Ocean Waves Workshop

Nov 17th, 1:30 PM - 2:00 PM

Session 3 Presentation: Current State of Wave Measuring Technology from Buoys

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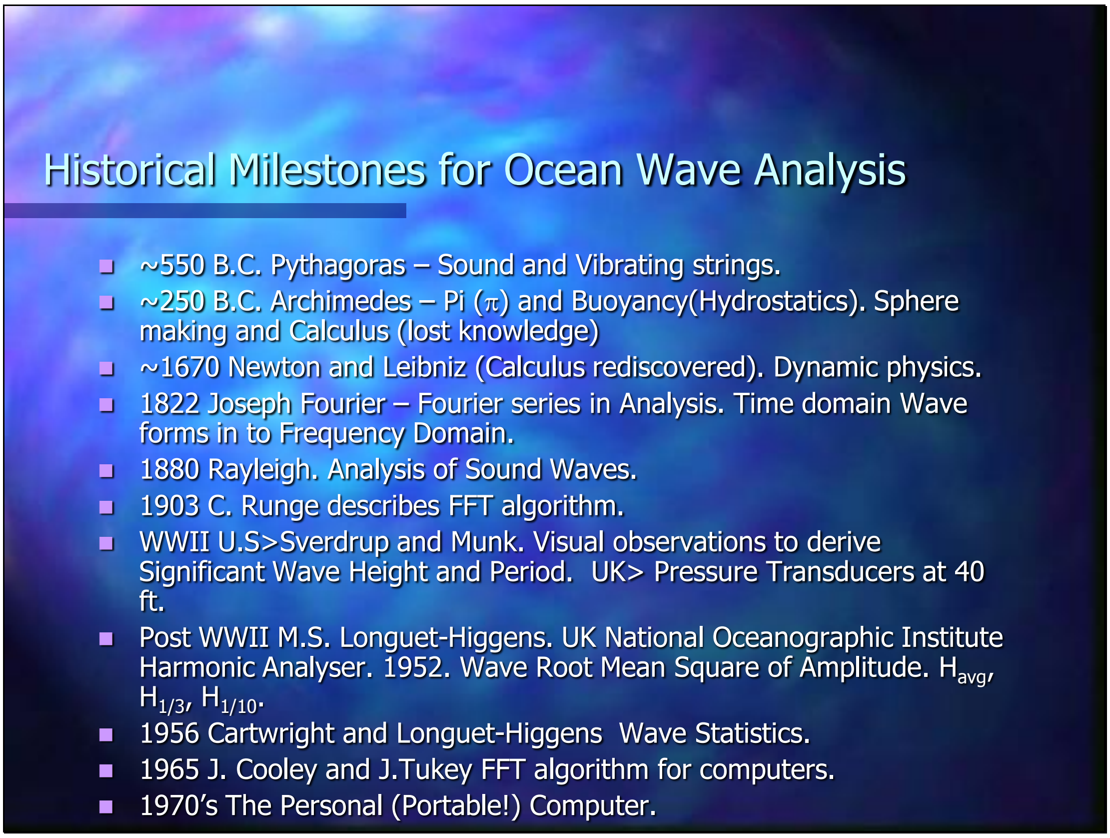
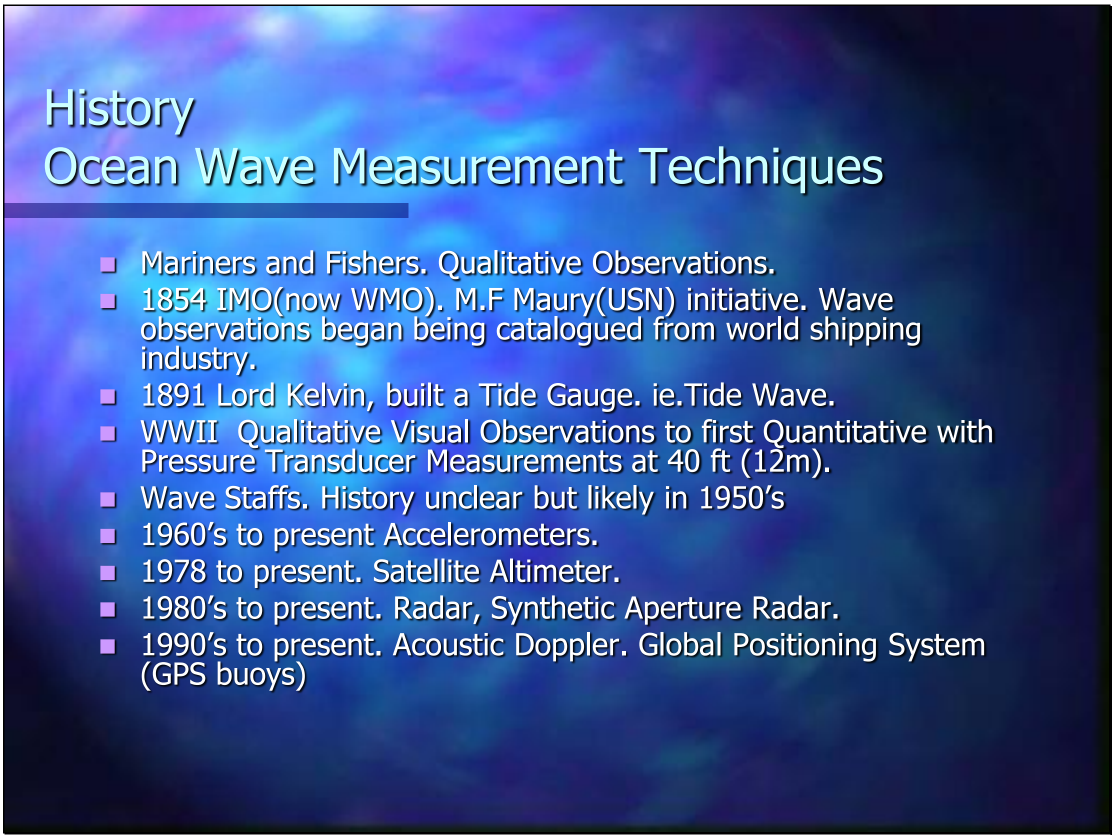
Session III— Recent advances and issues in wave buoy technologies.

This session describes the use of sensors such as accelerometers and inclinometers to measure the heave acceleration and the vertical displacement of wave buoys, which are then converted to wave parameters. Participants discuss data processing, transmission, and display, and some analysis. The following paper and extended abstracts provide information on the latest mooring components and devices such as acoustic Doppler current profilers which complement wave buoys.

Session Presentation by Mr. Randolph Kashino


Historical Milestones for Ocean Wave Analysis
~550 B.C. Pythagoras – Sound and Vibrating strings.
~250 B.C. Archimedes – Pi (π) and Buoyancy(Hydrostatics). Sphere making and Calculus (lost knowledge)
~1670 Newton and Leibniz (Calculus rediscovered). Dynamic physics.
1822 Joseph Fourier – Fourier series in Analysis. Time domain Wave forms in to Frequency Domain.
1880 Rayleigh. Analysis of Sound Waves.
1903 C. Runge describes FFT algorithm.
WWII U.S>Sverdrup and Munk. Visual observations to derive Significant Wave Height and Period. UK> Pressure Transducers at 40 ft.
Post WWII M.S. Longuet-Higgens. UK National Oceanographic Institute Harmonic Analyser. 1952. Wave Root Mean Square of Amplitude. H_{avg}, $H_{1/3}$, $H_{1/10}$.
1956 Cartwright and Longuet-Higgens Wave Statistics.
1965 J. Cooley and J.Tukey FFT algorithm for computers.
1970's The Personal (Portable!) Computer.


History
Ocean Wave Measurement Techniques
Mariners and Fishers. Qualitative Observations.
1854 IMO(now WMO). M.F Maury(USN) initiative. Wave observations began being catalogued from world shipping industry.
1891 Lord Kelvin, built a Tide Gauge. ie.Tide Wave.
WWII Qualitative Visual Observations to first Quantitative with Pressure Transducer Measurements at 40 ft (12m).
Wave Staffs. History unclear but likely in 1950's
1960's to present Accelerometers.
1978 to present. Satellite Altimeter.
1980's to present. Radar, Synthetic Aperture Radar.
1990's to present. Acoustic Doppler. Global Positioning System (GPS buoys)

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Seakem Oceanography Ltd to AXYS Technologies Inc.
Experience with Wave measurement

- 1982 started operation of the first wave buoy network on the Pacific Coast of Canada for the Canadian government, which consisted of 2 Datawell Waverider(tm), a WAVEC(tm) Buoy and an Endeco directional wave buoy. Developed software for Real-Time Acquisition and Analysis on Personal Computer.
- 1985 successful in procuring the contract let by Canadian Weather Service(AES now MSC) to build and service the first weather buoy network in Canada. With the aid of the NOAA National Data Buoy Center the weather buoys developed were based on the NOMAD and WHOI 3 meter buoy types. For project developed a Heave only wave sensor based on a single accelerometer.
- Oilfield Monitoring Projects in Atlantic Canada and Beaufort Sea using Datawell Buoys, Sea Data Wave/Tide Recorders, InterOcean S4 Current Meters. Also Motion sensors on Drill ships.
- 1997 partnership with Canadian Hydraulic Centre(CHC)of the National Research Council (NRC) who independently had been developing its own software for measuring waves using accelerometers with other motion sensors.
- 1998 Birth of the TriAxys™ Directional Wave Sensor and Buoy.
- 1998 to 2010 Triaxys Sensor Integrated into 3m buoy, Watchkeeper and WatchMate Buoys. Acoustic Doppler Profiler added to Triaxys™ Buoy Hull.
- 2010 Next Wave Triaxys™ Buoy - improvement to technology.

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Watchman ™ and Triaxys™ Wave Sensor

Single Accelerometer
analogue output

3 Accelerometers
3 Rate Gyros
Compass
Processor
Datalogger

Wave Measurement with Accelerometers

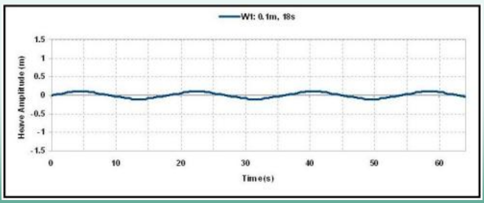
- Measurement of Acceleration must be double integrated to get heave.
- 1st Acceleration to Velocity. v=(a*t)/2
- 2nd Velocity to Displacement. d=(a*t^2)/2
- Datawell does this by using strain gauge accelerometer and electronic integrator. A feedback circuit. Similar for Watchman Wave Module.
- Triaxys NRC software does Double Integration using discrete Fourier Transform.

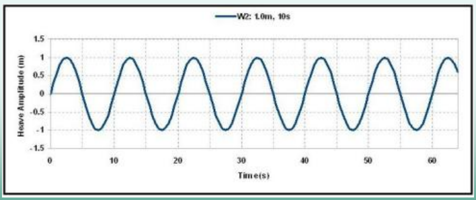
$$\zeta(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n \cos 2\pi n f t + b_n \sin 2\pi n f t)$$

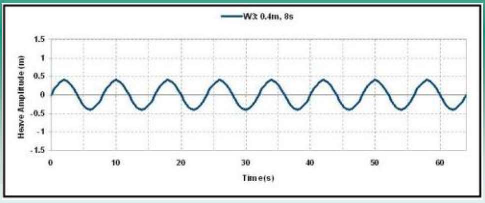
Spectral Analysis of Waves by using the Fourier Transform assumes that the observed sea state is the sum of a group of waves coming together.

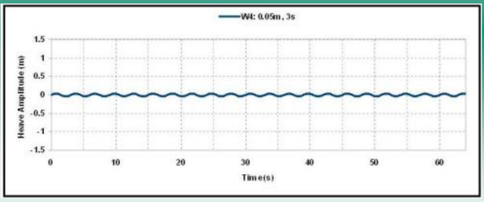
For example: a 128 sample FFT, assumes there are 64 waves of different Height and Period that are summing together.

- In this example there are waves of 4 different Heights and Periods

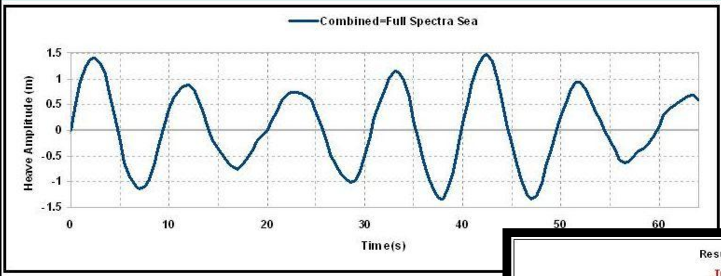


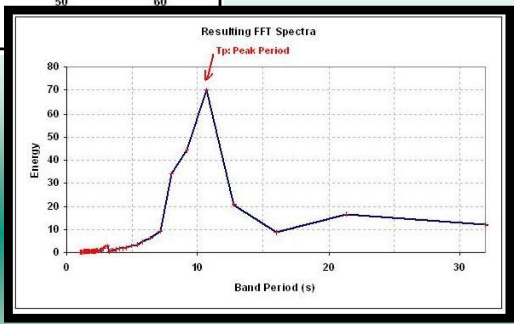






Even with only these 4 waves
the result is a seemingly random sea state





- **The FFT analysis results in a Spectra of the energy for each band periods (frequencies) of assumed 64 waves.**

Data Collection and Analysis
A 2 Step Process
1. Motion Analysis to determine buoy motion in 3 dimensions (6 degrees of freedom).

1. Sample at 4 Hz the X,Y and Z Accellerometers and X, Y, Z Rate Gyros and Compass
2. Demean the Accellerometer and Rate Gyro data
3. Rate Gyro data is used to correct Accellerometer for Pitch, Roll and Yaw.
4. The 4 Hz data is resampled using Cyclic Merging to fit 2^n sample for FFT.
5. High Pass Filter is applied to attenuate low frequency noise in the heave signal.
6. FFT is carried out for each of X, Y and Z motions.
7. The resulting Fourier spectral Coefficients (real and imaginary) are double integrated.
8. Once to obtain Velocity Spectra and a 2nd time to obtain Displacements Spectra.
9. An Inverse FFT is then carried out on the Displacements Spectrum to Derive 3 dimensional motions
10. The Compass data is used to correct Yaw motion to East, North, Heave motions.
11. Buoy Motion data is then stored for Analysis Process

Motion Analysis Process Reference

- For a more comprehensive description of the Motion Analysis Process go to the Axys Technologies Website Library and download:
- *Measurement of Six Degree of Freedom Model Motions Using Strapdown Acceleromters.* By M.D. Miles of the Canadian Hydraulic Centre-NRC

Data Collection and Analysis
A 2 Step Process
2. Analyze to determine Ocean Wave Statistics and Directional Spectrum.

1. Heave, surge and sway motions of the buoy from the Motion Analysis are used
2. Both Non-directional and Directional Analysis are performed
3. The KVH method is used to perform the directional wave analysis. i.e. the MeanDir and DirSpec files.
4. the first four Fourier coefficients A1(f), B1(f), A2(f) and B2(f) of the directional spreading function are also stored. i.e. Fourier files
5. Maximum Entropy Method (MEM) is used to determine Directional Spectra
6. Standard Ocean Wave Zero Crossing Analysis is done to determine standard wave statistics. e.g. Hmax, Hsig, Tz
7. Standard Ocean Wave Spectral analysis done to determine statistics. e.g. Hmo, Tp, Mean Wave Direction, Spreading.

Wave Analysis Process Reference

- For a more comprehensive description of the Motion Analysis Process go to the Axys Technologies Website Library and download:
- For KVH Method: KVH by Kuik, Van Vledder and Holthuijsen. *A Method for the Routine Analysis of Pitch and Roll Buoy Wave Data*
- For Maximum Entropy Method: *Wave Analysis and Generation in Laboratory Basins. Estimation of Directional Wave Spectra by the Maximum Entropy Method.* By O.U. Nwogu, E.P.D. Mansard et al.

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The 2 main wave buoys that use accelerometers are the Triaxys™ Buoy and the Datawell Waverider™

- Datawell Waverider^{tm} is a standard for buoys with accelerometers
- Datawell main accelerometer sensor is fine wire strain gauge in fluid on floating gimbal platform.

Operational Considerations when using Datawell Waverider™ :

1. Avoid Tangling of the fine wire Strain Gauge accelerometer. Do Not Spin Buoy!
2. If fluid freezes (<-4 C) it has to be replaced.
3. Over time gas bubbles can form in fluid making measurements questionable. This is managed by replacing fluid.
4. Telemetry is generally excellent but may be expensive.
5. Power consumption management is very good and buoys can be deployed for up to 18 to 24 months.

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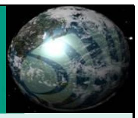

The Triaxys™ Buoy

- Solid State Electronics. Sensors are 3 accelerometers (x,y,z), 3 rate gyros (pitch,roll,yaw), and fluxgate compass. No moving parts that are Not damaged by Spinning or Freezing.
- Data processing in sensor derives 3 dimensional motion of sensor. i.e. 6 degrees of freedom. Canadian Hydraulics Centre, National Research Council Software.
- Results are stored on board and/or transmitted.

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The Triaxys Buoy: features

- Rechargeable Batteries that are Solar charged.
- Infrared Interface for short range wireless communication…and now Bluetooth available.
- Acoustic Doppler Profiler now an option.
- 2 way Inmarsat D+ satellite communication is standard. Inmarsat D+ terminal is also our GPS engine for position and timekeeping.

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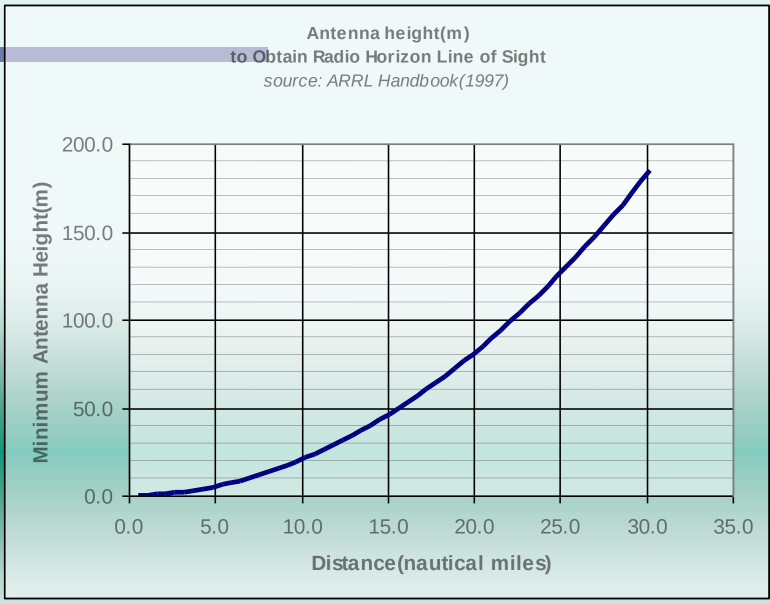
Primary Data Telemetry Options

1. RADIOMODEM TELEMETRY

- VHF: standard 30-50MHz. Other frequencies available depend on availability of transmitter-receivers.
- 400 MHz (EU) or 900 MHz (N.A.) Spread Spectrum. Line of site a necessity.
- GPRS/GSM cell phone. OK but depends on service. Do not be surprised at 40 to 60% data loss. HF (800-1900 MHz). Line of Site necessary, same as with Spread Spectrum.
- Direct to user Real Time Data. Good for Ships,Rigs, Near Shore operations and Drifting Studies.
- VHF is free… If you don't count the cost of antenna installation, maintenance, rental of office space for receiver, radio license fee administration.

ANTENNA HEIGHT FOR VHF LINE OF SITE



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Data Telemetry Options

2. SATELLITE TELEMETRY

- Good for Network of Buoys. Back up of Radio Data.
- Short Burst Data (SBD) Iridium becoming a standard instead of VHF for full data.
- Inmarsat D+ for Standard Wave Statistics: Hmo, Hmax, Tp, Tz, Ts, Mean Direction, Spreading. Status: Position, Battery, SST. Allows Reprogram of Setup.
- Argos is also available for short message.
- Orbcomm is available but we have found not reliable.

Moorings are a main component of the Wave Buoy System:

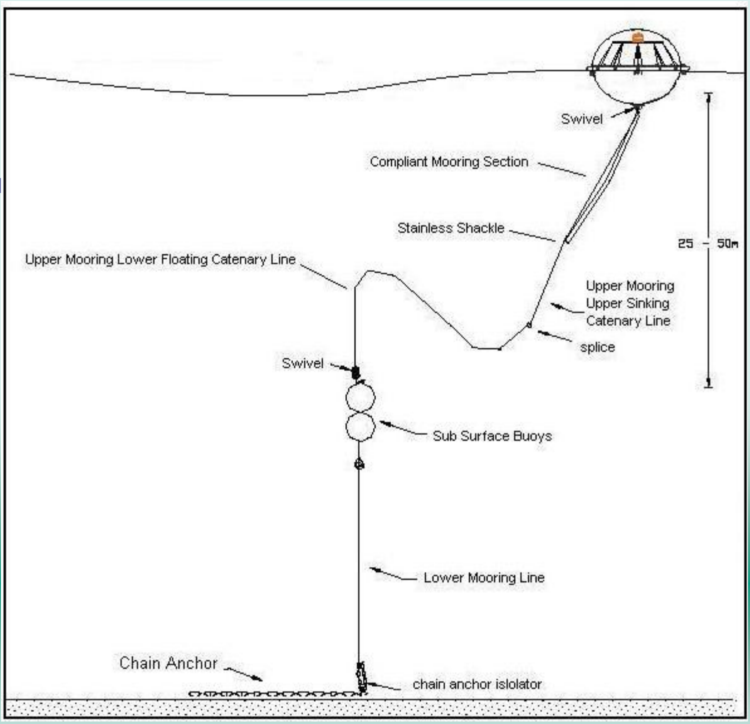
Depth Range

- For small buoys like Triaxys™ and Waverider™ Depth range from 5 to 300m.

  However, last year for a few months a Triaxys was deployed in 2600m off Newfoundland and a Waverider™ in 4000m in Pacific. Long term survivability is still uncertain.

This has become possible because of new mooring technology

- For large buoys like Watchkeeper, 3m Discus Buoy, NOMAD Buoy. Depth range from 10 to 6000m



Basic Philosophy is the Inverse Catenary Mooring with sub-surface buoy false bottom

The Mooring System must be designed to allow the buoy to follow the sea surface:

•The first connection to the buoy is a swivel system that allows the buoy to rotate as currents change.

•The next component is a compliant rubber cord section that easily stretches as tension is applied.

•The lower section needs to be designed to reduce as much tension as possible with considerations to water depth, ocean currents and, of course, wave height and period.

•The anchor must be able to hold the buoy on location.

Main limitation for deploying Wave Buoys is the effect of ocean currents on the buoy and mooring.

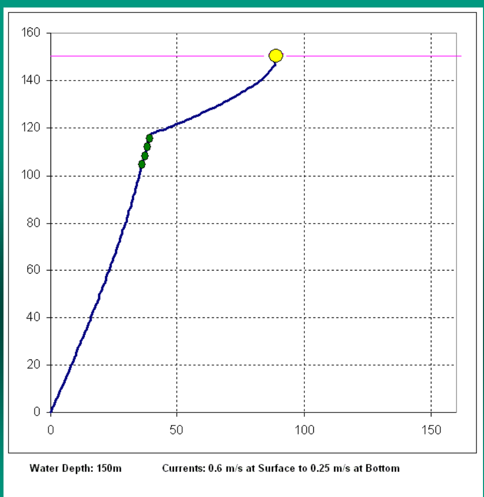
Keep in mind the hull speed of a 1m diameter buoy is about 2.3 knots.

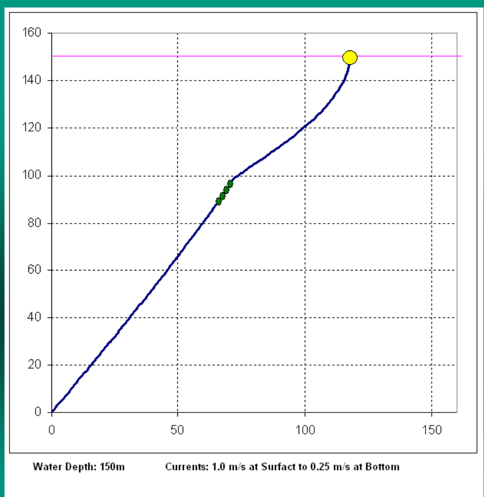
Moorings for Wave Buoys: Research your deployment site

- Mooring drag in strong currents can be significant. Drag increases with square of velocity and exposed surface area of rope(also a square).
- Drag(lbs) ~= Drag Coefficient x Area(in ft^2) x Velocity^2(in ft/s).
  Drag Coefficient about 1.2 for rope. 0.5 for buoy.
  For better estimate use a mooring simulation program.
  eg. WHOI CABLE, OrcaFlex, DSA ProteusDS®

Mooring Simulations will help design to get best performance

Mooring Simulations for varying currents





Moorings for Wave Buoys: Mooring Components : Rubber Cord

Moorings for Wave Buoys: Mooring Components: Rope Technology

New rope technology, such as Dyneema HMPE, Vectran, and HMPP is allowing from stronger rope with small diameter therefore lower drag and longer service life.

New Technology:

Dynema HMPE fiber:

12 Strand Single Braid

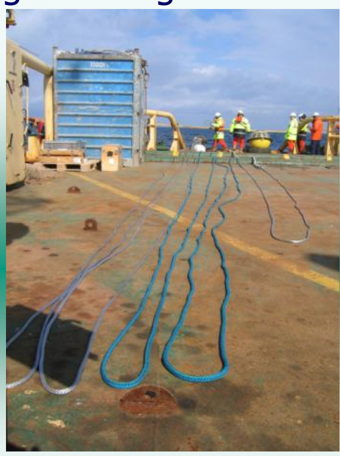
1/2” diameter has Breaking Strength of 34,000 lbs !

1/4” diameter strength= 8,600 lbs !

Old Technology:

Nylon fiber: 3 Strand Twisted

1/2” diameter has Breaking Strength of only 5,500 lbs



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Other Platforms for Wave Buoy Sensors

Smaller hulls like the MiniTriaxys™ Buoy and 0.7m Waverider™.

- Easier to deploy from small boats.
- Good for short deployments and Drifting deployments

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Other Platforms for Triaxys Sensor

- Watchkeeper Hull:

If problem with mariners it is a more visible buoy.

You also get winds and air temperature.

It can become a basic Met Buoy.

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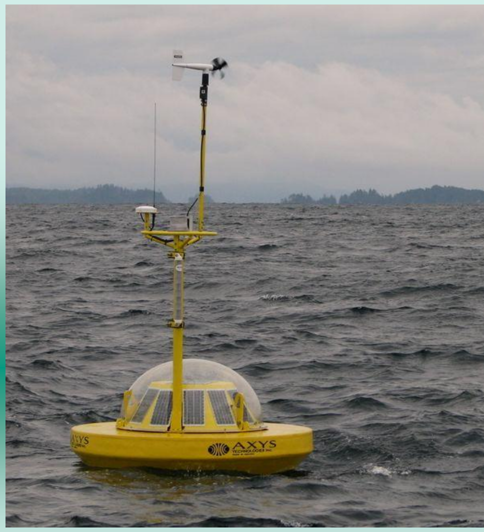
Other Platforms for Wave Buoy Sensors

e.g. Axys WatchMate™ Hull:
It is also more visible buoy.
More Sensors. The complete oceanographic buoy



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Other Platforms for Wave Buoy Sensors

- 3m Discus Hull is the other most used platform for wave buoy technology.
- Based on original WHOI LOTUS buoy design adopted by NDBC and Canadian Weather Service.
- Deep Ocean capability.
- Integrate with full suite of instruments eg. CTD, Doppler Profilers, OBS, Meteorological.

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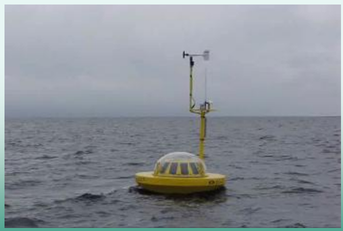
Movie Clips



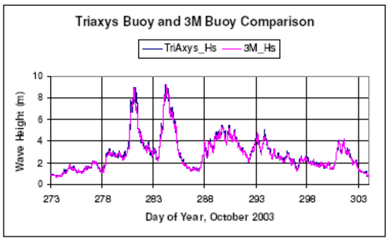


Figure1. Comparison of Significant Wave Height (Hs).

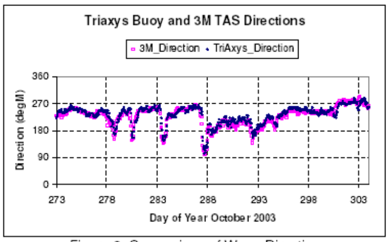


Figure 2. Comparison of Wave Directions.

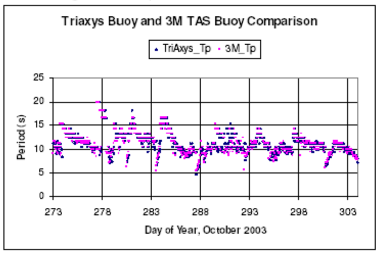


Figure 3. Comparison of Peak Periods (Tp).

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Movie Clips

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Future of Wave Buoy Technology

- New accelerometers as they are developed.
- New Microprocessors to improve data processing, power consumption, data logging capacity and more.
  e.g. Triaxys™ Next Wave and Waverider™ SG. The Triaxys™ NW is now able to do 5 Hz and 10 Hz sampling.
- New battery and solar charging technology as it becomes available.
- SBD Iridium is becoming the standard for primary Data Telemetry.
- GPS Technology to measure waves is likely to become more prevalent as power consumption lowers and software improves.
- Mooring Technology improvements will extend possible deployment depths.
- Addition of supplimentary sensors to small wave buoys will increase versatility.

Now it's back to my job of measuring Waves