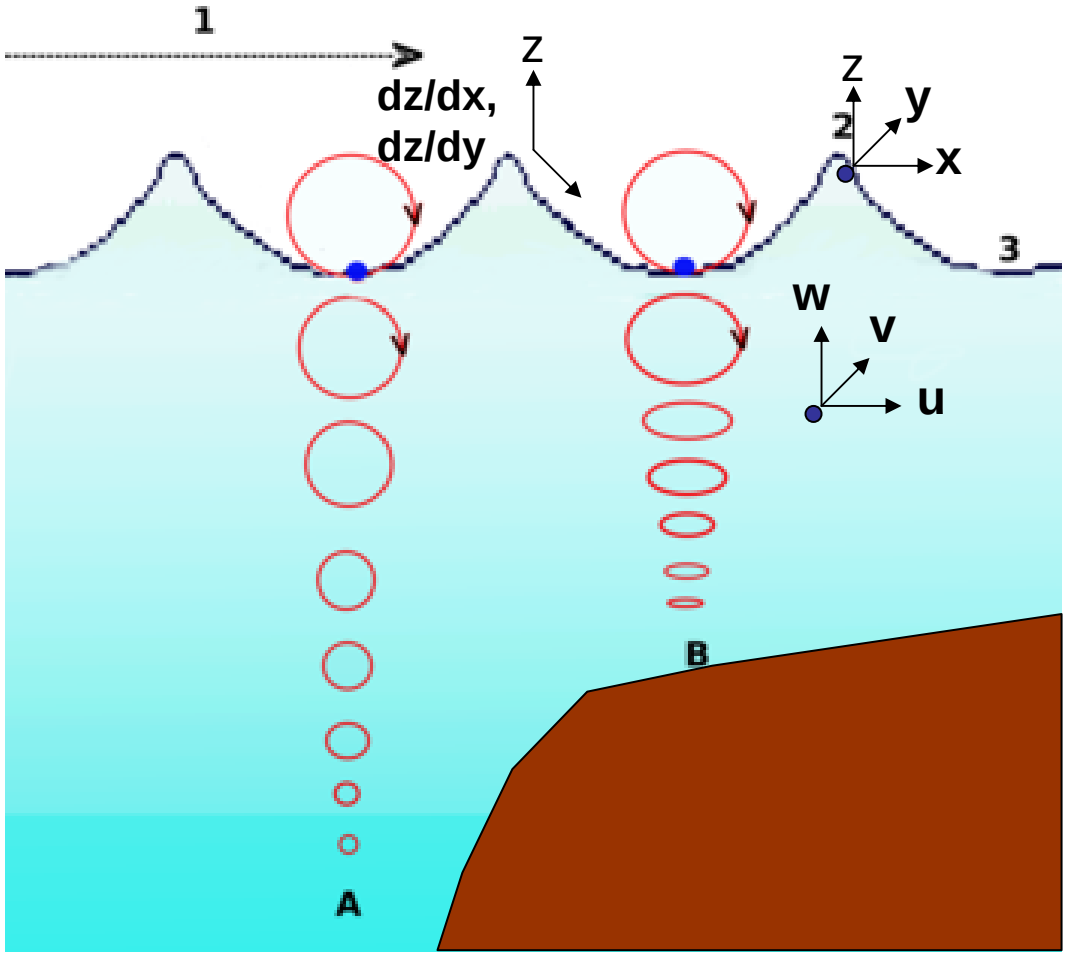
The IOOS ‘First 5 Standard’ for Directional Wave Measurements

1) What are the First 5?

2) Developing a First 5 standard through instrument intercomparisons.

3) The multi-use platform challenge.

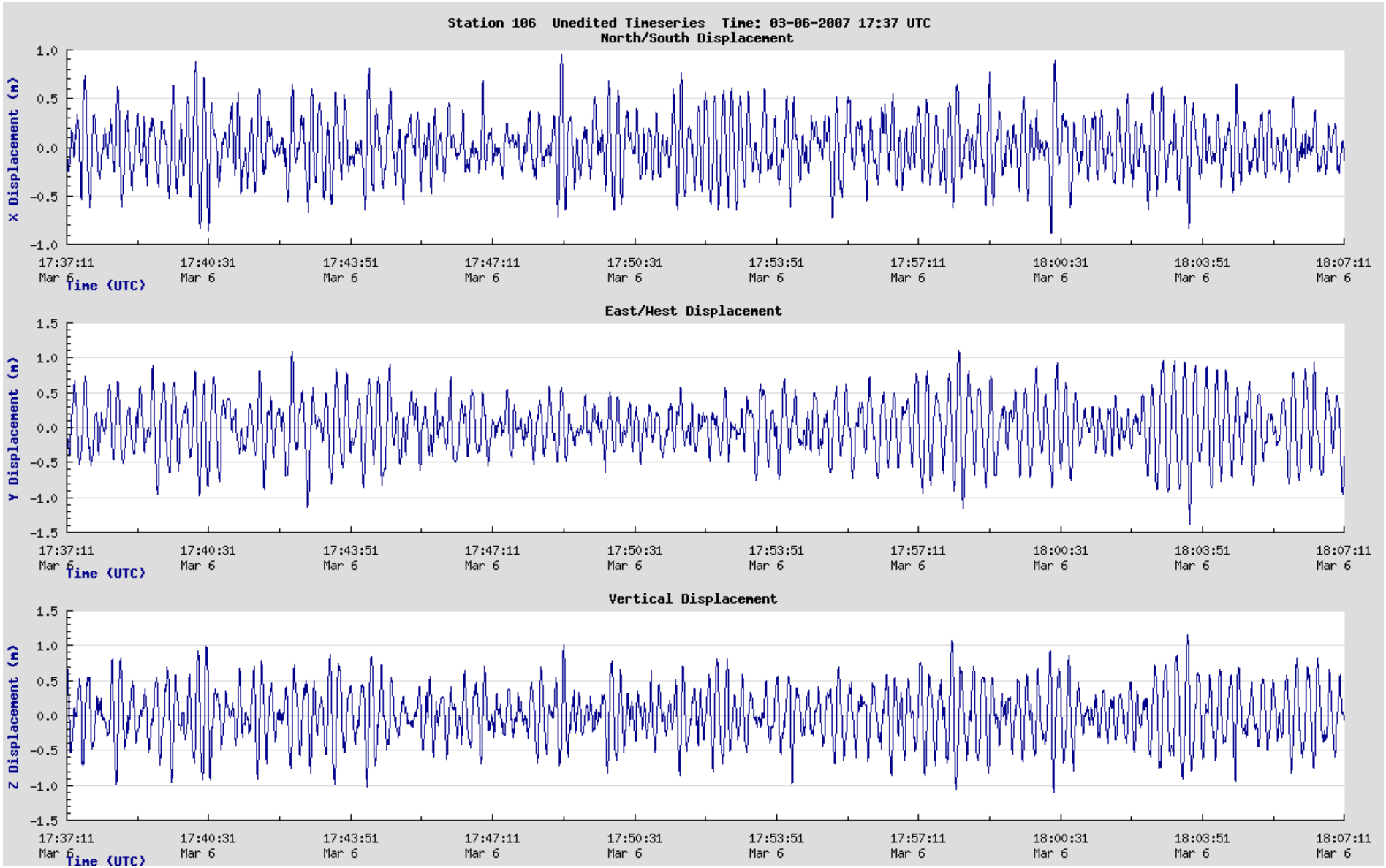
The Basics: Estimating the Motion of a Sea Surface Particle



The Big 3

X, Y, Z

Pressure Sensors
Accelerometers
Tilt sensors
Angular Rate Sensors
Acoustic Sensors
GPS


Station 106 Unedited Timeseries Time: 03-06-2007 17:37 UTC
North/South Displacement
X Displacement (m)
1.0
0.5
0.0
-0.5
-1.0
17:37:11 Mar 6
17:40:31 Mar 6
17:43:51 Mar 6
17:47:11 Mar 6
17:50:31 Mar 6
17:53:51 Mar 6
17:57:11 Mar 6
18:00:31 Mar 6
18:03:51 Mar 6
18:07:11 Mar 6
Time (UTC)
East/West Displacement
Y Displacement (m)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
17:37:11 Mar 6
17:40:31 Mar 6
17:43:51 Mar 6
17:47:11 Mar 6
17:50:31 Mar 6
17:53:51 Mar 6
17:57:11 Mar 6
18:00:31 Mar 6
18:03:51 Mar 6
18:07:11 Mar 6
Time (UTC)
Vertical Displacement
Z Displacement (m)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
17:37:11 Mar 6
17:40:31 Mar 6
17:43:51 Mar 6
17:47:11 Mar 6
17:50:31 Mar 6
17:53:51 Mar 6
17:57:11 Mar 6
18:00:31 Mar 6
18:03:51 Mar 6
18:07:11 Mar 6
Time (UTC)

The Big 3: X, Y, Z → Time Series Analysis → The First 5: S(f),a1(f),b1(f),a2(f),b2(f) !!

S

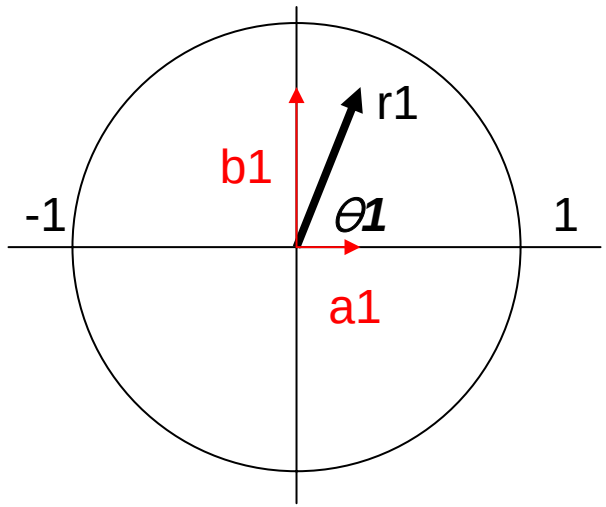
freq Hz	Band width	energy m*m/Hz	Dmean deg	a1	b1	a2	b2
0.0250	0.0050	0.0028	321	0.1920	-0.1567	-0.3925	-0.6345
0.0300	0.0050	0.0035	115	-0.1076	0.2259	-0.5132	-0.5796
0.0350	0.0050	0.0046	173	-0.2883	0.0348	-0.2973	-0.5084
0.0400	0.0050	0.0062	303	0.2602	-0.4085	-0.1606	-0.6449
0.0450	0.0050	0.0106	241	-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

- mean direction
- directional spread
- skewness
- kurtosis

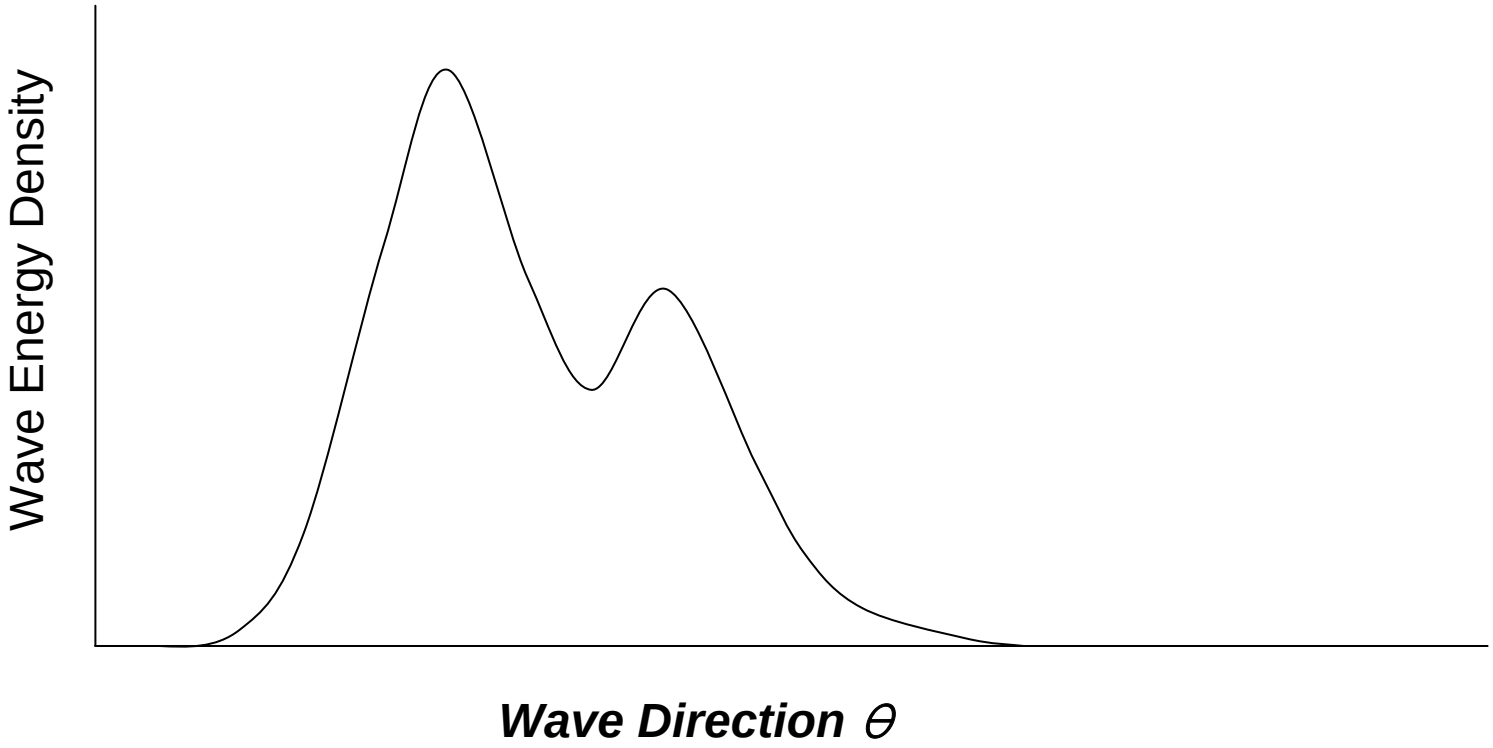
a1,b1,a2,b2

or, in NDBC format

- first-moment mean direction (*θ1*)
- first-moment spread parameter (*r1)*
- second-moment mean direction (*θ2*)
- second-moment spread parameter (*r2)*

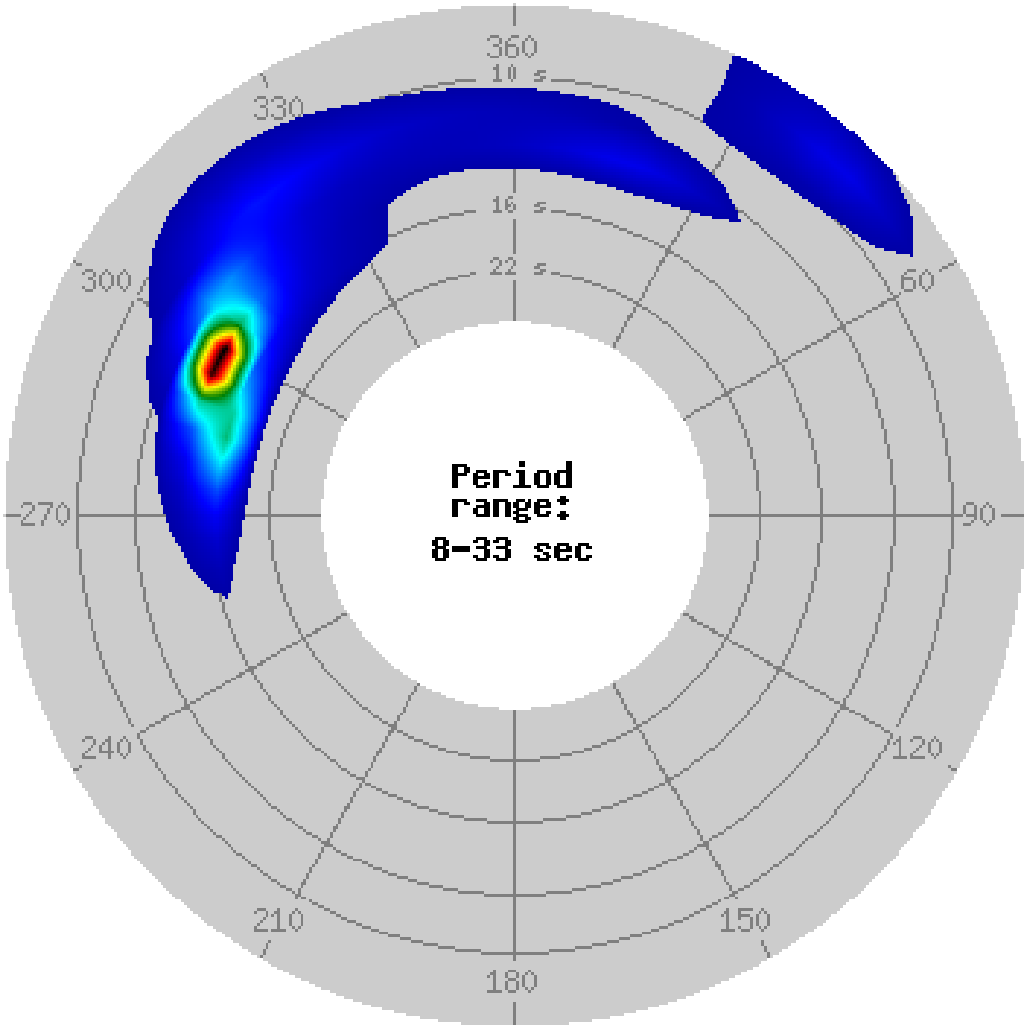


The Directional Spectrum



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

First 5 + Maximum Entropy Method

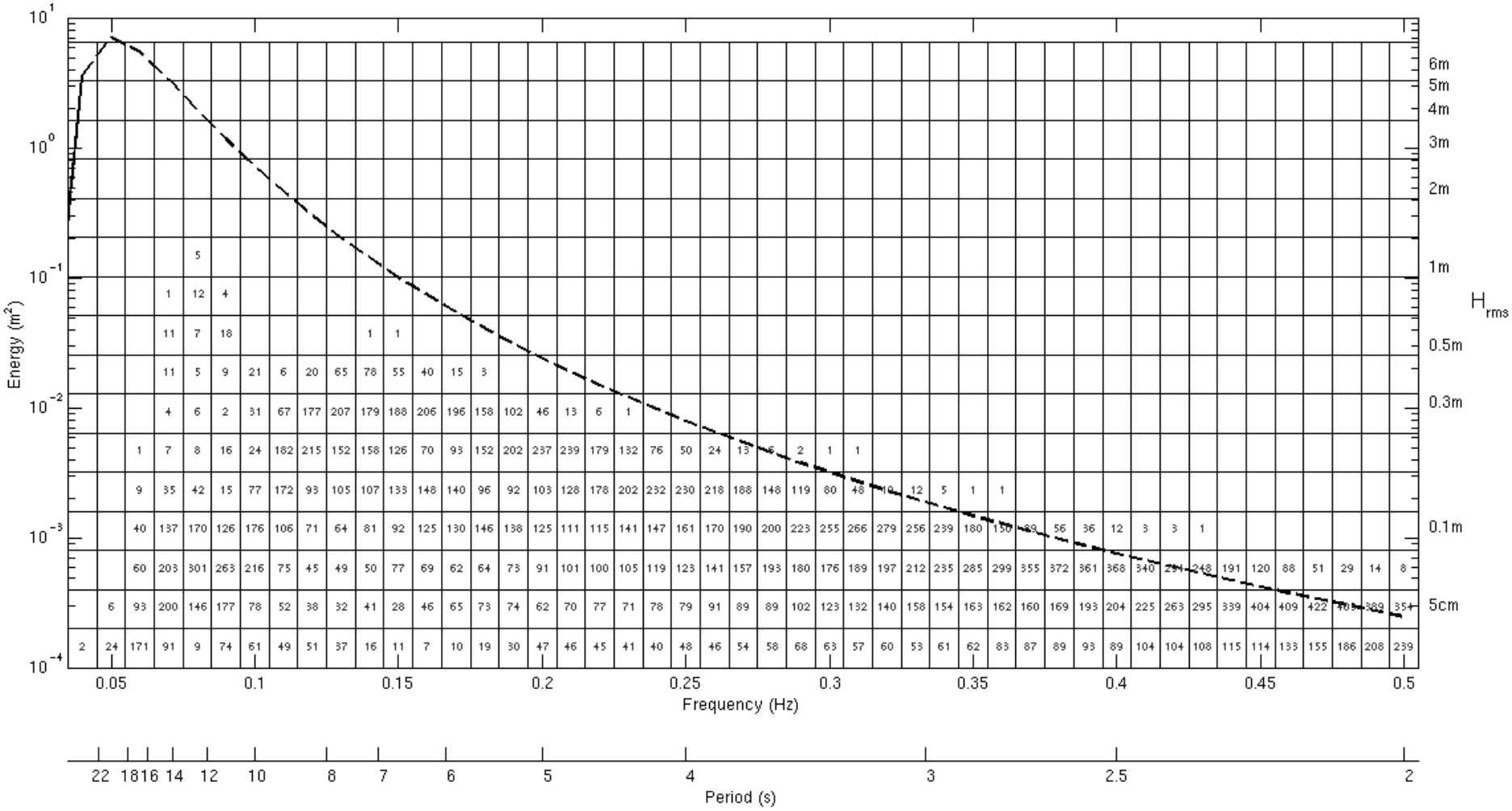


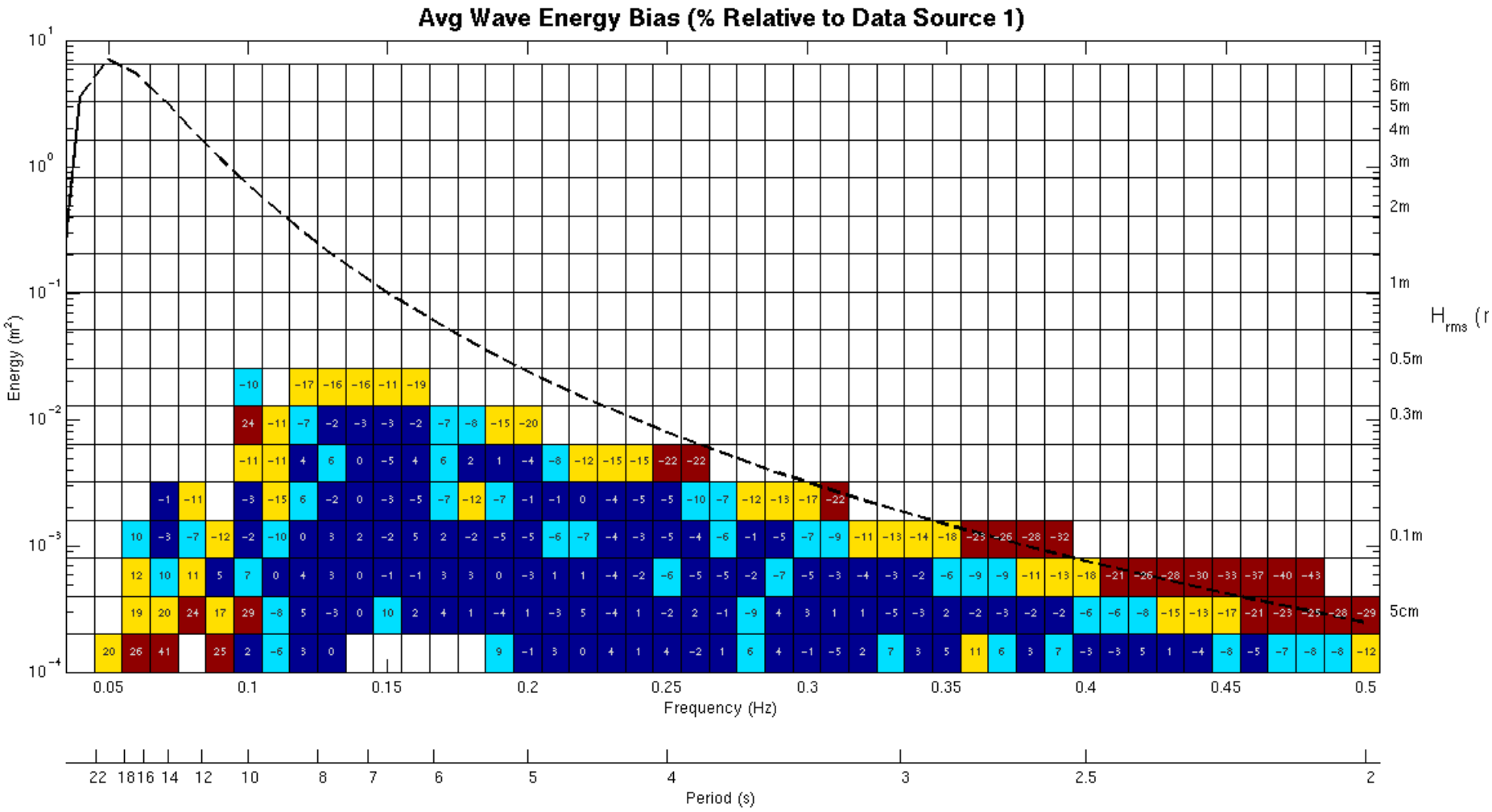
First 5 Intercomparisons

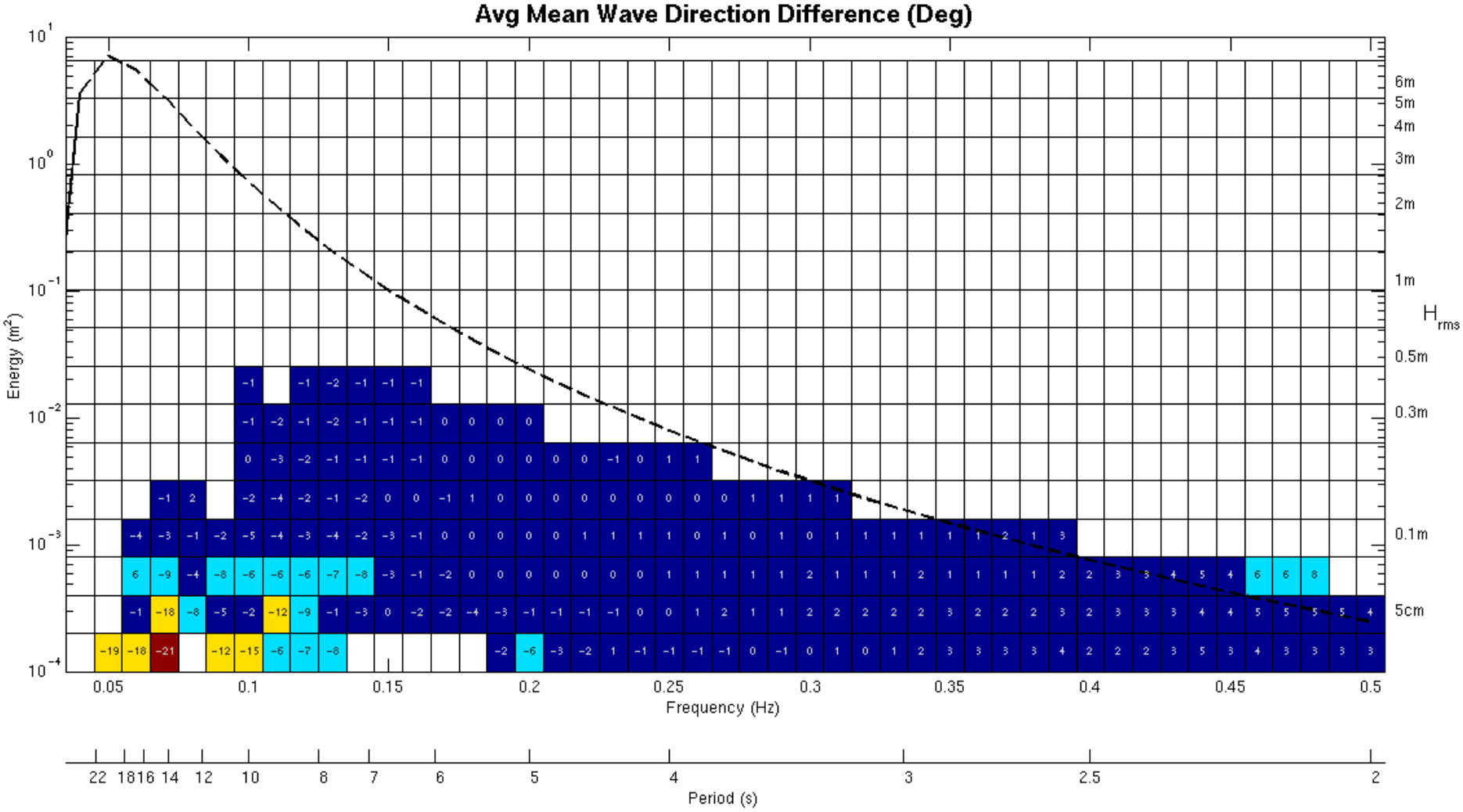
A “Wave Component” Approach

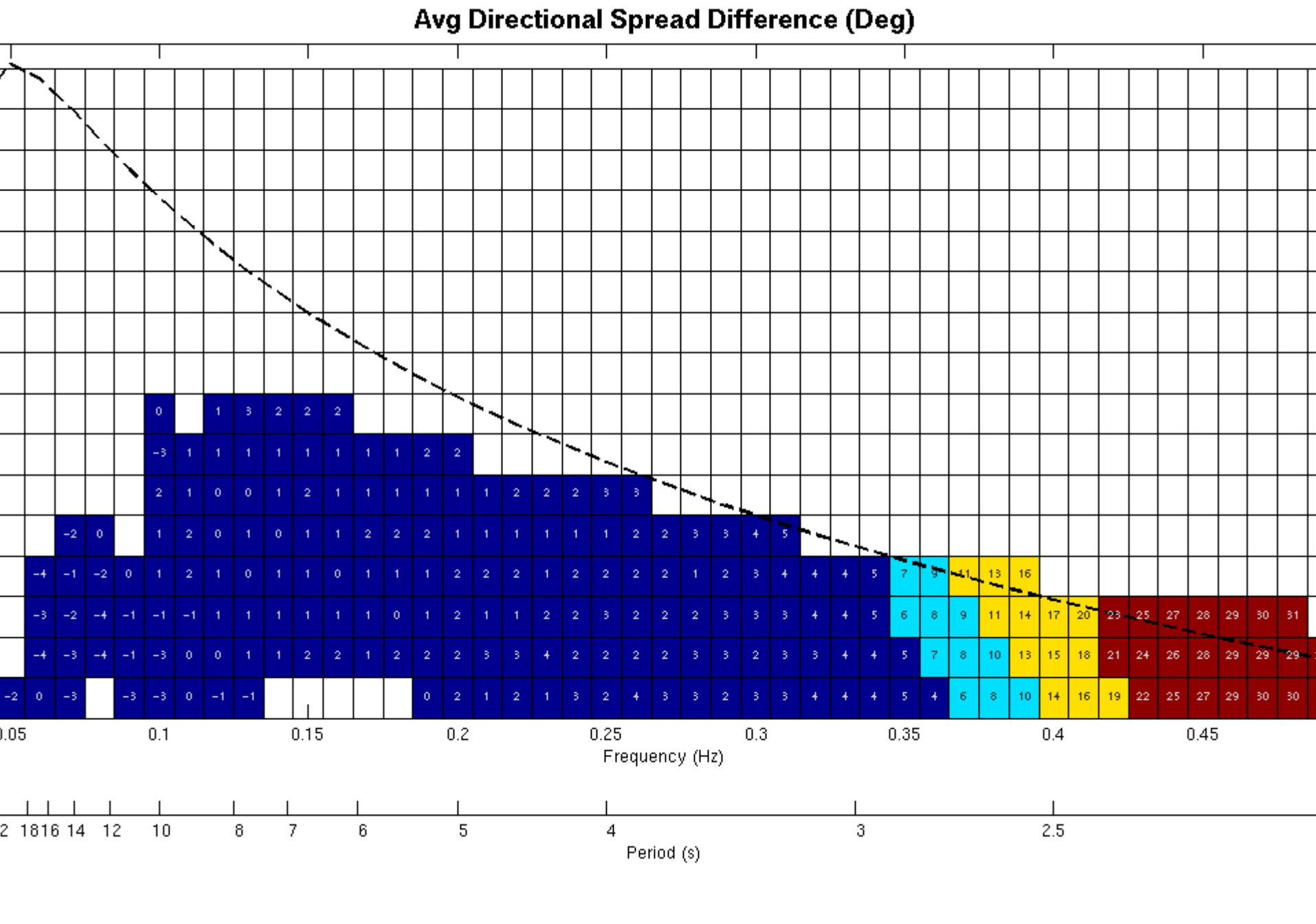
- Measurement errors are frequency and energy dependent.
- A wide range of sea states need to be observed.

Bouy 1 v. Buoy 2 Intercomparison

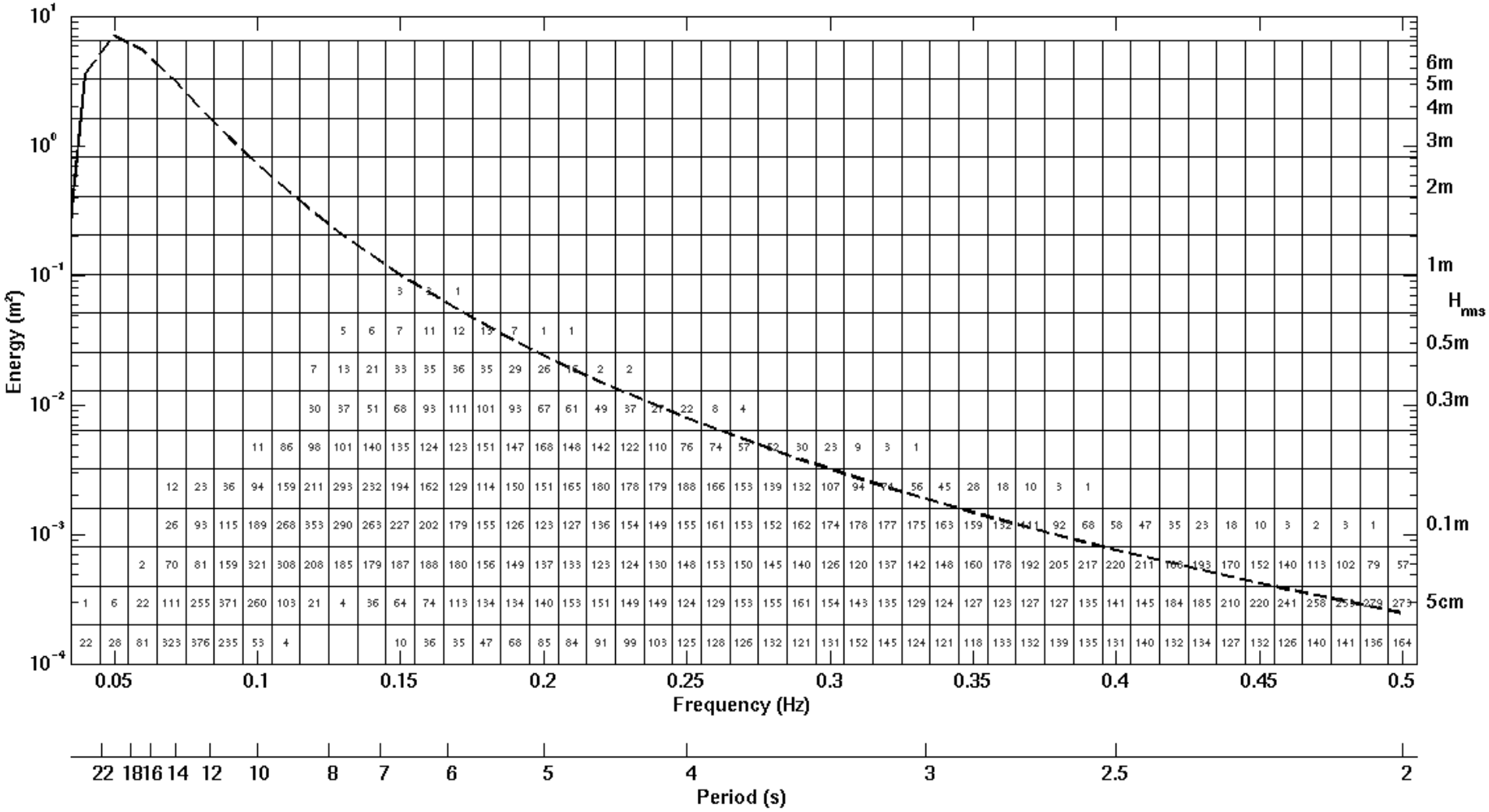


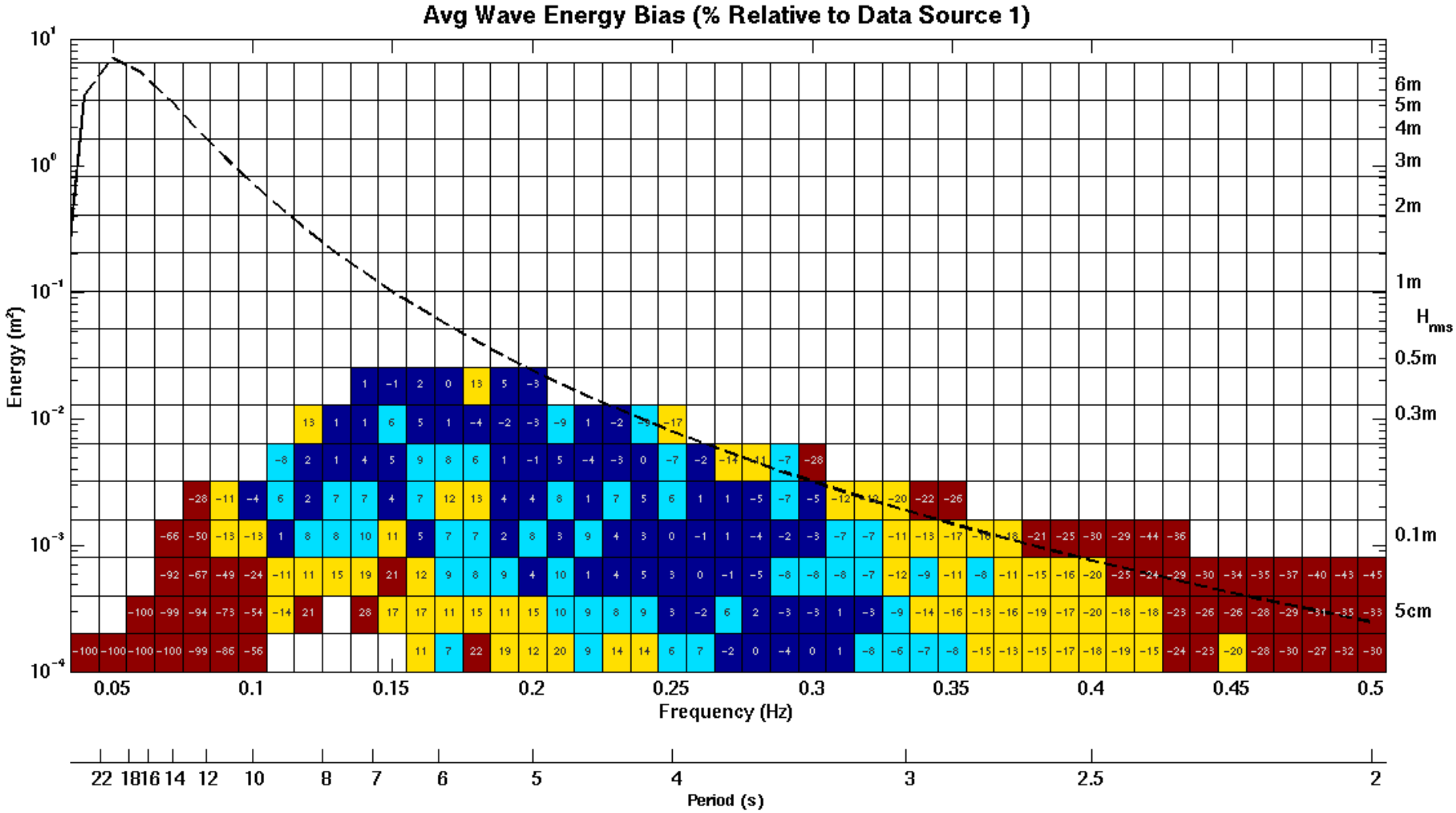

Avg Wave Energy Bias (% Relative to Data Source 1)
Energy (m²)
Frequency (Hz)
Period (s)
H_rms (r
6m
5m
4m
3m
2m
1m
0.5m
0.3m
0.1m
5cm


Avg Mean Wave Direction Difference (Deg)
Energy (m²)
Frequency (Hz)
Period (s)
H rms
6m
5m
4m
3m
2m
1m
0.5m
0.3m
0.1m
5cm


Avg Directional Spread Difference (Deg)
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
Frequency (Hz)
2
18
16
14
12
10
8
7
6
5
4
3
2.5
Period (s)

Bouy 1 v. Buoy 3 Intercomparison

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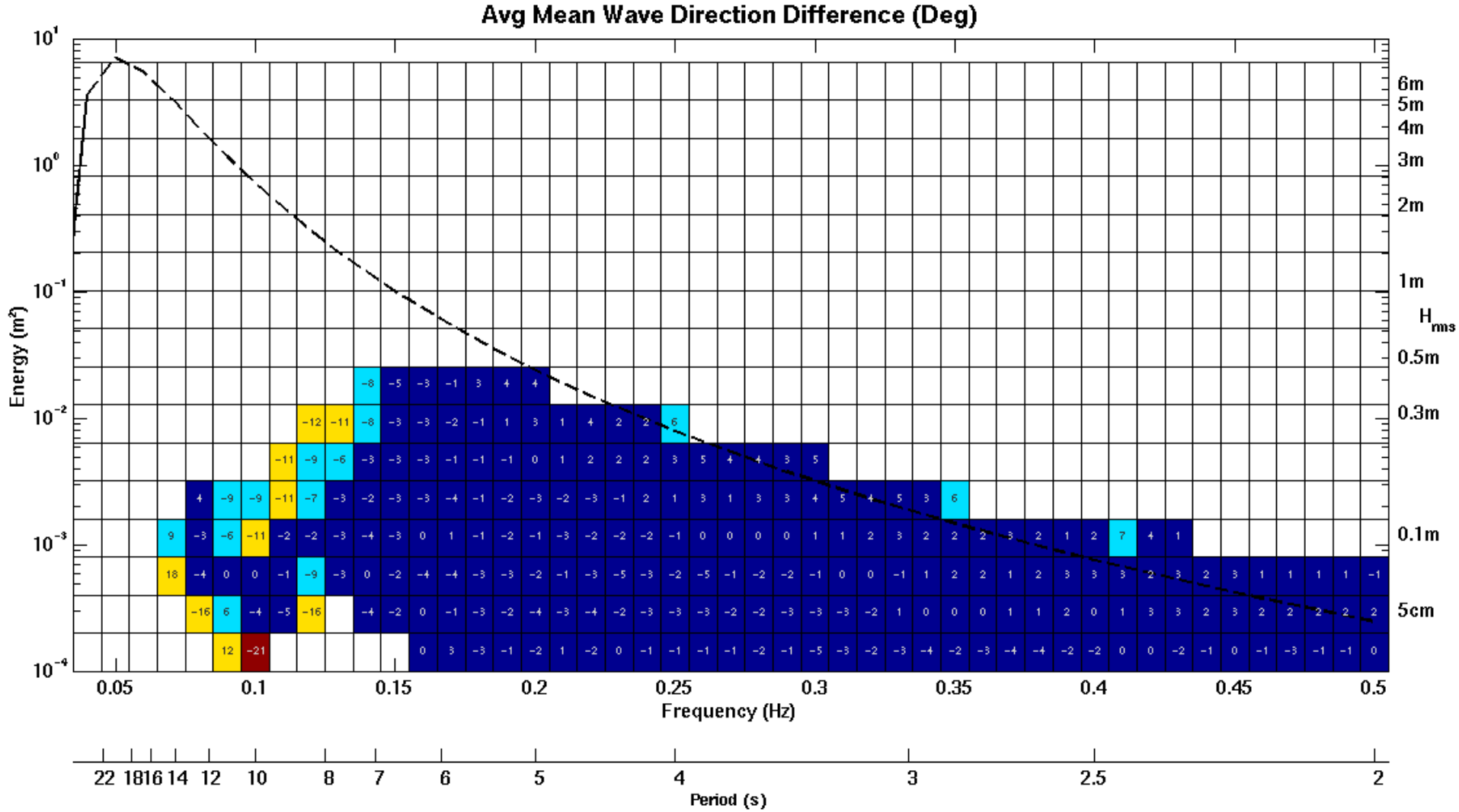
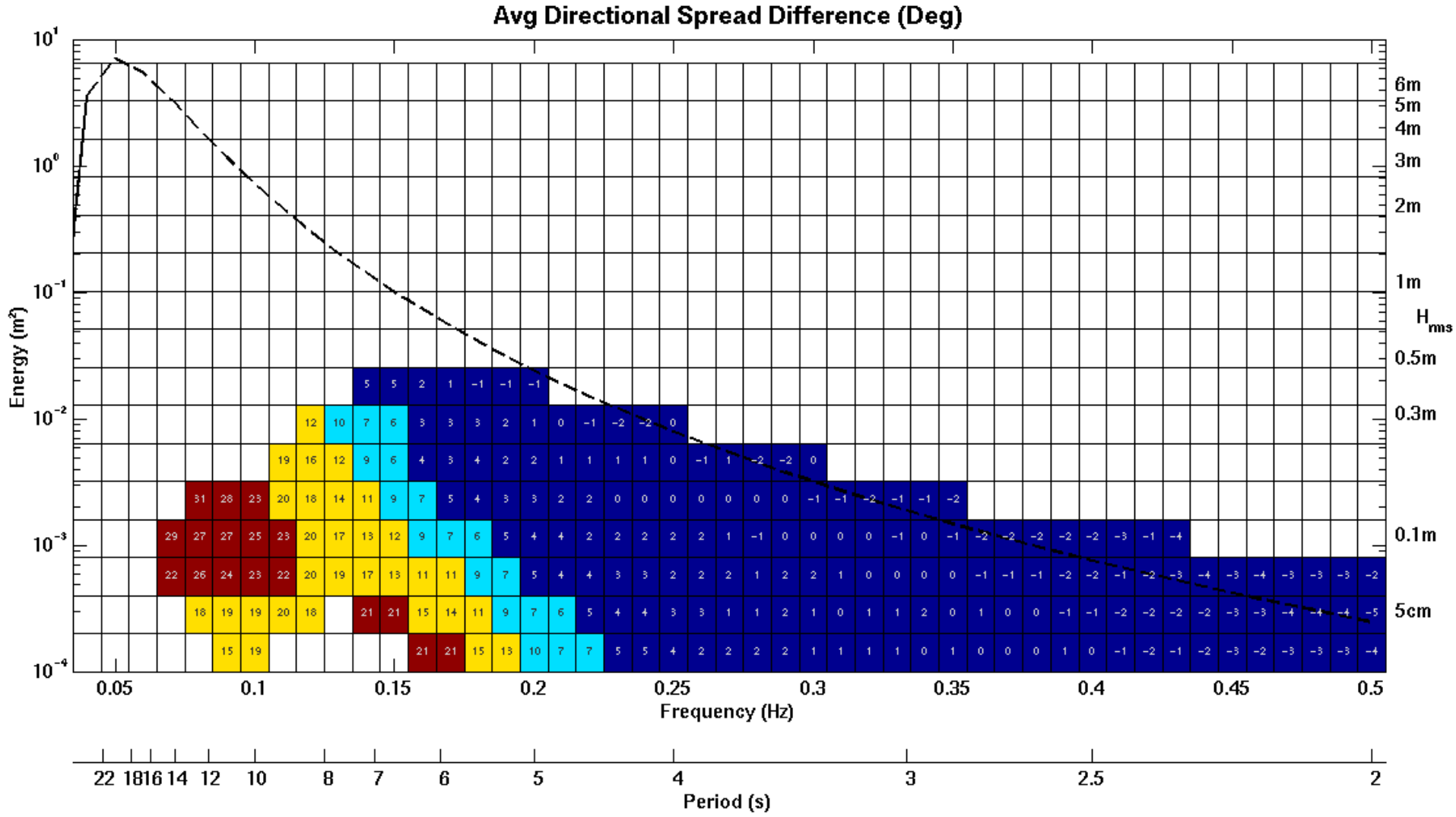
Energy (m²)
Frequency (Hz)
Period (s)
H rms
6m
5m
4m
3m
2m
1m
0.5m
0.3m
0.1m
5cm


Avg Mean Wave Direction Difference (Deg)
Energy (m²)
Frequency (Hz)
Period (s)
H_rms
6m
5m
4m
3m
2m
1m
0.5m
0.3m
0.1m
5cm


Avg Directional Spread Difference (Deg)
Energy (m²)
Frequency (Hz)
Period (s)
H rms
6m
5m
4m
3m
2m
1m
0.5m
0.3m
0.1m
5cm

3) The Multi-use Platform Challenge

Wave Measurement Methods

1) Wave Followers (xyz translation, heave-pitch-roll)

2) Corrected Wave Follower (heave-pitch-roll with transfer function)

3) Corrected Fixed Platform (subsurface acoustic)

4) Fixed Platform (pressure, acoustic)

3) The Multi-use Platform Challenge

Wave Measurement Methods

1) Wave Followers (xyz translation, heave-pitch-roll)

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4) Fixed Platform (pressure, acoustic)

3) The Multi-use Platform Challenge

Wave Measurement Methods

1) Wave Followers (xyz translation, heave-pitch-roll)

2) Corrected Wave Follower (heave-pitch-roll with transfer function) often a complex function of sea-state, mooring system, wind loads etc.

3) Corrected Fixed Platform (subsurface acoustic)

4) Fixed Platform (pressure, acoustic)

The NDBC Offshore Approach

Waves-only Companion Buoy near the Multi-use Platform