Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology

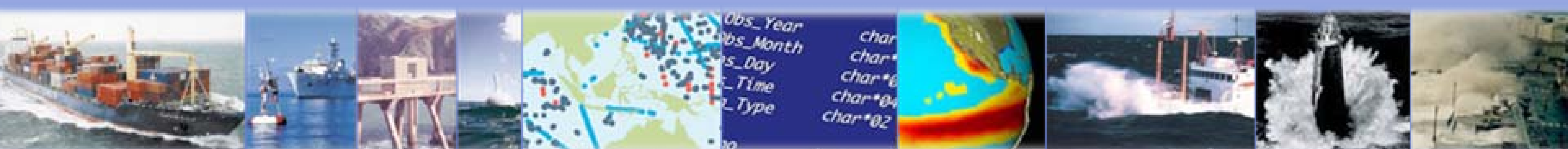
JCOMM Technical Workshop on Wave Measurements from Buoys

Val Swail and David Meldrum

Chair, JCOMM Expert Team on Wind Waves and Storm Surges

Chair, Data Buoy Cooperation Panel

with assistance from the 50+ Workshop participants



WMO

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JCOMM Technical Workshop on Wave Measurements from Buoys – Program Overview

- **Session A: Review existing plans and requirements**
- **Session B: Review Scientific/Technical issues and developments (1)**
- **Session C: Review Scientific/Technical issues and developments (2)**

- **Discussion Session – Requirements for drifters**
- **Discussion Session – Requirements for moored buoy measurements**
- **Discussion Session – Technical aspects**

- **Discussion Session – Recommendation to JCOMM including DBCP and its Action Groups**
- **Discussion Session – Input to technical work plan, pilot projects**

Outcomes

- Workshop materials including presentations are available online now at workshop web page www.jcomm.info/wavebuoys
- Presentations will be included in JCOMM TR of the meeting, with meeting summary and recommendations and actions
- Presentations to DBCP XXIV Technical Workshop and session

OBSERVATION REQUIREMENTS FOR WIND WAVES

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

Applications:

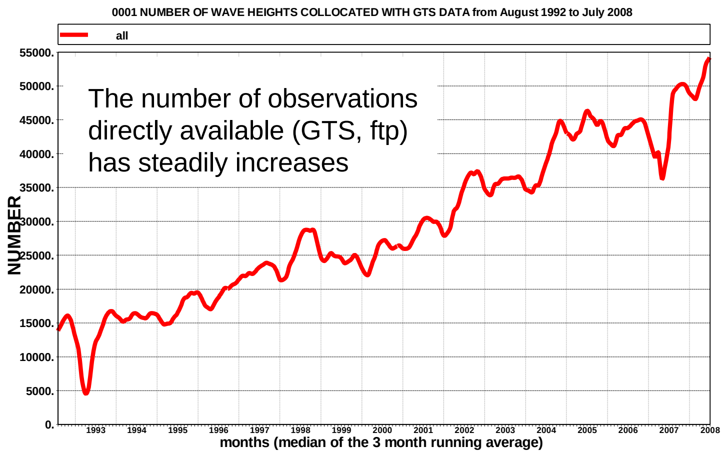
- Assimilation into offshore wave forecast models
- Validation of wave forecast models
- Calibration / validation of satellite wave sensors
- Ocean wave climate and variability
- Role of waves in coupling

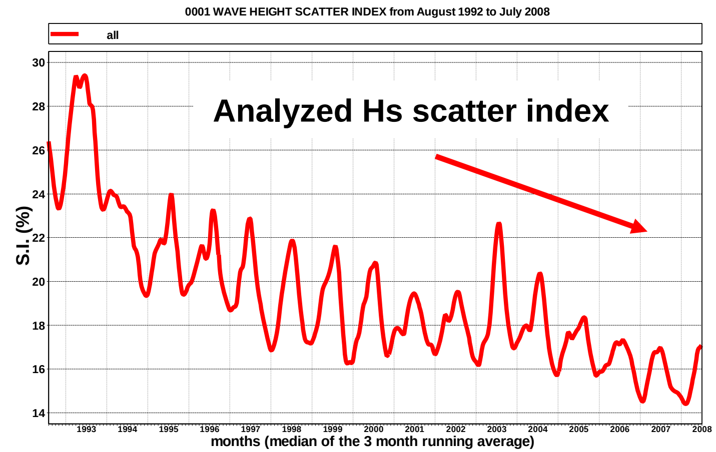
- Reference:
- *OceanObs99 paper Swail et al.*
- *DBCP-22 Meeting Report October 2006*
- *ETWS-II Meeting Report March 2007*
- *CBS/OPAG-IOS/ET-EGOC-3 Doc. 7.2.6*

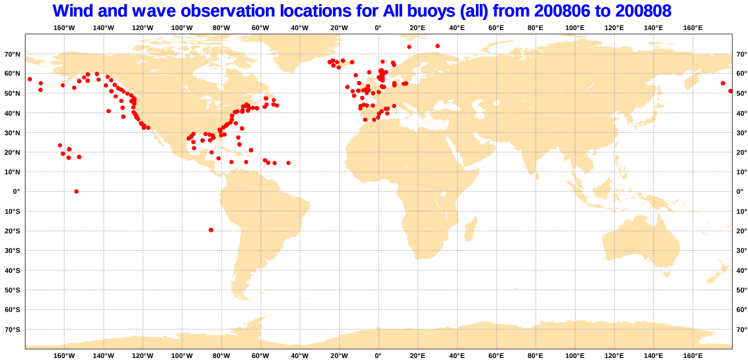
WMO IOC/UNESCO

Introduction: wave in-situ data for in-house verification

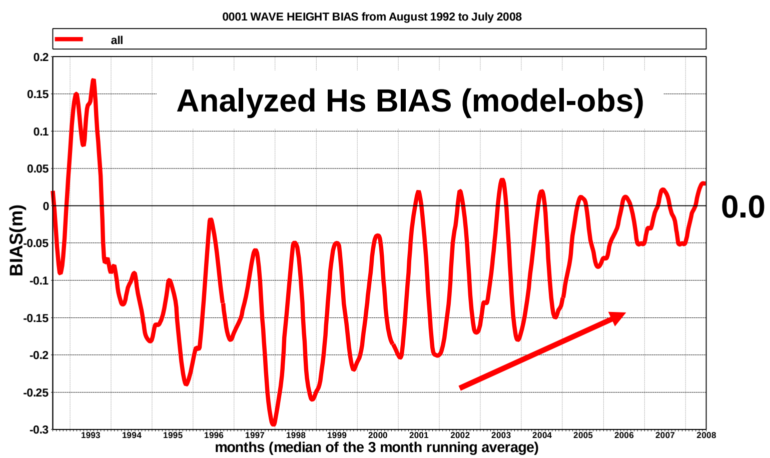
In situ wave observations have been used
to assess the quality of the ECMWF wave model
analyses and forecasts since 1992.
e.g.



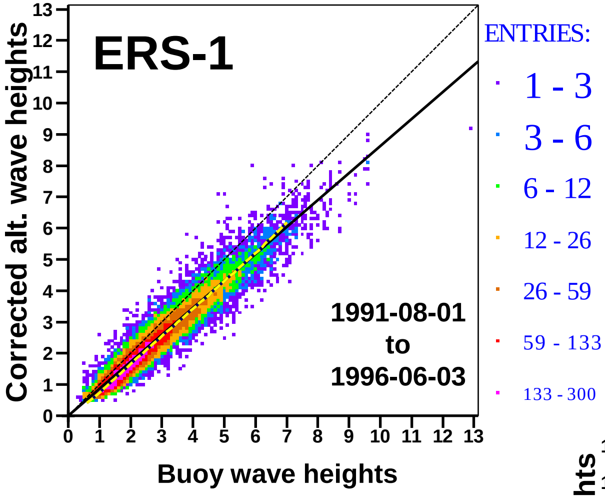




Locations of moored buoys, platforms and ships from which wind and wave observations are used in this verification.

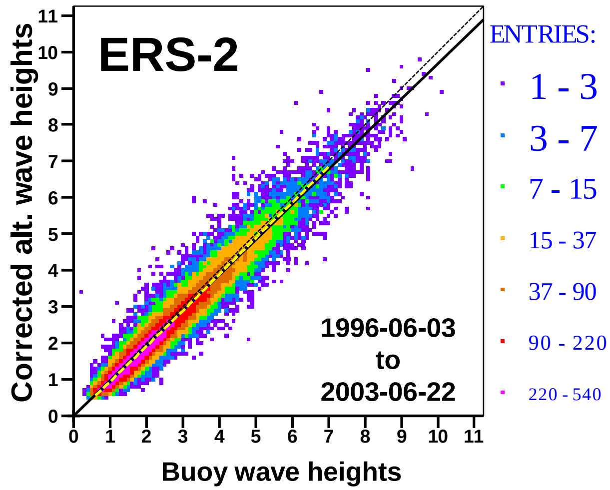


Using all in-situ wave data for the interim reanalysis :

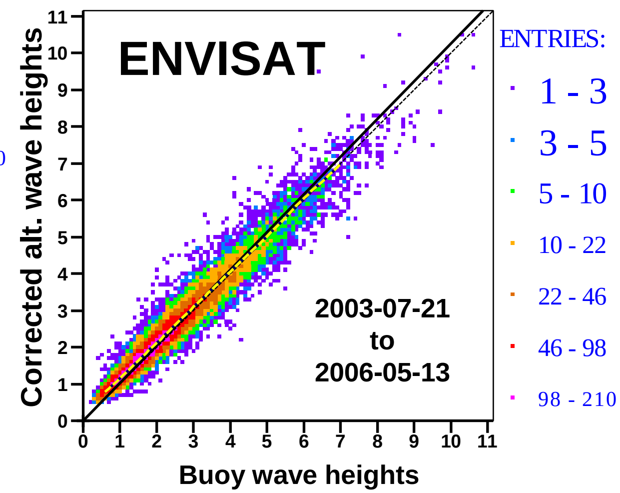


ERS-1 OPR wave heights are biased low when compared to buoys

ERS-2 OPR wave heights are slightly biased low when compared to buoys

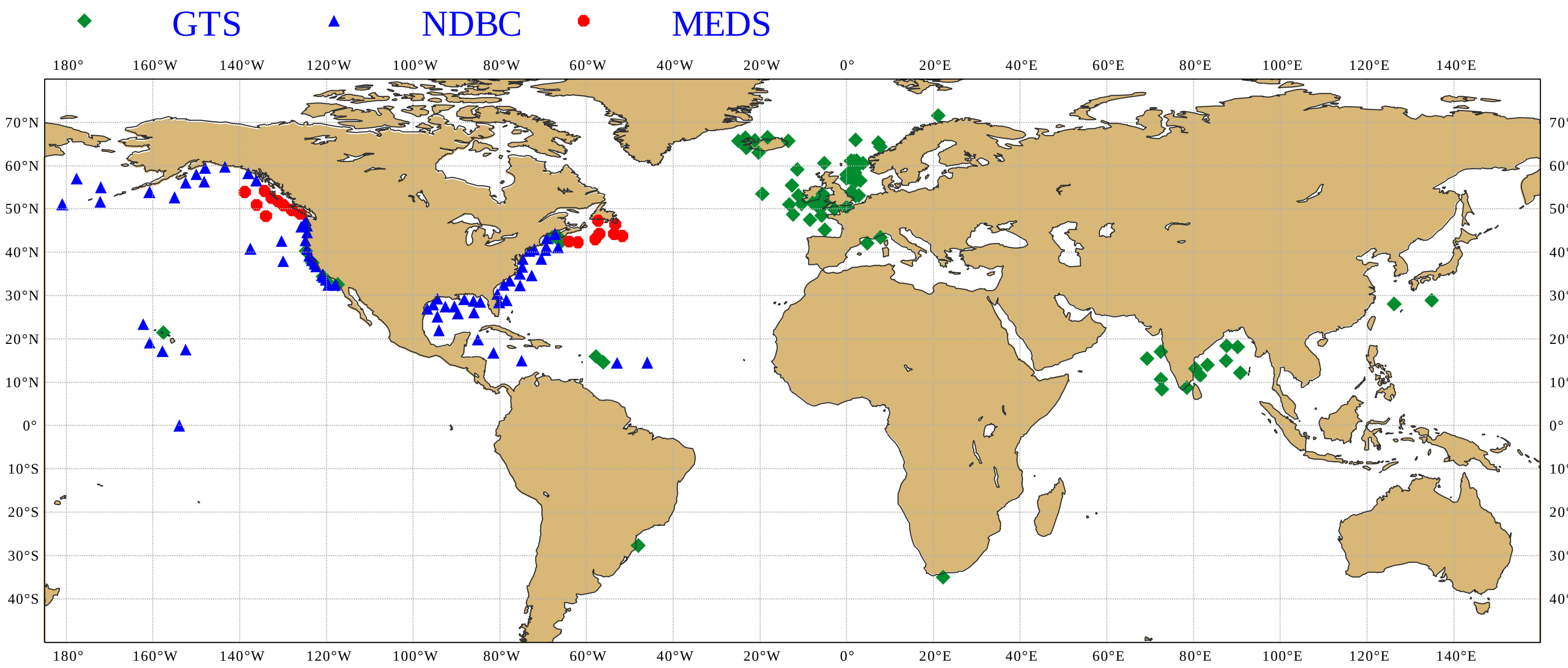


ENVISAT wave heights are slightly biased high when compared to buoys



Note: Jason-1 is similar to results for ENVISAT

Discrepancies in wave observations: data used for the altimeter calibration

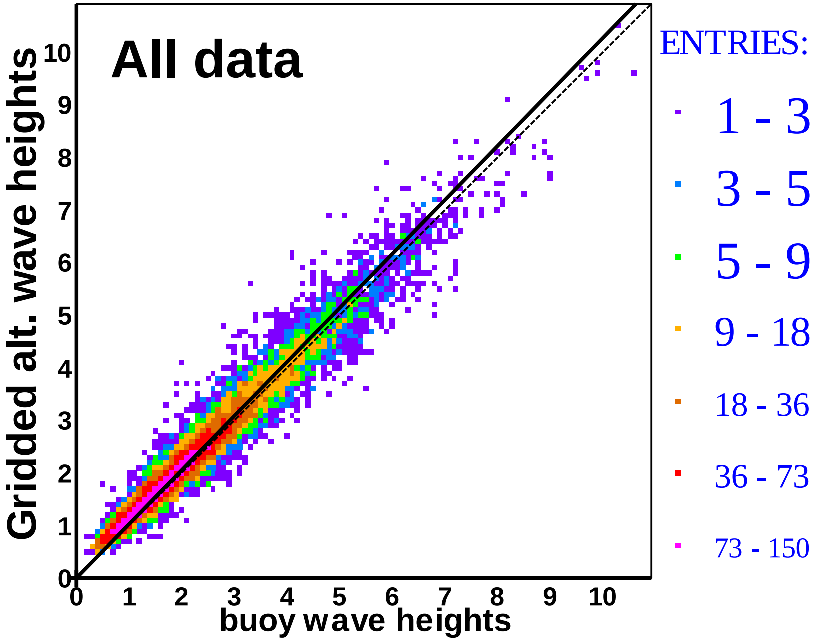


Data are from different sources:
NDBC (from NODC archive (ftp)), MEDS archive online.
GTS: data that were distributed by the Global Telecommunication System and archived at ECMWF.
These are mainly from European buoys (UK, France, Ireland, Iceland), Japanese buoys, Indian buoys,
Other American centres (Scripps, GoMoos,…), UK and Norwegian platforms and one South African platform (NDBC and MEDS are also on the GTS but slightly better data were obtained from the web).

Discrepancies in wave observations:

Collocation with ENVISAT

ENVISAT 2003072112_2006093018 ALL



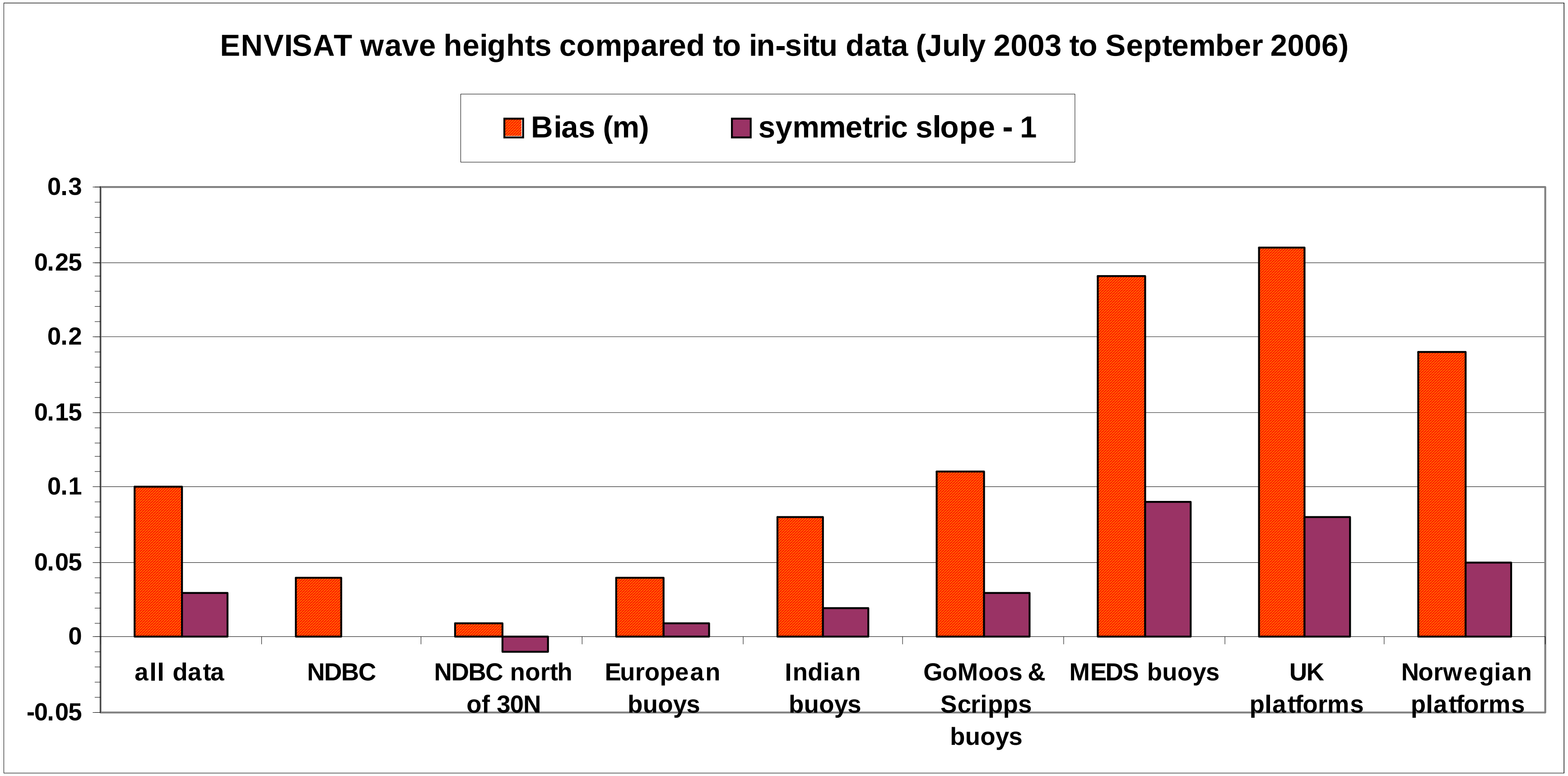
23091	41010	42041	44138	46023	46069	46207	62090	63055	ZSWA\
23092	41012	42055	44139	46025	46070	46208	62092	63103	
23096	41013	42056	44140	46026	46071	46213	62105	63108	
23097	41025	42057	44141	46027	46072	46214	62108	63112	
23099	41040	42058	44142	46028	46073	46218	62109	63113	
23100	41041	44004	44251	46029	46075	46219	62111	64045	
23101	41100	44005	44255	46035	46076	46227	62112	64046	
23167	41101	44008	46001	46036	46078	46229	62116	LDWR	
23168	41112	44011	46002	46041	46080	51001	62117	LF3F	
23169	42001	44014	46004	46042	46083	51002	62119	LF3J	
23170	42002	44017	46005	46047	46084	51003	62132	LF3N	
23172	42003	44018	46006	46050	46086	51004	62133	LF4B	
23174	42019	44024	46011	46053	46089	51028	62142	LF4C	
3FYT	42020	44025	46012	46054	46132	61002	62144	LF4H	
41001	42036	44027	46013	46059	46147	62001	62145	LF5U	
41002	42038	44037	46014	46062	46184	62029	62162	TFBLK	
41004	42039	44038	46015	46063	46205	62052	62163	TFSRT	
41009	42040	44137	46022	46066	46206	62081	62164	TFSTD	

ENTRIES = 13528
ALTM MEAN = 2.46 STDEV = 1.270
BUOY MEAN = 2.35 STDEV = 1.314
LSQ FIT: SLOPE = 0.942 INTR = 0.240
RMSE = 0.313 BIAS = 0.103
CORR COEF = 0.974 SI = 0.125
SYMMETRIC SLOPE = 1.026

Comparison of gridded altimeter with buoy wave heights for
100. km, 5 % max RCE and 45. degrees max in mean wave dir

Triple collocations are used, in which a model hindcast is also used to determine whether or not altimeter and buoy should be collocated.
RCE: Relative Collocation Error (abs(alt-buoy)/mean(alt,buoy)).
Model mean wave directions at both altimeter location and buoy should not be larger than 45°.

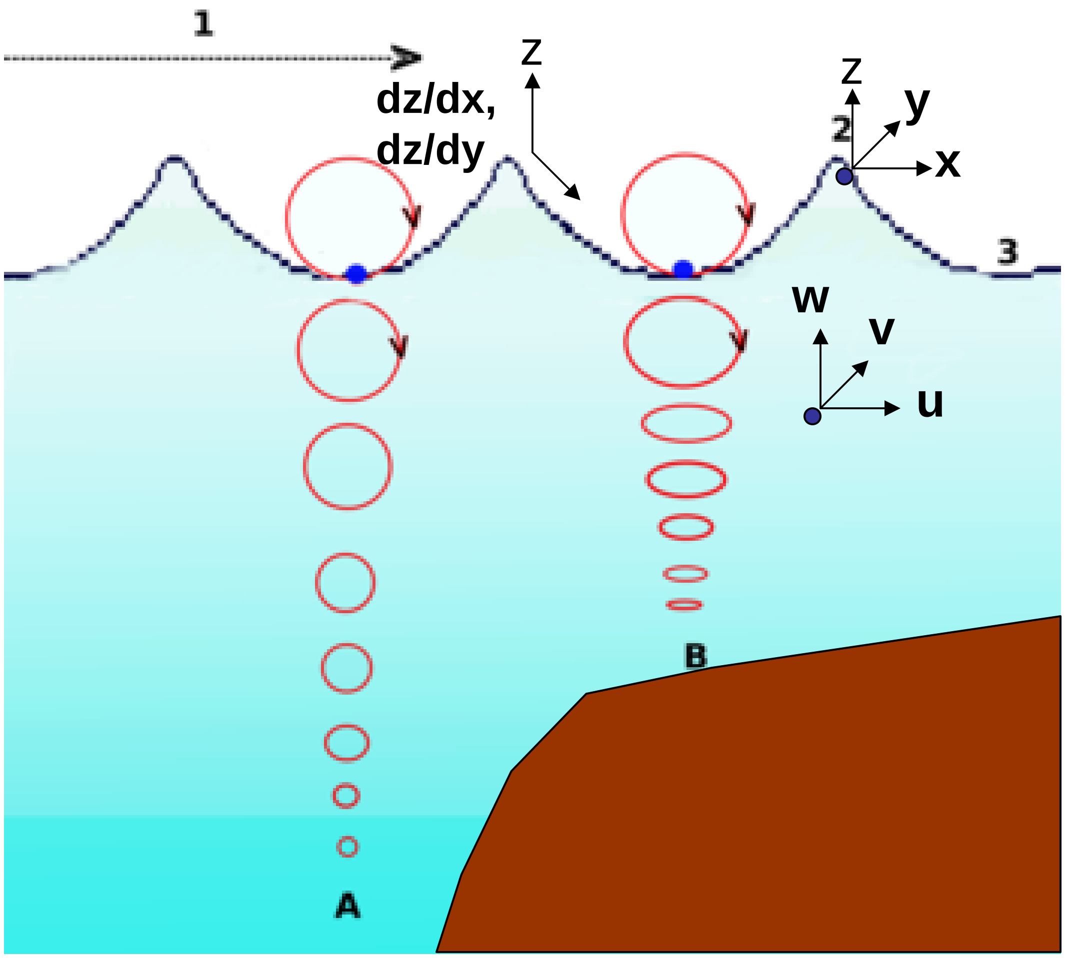
Discrepancies in wave observations:



Bias: altimeter Hs – in-situ Hs

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

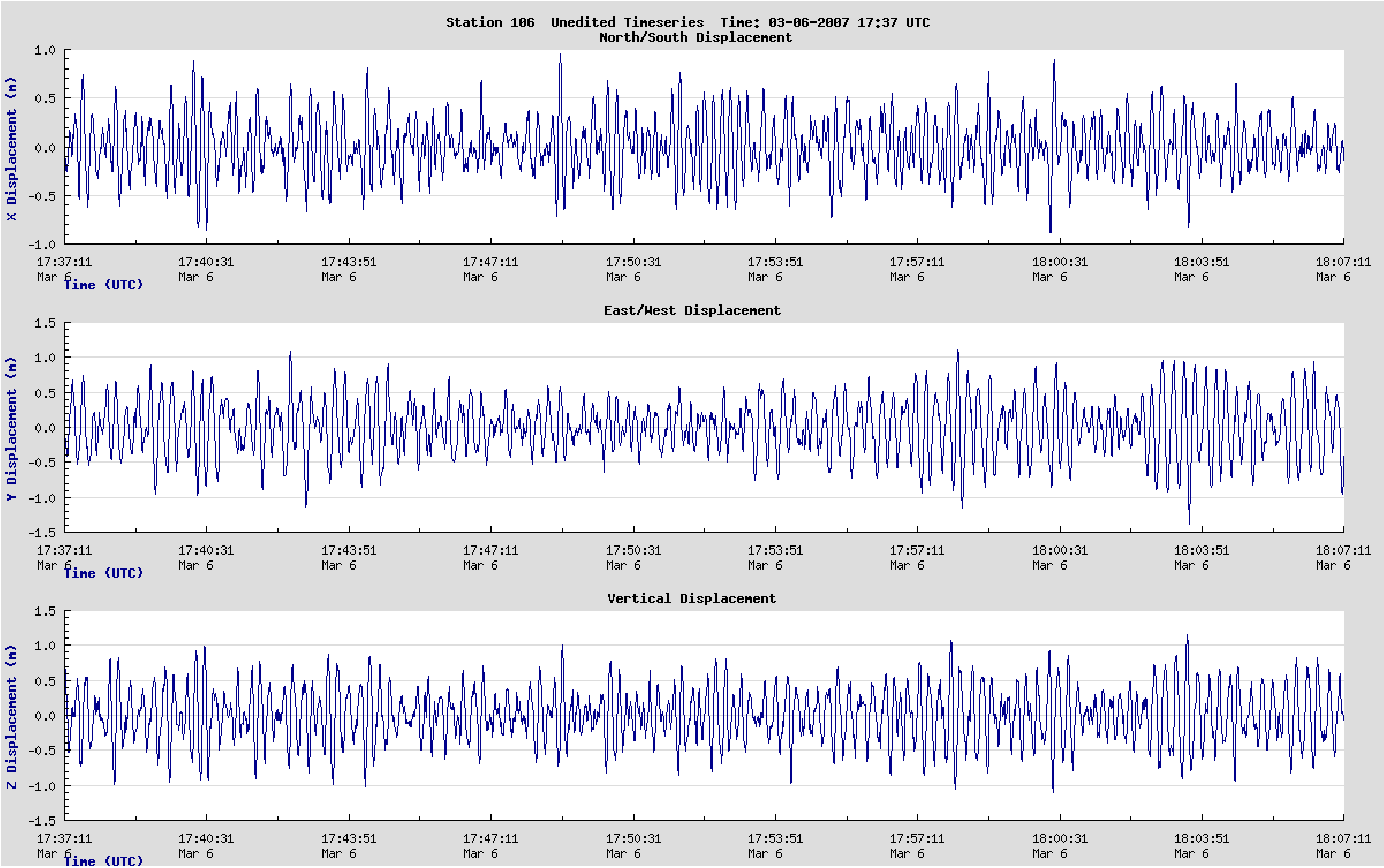
The Basics: Estimating the Motion of a Sea Surface Particle



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

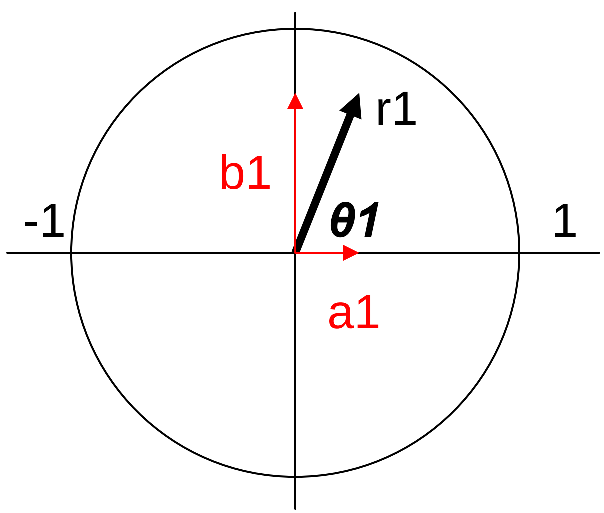
freq Hz	Band width	energy m*m/Hz	Dmean deg	a1	b1	a2	b2
0.0250	0.0050	0.0028	321	0.1920	-0.1567	-0.3925	-0.6345
0.0300	0.0050	0.0035	115	-0.1076	0.2259	-0.5132	-0.5796
0.0350	0.0050	0.0046	173	-0.2883	0.0348	-0.2973	-0.5084
0.0400	0.0050	0.0062	303	0.2602	-0.4085	-0.1606	-0.6449
0.0450	0.0050	0.0106	241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

a1,b1,a2,b2

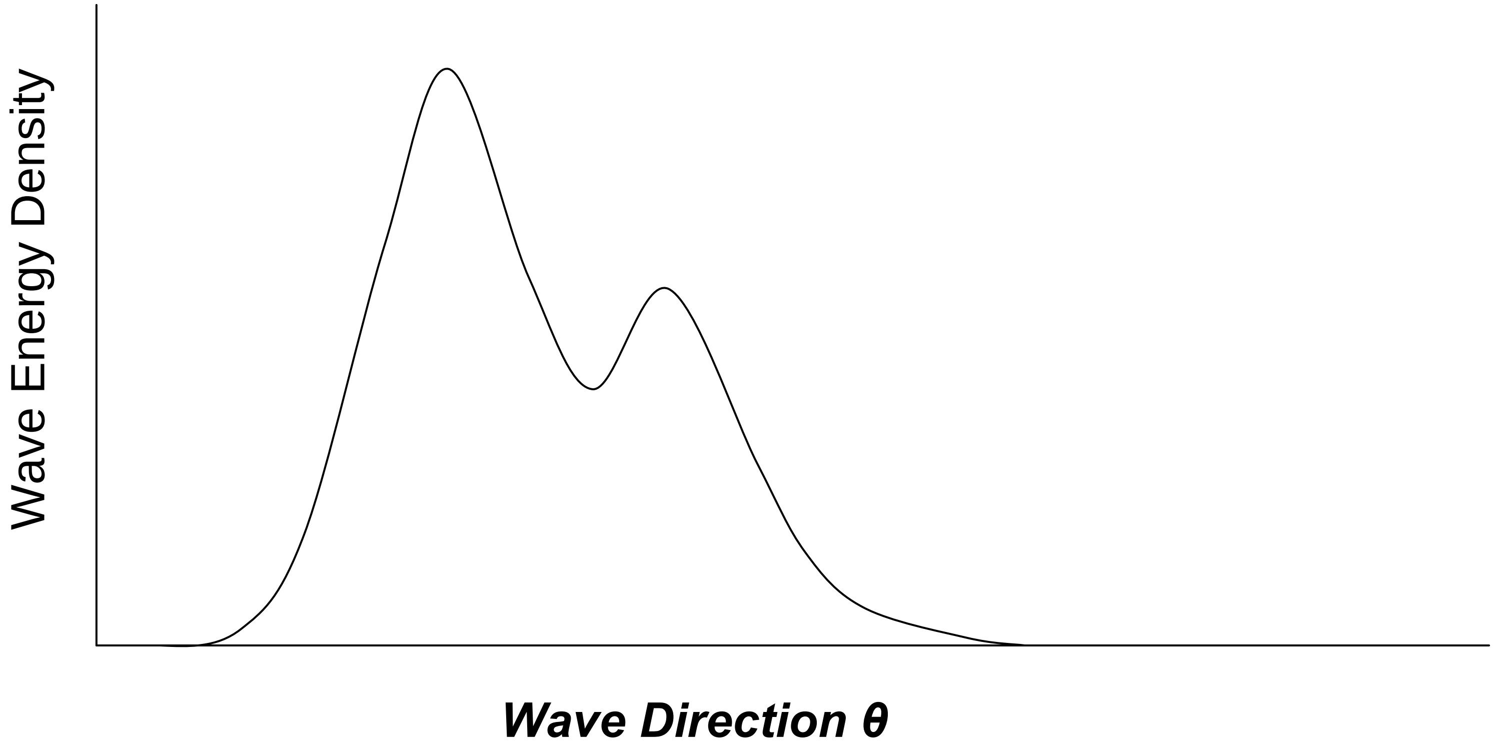
- mean direction
- directional spread
- skewness
- kurtosis

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



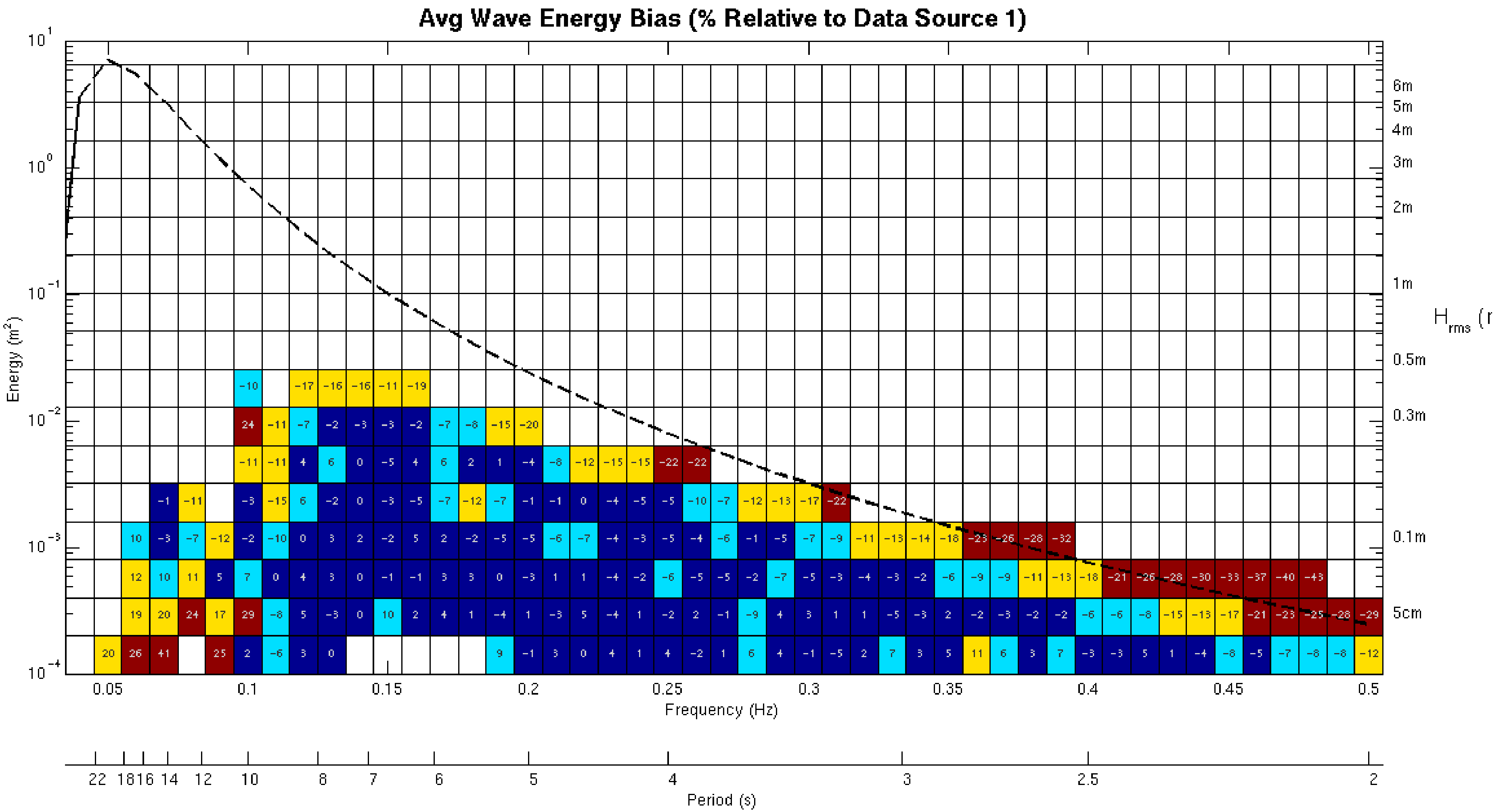
$$S(f,\theta)=S(f)[a1\cdot\cos(\theta)+b1\cdot\sin(\theta)+a2\cdot\cos(2\theta)+b2\cdot\sin(2\theta)+a3\cdot\cos(3\theta)+b3\cdot\sin(3\theta)+a4\cdot\cos(4\theta)+b4\cdot\sin(4\theta)+\ldots\ldots\ldots\text{infinity and beyond}]$$

“First 5” Intercomparisons

A “Wave Component” Approach

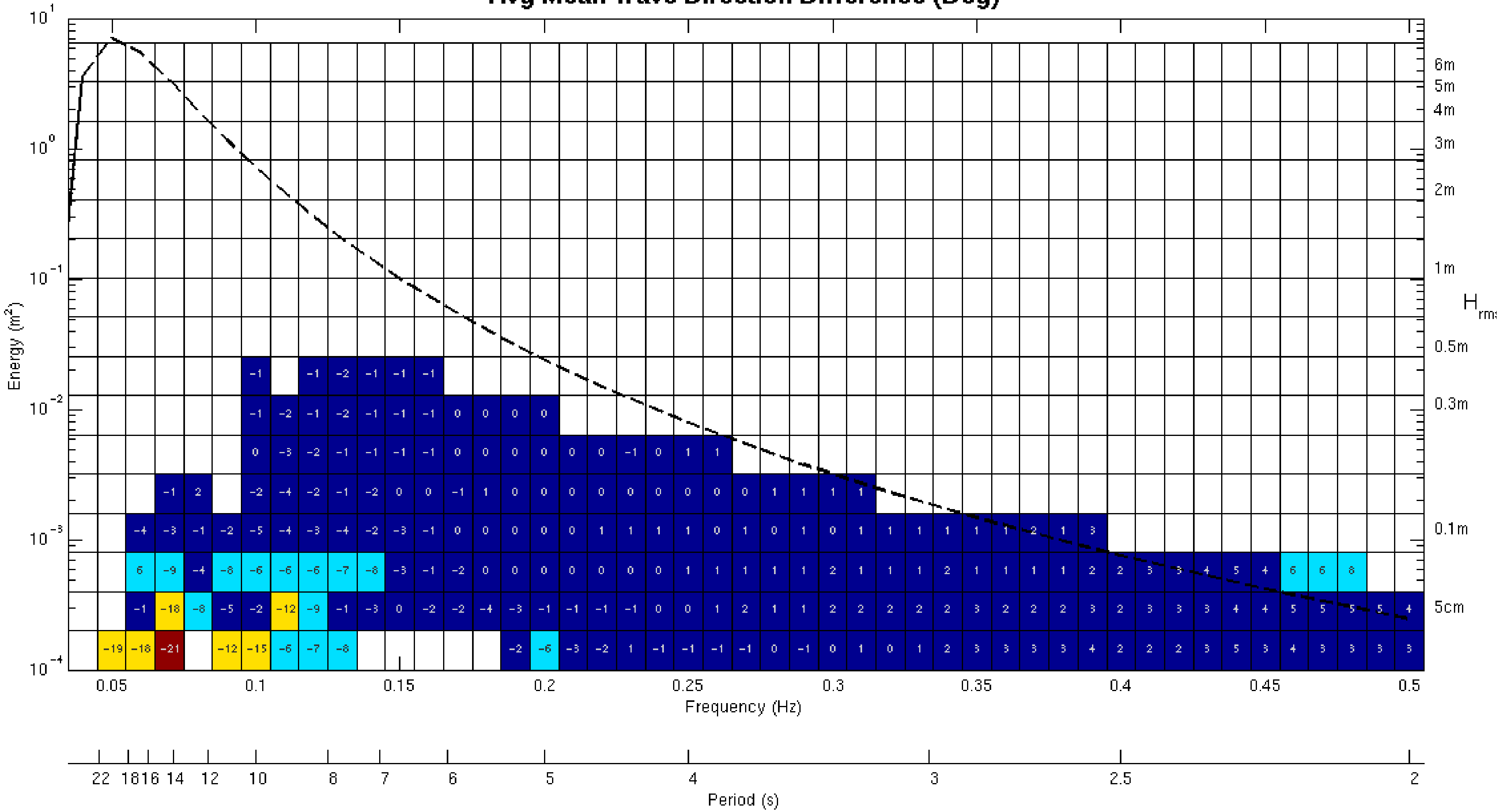
- Measurement errors are frequency and energy dependent.

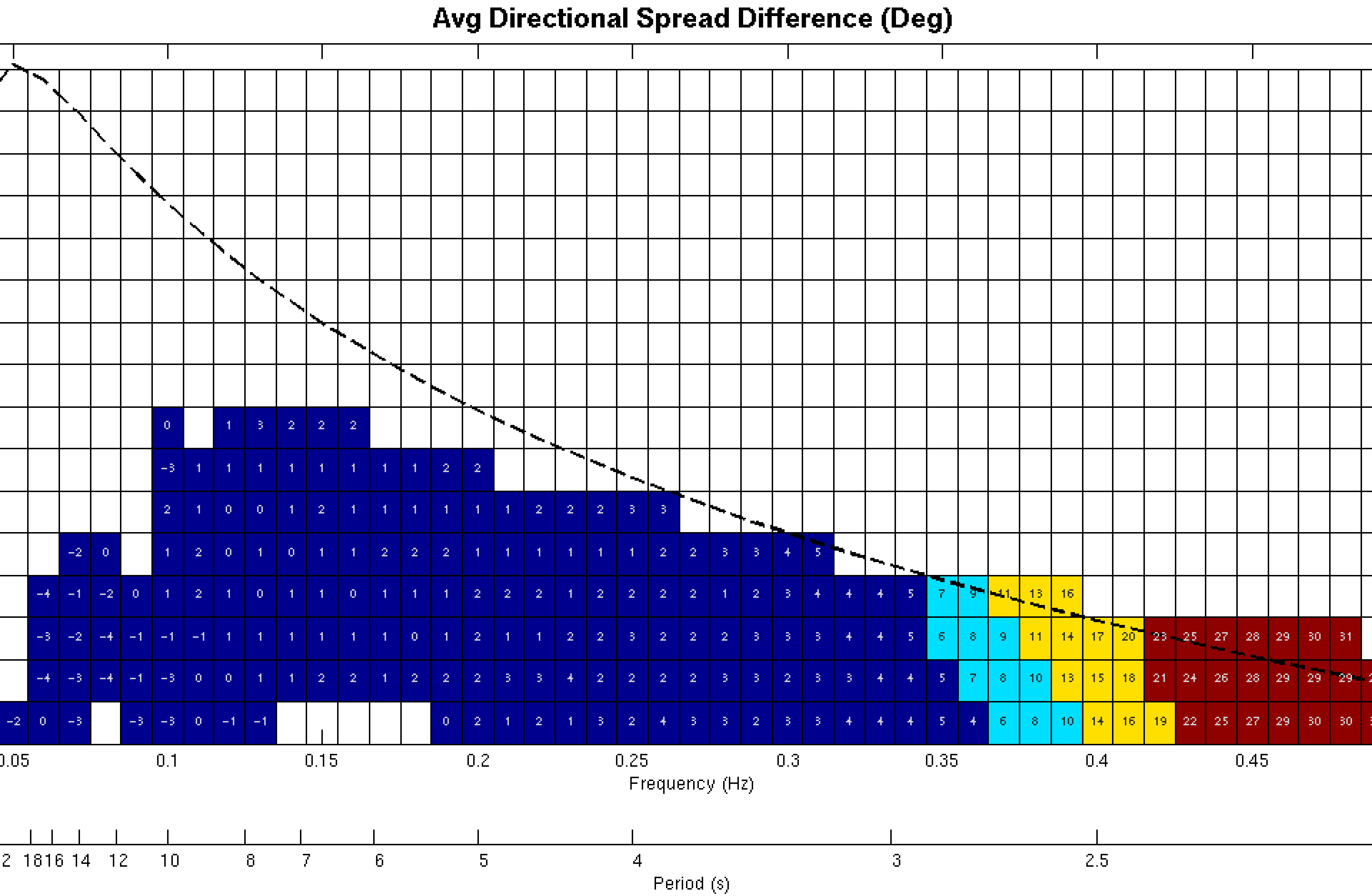
- A wide range of sea states need to be observed.

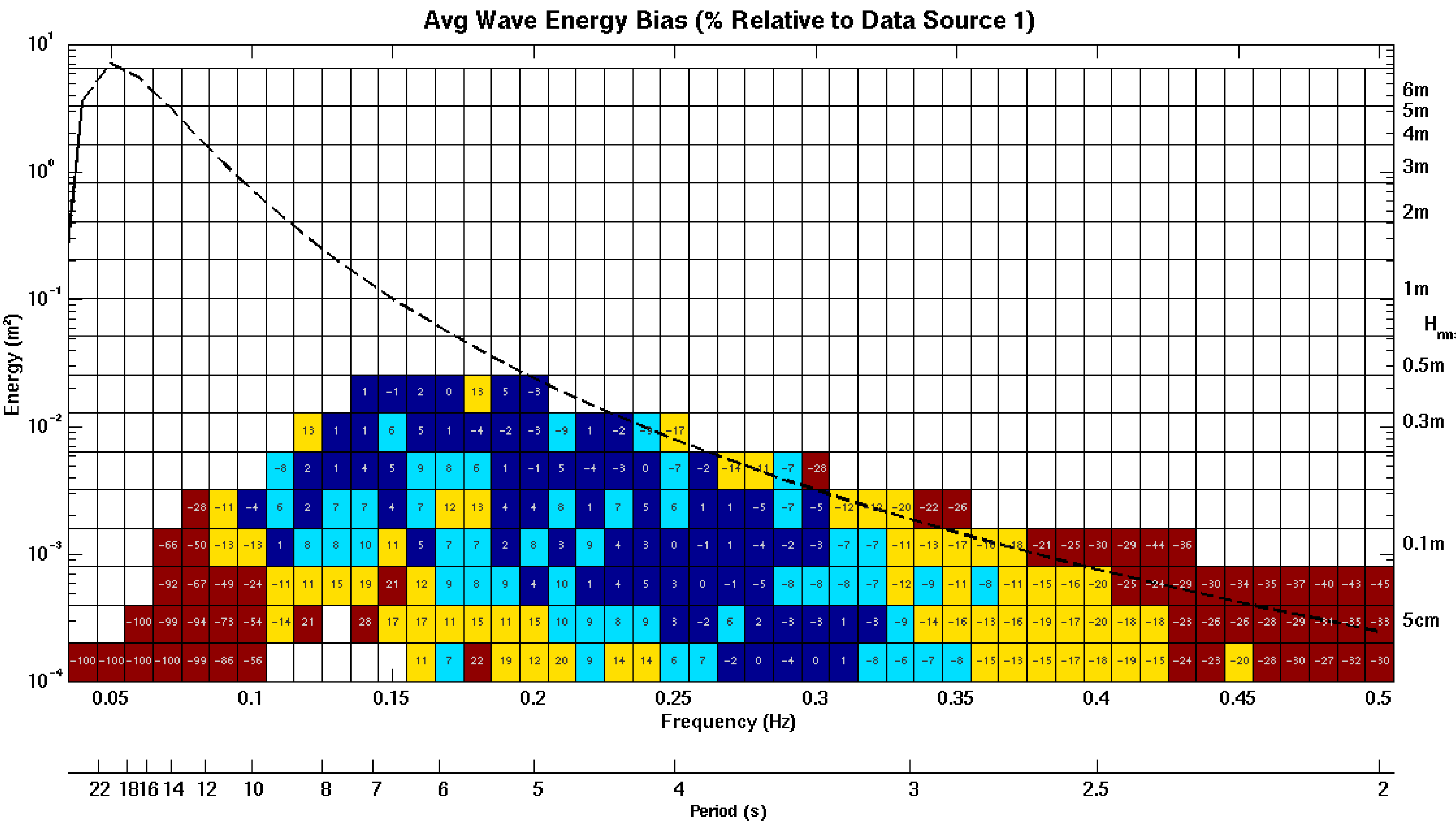


Avg Wave Energy Bias (% Relative to Data Source 1)
Energy (m²)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
Frequency (Hz)
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Period (s)
22
18
16
14
12
10
8
7
6
5
4
3
2.5
2
Hrms (m)
6m
5m
4m
3m
2m
1m
0.5m
0.3m
0.1m
5cm

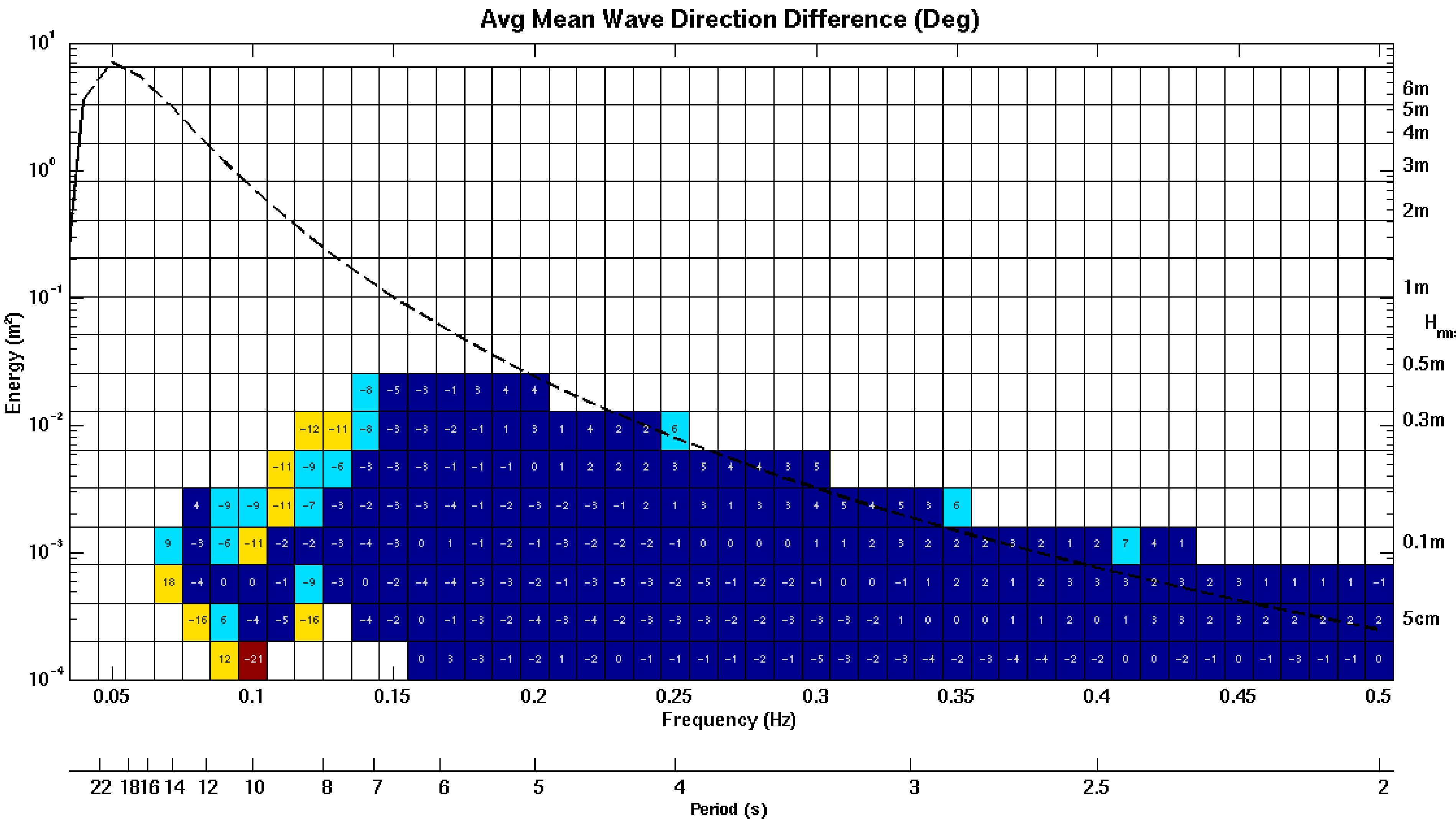
Avg Mean Wave Direction Difference (Deg)

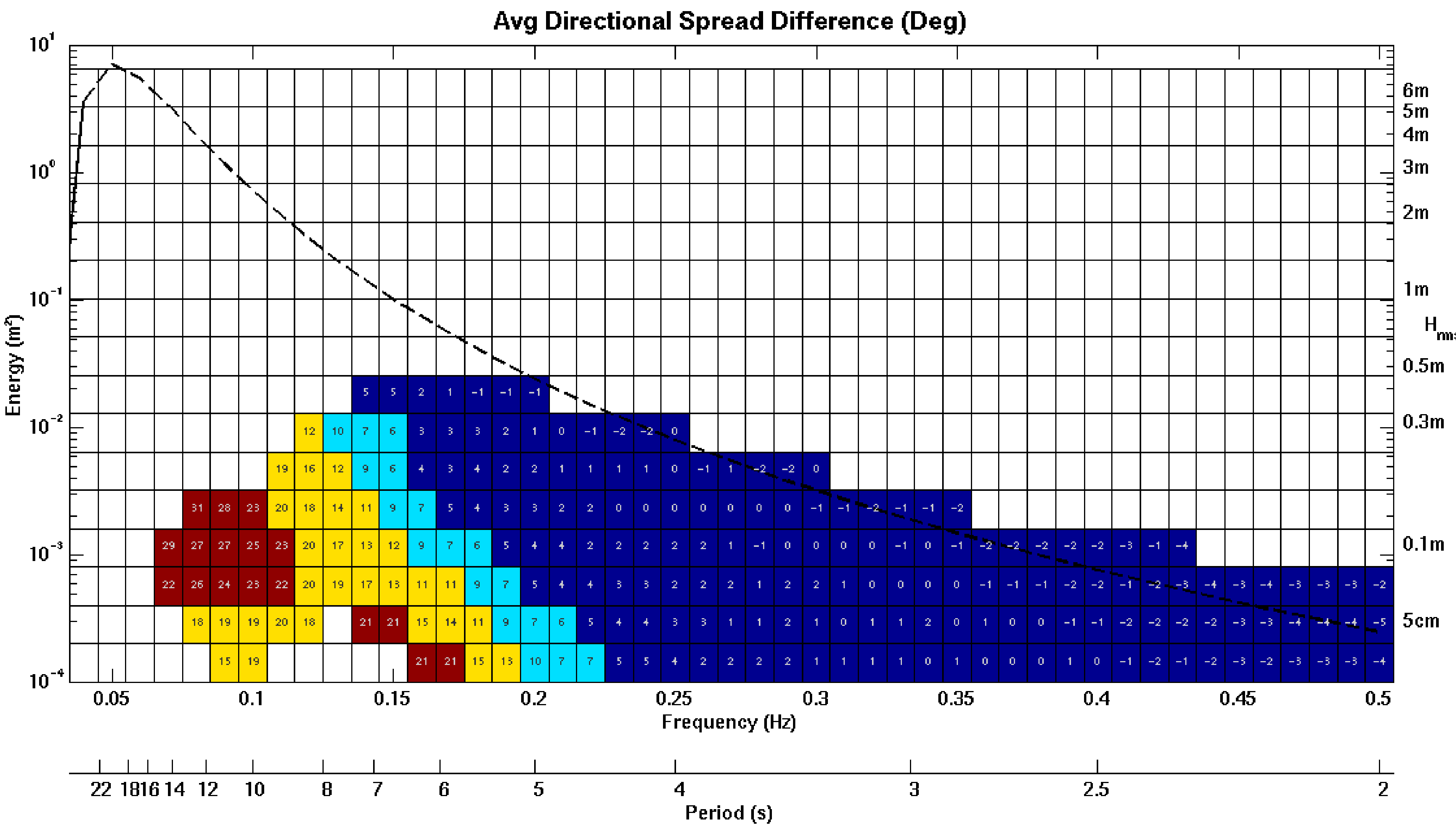



Avg Directional Spread Difference (Deg)
Frequency (Hz)
Period (s)
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45



Avg Wave Energy Bias (% Relative to Data Source 1)
Energy (m²)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
6m
5m
4m
3m
2m
1m
Hrms
0.5m
0.3m
0.1m
5cm
1 -1 2 0 13 5 -3
13 1 1 6 5 1 -4 -2 -3 -9 1 -2 -17
-8 2 1 4 5 9 8 6 1 -1 5 -4 -3 0 -7 -2 -14 -11 -7 -28
-28 -11 -4 6 2 7 7 4 7 12 13 4 4 8 1 7 5 6 1 1 -5 -7 -5 -12 -12 -20 -22 -26
-66 -50 -13 -13 1 8 8 10 11 5 7 7 2 8 3 9 4 3 0 -1 1 -4 -2 -3 -7 -7 -11 -13 -17 -16 -18 -21 -25 -30 -29 -44 -36
-92 -67 -49 -24 -11 11 15 19 21 12 9 8 9 4 10 1 4 5 3 0 -1 -5 -8 -8 -8 -7 -12 -9 -11 -8 -11 -15 -16 -20 -25 -24 -29 -30 -34 -35 -37 -40 -43 -45
-100 -99 -94 -73 -54 -14 21 28 17 17 11 15 11 15 10 9 8 9 3 -2 6 2 -3 -3 1 -3 -9 -14 -16 -13 -16 -19 -17 -20 -18 -18 -23 -26 -26 -28 -29 -31 -35 -33
-100 -100 -100 -100 -99 -86 -56 11 7 22 19 12 20 9 14 14 6 7 -2 0 -4 0 1 -8 -6 -7 -8 -15 -13 -15 -17 -18 -19 -15 -24 -23 -20 -28 -30 -27 -32 -30
0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5
Frequency (Hz)
22 18 16 14 12 10 8 7 6 5 4 3 2.5 2
Period (s)


Avg Mean Wave Direction Difference (Deg)
Energy (m²)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
Frequency (Hz)
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Period (s)
22
18
16
14
12
10
8
7
6
5
4
3
2.5
2
H rms
6m
5m
4m
3m
2m
1m
0.5m
0.3m
0.1m
5cm


Avg Directional Spread Difference (Deg)
Energy (m²)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
6m
5m
4m
3m
2m
1m
Hrms
0.5m
0.3m
0.1m
5cm
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Frequency (Hz)
22
18
16
14
12
10
8
7
6
5
4
3
2.5
2
Period (s)

The Coastal Data Information Program
Integrative Oceanography Division

Recent | Historic | Documents

Station ID | search

Documentation

FAQs & Summaries
Glossary
Publications

Introduction
History and Funding
Program Goals
Wave Measurement
Wave Generation
Wave Dynamics
Irregular Waves
Spectral Analysis
Gauging Waves
Hurricane Events
Tsunami Events
Instrumentation
Instrument Types
Deployment & Use
Data Acquisition
System Organization
Hardware
Software
Data Processing
System Organization
Software
Quality Control
Data Management
Stations and Sets
Files and Storage
CDIP Products
Data Formats
Web Products
COOS Integration
QARTOD
Sensor Comparisons
Metadata
Custom Products
NDBC XML/NWS Format
NDBC Dial-A-Buoy
Access Instructions

Related Links

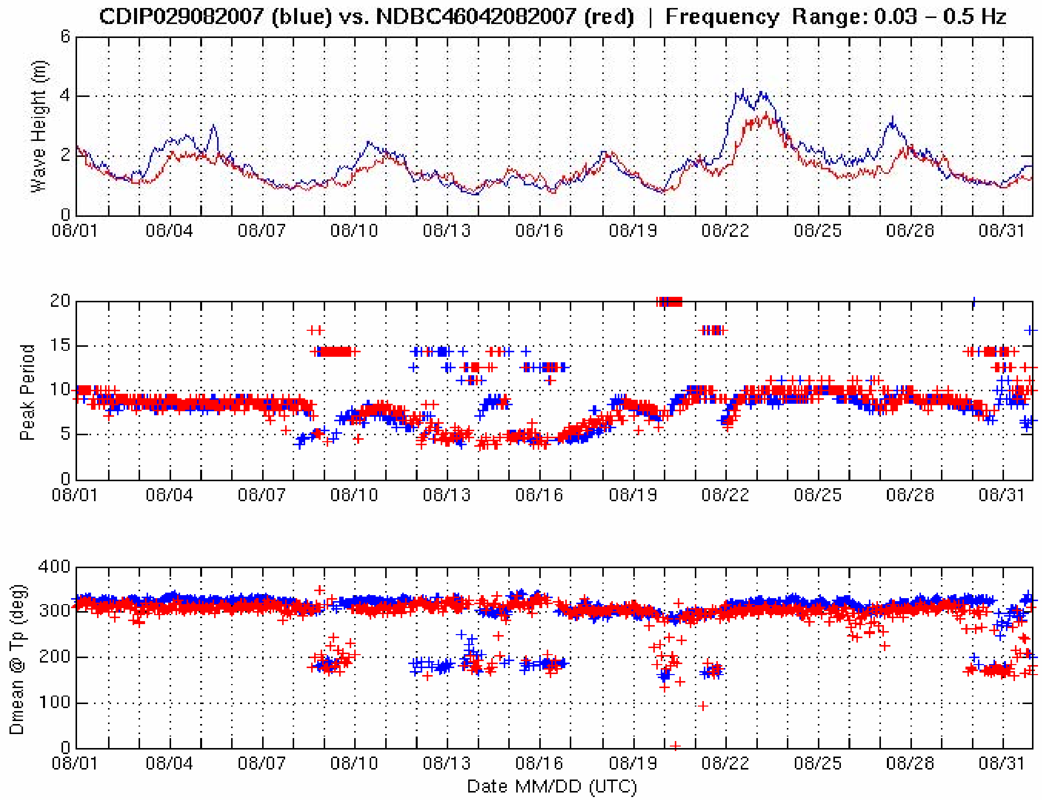
Wave Sensor Comparisons

CDIP029082007_v_NDBC46042082007

Time Series Plots | Wave Component Plots | Scatter Plots (future)

All Waves 0.03-0.50Hz | Forerunners 0.03-0.05Hz | Long Swell 0.05-0.08Hz | Short Swell 0.08-0.12Hz | Long Seas 0.12-0.25Hz | Short Seas 0.25-0.40Hz | Wind Chop 0.40-0.50Hz

Hs, Tp , Dm @ Tp
Freq Peak & Centroid
a1,b1 Mean Dir & Spread
a2,b2 Mean Dir & Spread
Skewness & Kurtosis



CDIP Wave Spectra Comparison Tool, Beta Version

CDIP Quality Control Measures

The tests applied are determined by data/processing type, as summarized in the table below. Note that CDIP's time series products are for the most part unedited; other than checking for gaps in the data and incorrect times, the times series values are not quality-controlled. It is only when the time series are used for spectral and parameter processing that they are submitted to CDIP's full set of quality control routines.

- AR = Directional Array of Pressure Sensors
- BS = Basin Energy Processing, Pressure Sensor
- DW = Datawell Directional Buoy
- NB = Non-directional Buoy
- PR = Single Point Pressure Sensor
- SG = Surge Processing, Pressure Sensor

TIME SERIES VALUES						
TEST: description (click name for more details)	AR	BS	DW	NB	PR	SG
GAP TEST: edit or discard time series with missing values.	✓	✓		✓	✓	✓
DW STATUS/TRANSMISSION BYTE: discard imperfectly received data.			✓			
MAX WAVE HEIGHT: check wave height against max in archive.	✓	✓		✓	✓	✓
FLAT EPISODES TEST: test if time series is changing too slowly.	✓			✓	✓	
SPIKE EDIT: replace spikes with average of point and previous.	✓	✓		✓	✓	✓
MAX/MIN VALUE TEST: for water column, check if values are sensible	✓				✓	
MEAN SHIFT TEST: check for a shift in the mean in the series.	✓	✓		✓	✓	✓
EQUAL PEAKS TEST: check for successive peaks with the same value.	✓				✓	✓
ACCELERATION TEST: check if acceleration is greater than 1/3 g	✓	✓			✓	✓
MEAN CROSSING TEST: check if there are too few mean crossings.	✓			✓	✓	
PERIOD DISTRIBUTION TEST: check for excessive long-period waves.	✓			✓	✓	
UNCORRECTED ENERGY COMPARISON: compare time series variance.	✓					
DEPTH COMPARISON: compare time series means.	✓					
SERIES COMPARISON: check correlation of time series.	✓					
CORRECTED ENERGY COMPARISON: compare depth-corrected variance.	✓					
SPECTRAL VALUES						
TEST: description (click name for more details)	AR	BS	DW	NB	PR	SG
INCIDENT WAVE TEST: check that directions are incident to shore.	✓					
DW STATUS/TRANSMISSION BYTE: discard imperfectly transmitted data.			✓			
BAND DIRECTION MAX/MIN: check Dmean for each band.			✓			
DW CHECK FACTORS: issue warning for bad check factors.			✓			

The Multi-use Platform Challenge

Wave Measurement Methods

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

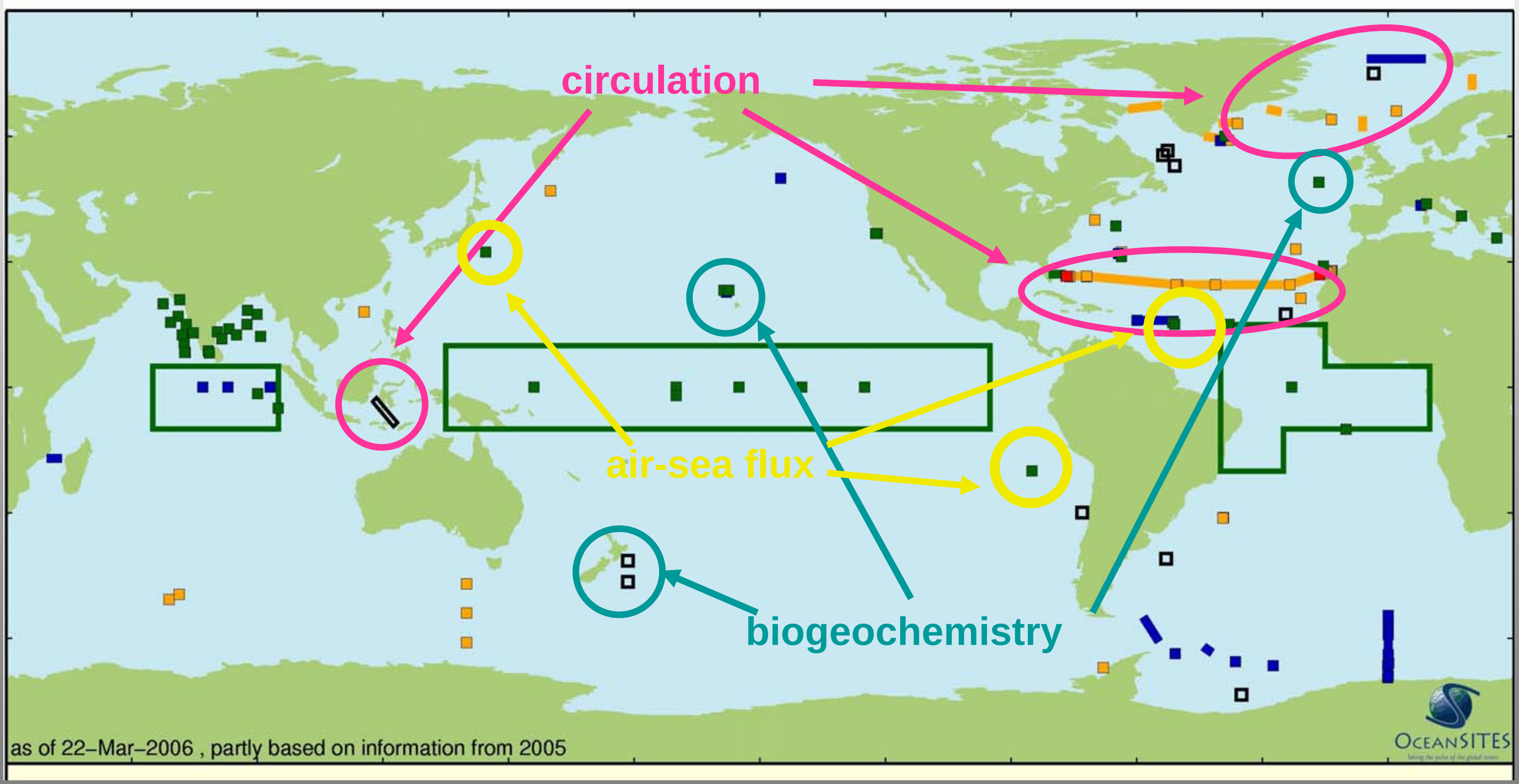
2) Corrected Wave Follower (heave-pitch-roll with transfer function)
often a complex function of sea-state, mooring system, wind loads etc. including buoy configuration, batteries…

3) Corrected “nearly” Fixed Platform (subsurface acoustic)

4) Fixed Platform (pressure, acoustic)

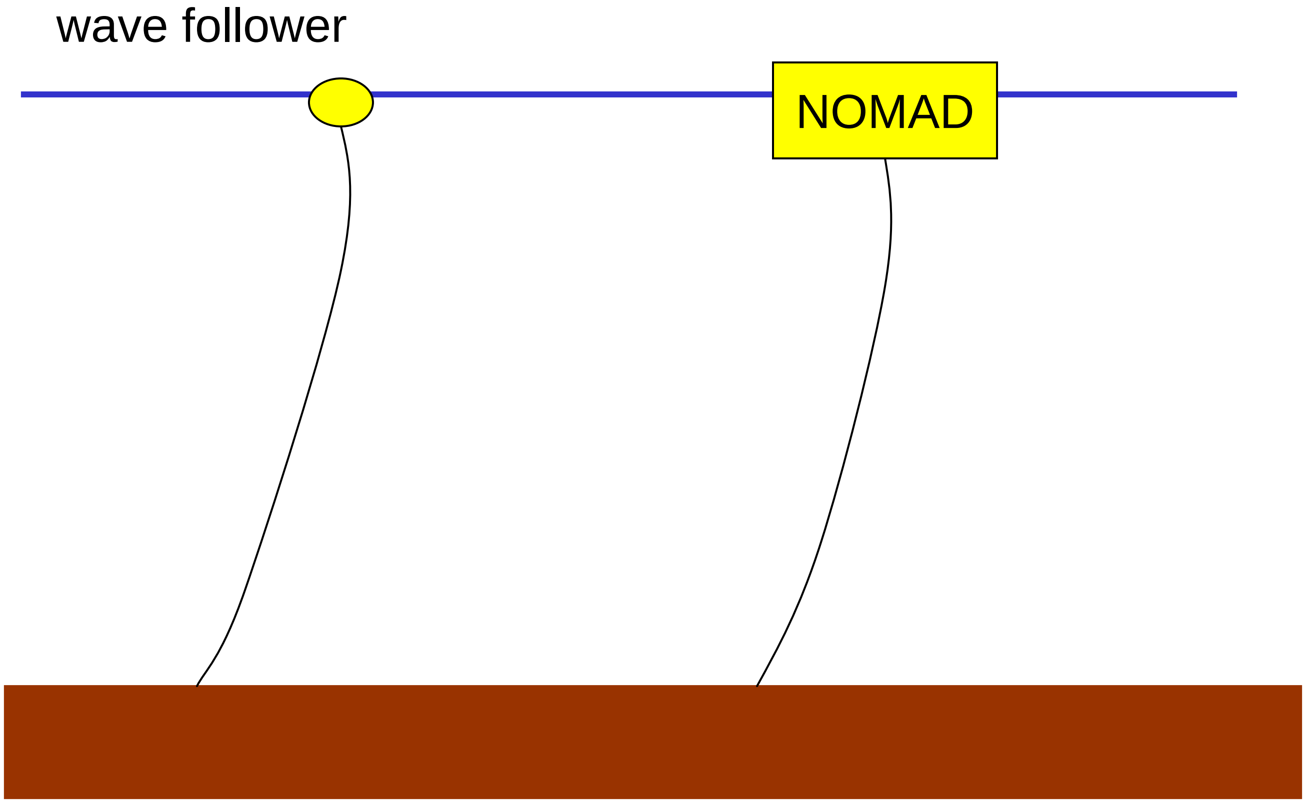
However… difficult to develop users and demonstrate value of the network because :

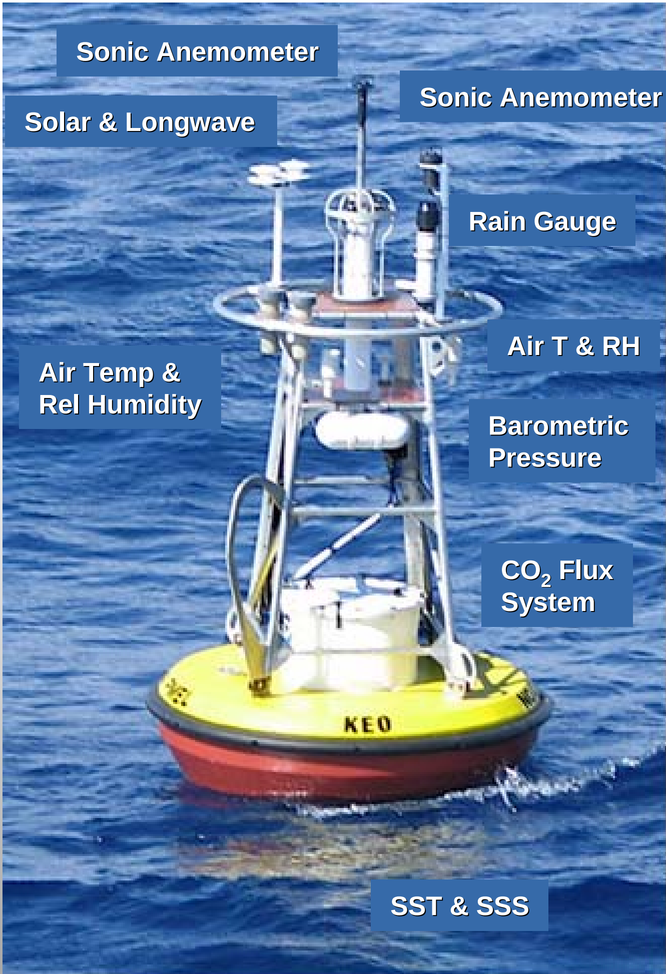
- Current sites are very inhomogeneous
- Difficult or no data access and comparable QC procedures
- lack of products useful for the community



The NDBC Offshore Approach

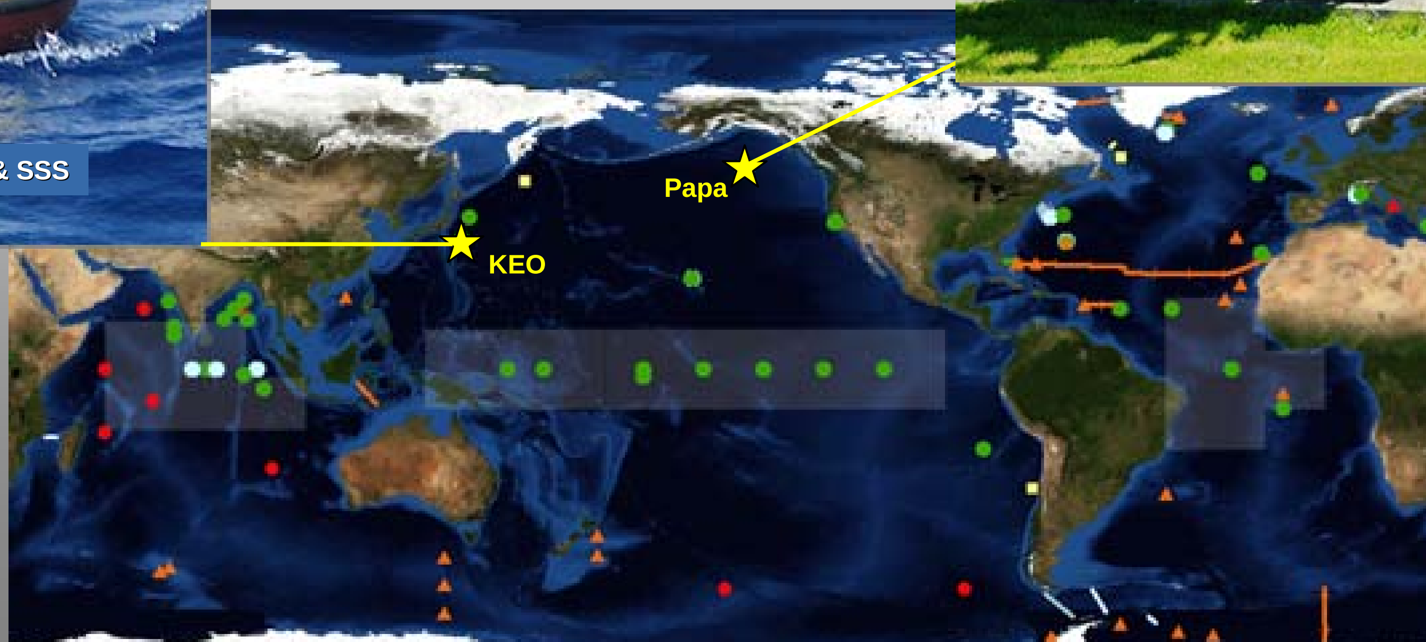
Waves-only Companion Buoy near the Multi-use Platform

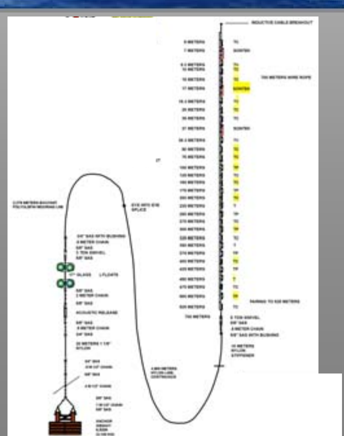




NOAA PMEL has strong intentions to measure directional wave spectra from their multi-disciplinary/carbon moorings (PAPA, KEO), pending funding.

http://www.pmel.noaa.gov/OCS/





http://www.oceansites.org/

Partial List of Technical Issues to be Addressed

- Buoy Response and Transfer Functions
- Power Budget
- Transmission Requirements
- Sensor Accuracy
- Buoy Intercomparison – buoy farm?
- Change in program, e.g. for directional requirement
- Technical documentation and evaluation of differences due to hull, payload, mooring, sampling frequency and period, processing (e.g. frequency bands & cutoff), precision, transmission
- Funding

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Outcome of the meeting – Moored buoys

- Wave buoy data geographical coverage limited, especially directionality
- A thorough and comprehensive understanding of the performance of existing technologies under real-world conditions is currently lacking
- Continuity of established buoy networks, expansion of directional measurements priority for operations and climate assessment
- Expanding wave observing capabilities to other parts of the worlds oceans desirable from an operational point of view
- Guidelines of best practices for buoy wave measurements important in making buoy measurements consistent across networks and instrumentation types.
- Agreed with the WIGOS Concept of Operations (CONOPS) recommendation that all wave observational data and metadata should adhere to WIGOS standards for instruments and methods of observation
- Agreed with development of best practices and standards documents related to waves and development of wave metadata within the Meta-T framework
- No “perfect” wave measurement system against which to inter-compare other types of wave measurement. However, the Datawell sensors viewed as the best available and should form the basis for comparisons

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Outcome of the meeting – Moored buoys (2)

- Real need to inter-compare various buoy networks, platforms, and instrumentation to establish consistency for the "first 5 standard" wave measurements.
  - Development of standardized procedures for buoy inter-comparison required.
  - Proper directional wave measuring device should reliably estimate "first 5"
  - Collocate different buoys with reference standard (Datawell waverider) for at least a year at one or more reference sites;
  - Moving intercomparison technology was endorsed,
- For buoys not designed to follow wave slope/particle motion, may be better to do away with assumptions and transfer function correction - measure buoy motion and then observe waves directly like from a fixed platform
- Raise awareness of sensor options, quality, prospects; transfer function problems.

❖ **<u>Develop a Pilot Project on Wave measurement Evaluation and Test for moored buoys for consideration at DBCP XXIV</u>**

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How is your wave measurement?

Courtesy C-C Teng

JCOMM Technical Workshop on Wave Measurements from Buoys New York, USA October 2-3, 2008

- **OBJECTIVES** :

  - to provide a forum for the exchange of ideas and information related to wave measurement from moored and drifting buoys, taking into consideration the users' requirements;

  - to discuss priorities for the development of cost-effective wave observing technology and for extending the network of wave measuring buoys;

  - to develop a technical work plan for implementation of enhanced global wave measurements

- **EXPECTED RESULTS:**

  - **Input to technical work plan for implementation of enhanced spatial and temporal coverage of wave measurements on a global basis and assessment of existing and future wave measurement technology for consideration at DBCP-XXIV by DBCP and its Action Groups.**

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