The provenance of the accuracy statement for NDBC's wave direction measurements

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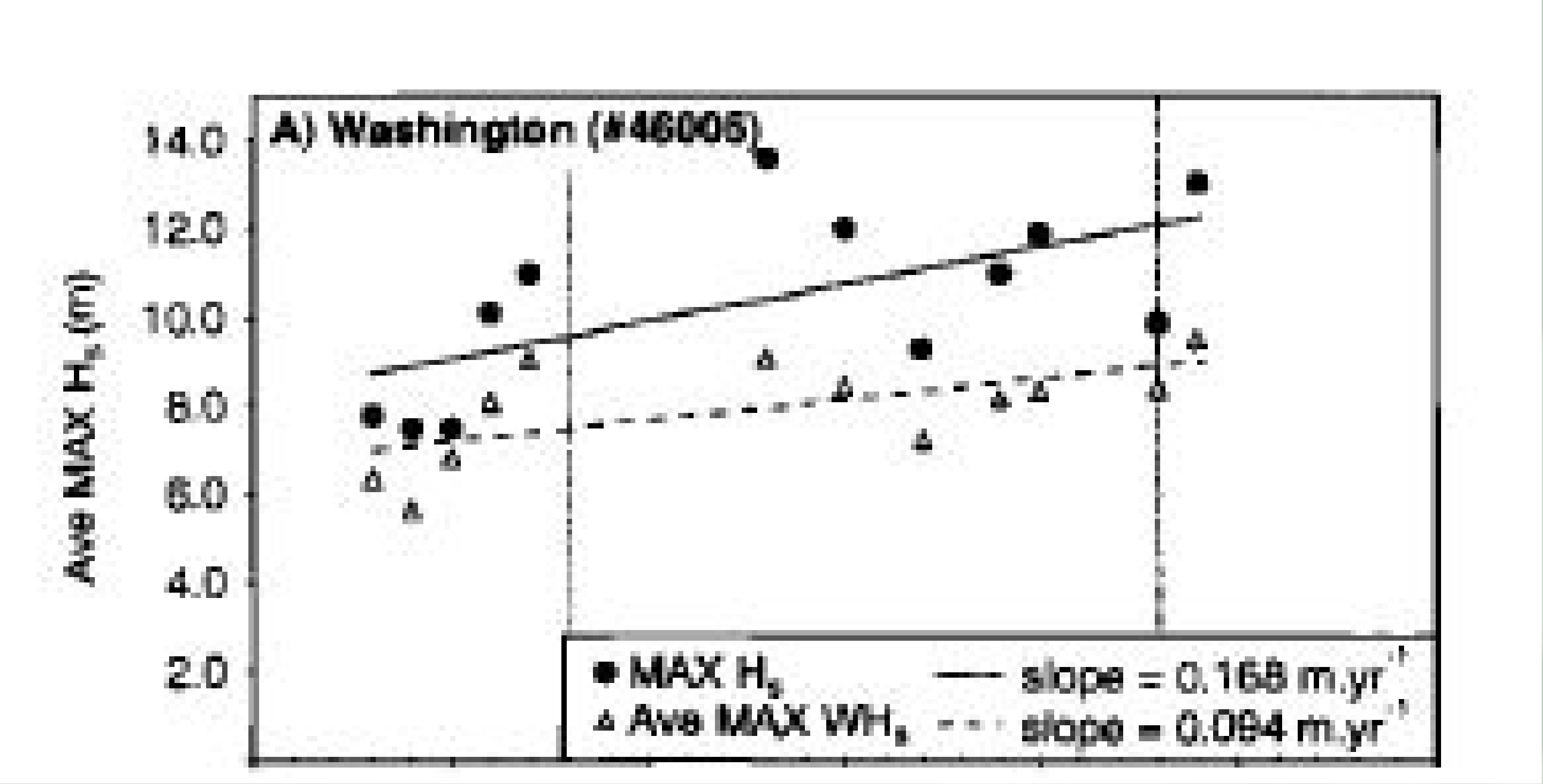
Provenance

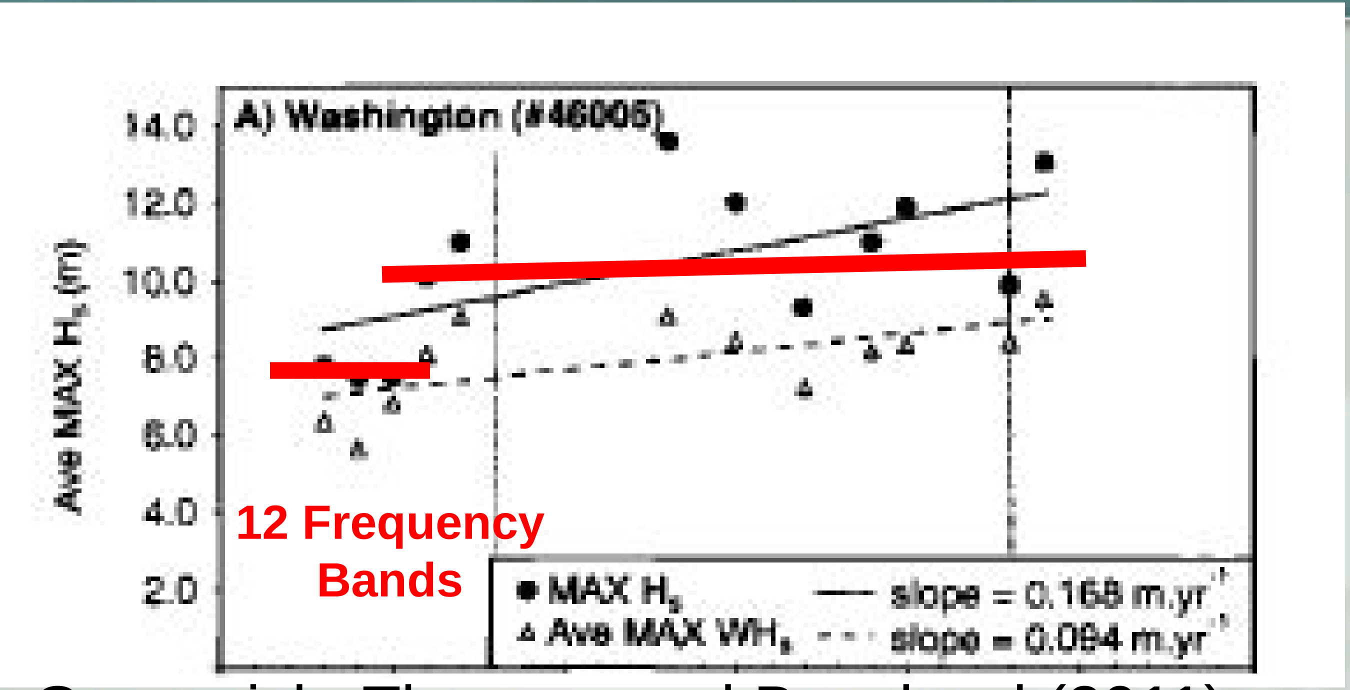
- **the place of origin or earliest known history of something.**
- **the beginning of something's existence; something's origin.**
- **a record of ownership of a work of art or an antique, used as a <u>guide to authenticity or quality</u>.**

Are Ocean Wave Heights Increasing in the Eastern North Pacific? - Allan and Komar, *Eos*, Vol. 81, No. 47, November 21, 2000



1975 1983 1998

Not Aware of System Changes



Gemmrich, Thomas, and Bouchard (2011):

Several recent studies reported long-term trends extracted from these records. However, significant modifications of the wave measurement hardware as well as the analysis procedures since the start of the observations result in inhomogeneities of the records.

www.ndbc.noaa.gov/rsa.shtml

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- Email Access

Station Status
- NDBC Maintenance
- NDBC Platforms
- Partner Platforms

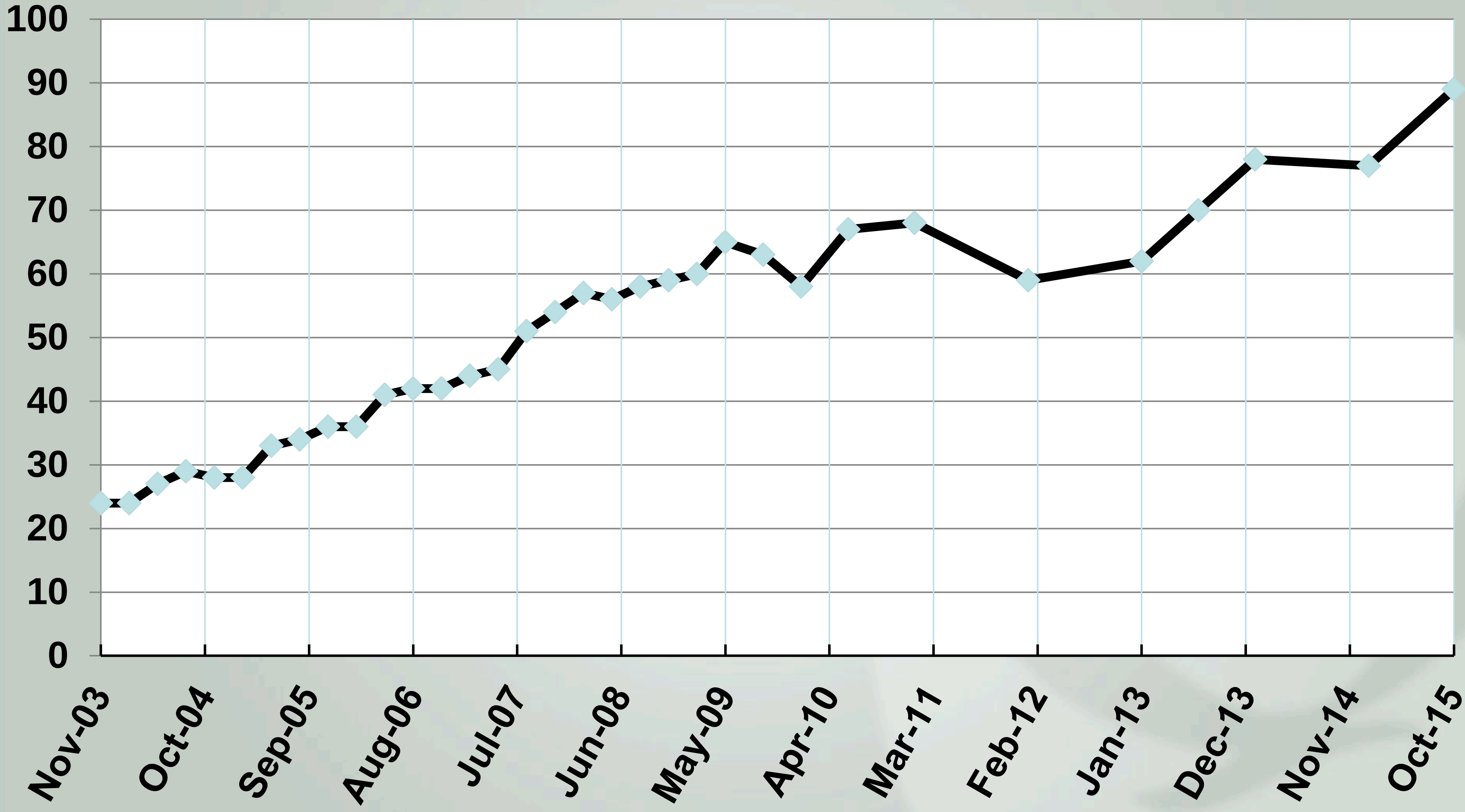
Program Info

The payload (on-board computer system) presently installed at each station is given in the opening paragraph of each station's present data page. For information on what payloads were used historically at each station, consult the NDBC data inventory.

ARES Payload

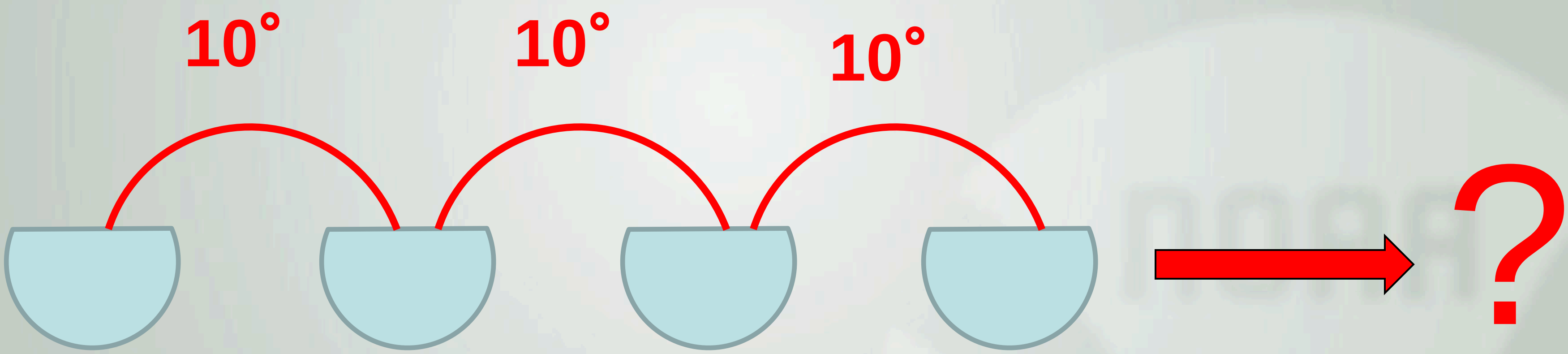
PARAMETER	RANGE	FREQ.	AVG. PERIOD	RESOLUTION	ACCURACY
Wind Dir.	0 to 360	1.71 Hz	2/8 min *	1.0 deg	+/- [illegible] deg
Wind Speed	0 to 62 m/s	1.71 Hz	2/8 min *	0.1 m/s	+/- [illegible] m/s or 10% ***
Wind Gust	0 to 82 m/s	1.71 Hz	3 & 5 sec	0.1 m/s	+/- [illegible] m/s or 10% ***
Air Temp.	-40 to +60 C	1.71 Hz	2/8 min *	0.1 C	+/- [illegible] C
Pressure	800 to 1100 hPa	1.71 Hz	2/8 min *	0.1 hPa	+/- [illegible] hPa
Sea Surface Temp.	-5 to +40 C	1.71 Hz	2/8 min *	0.1 C	+/- [illegible] C
Rel. Humidity	0 to 100%	1.71 Hz	2/8 min *	0.1%	+/- [illegible]
Wave Height	0 to 35 m	1.71 Hz	40/20 min §	0.1 m	+/- [illegible] m
Wave Period	0 to 30 SEC	1.71 Hz	40/20 min §	1.0 sec	+/- [illegible] sec
Wave Spectra	0 to 99 m*m/Hz	1.71 Hz	40/20 min §	0.01 Hz[1]	N/A
Wave Dir.	[illegible]	[illegible]	[illegible]	[illegible]	+/- 10 deg
Dew Point	-35 to +30 C	1.71 Hz	2/8 min *	0.1 C	+/- 1.0 C
Solar Radiation	0 to 2150 W/m*m	1.71 Hz	2/8 min *	0.5 W/m*m	+/- 5%
Water Level	0 to 99.99 ft	1.71 Hz	10 min	0.1 ft	.01%
Visibility	0 to 8 mi	1.71 Hz	2/8 min *	0.125 mi	+/- 10%
ADCP	-10 to 10 m/s	1.71 Hz	20 min	0.1 cm/s	+/- 2 cm/sec
Rain Accumulation	0 to 999 mm	1/min	16 min	1 mm	1 mm
10-Minute Rain Rate	0 to 999 mm/hr	1/min	16 min	1 mm	1 mm
24-Hour Rain Rate	0 to 999 mm/hr	1/min	16 min	1 mm	1 mm

4X Increase in Directional Wave Stations
Almost all are not Datawell Hippy 40



Accuracy Criteria Used in Certifying New Systems for Operational Use

Comparison is to Existing Operational System Through a Limited Field Evaluation Evaluation Considers Overall Performance



What Do We Mean by Wave Direction?

- NDBC uses the method of Longuet-Higgins, Cartwright and Smith (1963) for heave, pitch, and roll from a moored DISCUS buoy
- Pitch and Roll from:
  - Datawell Hippy 40
  - Integration of three orthogonal angular rate sensors (ARS)
  - Partitioning Magnetometer Measurements (MO)
- Make Slopes
- Determine magnetic heading of the buoy
- Magnetic declination then rotates to True North
- Slopes (wrt True North) are passed through an FFT -> Real and Imaginary Components that are combined into Co- and quadrature spectra
- the first and second order Fourier Coefficients to determine directional wave spectra

First and Second Order Fourier Coefficients:

$\bar{a}_{1(f)}$, $\bar{b}_{1(f)}$, $\bar{a}_{2(f)}$, $\bar{b}_{2(f)}$

First order are functions of the quad-spectra; Second order, co-spectra
Overbar indicates band-averaging, ~ 580 frequencies -> 47

Mean Wave Direction (alpha1), WMO (1995):

$$\alpha_{1(f)} = \frac{3\pi}{2} - \tan^{-1}\left(b_{1(f)}, a_{1(f)}\right)$$

Use of the term and symbol *α* follows the IAHR (1997) convention:

As the angle between true north and the direction <u>from</u> where the waves are coming. Clockwise is positive…

Wave Direction Parameter…

- …used in Certification is **the Mean Wave Direction** (at the Peak Frequency (Dominant Period): α_1(f=max spectral density))
- NDBC webpages as *MWD*

Previous observations

MM	DD	TIME (GMT)	WDIR	WSPD kts	GST kts	WVHT ft	DPD sec	APD sec	MWD	PRES in	PTDY in	ATMP °F	WTMP °F	DEWP °F	SAL psu	VIS nmi	TIDE ft
10	09	1450	E	7.8	7.8	2.0	5	4.2	ESE	30.04	+0.05	81.1	83.3	73.0	-	-	-
10	09	1350	SE	11.7	13.6	2.0	5	4.2	ESE	30.03	+0.06	81.0	83.3	74.7	-	-	-
10	09	1250	SSE	9.7	11.7	2.0	5	4.3	E	30.00	+0.05	81.9	83.3	75.0	-	-	-
10	09	1150	N	1.9	3.9	1.6	5	4.2	E	29.99	+0.04	79.2	83.3	74.1	-	-	-
10	09	1050	ESE	5.8	7.8	2.0	5	4.2	E	29.97	+0.01	81.5	83.5	74.3	-	-	-
10	09	0950	ESE	7.8	9.7	2.0	5	4.1	NE	29.95	-0.01	81.7	83.3	73.2	-	-	-
10	09	0850	ESE	9.7	11.7	2.0	5	4.1	NE	29.95	-0.02	81.7	83.3	73.9	-	-	-

Background on Field Evaluations

- **Other directional parameters are evaluated, but MWD has best S/N ratio**
- **Field evaluations over a limited time, usually at the beginning of a deployment**
- **Generally:**
  - **Eliminate failed QC reports**
  - **Isolate directional error**
  - **Statistic is either Root Mean Square Deviation (RMSD) or Functional Precision (Hoehns, 1977 & Gilhousen, 1987)**

$$FP = \sqrt{BIAS^2 + STDDiff^2}$$

NDBC's Directional Wave Family Tree

Red indicates WPM or derivative

Nomenclature	Short Name	First Deployed	Last Deployed	Reference
Experimental Environmental Research Buoy	XERB	~1977	?	Steele *et al.*, 1985
Directional Wave Data Analyzer	DWDA (2 Hz/1 Hz, f = 0.030 : 0.30Hz), Hippy 40	~1980	?	Steele *et al.*, 1985
Directional Wave Analyzer	DWA (2Hz/1Hz) f= 0.03: 0.35 Hz	~1986	MO, Dec 2010, Great Lakes	NDBC, 1996
Wave Processing Module	**WPM (1.7066Hz, 47 bands, 0.0325 to 0.485 Hz, variable bandwidths)**	~1989	MO, Oct 2009, Great Lakes	NDBC, 1996
Directional Wave Processing Module	**DWPM**	~1999	Analog, still used with Hippy 40	NDBC, 1996
Wave and Marine Data Acquisition System	**WAMDAS**	March 2006	~2010 NDBC 1.8m & still on WHOI ASI	Teng *et al.*, 2007; Crout *et al.*, 2008
Digital Directional	**DDWM,**	April 2007	Operational	Teng *et al.*, 2009;

Candidate System	Reference Station	PoR	# Samples	Statistic Type	Result (°)
DDWM 2.03	46042, DWPM Hippy, co-Host	Jan - Jun 2012	3510	MWD, RMSD	13.3
DDWM 1.0	51000, DWPM Hippy, co-host	May 2009	607	MWD & Unimodal MWD (UM), RMSD	All 21, UM 10
DWPM 20-minute	42056, DWPM Hippy 40-minute, Co-host	May- Sep 2008	3417	MWD, FP	7.9
DWPM, ARS	42001, Gulf of Mexico, co-host	Aug 2003 – Apr 2004	5940	MWD, FP	14.5
DWPM, Hippy	42003, GoM, WPM-MO, co-host	Sep-Oct 2003	253	MWD, FP	8
WPM, MO	46014, Hippy DWA, co-host	Jun – Aug 92	918	MWD(f)	~8 - 15
DWA, MO (Wang, 1995)	Monterey Bay, DWA Hippy	Oct 91-Mar 92	4268	MWD (f), Bias and STDDiff	~11 - 15
DWA , Hippy (Gilhousen, 1990)	42015 & 42016 (Mobile) & 44006 (Duck)	Apr-May 1988 & Jan 1988	306 & 306	consistency between buoys and wind direction	10

How Stable are Wave Directions?

Before leaving NDBC, buoy heading accuracy < |4|°

5 buoys have been returned intact for post-deployment calibration

Buoy Hull Number	*3D87*	*3DV13*	*3D33*	*3D24*	*3DV11*
In-service (years)	2.75	1.9	1.4	3.9	3.75
In-service Temperature (C)	-5 to 32	2 to 30	7 to 31	7 to 22	4 to 32
Deployment Location (WMO Station Number)	44014	41012	41009	46011	42020
Pre-Cal Age (years)	2.8	3.2	1.9	4.0	4.2
Wave Instrument Age (years)	2.2	2.8	4.4	8.7	7.7
Battery Age (years)	3	4	2.2	5.25	4.5
Air Temperature at Pre-Cal (C)	18-22	16-24	16-27	28	17-32
Air Temperature at Post-Cal (C)	4-10	2-16	2-16	22	23-29
Max Post-Cal Heading Error (Deg)	**6.7**	**-6**	**-6**	**5.0**	**8.2**

Other Studies

Harvest Platform (O'Reilly *et al.*, 1996)
3-m discus DWA Hippy 40 & Datawell Waverider & pressure array at the platform
Focused on Pacific swell; α_1 (f) integrated over the swell band (0.06 – 0.14 Hz)

TABLE 1. Correlation and bias between buoy and array estimates of wave energy and the KVH directional parameters. The Datawell results in parentheses use fewer Datawell data records to roughly match the degrees of freedom in the NDBC results.

	Correlation		Bias	
	Datawell	NDBC	Datawell	NDBC
Energy	0.98 (0.98)	0.98	0.9% (1.3)	−2.8%
Direction	0.98 (0.97)	0.96	3.4° (3.4)	2.3°
Spread	0.96 (0.96)	0.86	0.3° (0.3)	5.7°
Skewness	0.88 (0.87)	0.50	0.14 (0.15)	−0.44
Kurtosis	0.89 (0.88)	0.72	0.85 (0.86)	−0.57

Pre-SWADE (Anctil *et al*., 1993)
– 3-m discus, DWA using Hippy 40
– Deep-water Gulf of Mexico with platform
– MWD, directional width, skewness and kurtosis, May – June 1989, 68 measurements
– Poor correlation with skewness and kurtosis, better in higher seas
– Direction and width: ~45/68 within 90% confidence limits!

BUOY DIRECTIONAL WAVE OBSERVATIONS IN HIGH SEAS, Wang and Teng (1989)
14 – 18 December 1987, Monterey Bay, H_s ~ 9 meters, Hippy 40 DWA;
MWD and S, Wave response to wind

As a result, we have increased confidence in the utility and quality of the data produced by NDBC's directional wave measurement buoys.

Summary

- Background and insight on the accuracy statement
  - Methodologies have varied over the years, and
  - NDBC Directional WavesCandidate systems evaluated against operational systems
- **Fourier Coefficients** are the basis of NDBC wave parameters
- Encouraging results of post-deployment heading verifications
- Solicit ideas on standardized and practical methodologies and statistics
- Now have the ability to gage accuracy versus an accepted standard with the NDBC's contribution to the Wave Evaluation and Test Pilot Project (PP-WET)

Thanks

- **Journal Articles & Conference Proceedings:**
  - **NOAA Library, Boulder, CO**
  - **Maury Oceanographic Library, Naval Oceanographic Office, Stennis Space Center**
- C. Reid Nichols, SURA; and, Axys
  - An early version was presented at the Wave Workshop, New Orleans, January 2015
- **Chung-Chu Teng, Ken Steele, Dave Gilhousen, David Wang, Rex Hervey, Ted Mettlach†, Bob Jensen**

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