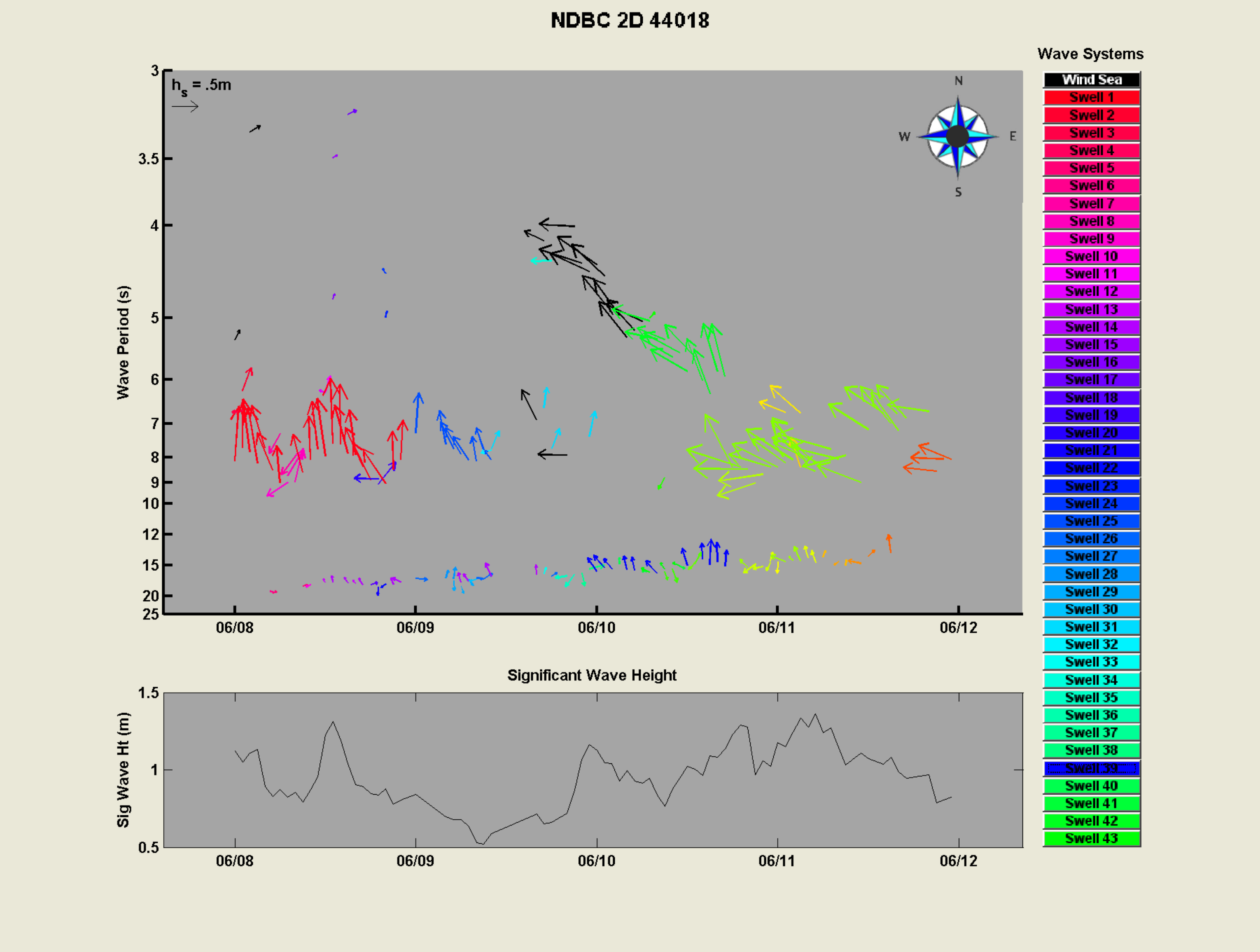
Evaluation Procedure 2

3DM



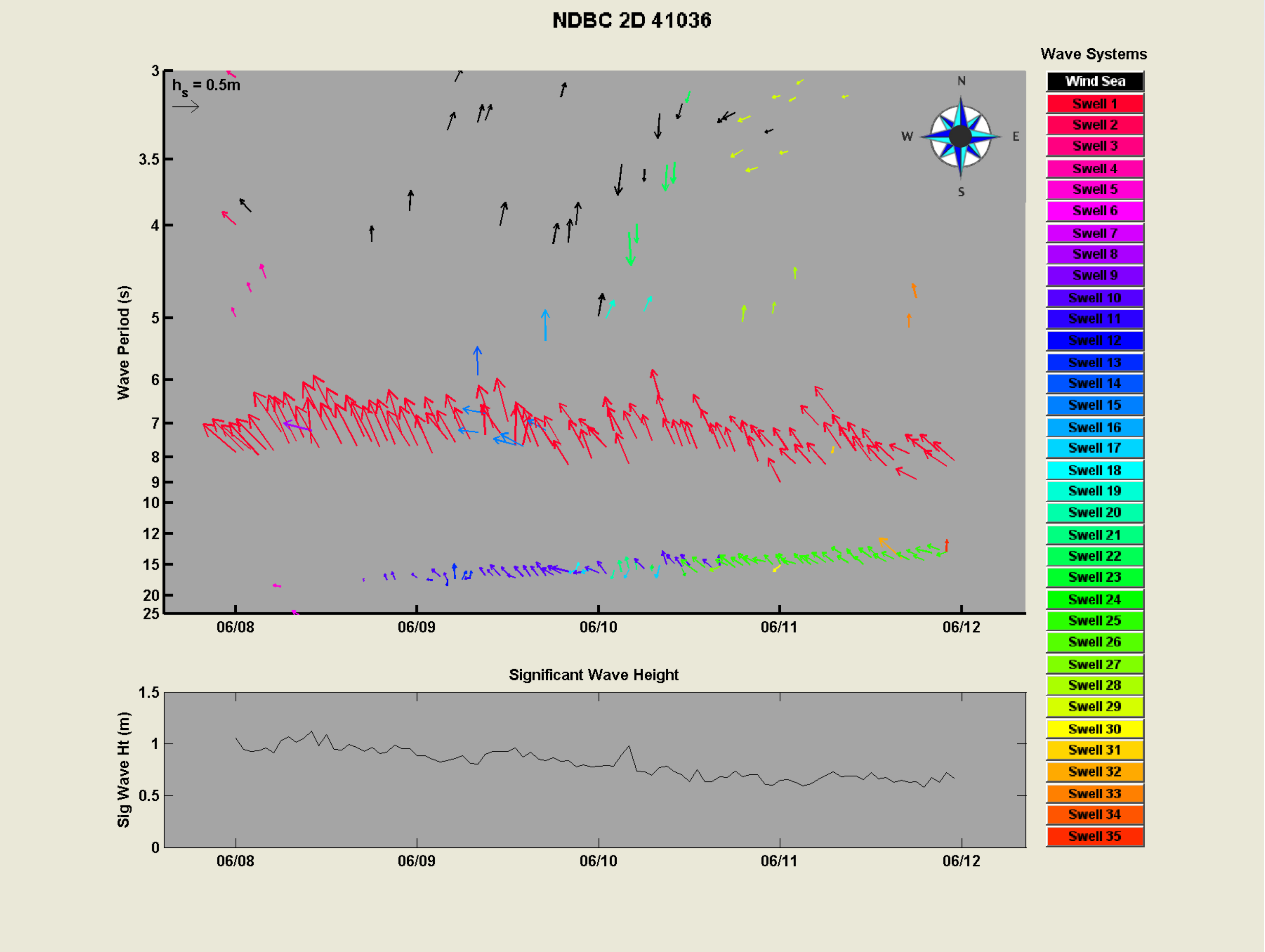
Evaluation Procedure 2

3DM



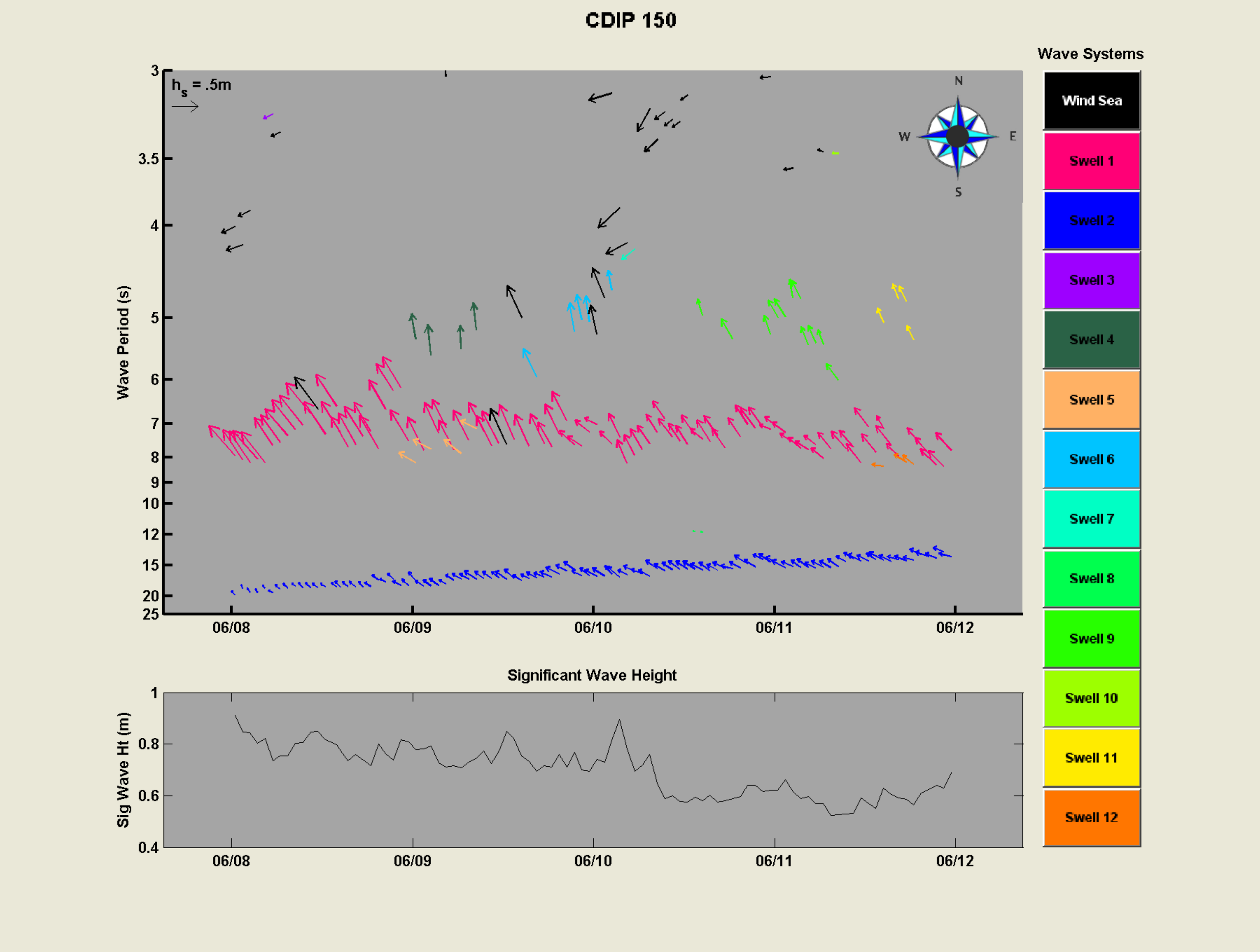
Evaluation Procedure 2

ARS



Evaluation Procedure 2

HIPPY



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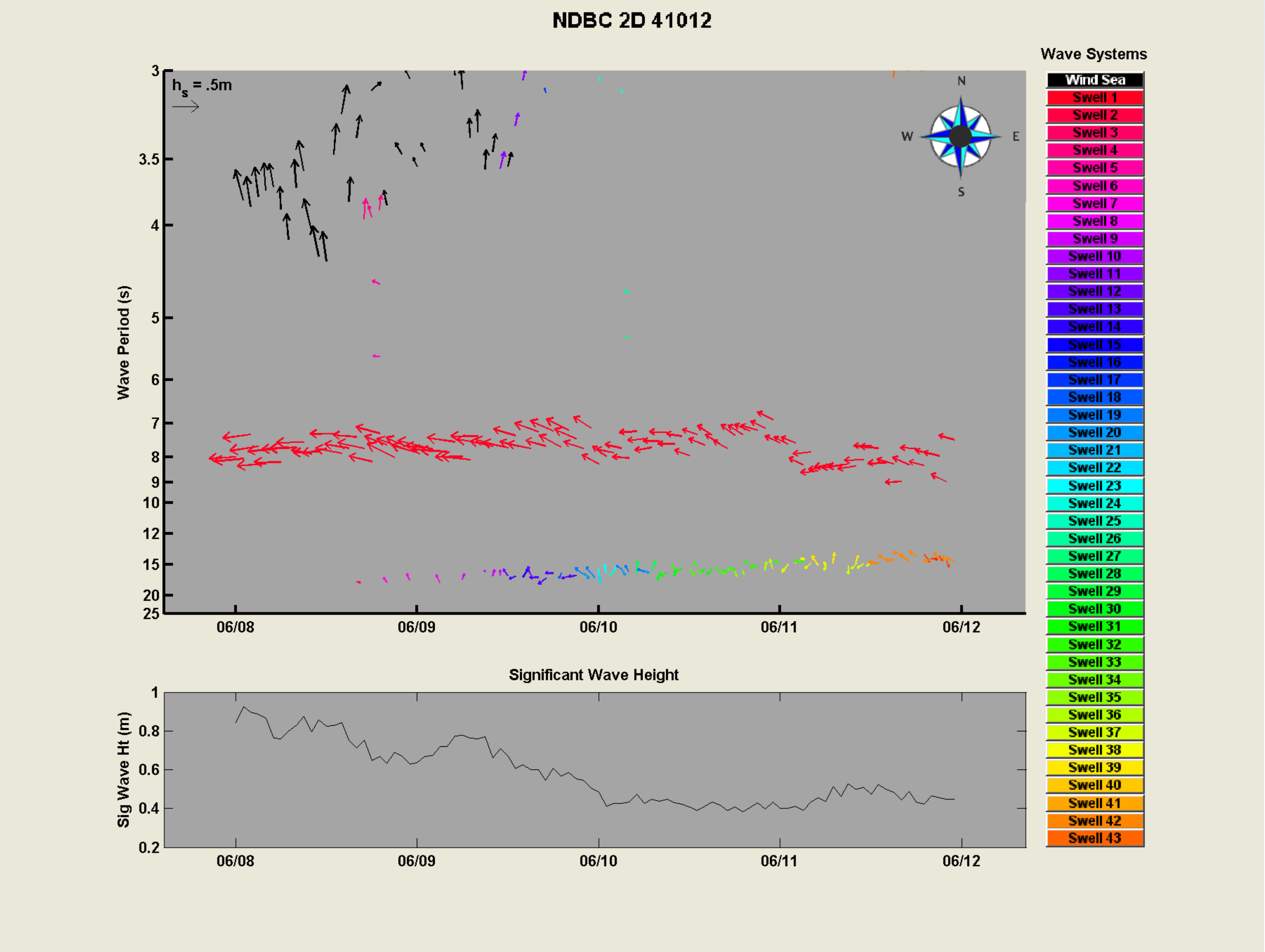
Evaluation Procedure 2

3DM



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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
- Our goal is to evaluate based on First-5 principles
  - TBD (PP-WET/DBCP Tuesday Afternoon)
  - Does not rule out non-directional wave measurements
  - Compliance for universal criteria
    - Reduces uncertainty in wave measurements
      - Provides consistency
      - Device to device
      - Underlying processes correctly evaluated

Questions