

NDBC Buoy Wave Measurement Systems and Program

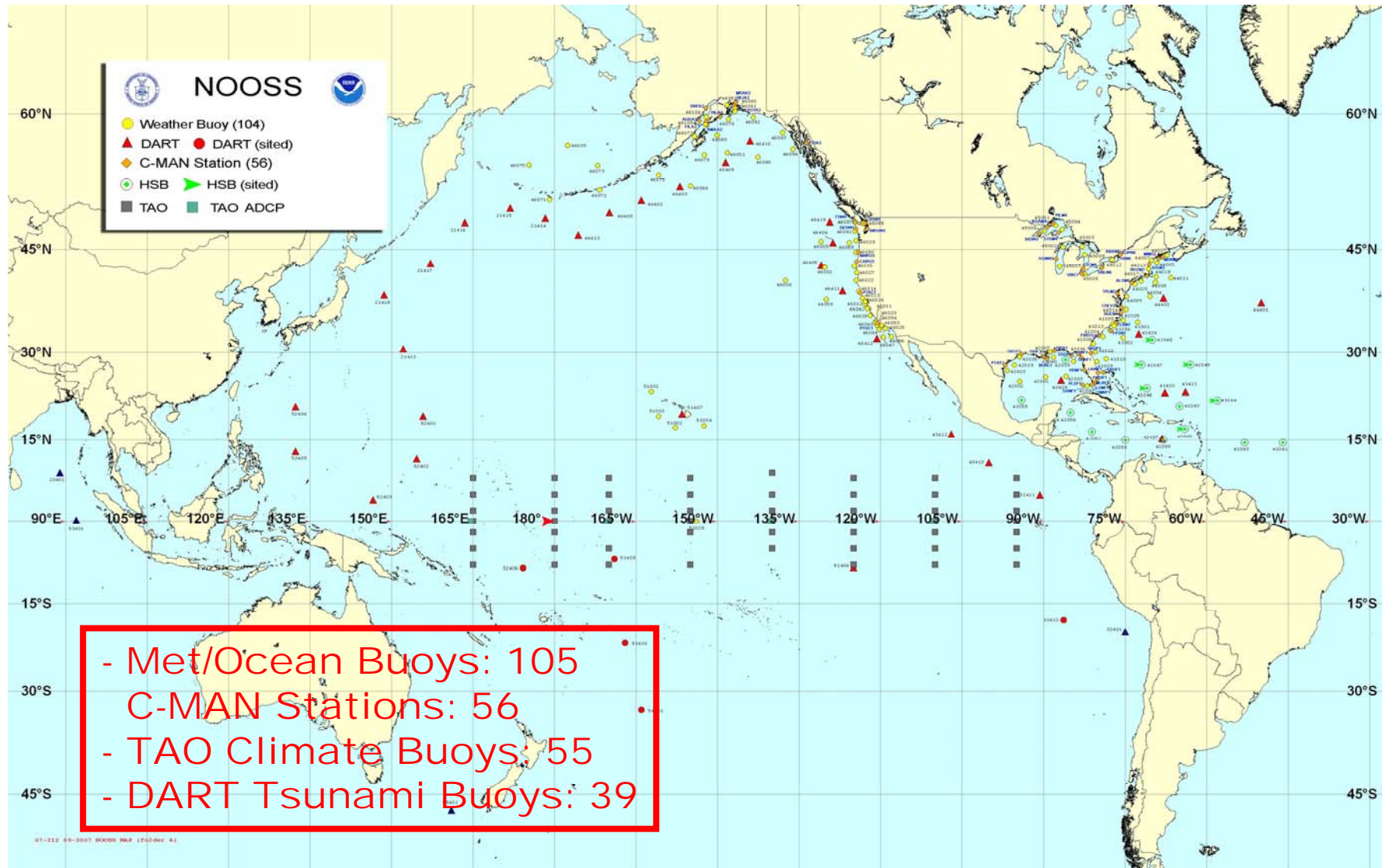
**Chung-Chu Teng
U.S. NOAA National Data Buoy Center**

2 October 2008





NWS/NDBC Ocean Observing System of Systems (NOOSS)

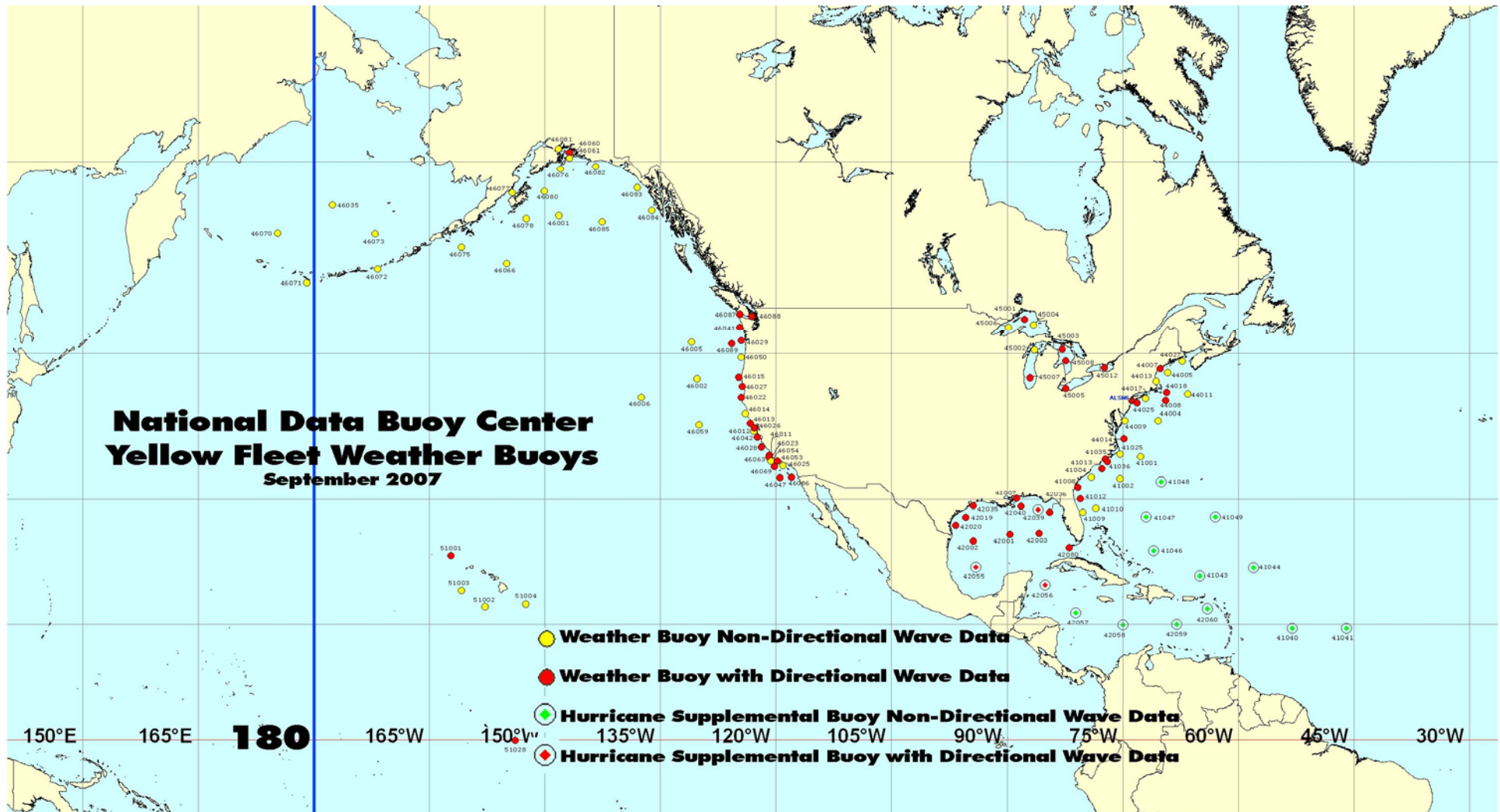




NDBC Wave Buoys

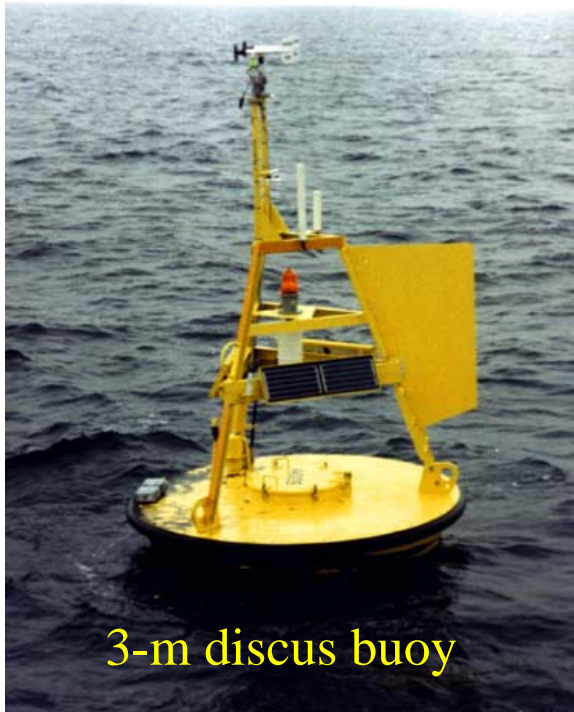


105 buoys – all measure non-directional waves
58 of them measure directional waves





Buoy Wave Measurements



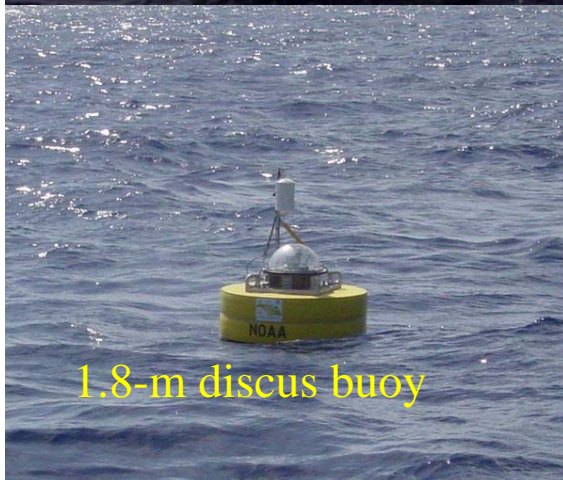
3-m discus buoy



10-m & 12-m discus buoy



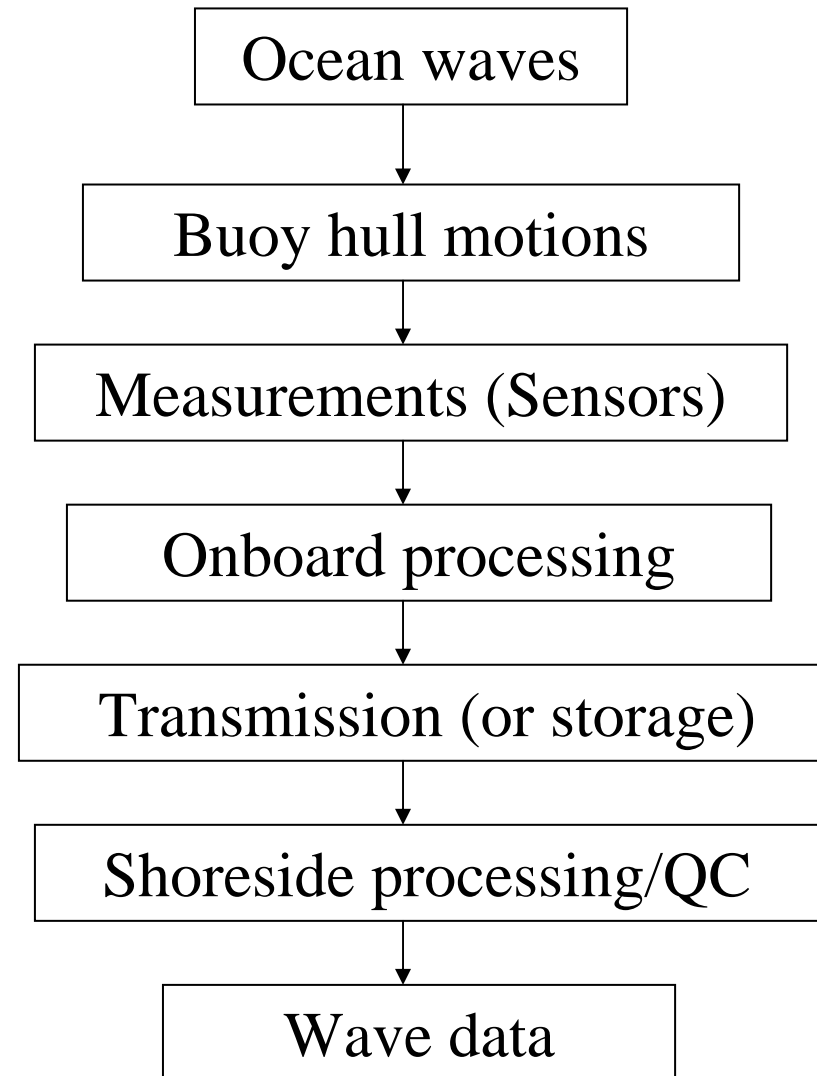
6-m NOMAD buoy



1.8-m discus buoy



Buoy Wave Measurement

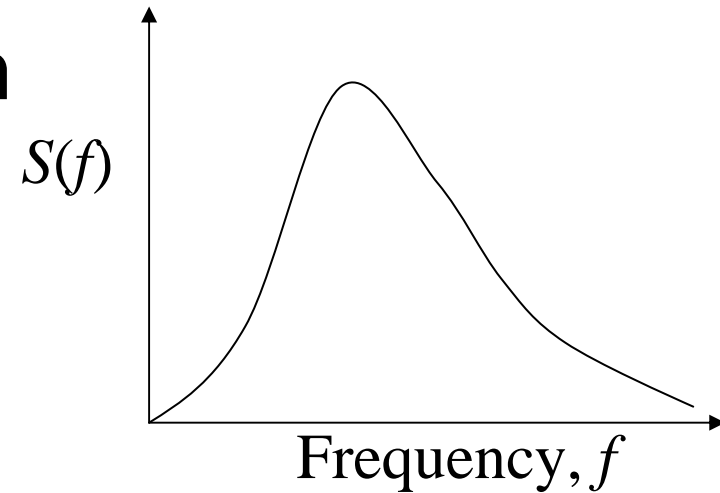


**Indirect
Measurement!**



Non-directional wave data

- Wave energy spectrum



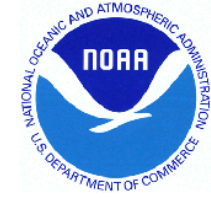
- Wave parameters:

Peak (or dominant) wave period, T_p

Mean (or average) wave period, T_z or T_a

Significant wave height, H_s

$$H_s = 4 \cdot \sqrt{m_0} \quad \text{and} \quad T_z = 2\pi \sqrt{\frac{m_0}{m_2}}$$



Non-directional wave data from buoys

- ▶ From buoy motion to wave data

$$S_w(f) = \frac{S_h(f)}{PTF}$$

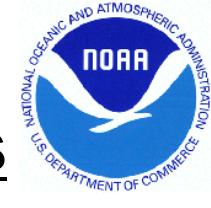
$S_h(f)$: spectrum of buoy heave motion

$S_w(f)$: wave spectrum (acceleration)

PTF: power transfer function

- ▶ From acceleration to displacement

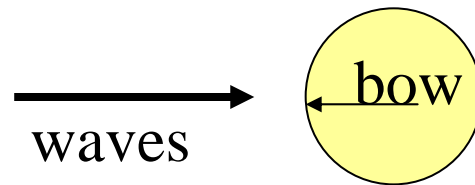
$$\text{displacement spectrum} = \frac{\text{acceleration spectrum}}{(2\pi f)^4}$$



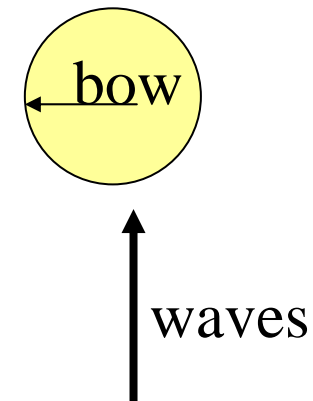
Directional wave measurement from buoys

Based on “slope following” principle

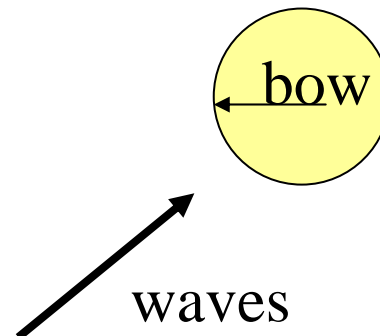
(a) Pitch only

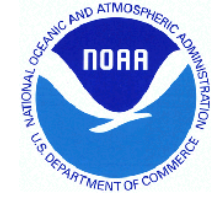


(b) Roll only



(c) Both pitch & roll





Directional wave algorithm (1)

$$S(f, \theta) = \frac{a_0}{2} + a_1 \cdot \cos \theta + b_1 \cdot \sin \theta \\ + a_2 \cdot \cos 2\theta + b_2 \cdot \sin 2\theta + \dots$$

f : wave frequency; θ : wave direction

$$a_0 = \frac{1}{\pi} C_{11}; \quad a_1 = \frac{1}{\pi k} Q_{12}; \quad b_1 = \frac{1}{\pi k} Q_{13}$$

$$a_2 = \frac{1}{\pi k^2} (C_{22} - C_{33}); \quad b_2 = \frac{2}{\pi k^2} C_{23}$$

K : the wave number

C and Q : co- and quad-spectra

1: vertical motion (heave)

2: N-S slope (pitch)

3: W-E slope (roll)



Directional wave algorithm (2)



$$S(f, \theta) = C_{11} \cdot \frac{1}{\pi} \left[\frac{1}{2} + r_1 \cos(\theta - \theta_1) + r_2 \cos 2(\theta - \theta_2) \right]$$

$$r_1 = \frac{1}{a_0} \sqrt{a_1^2 + b_1^2}; \quad r_2 = \frac{1}{a_0} \sqrt{a_2^2 + b_2^2}$$

$$\theta_1 = \tan^{-1}(b_1, a_1); \quad \theta_2 = \frac{1}{2} \tan^{-1}(b_2, a_2)$$

θ_1 and θ_2 : mean and principal wave directions
 r_1 and r_2 : directional energy spreading



NDBC directional wave systems

- Based on the slope-following principle. Requires axis-symmetrical buoys.
- Only discus buoys (1.8-m, 3-m, 10-m, and 12-m) can measure directional waves.
- The boat-shaped 6-m NOMAD buoys cannot measure directional waves.
- Wave data are derived from buoy's heave, pitch, and roll motion.
- Buoy pitch and roll information are required to determine directional wave data.



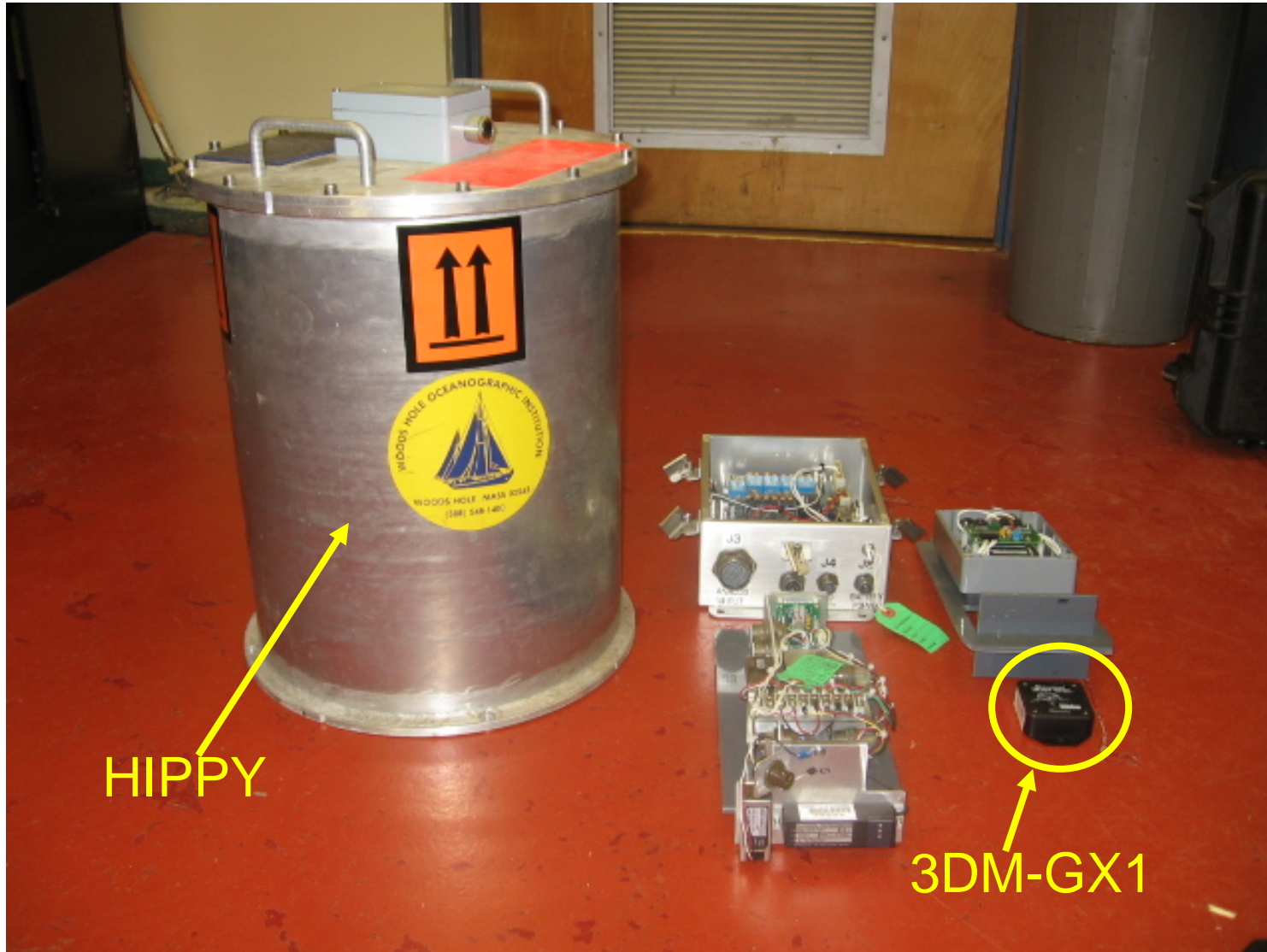
Configurations of NDBC directional wave systems

Obtaining pitch and roll information

- **HIPPY** – a gimbaled gyro system that measure pitch and roll directly
- **MO** – use only magnetometer outputs to estimate buoy pitch and roll
- **ARS** – derive buoy pitch and roll from angular rate sensors



HIPPY and Angular Rate Sensor (ARS)

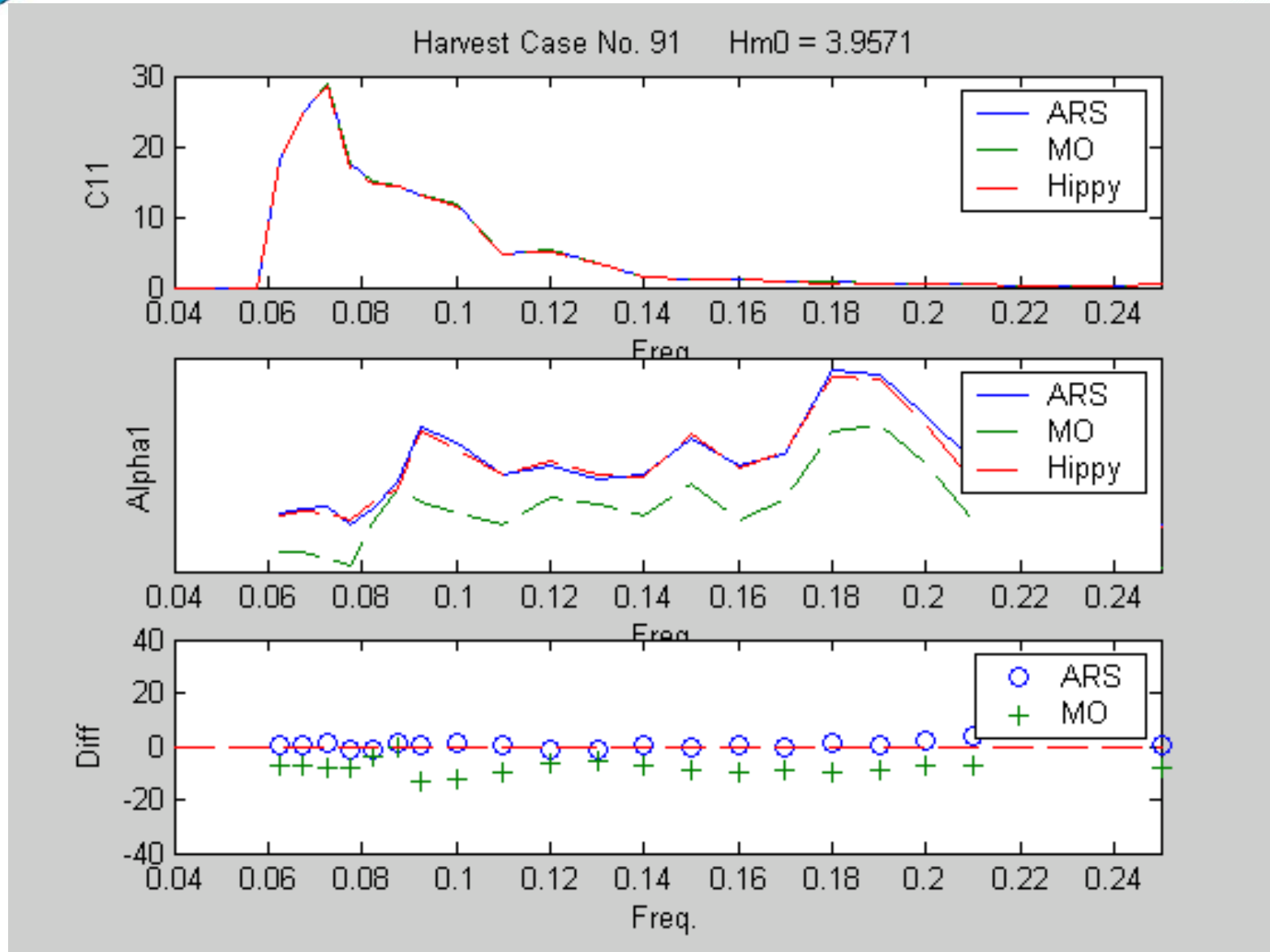


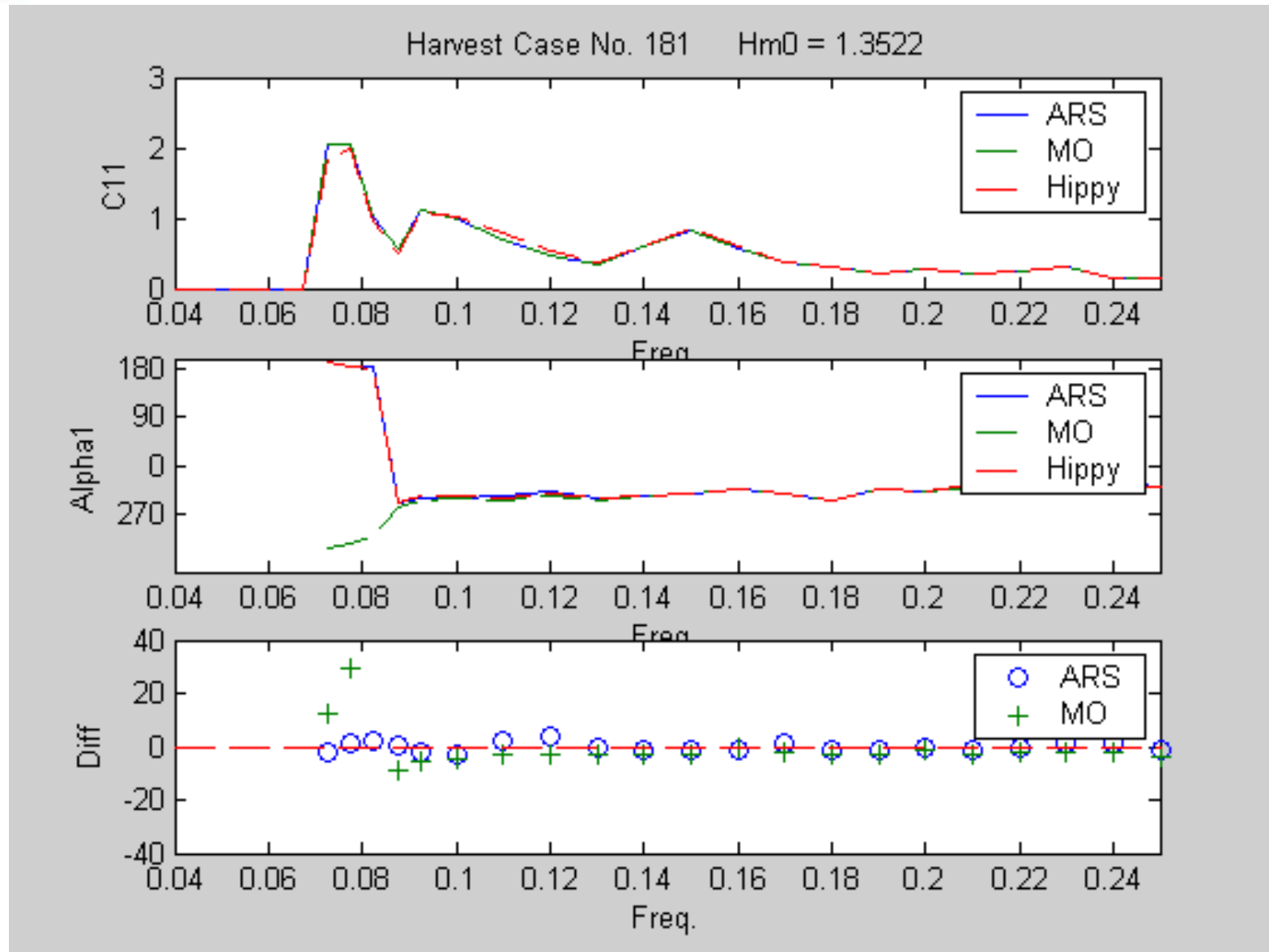


HIPPY and Angular Rate Sensor (ARS)

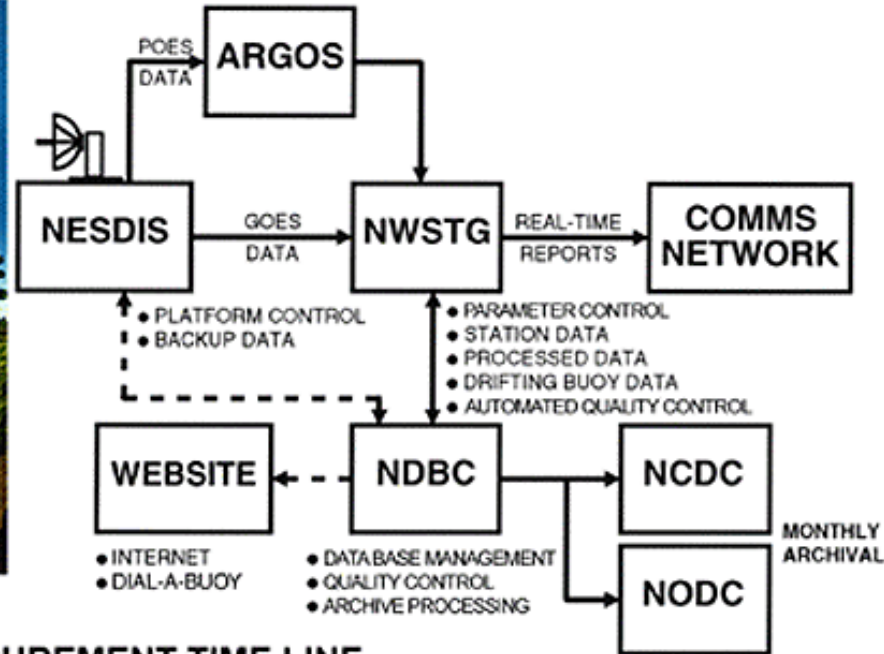
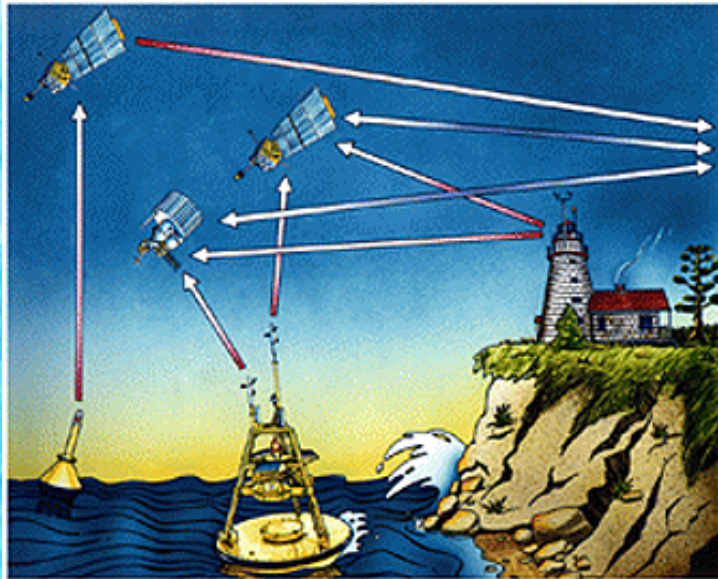


	HIPPY MK-II	ARS (3DM-GX1)
Size	410mm (D) × 560mm (H) 16.2" (D) × 22.1" (H)	65mm × 90mm × 25mm 2.6" × 3.5" × 1.1"
Volume	66,012 cm ³ 4,517 in ³	146 cm ³ 10 in ³
Weight	36 Kg 79 lbs	0.075 Kg 2.6 Oz
Cost	\$17,500 US	\$1,300 US
Temperature	-5°C to +35°C	-40°C to +70°C
Handling	Mechanical/fluid system Handle carefully	No moving parts Easy handling
Accuracy for waves	Excellent	Good and improving



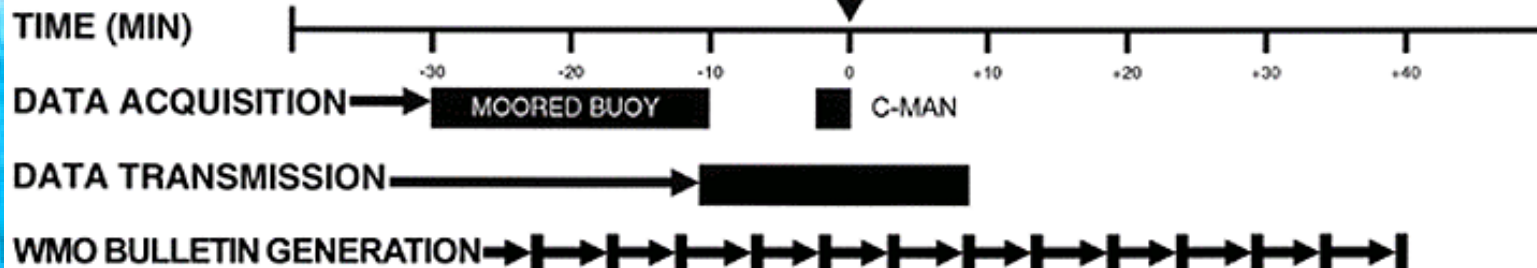


DATA FLOW



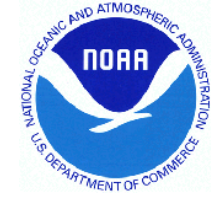
MEASUREMENT TIME LINE

OBSERVATION TIME



NOAA





Data Quality Control:

The Last Line of Defense, after...

- Sensor Evaluations
- Individual Sensor Calibrations
- Payload Software Testing
- Burn-In
- Data Evaluation at deployment



Data Quality Control

- Performed On:
 - NDBC and Regional Observatory Data
- Consists Of:
 - Automated Real-Time Checks
 - Next Day Man-Machine Mix
- Outputs:
 - Withhold, adjust real-time data
 - NOTICE: Users don't see flags
 - Archive Data Set



Wave data analysis and QC

- NDBC's wave data processing document: *Nondirectional and Directional Wave Data Analysis Procedures*
<http://www.ndbc.noaa.gov/wavemeas.pdf>
- NDBC's quality control document: *Handbook of Automated Data Quality Control Checks and Procedures of the National Data Buoy Center*
<http://www.ndbc.noaa.gov/handbook.pdf>



NDBC Wave Products



- Real-time
 - Web pages
 - Global Telecommunications System
 - WMO FM-13 SHIP
 - WMO FM-65 WAVEOB
 - OPenDAP/DODS server in netCDF
 - <http://dods.ndbc.noaa.gov/>
 - Sensor Observation Service (SOS)
 - <http://sdf.ndbc.noaa.gov/sos/>
- Archive monthly at National Ocean Data Center (NODC), Suitland MD in F291 format
<http://www.nodc.noaa.gov/BUOY/buoy.html>
Contains 35786 "Buoy-Months" as of Aug '08



NDBC Web Site



<http://www.ndbc.noaa.gov>
106 Million Hits in August 2008

The screenshot shows the National Data Buoy Center website as it appeared in a Netscape browser window. The browser title is "National Data Buoy Center - Netscape". The website header features the NOAA logo on the left, the text "National Data Buoy Center" and "Center of Excellence in Marine Technology" in the center, and the "NATIONAL WEATHER SERVICE" logo on the right. A navigation menu includes links for Home, FAQ, Links, What's New?, Contact Us, and a search box. Below the navigation is a horizontal menu with tabs for "Recent Data", "Historical Data", "Observations Search", "NOAA Marine Observations", "APEX", "NOAA Coastal Storms Initiative", and "DART". The main content area displays a world map with several rectangular boxes highlighting specific regions. A red text warning below the map states: "Not All Stations Depicted are Operated by the National Data Buoy Center." The left sidebar contains a "Station ID Search" form, a "Station List", and various menu items under "Observations", "Station Status", "Ship Observations", "About NDBC", "Publications", and "Contact Us". The footer includes contact information for the U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, and National Data Buoy Center, along with a disclaimer, privacy policy, and webmaster link. The page was last modified on November 25, 2003. The browser status bar at the bottom shows "Document: Done".



NDBC wave data on the web



- Real-time wave data
- Real-time detailed wave summary
- Previous 24 observations
- Data for the last 45 days in tabular form
- Historical data in tabular form



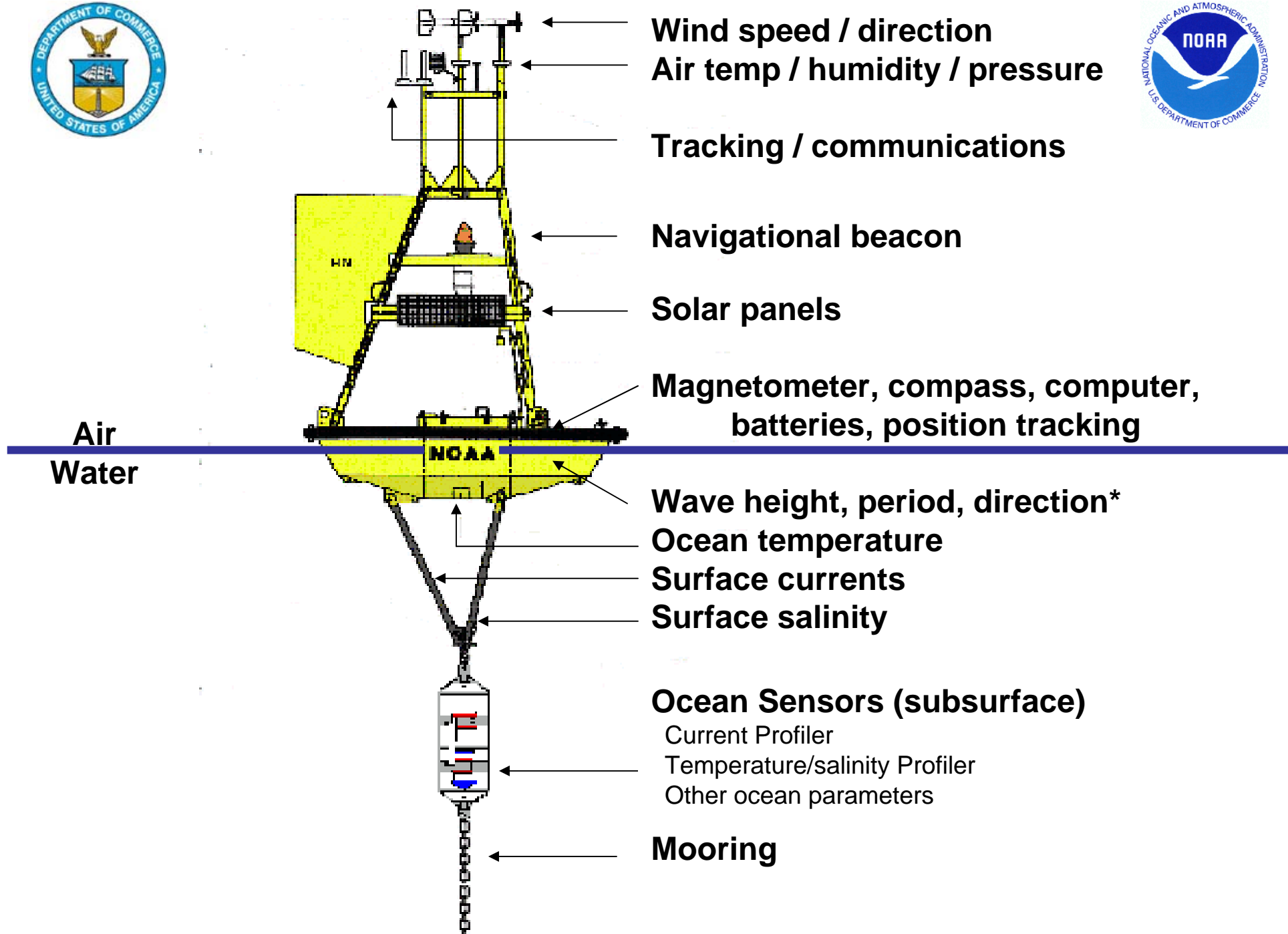
WEEKLY STATUS REPORT ON NDBC DIRECTIONAL WAVE SYSTEMS

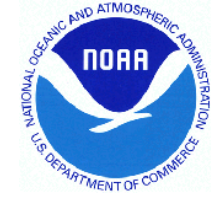


For the week beginning September 14, 2008

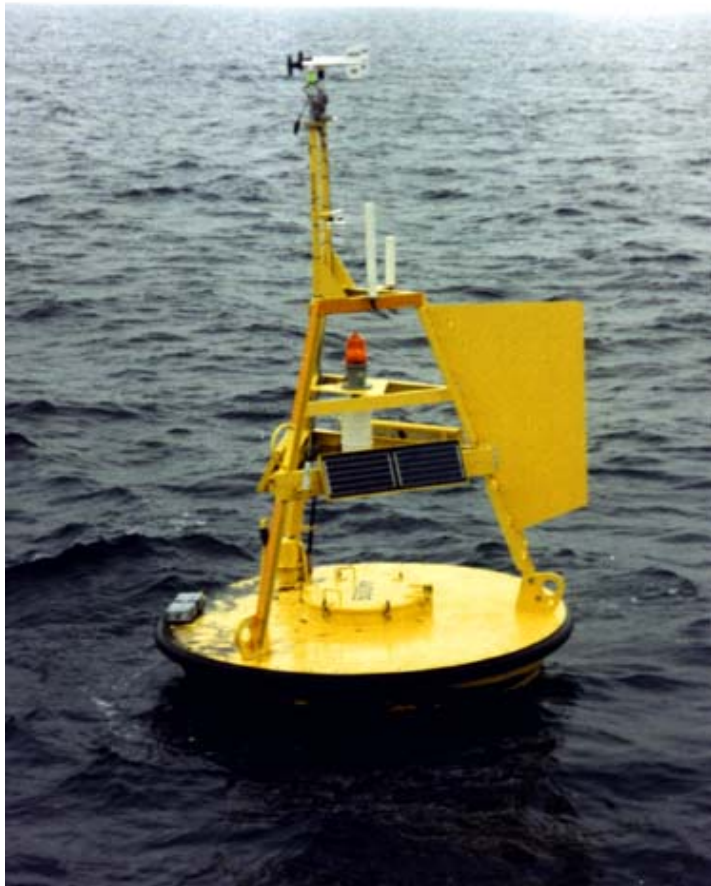
Station ID	Hull	Payload Type	Wave System	Config-uration	Buoy/DW Sponsor	NWS Status	Status Date	Comments
41008	3D14	ARES	DWPM	ARS	NWS/ConWxB	Released		
41012	3D72	ARES	DDWM	3DM	NWS	Released		
41013	3D55	ARES	DDWM	3DM	NWS/COE	Released		
41035	3D49	ARES	DWPM	ARS	NWS	Released	7/27/08	Wave direction failed. ARS bracket failed.
41036	3D80	ARES	DWPM	ARS	NWS	Released		
41047	12D14	ARES	DWPM	ARS	NWS	Not Released	8/8/08	Battery failing.
41A47		ARES	DWPM	ARS	NWS	Released		
41048	12D03	ARES	DWPM	ARS	NWS	Released	5/30/08	Iridium enabled. GOES parity errors.
41A48		ARES	DWPM	ARS	NWS	Not Released	4/22/08	Magnetometer data failed.
42001	12D11	ARES	DWPM	HIPPY	NWS/COE	Not Released	6/6/07	Magnetometer data failed.
42A01		ARES	DWPM	ARS	NWS	Released	4/29/08	Directional wave data failed.
42002	10D10	ARES	DWPM	ARS	NWS/COE	Not Released	8/24/08	Message truncations cutting off wave data.
42A02		ARES	DWPM	ARS	NWS	Released		Released waves only. Met data from 42002.
42003	10D11	ARES	DWPM	ARS	NWS/COE	Not Released	11/12/07	Iridium SBD transmits failed.
42A03		ARES	DWPM	ARS	NWS	Not Released	8/31/08	GOES transmits failed.
42007	3D36	DACT	DWA	MO	NWS	Released		
42019	3D35	DACT	DWA	MO	NWS/COE	Released	6/10/08	Sporadic low frequency spiking.
42020	3D44	DACT	DWA	MO	NWS/COE	Released	6/10/08	Sporadic low frequency spiking.
42035	3D54	ARES	DDWM	3DM	NWS/COE	Released	9/12/08	Buoy adrift.
42036	3D09	ARES	DWPM	ARS	NWS/COE	Released		
42055	12D12	ARES	DWPM	ARS	NWS	Not Released	5/14/08	No transmits
42A55		ARES	DWPM	ARS	NWS	Released		
42056	12D13	ARES	DWPM	ARS	NWS	Released		
42A56		ARES	DWPM	ARS	NWS	Not Released		
42057	10D09	ARES	DWPM	ARS	NWS	Released		
42A57		ARES	DWPM	ARS	NWS	Not Released	5/26/08	No transmits
42058	10D07	ARES	DWPM	ARS	NWS	Released		
42A58		ARES	DWPM	ARS	NWS	Not Released		
44007	3D25	ARES	DDWM	3DM	NWS/ConWxB	Released		
44008	3D06	ARES	DWPM	ARS	NWS/ConWxB	Released		
44014	3D42	ARES	DWPM	HIPPY	COE	Released		
44017	3D61	ARES	DWPM	ARS	NWS	Released		
44018	3D29	ARES	DDWM	3DM	NWS/ConWxB	Released		
44025	3D70	ARES	DDWM	3DM	NWS/COE	Released		
45001	3D05	DACT	DWA	MO	NWS/COE	Released		
45002	2.4DV04	ARES	DDWM	3DM	NWS	Released		
45003	3DV03	VEEP	WPM	MO	NWS/COE	Not Released	7/13/08	Wave system failed.
45005	3D63	DACT	DWA	MO	NWS/COE	Released		
45007	3D28	DACT	DWA	MO	NWS	Released		
45008	3D41	ARES	DWPM	ARS	NWS	Released		
45012	3DV02	VEEP	WPM	MO	NWS/COE	Released		
46011	3D68	ARES	DDWM	3DM	NWS/ConWxB	Released		
46013	3D17	ARES	DWPM	ARS	NWS/ConWxB	Released		
46015	3D62	ARES	DDWM	3DM	NWS/ConWxB	Not Released	7/30/08	Recovered to port.
46022	3D16	ARES	DDWM	3DM	NWS/ConWxB	Released	3/15/08	Message truncations cutting off wave data.
46025	3D57	ARES	DDWM	3DM	NWS/ConWxB	Released		
46026	3D27	ARES	DWPM	ARS	NWS/ConWxB	Released		
46027	3D78	ARES	DWPM	ARS	NWS/ConWxB	Released		
46028	3D53	ARES	DDWM	3DM	NWS/ConWxB	Released	3/10/08	Frequent message parity errors
46029	3D15	ARES	DDWM	3DM	NWS/COE	Released		
46041	3D64	ARES	DWPM	HIPPY	NWS/COE	Released		
46042	3D33	ARES	DWPM	HIPPY	NWS/COE	Released	3/21/08	Message truncations cutting off wave data.
46047	3D12	ARES	DWPM	ARS	NWS/ConWxB	Released		
46050	3D40	ARES	DDWM	3DM	NWS/ConWxB	Released		
46053	3D10	ARES	DWPM	ARS	NWS/ConWxB	Released		
46060	3D52	ARES	DDWM	3DM	NWS/ConWxB	Released		
46063	3D60	ARES	DWPM	ARS	NWS/ConWxB	Released		
46069	3D39	ARES	DWPM	HIPPY	NWS/ConWxB	Released		
46086	3D20	ARES	DWPM	HIPPY	NWS/ConWxB	Not Released	5/21/08	Iridium SBD transmits failed.
46087	3D74	ARES	DWPM	ARS	USCG	Released	5/19/08	Message truncations cutting off wave data.
46088	3D71	ARES	DWPM	ARS	USCG	Released		
46089	3D32	ARES	DDWM	3DM	NWS/ConWxB	Released		
46105	1.8D11		WAMDAS	3DM	NWS/ConWxB	Released	9/10/08	Message truncations cutting off wave data.
46106	1.8D05		WAMDAS	3DM	NWS/ConWxB	Released		
46107	1.8D09		WAMDAS	3DM	NWS/ConWxB	Released		
51001	3D81	ARES	DWPM	HIPPY	NWS	Released		
51028	3D30	ARES	DWPM	HIPPY	Boeing	Not Released	4/15/08	Hippy output erratic, unreliable

Weekly Status Report on Directional Wave Systems





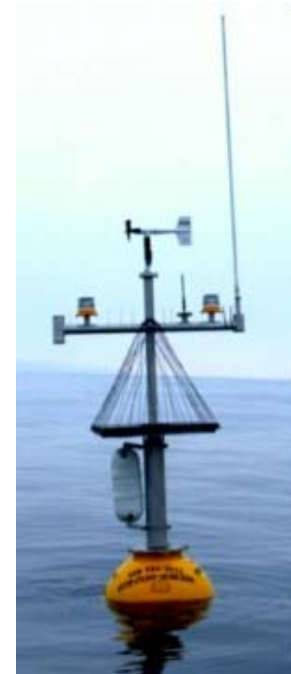
“Waves + Others” vs. “Waves only”



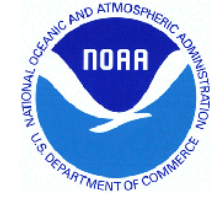
NDBC 3-m discus buoy



CDIP
Waverider buoy

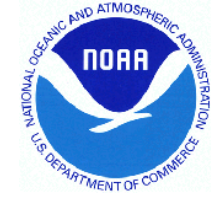


CDIP
Wind buoy



How is your wave measurement?





We always improve our wave systems to make wave measurement more accurate.



Contact Information

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Thank You

U.S. NOAA National Data Buoy Center

