Resources

COMET® and MetEd Programs

Spanish Versions also have French versions

Wave Life Cycle I: Generation

http://www.meted.ucar.edu/marine/mod2_wlc_gen/index.htm

Ciclo de vida de las olas I: Generación

http://www.meted.ucar.edu/marine/mod2_wlc_gen_es/index.htm

Wave Life Cycle II: Propagation & Dispersion

http://www.meted.ucar.edu/marine/mod3_wlc_propdis/index.htm

Ciclo de vida de las olas II: propagación y dispersión

http://www.meted.ucar.edu/marine/mod3_wlc_propdis_es/index.htm

Wave Types and Characteristics

http://www.meted.ucar.edu/marine/mod1_wv_type_char/index.htm

Tipos de olas y sus características

https://www.meted.ucar.edu/training_module_es.php?id=1017

Analyzing Ocean Swell

http://www.meted.ucar.edu/oceans/ocean_swell

National Data Buoy Center

Some Theory and Application of Calibration Techniques for NDBC Wave Measurement Buoys

by

Richard H. Bouchard, Kenneth E. Steele,
Chung-Chu Teng, Laura Fiorentino, and Terry Rutledge

Presentation

to

The 2nd WIGOS/JCOMM Technical Exchange Workshop on Marine Instrumentation for the WMO Regional Association IV

March 02, 2016

Mother Nature Piles It On

Additionally, many EMs expressed ***surprise at the large and damaging waves*** *Sandy caused. Of coastal residents surveyed after Sandy, 77 percent described* ***the impact of waves as more than they expected*** *(Gladwin, Morrow & Lazo, 2013). Even small to moderate storm surges can cause life-threatening and damaging conditions because of* ***severe coastal waves on top of surge.***

– *NWS Sandy Assessment* (2013)

Katrina had already generated large northward-propagating swells, leading to ***substantial wave setup*** *along the northern Gulf coast, when it was at Category 4 and 5 strength during the 24 hours or so before landfall.*

– Knabb, *et al.* (2005), *Tropical Cyclone Report, Hurricane Katrina*

National Data Buoy Center

382 IEEE JOURNAL OF OCEANIC ENGINEERING, VOL. OE-10, NO. 4, OCTOBER 1985

Theory and Application of Calibration Techniques for an NDBC Directional Wave Measurements Buoy

KENNETH E. STEELE, JOSEPH CHI-KIN LAU, AND YUAN-HUANG L. HSU

(*Invited Paper*)

- NDBC still uses many of these techniques in fielding new Heave/Pitch/Roll wave systems.
- *Google Scholar* shows 54 non-NDBC citations, 5 since 2012
- Some of the techniques applicable to other moored buoy systems
- Due to time constraints, will limit discussion to development and application of:

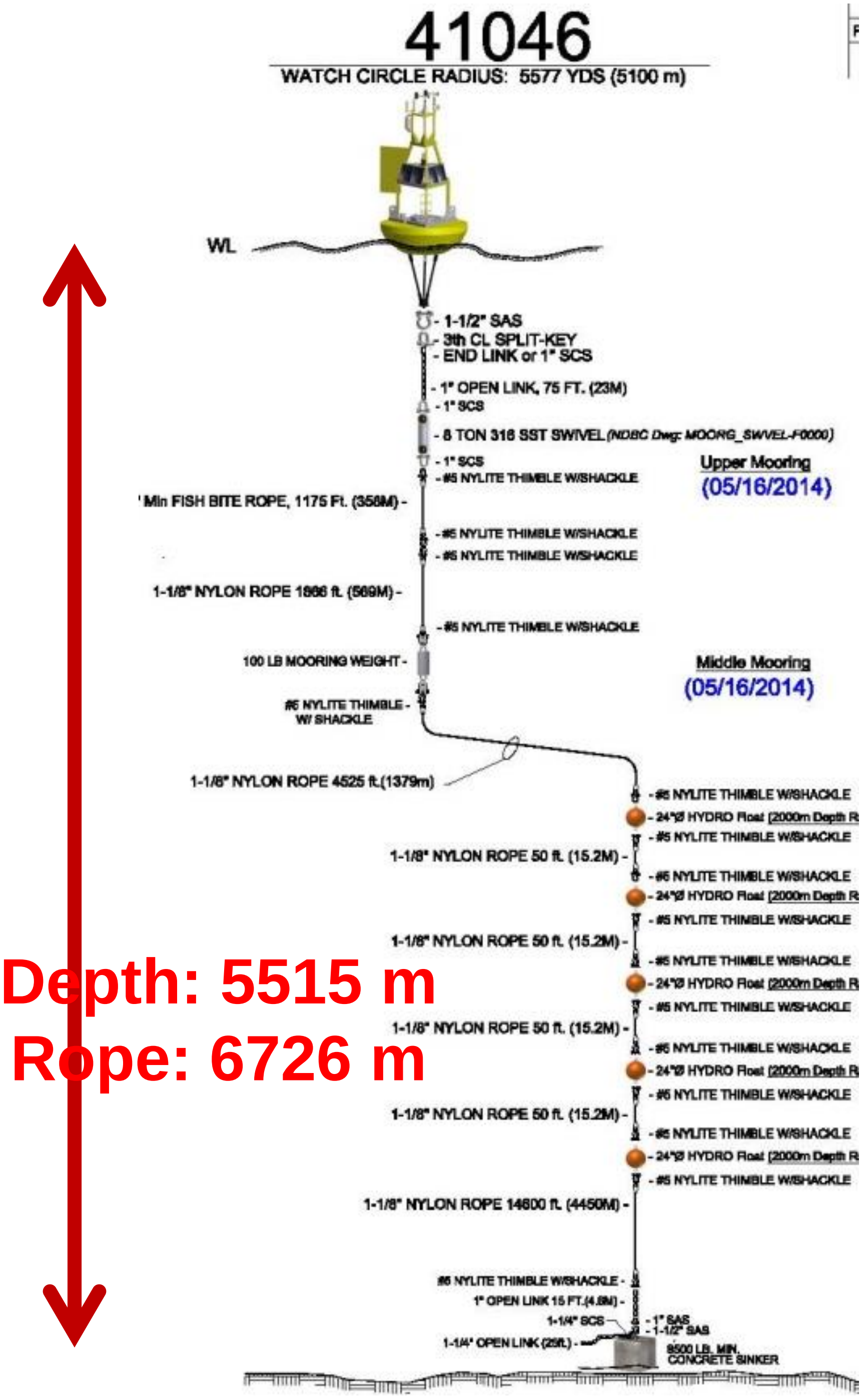
Power Transfer Functions (PTF)

Noise and Tilt Corrections

Hull Magnetic Corrections

Waves from Moored Buoys

Hull Diameter /Material/ Shape	Weight (kg)
12-m/ Steel/Discus	87,500
10-m/ Steel/Discus	52,400
6-m/ Aluminum/ NOMAD	6,300
3-m/ Aluminum/ Discus	1,720



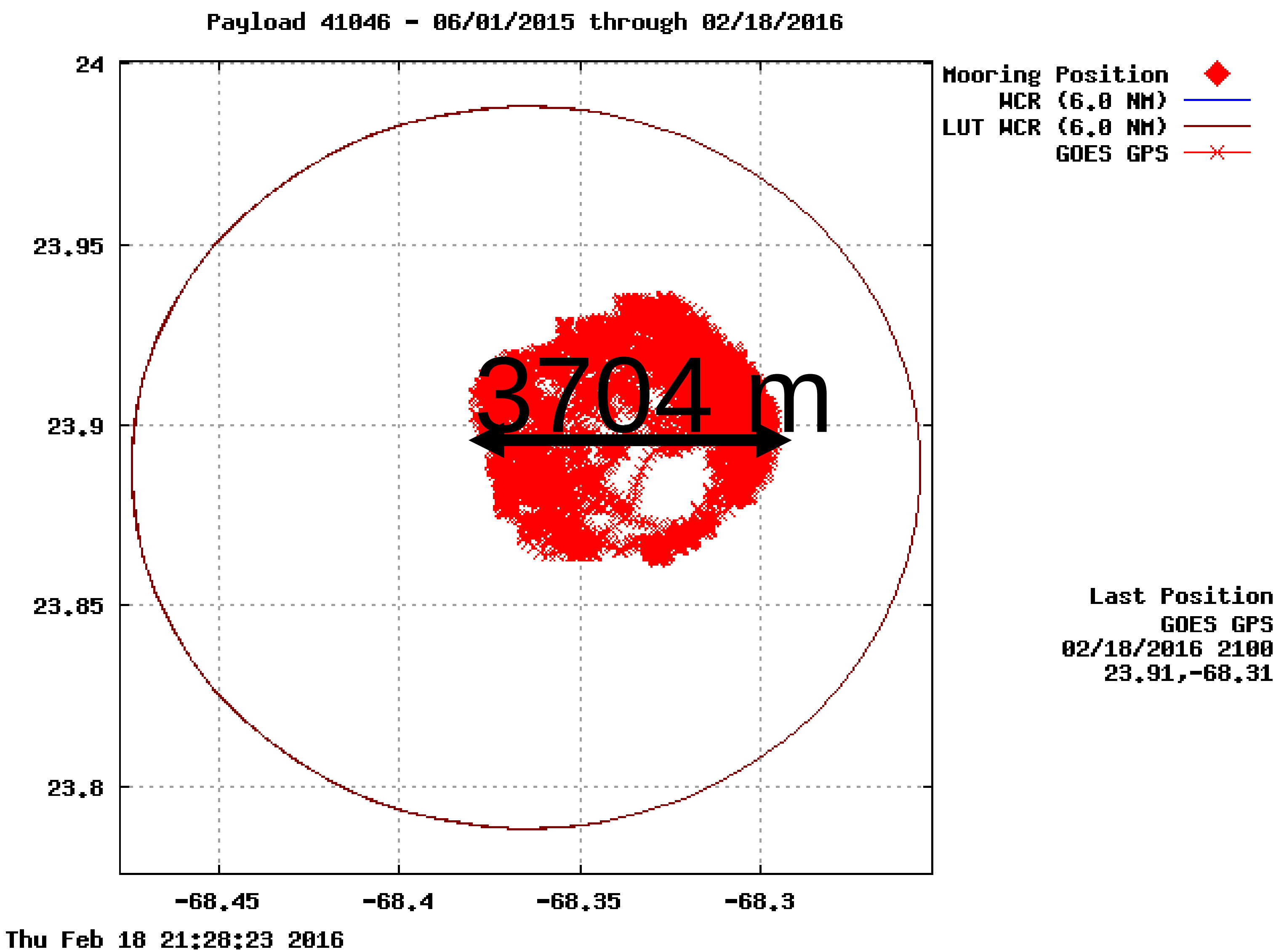
http://www.ndbc.noaa.gov/mooredbuoy.shtml

Then we hang all sorts of stuff on it!

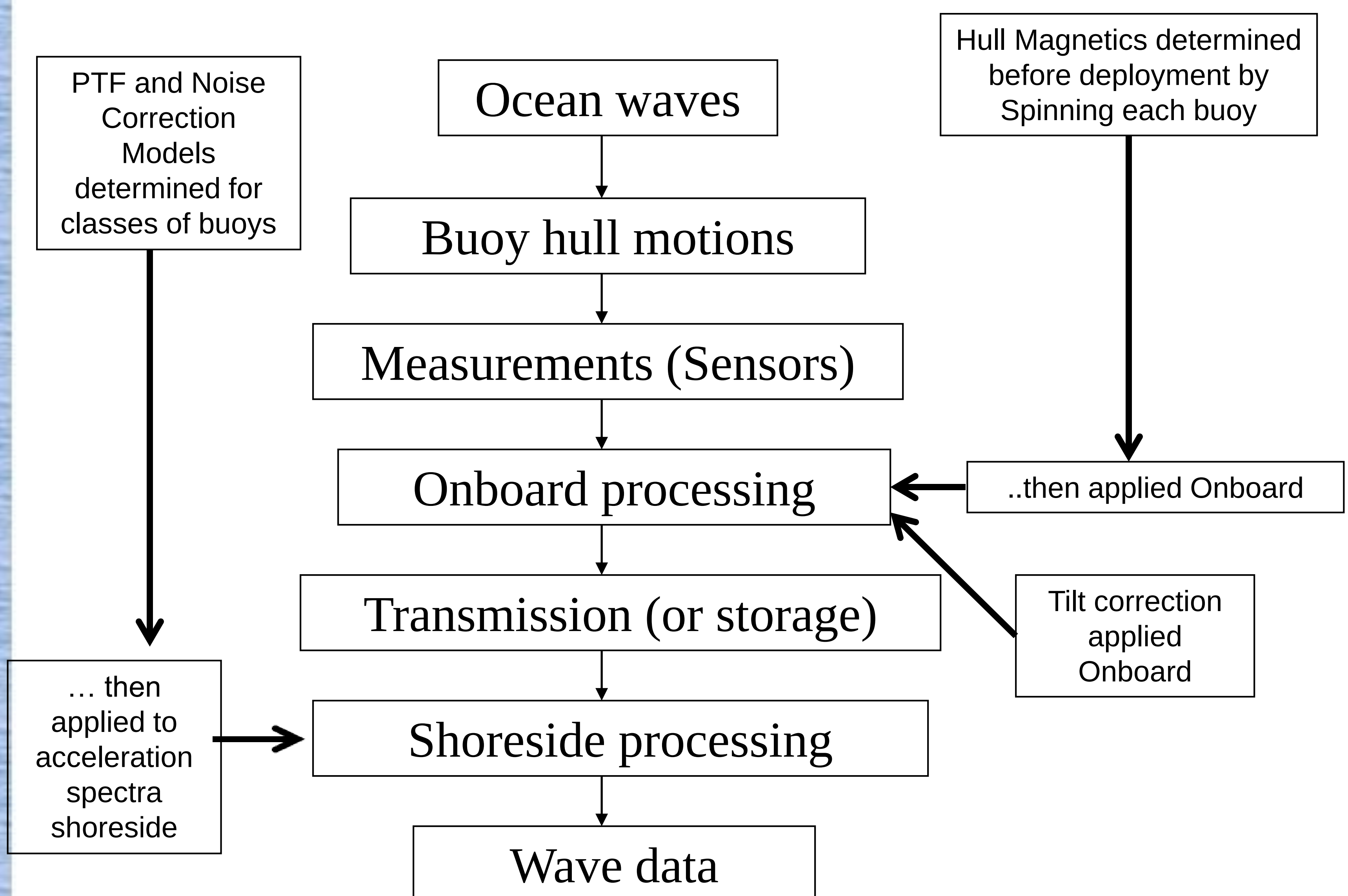
Waves are not our only measurement

And We need Power,
And,We need Communications

.. and then it moves!



Buoy Wave Measurement



Power Transfer Function (PTF)

Consists Four Frequency-dependent Response Amplitude Operators (RAO):

- R^{hH}: Amplitude changes to vertical displacement (H - Heave) from hull (h) and mooring effects
- R^{sH}: Amplitude changes to vertical displacement (H) from displacement sensor
  - NDBC no longer uses displacement sensors, this now holds double integrator values, $\mathbf{(2\pi * f)^2}$
- R^{fa}: Anti-aliasing analog (a) filter (f)
- R^{fn}: Numerical (n) filter (f)
  - R^{fa} & R^{fn} = 1 for latest NDBC systems

$$\mathbf{PTF = (R^{hH} * R^{sH} * R^{fa} * R^{fn})^2}$$

$$\mathbf{PTF(f) = (R^{hH}(f) * (2\pi * f)^2)^2}$$

Where f is now frequency in Hz.

Developing Hull-Mooring RAO (R^{hH})

- Steps detailed in Teng *et al*., 1996.
- Initial RAO from hydrodynamic model or scaled from existing hull/moorings
- Then deploy near a reference buoy like a Datawell Waverider
- Perform a modified least squares fit between Waverider (small hull) and NDBC hull (large hull)
  - Details in Murphy and Steele, 1982

R^{hH} and PTF

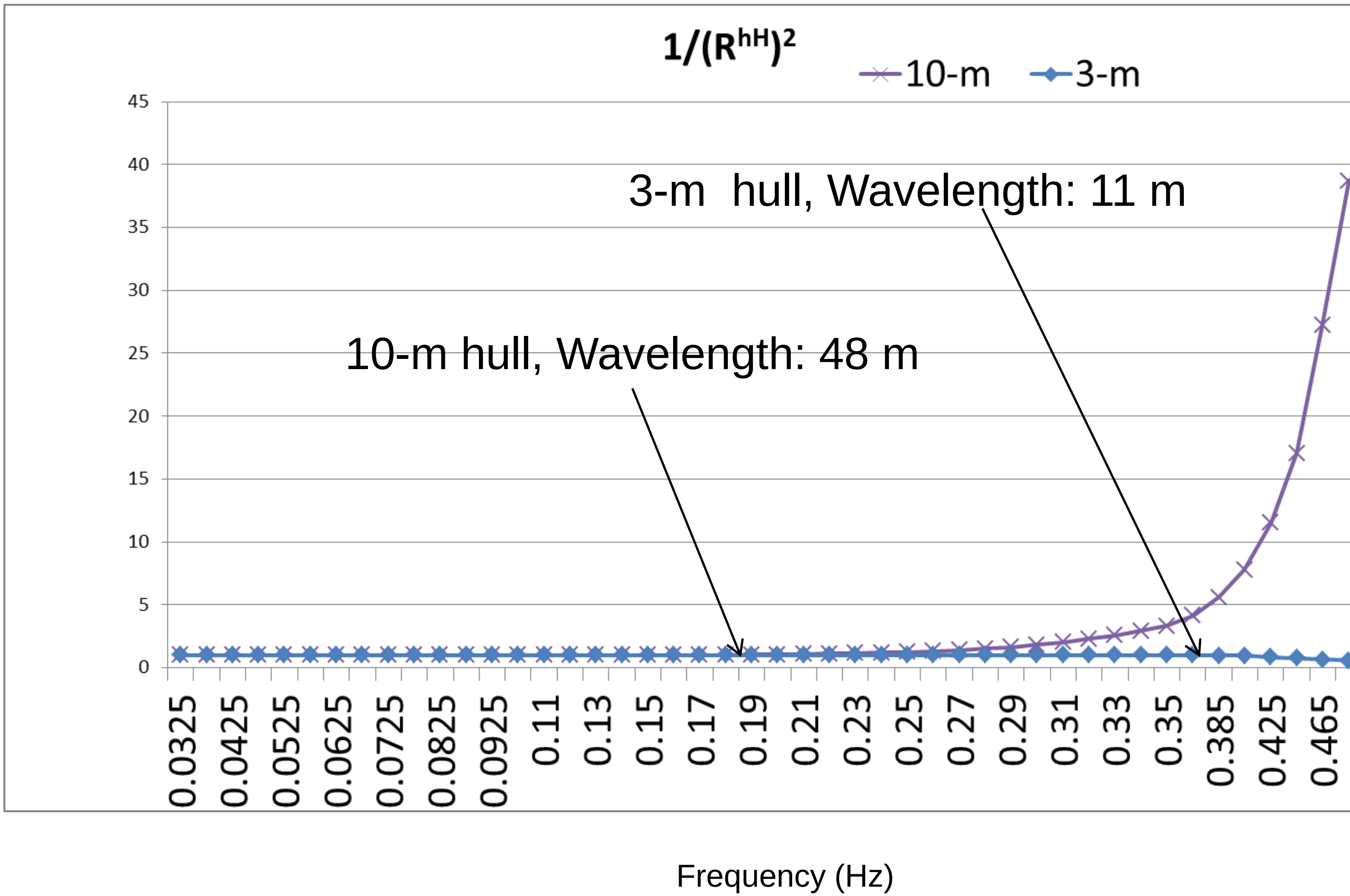
$$R^{hH}(\mathrm{f}) = \sqrt{\frac{C_{11}(\mathrm{f})(\text{large buoy})}{C_{11}(\mathrm{f})(\text{small buoy})}}$$

C_{11}(f) = C_{11}m(f)/PTF(f)
C_{11}(f): Displacement Spectrum
C_{11m}(f): Acceleration Spectrum

Does not attempt to account for damping, added mass, or wind

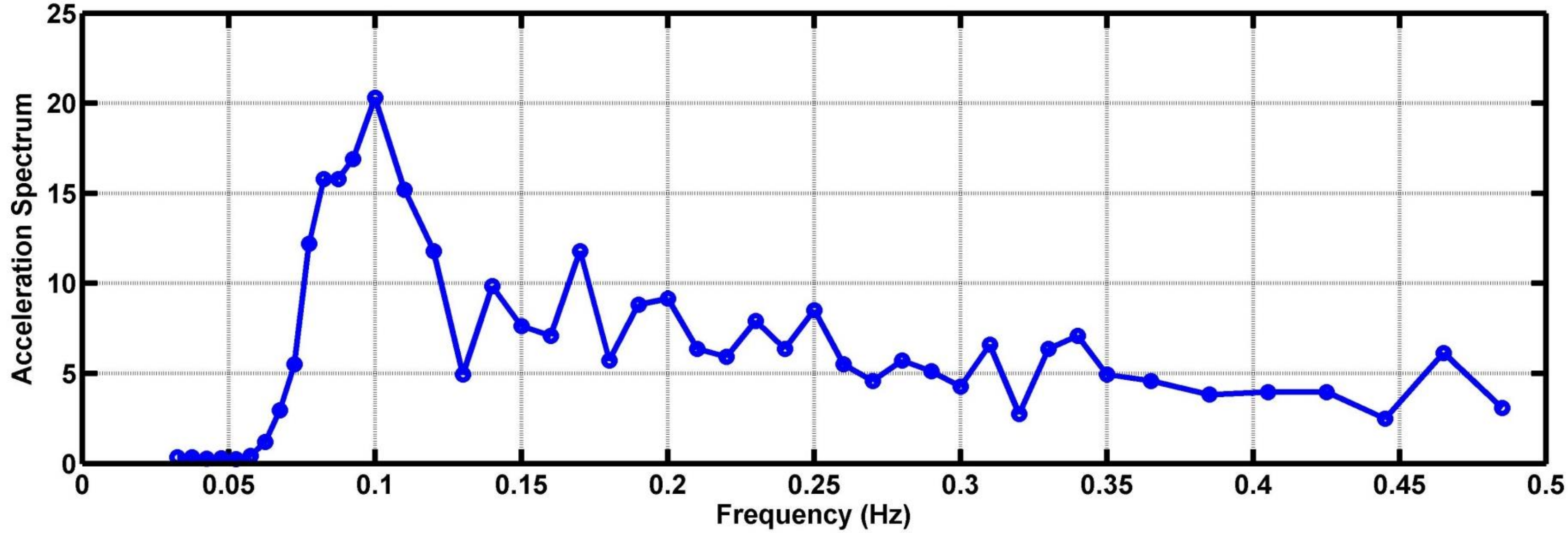
Hull/Mooring RAO

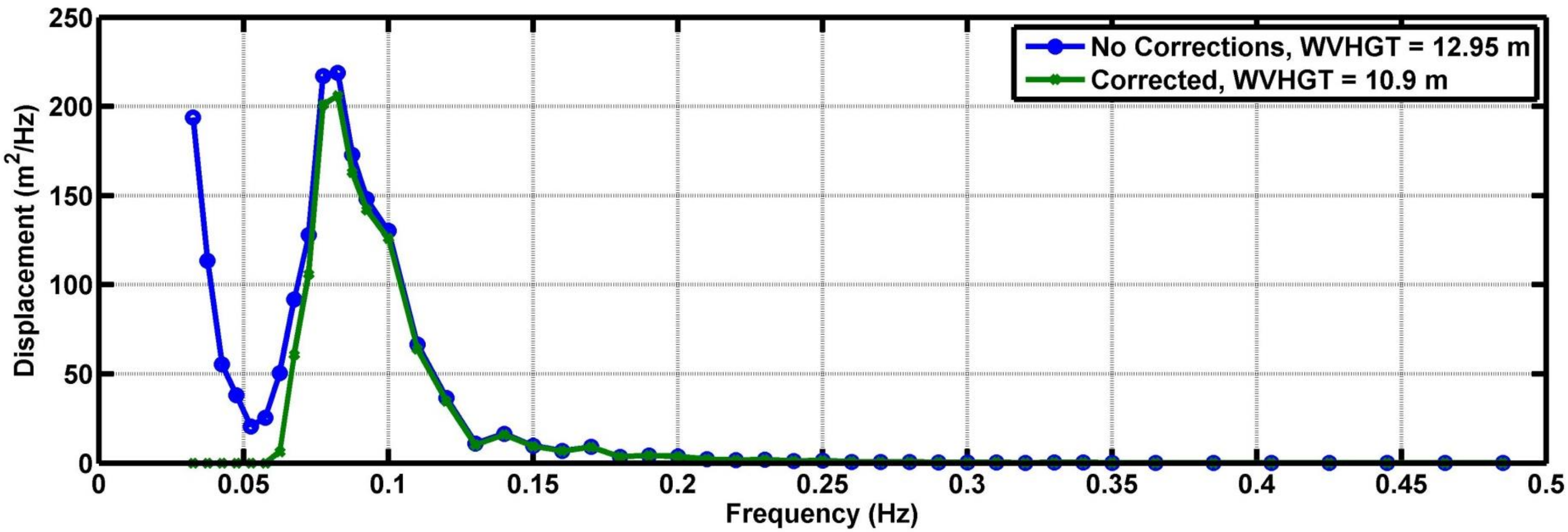
Examples



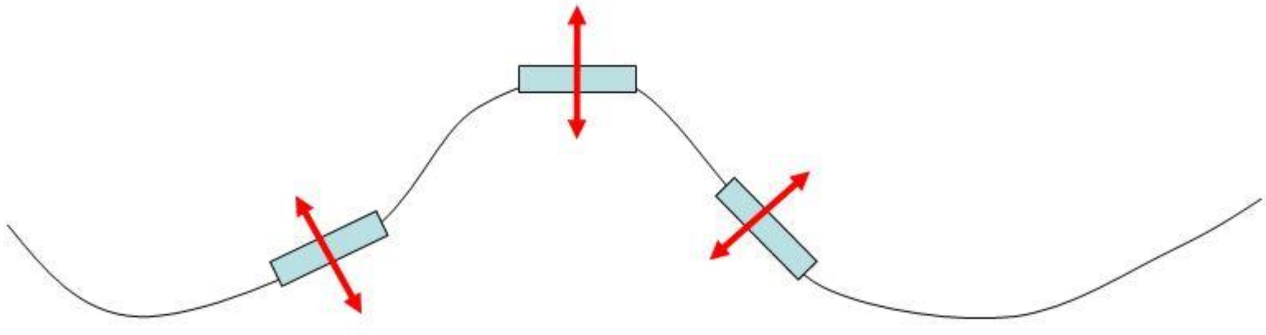
Need for Low-Frequency Corrections for Strapped-down accelerometers

Double integration (dividing by f^4) can amplify noise





Empirical Noise Correction for Strapped-down Accelerometer



- 1977 to ~1986 NDBC tried different noise corrections

- 1987 Lang: Empirical function based on the magnitude of noise bands
  - Assumes acceleration spectra below 0.03 Hz is noise
  - Noise bands centered on 0.01 and 0.02 Hz
  - Fits least-squares line to determine coefficients and cut-off frequency
  - Maximum values to eliminate any possibility of noise amplication
  - Different values depending on hull type and water depth

- 2000 Hervey-Lang correction
  - Hervey using Lang's approach develops correction for WPM single noise band system
  - Also used to determine cutoff frequency for integration of Angular Rates for directional waves

Lang,1987

- **Max (C_{11m}(f)/G(f))**

G(f) = 0.5*(Sum of the noise bands)

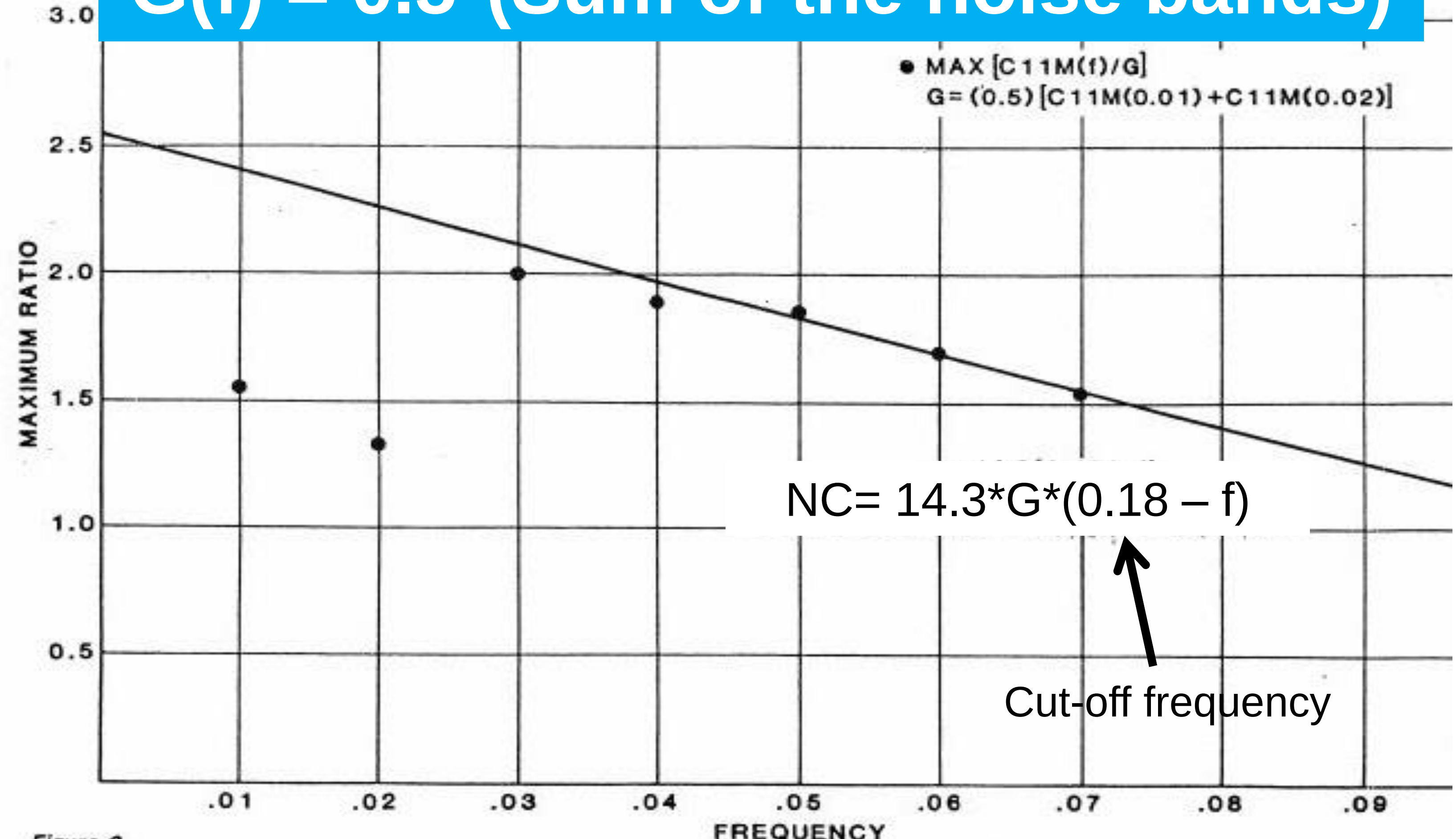
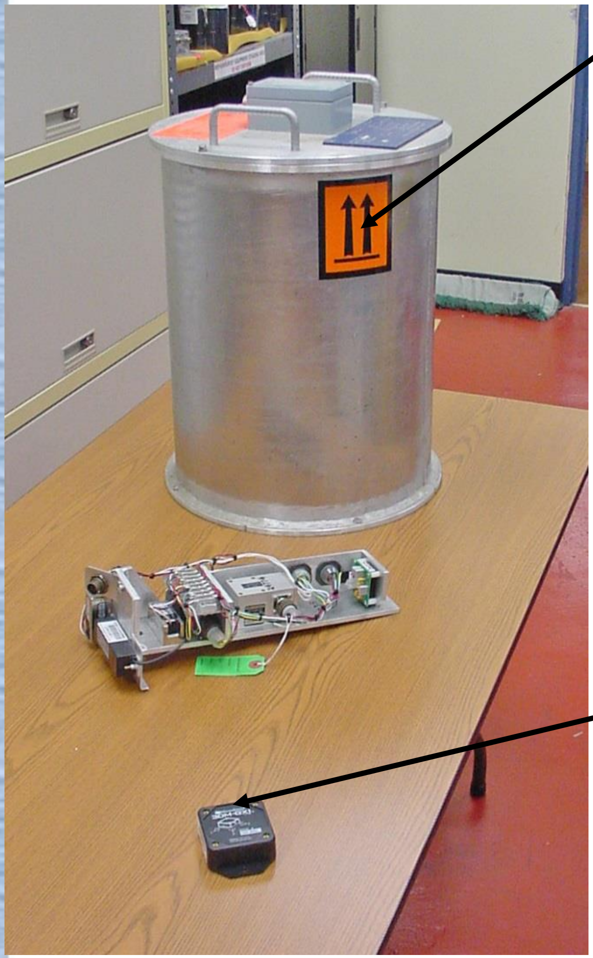


Figure 2.

Wave Sensors



Datawell Hippy 40 Mark II
• **Stabilized platform to minimize tilt effects on vertical acceleration**
•Guts of Datawell Waverider

MicroStrain 3DMGX1
• Integrated sensors
• **Acceleration (strapped-down)**, angular rate sensors, and magnetometers in 3 orthogonal axes

However,

- Bender, *et al.*, 2010 & 2011 showed that increased noise (~26% - 56%) with strapped-down accelerometer:
  - Mean Tilt > 6°
  - Small-hull
  - Shallow water
- Confirmed by lab tests and field tests with NDBC's dual wave buoys
- 2011 NDBC instituted on-board tilt correction of vertical acceleration time series using pitch, roll, and the horizontal accelerations (Riley *et al*., 2011)
- We now need pitch & roll for nondirectional purposes

NDBC Dual Wave Buoys

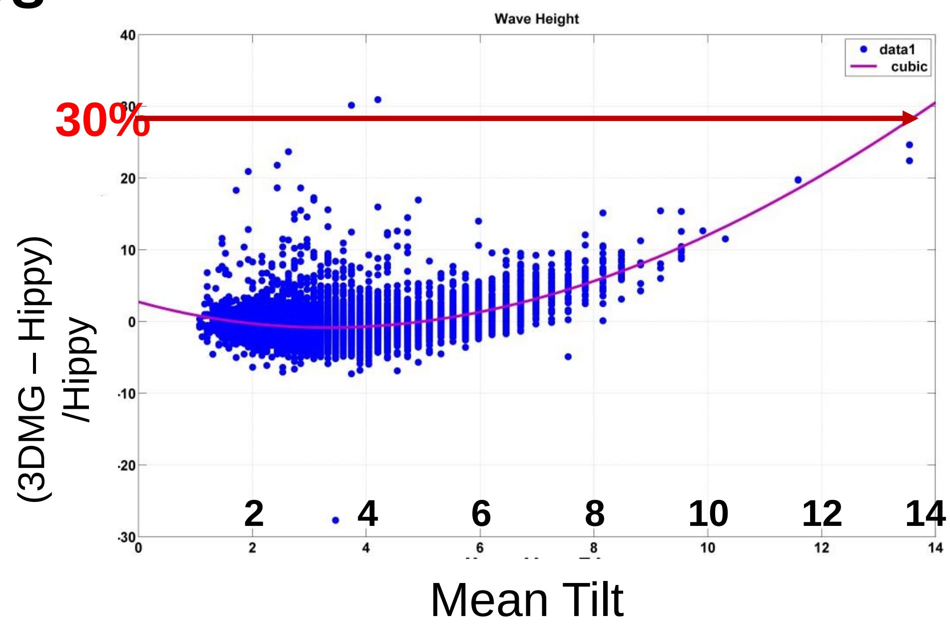
Columbia River Bar

No Tilt Correction

Error up to 30%

Compared to vertically stabilized Hippy 40

Max wave 9.2 m



PP-WET Monterey

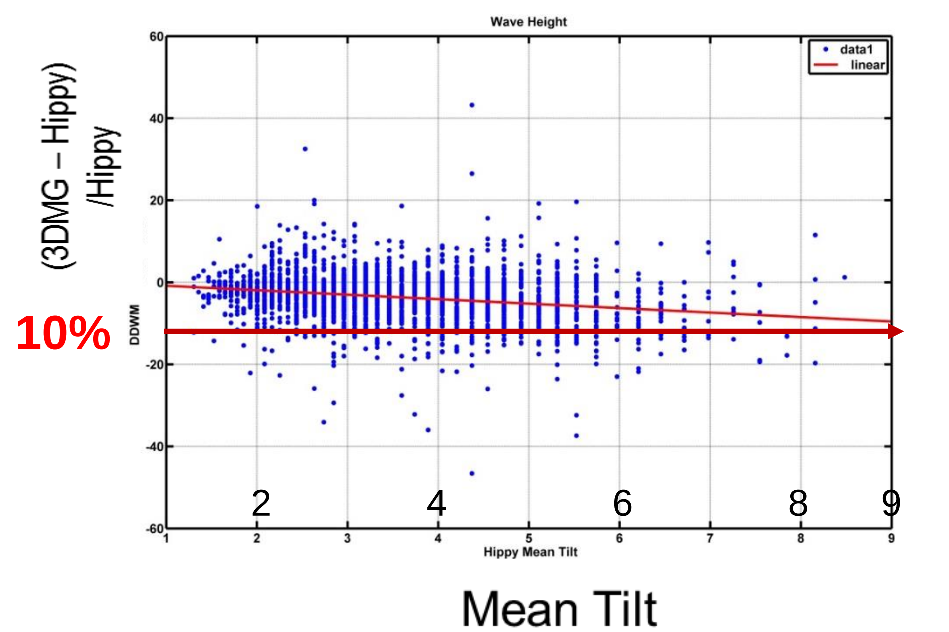
With Tilt Correction

Ski Jump Trend Removed

Now underreporting

Compared to Hippy 40

Max wave 8.9 m



Hull Magnetic Coefficients

A. Sensors Aligned with Buoy Frame of Reference

B. Directional Wave Products are in True North

C. We get from A to B by

Step 1: Buoy orientation with respect to magnetic north

Step 2: Adding location-specific magnetic declination to rotate into True North

Step 1 is calculated from measurements of Earth Magnetic Fluxes using 2 orthogonal magnetometers

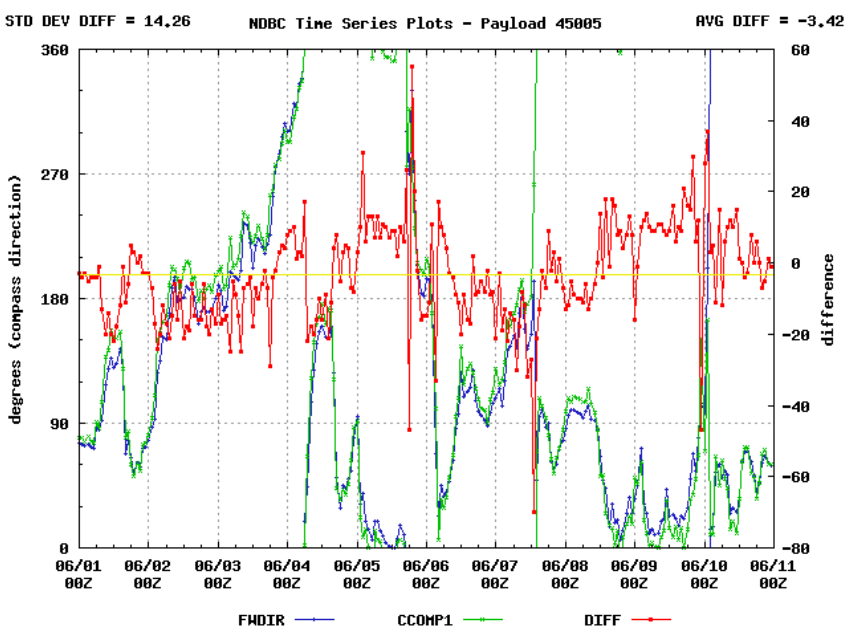
However, the magnetometers will measure any magnetic influences

Need to correct for these influences by Spinning the Buoy

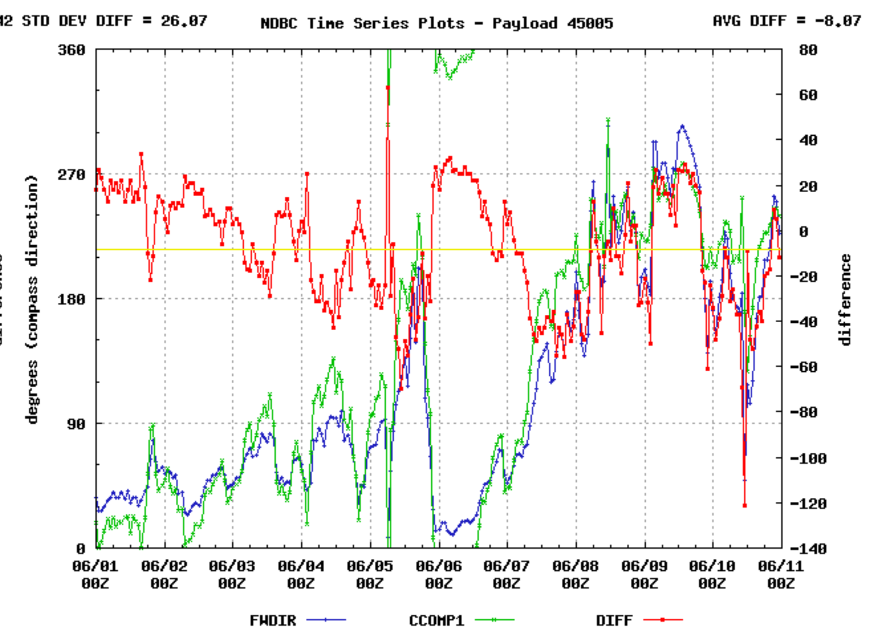
What if You Don't Spin the Buoy?

We check the wave azimuth with wind azimuth

2014: total difference ~ 15 degrees



2015: total difference ~ 30 degrees



Put New Batteries in without New Spin

2 equations of the horizontal magnetometer measurements (***$B_{i=1}$(bow)*** and ***$B_{i=2}$(starboard)***) and 2 unknowns (**sin(A)** and **cos(A)**)

Buoy Spin calculates:

Offsets (Residual or Hard Iron): b_{10} and b_{20}

Scaling factors (Induced or Soft Iron): b_{11}, b_{22}, b_{12}, and b_{21}

B_{ey} and B_{ez} are location-specific Earth magnetic fluxes (horizontal and vertical) either from geodetic model (NOAA's NCEI) or mean measurements; P = Pitch; R = Roll.

$$B_i = b_{i0} + B_{ez}\left[b_{i1}\sin(P) - b_{i2}\cos(P)\sin(R)\right] +$$

$$B_{ey}\left\{\left[-b_{i2}\cos(R)\right]\sin(A) +\right.$$

$$\left.\left[+b_{i1}\cos(P) + b_{i2}\sin(P)\sin(R)\right]\cos(A)\right\}$$

- Spin is done at the dock so Pitch and Roll are Zero. Sine terms go to zero, Cosine terms to 1. Azimuth is now known from the Gyro.
- B_i equations simplify to:

$$B_i = b_{i0}$$

$$+ B_{ey}\left\{\left[- b_{i2}\cos(R)\right]\sin(A) + \left[+ b_{i1}\cos(P)\right]\cos(A)\right\}$$

- Unknowns are now the constants and coefficients (HMC)

Buoy Spin

- Buoy rotated and sets of equations accumulated
- The mean of several sets of measurements that pass variance test become the constants and coefficients
- Details in Steele and Lau, 1986 and Remond and Teng, 1990
- Verified by using the HMCs and testing 8 compass points all must be <= 4°

Reading

NDBC Technical Document 96-01, Nondirectional and Directional Wave Data Analysis Procedures, on-line at:

http://www.ndbc.noaa.gov/wavemeas.pdf

undergoing revision

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http://www.rsaqua.co.uk/uploads/pdfs/Products/Datawell/Motion%20Sensors/datawell_brochure_hippy-40.pdf

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Thank You

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