NDBC Buoy Wave Measurement Systems and Program

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- Met/Ocean Buoys: 105
- C-MAN Stations: 56
- TAO Climate Buoys: 55
- DART Tsunami Buoys: 39
NDBC Wave Buoys

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

3-m discus buoy

6-m NOMAD buoy

10-m & 12-m discus buoy

1.8-m discus buoy
Buoy Wave Measurement

Ocean waves → Buoy hull motions → Measurements (Sensors) → Onboard processing → Transmission (or storage) → Shoreside processing/QC → Wave data

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

\[ S_w(f) = \frac{S_h(f)}{PTF} \]

- 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)

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

\( f \): wave frequency; \( \theta \): 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)

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

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

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

\( \theta_1 \) and \( \theta_2 \): 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)

<table>
<thead>
<tr>
<th></th>
<th>HIPPY MK-II</th>
<th>ARS (3DM-GX1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>410mm (D) × 560mm (H)</td>
<td>65mm × 90mm × 25mm</td>
</tr>
<tr>
<td></td>
<td>16.2” (D) × 22.1” (H)</td>
<td>2.6” × 3.5” × 1.1”</td>
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<tr>
<td><strong>Volume</strong></td>
<td>66,012 cm³</td>
<td>146 cm³</td>
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<tr>
<td></td>
<td>4,517 in³</td>
<td>10 in³</td>
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<tr>
<td><strong>Weight</strong></td>
<td>36 Kg</td>
<td>0.075 Kg</td>
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<tr>
<td></td>
<td>79 lbs</td>
<td>2.6 Oz</td>
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<tr>
<td><strong>Cost</strong></td>
<td>$17,500 US</td>
<td>$1,300 US</td>
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<tr>
<td><strong>Temperature</strong></td>
<td>-5°C to +35°C</td>
<td>-40°C to +70°C</td>
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<tr>
<td><strong>Handling</strong></td>
<td>Mechanical/fluid system</td>
<td>No moving parts</td>
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<tr>
<td></td>
<td>Handle carefully</td>
<td>Easy handling</td>
</tr>
<tr>
<td><strong>Accuracy for waves</strong></td>
<td>Excellent</td>
<td>Good and improving</td>
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</table>
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*

- NDBC’s quality control document: *Handbook of Automated Data Quality Control Checks and Procedures of the National Data Buoy Center*
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
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**

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<tr>
<th>Station ID</th>
<th>Call</th>
<th>Install Type</th>
<th>Wave System</th>
<th>Code</th>
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- **Weekly Status Report on Directional Wave Systems**
Wind speed / direction
Air temp / humidity / pressure
Tracking / communications
Navigational beacon
Solar panels
Magnetometer, compass, computer, batteries, position tracking
Wave height, period, direction*
Ocean temperature
Surface currents
Surface salinity
Ocean Sensors (subsurface)
Current Profiler
Temperature/salinity Profiler
Other ocean parameters
Mooring
“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