Exploring Possibilities and Practicalities of MEMS Sensors for Wave Measurement

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Overview

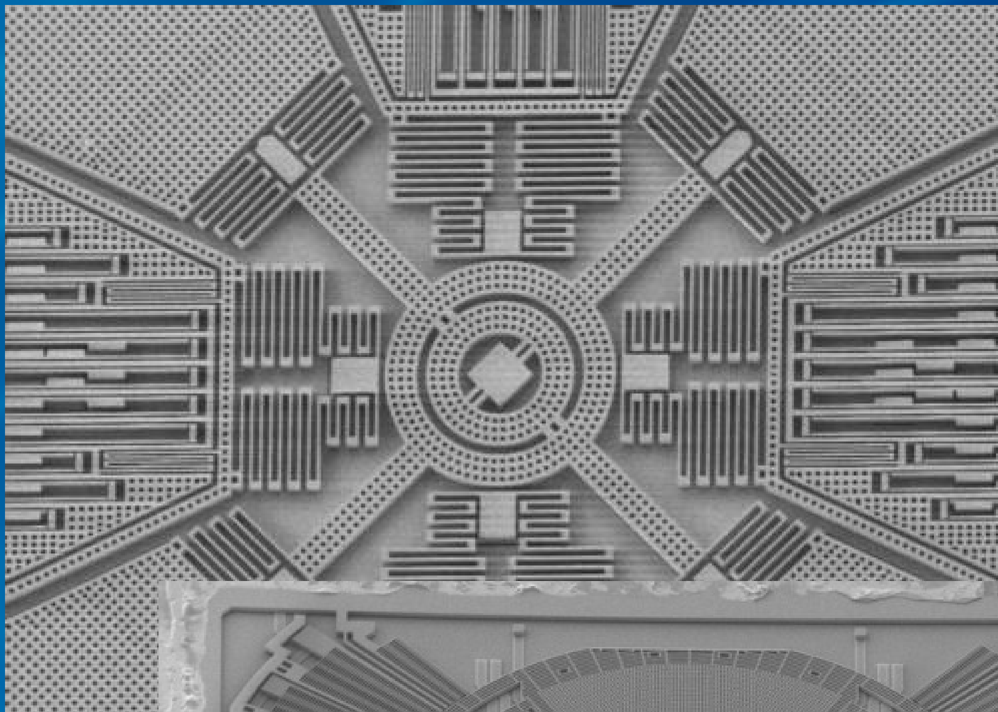
- **All aboard: MEMS sensors and why they are becoming ubiquitous**
- **Wave measurement strategies/concerns**
- **Making the most of MEMS sensors: Where could they go?**
- **Conclusions and future work...**

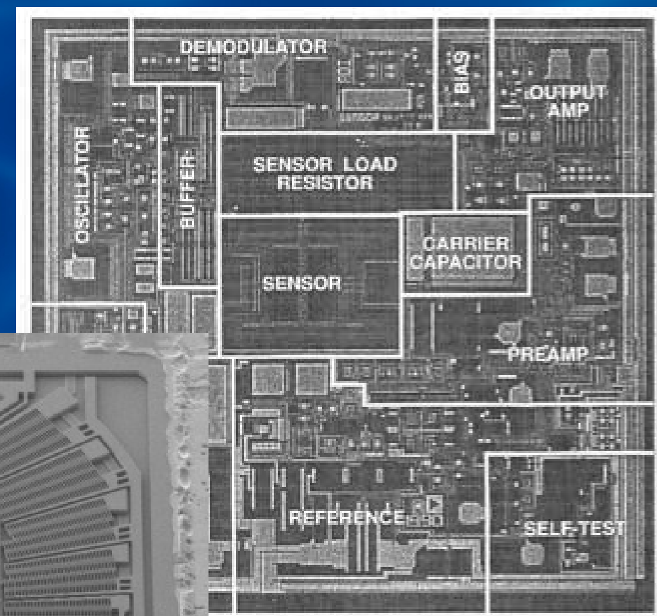
The Smartphone Principle

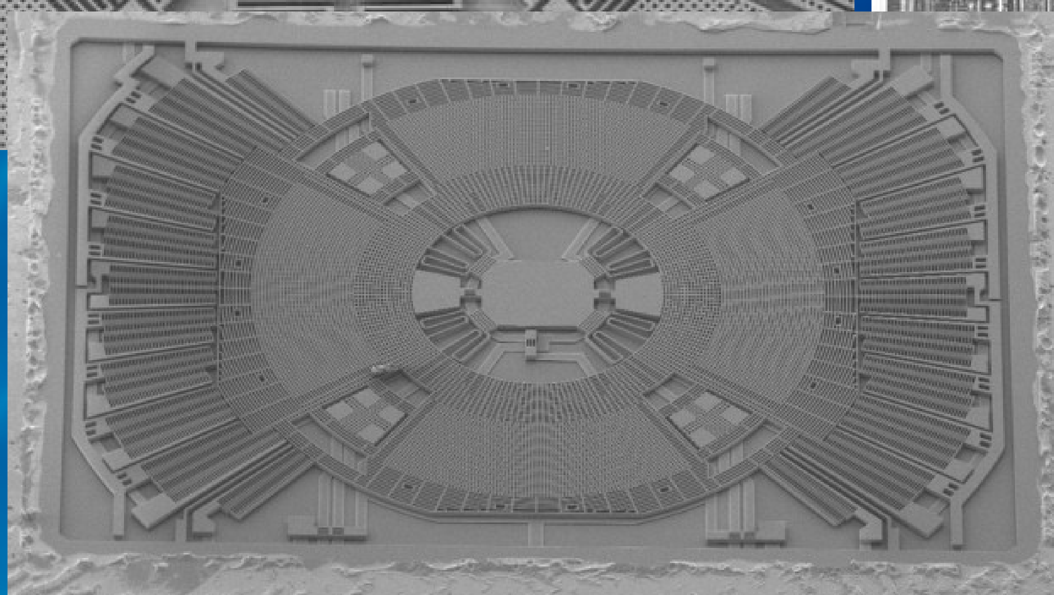
If it's used in smartphones (game controllers, smart cars, etc...) well-capitalized companies will invest vast sums to try to make it smaller, more accurate, faster, more power efficient, and highly integrated.

How will land based developments spill over and enable floating/underwater applications?

Today's MEMS Sensors







Source:

Geek.com
MikroElektronika

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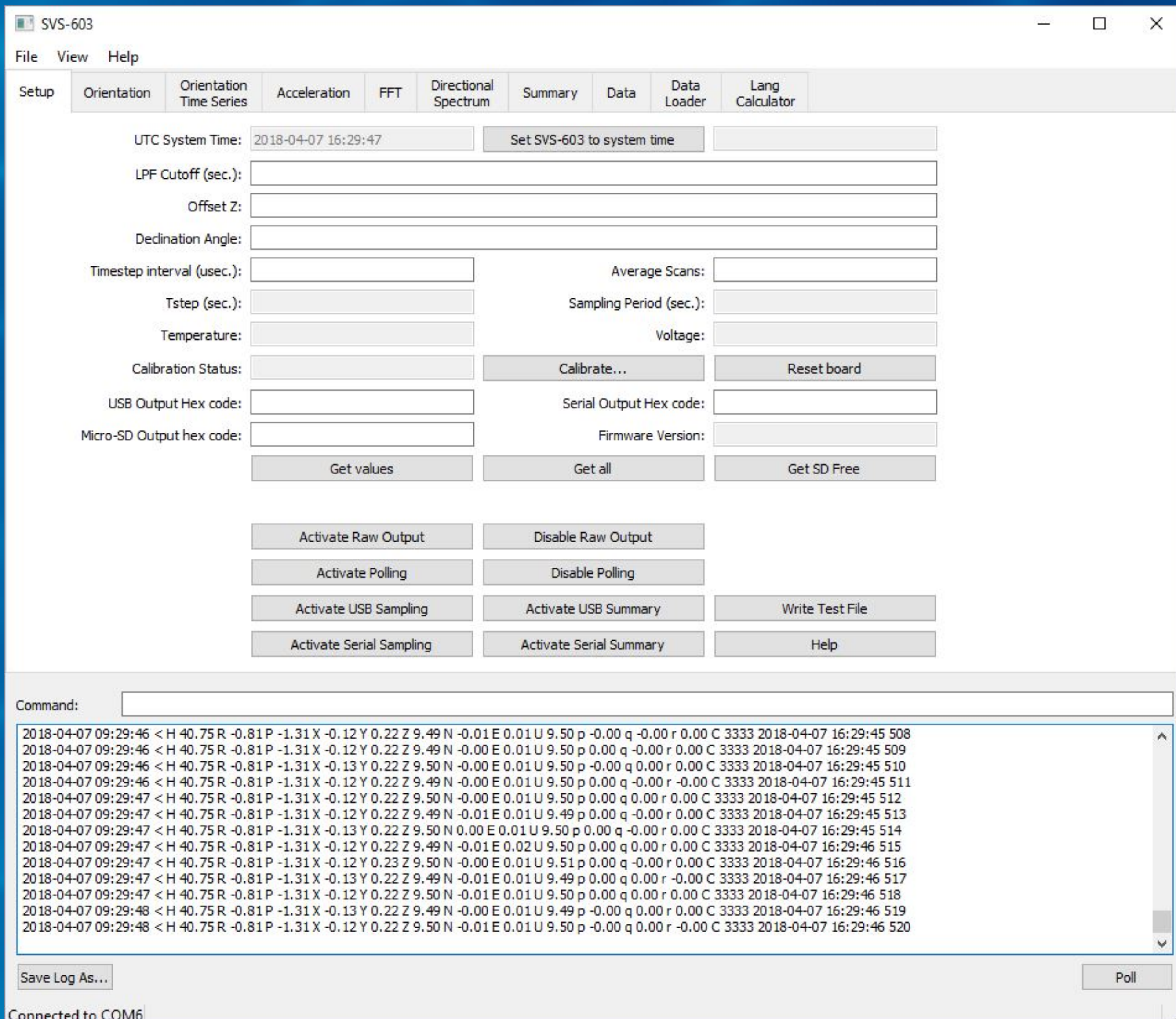
But how small/efficient/accurate/versatile are they?

SVS-603 wave sensor software environment



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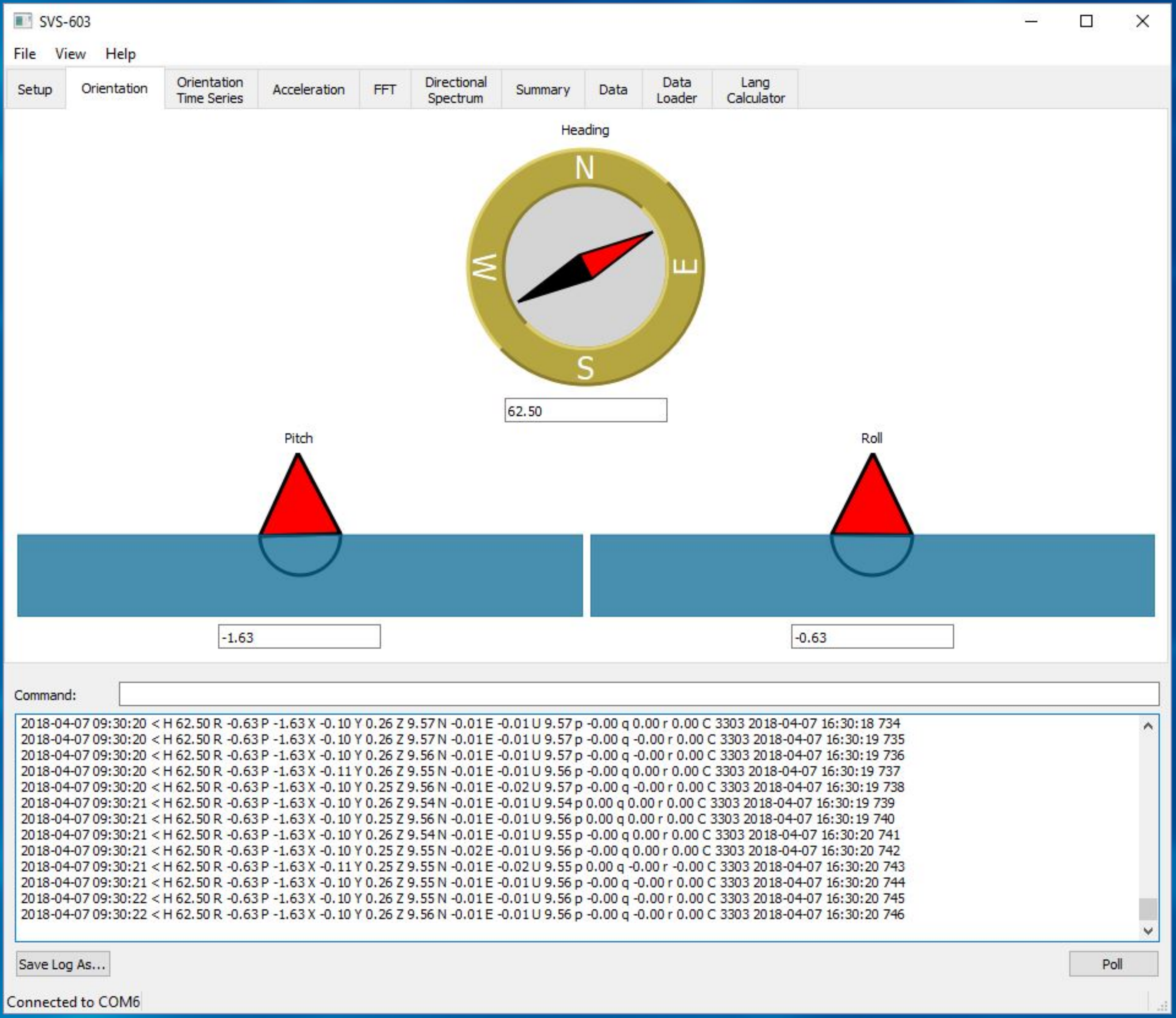
SVS-603 wave sensor software environment



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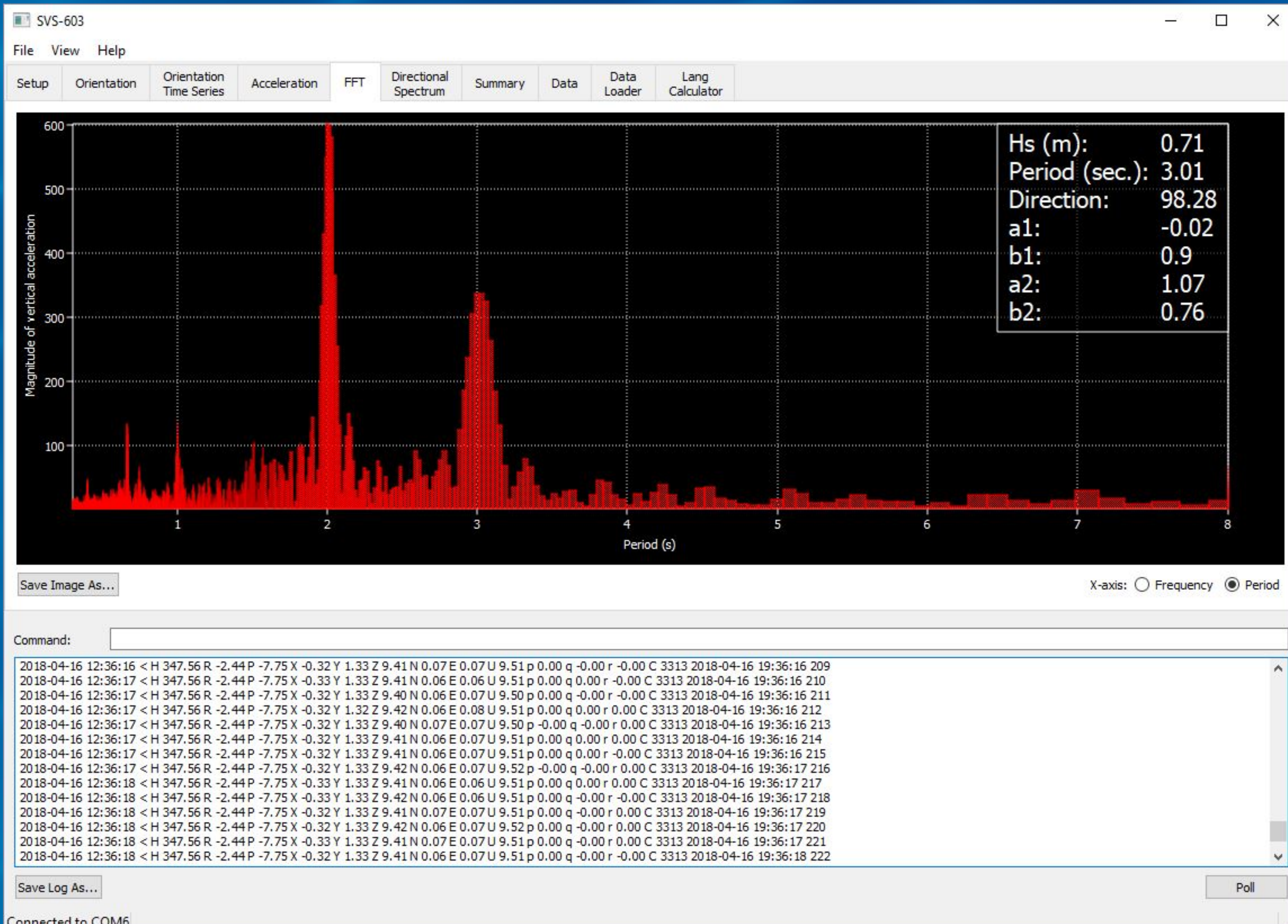
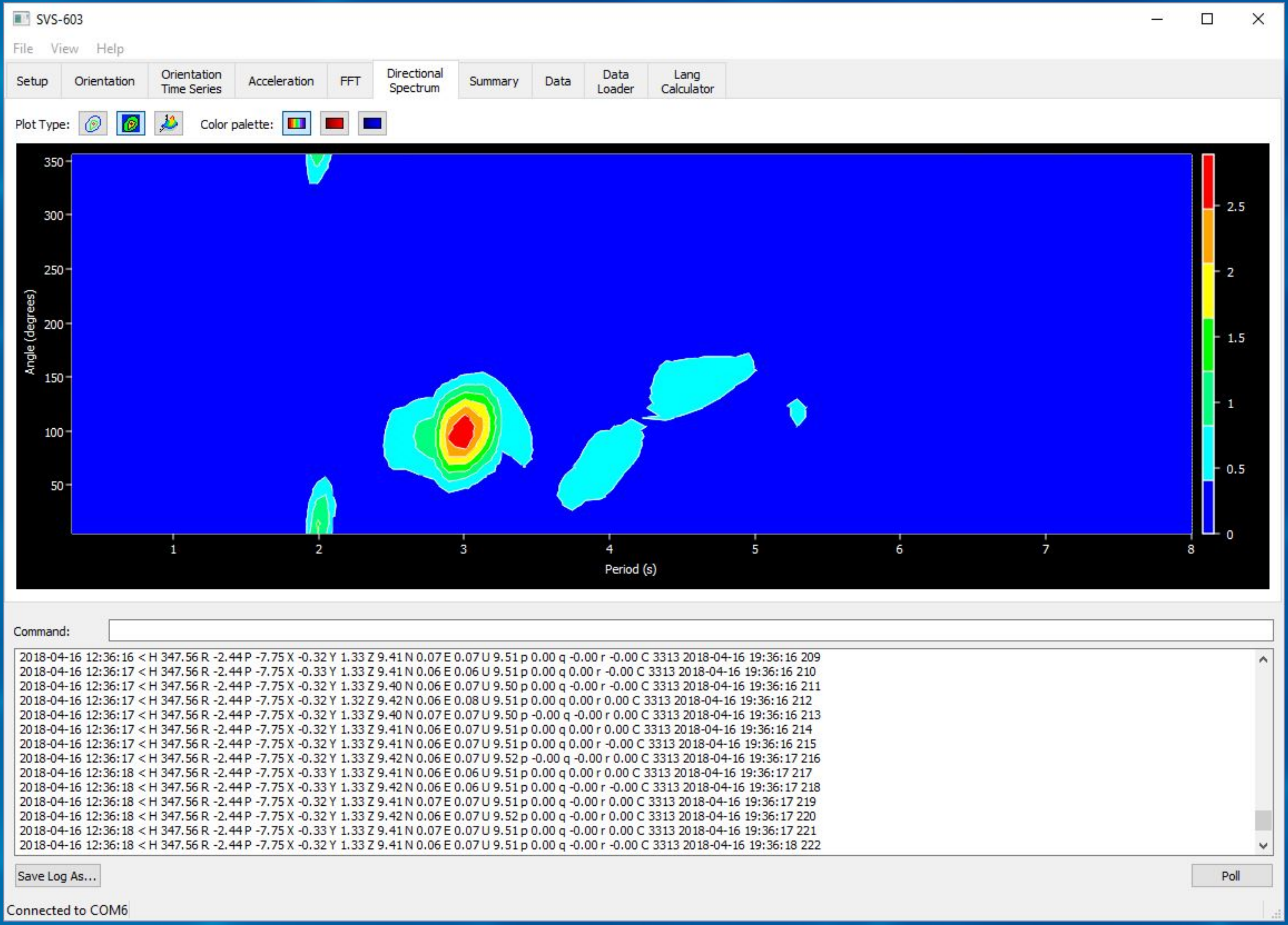
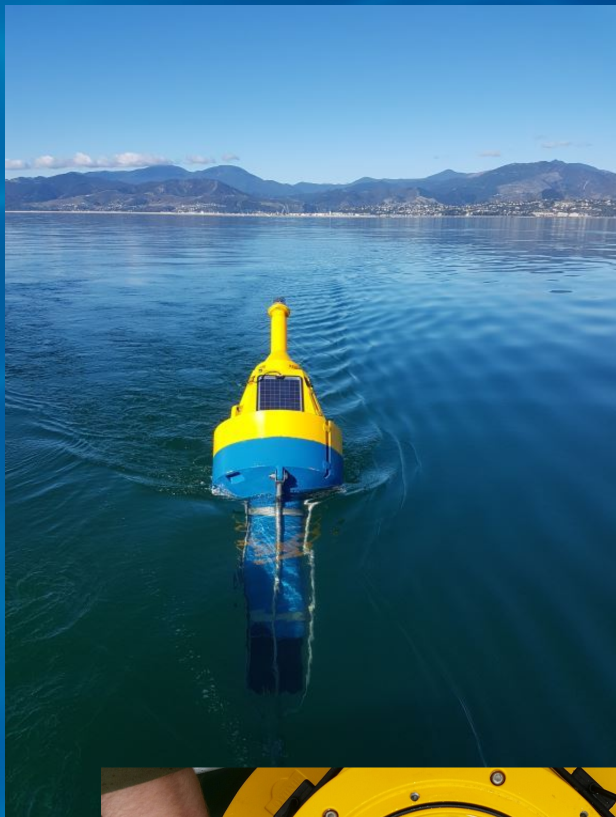
SVS-603 wave sensor software environment

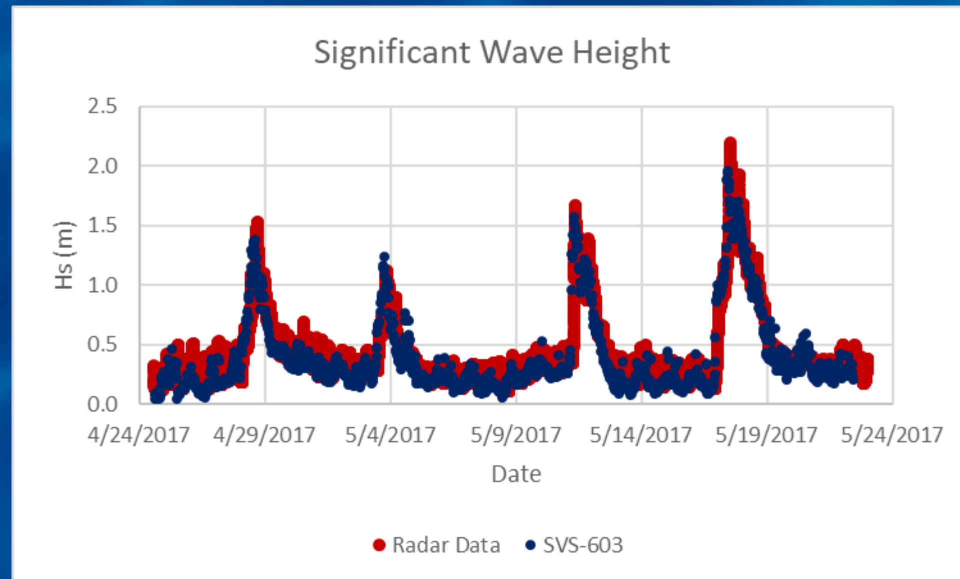


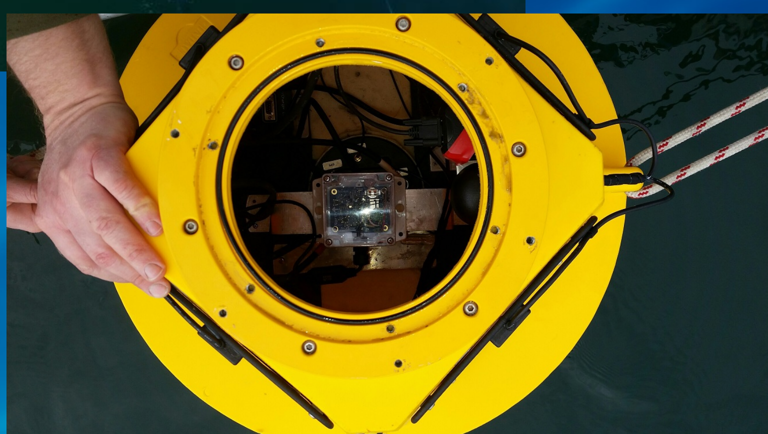
SVS-603 wave sensor software environment



Small Lightweight Buoy (New Zealand)

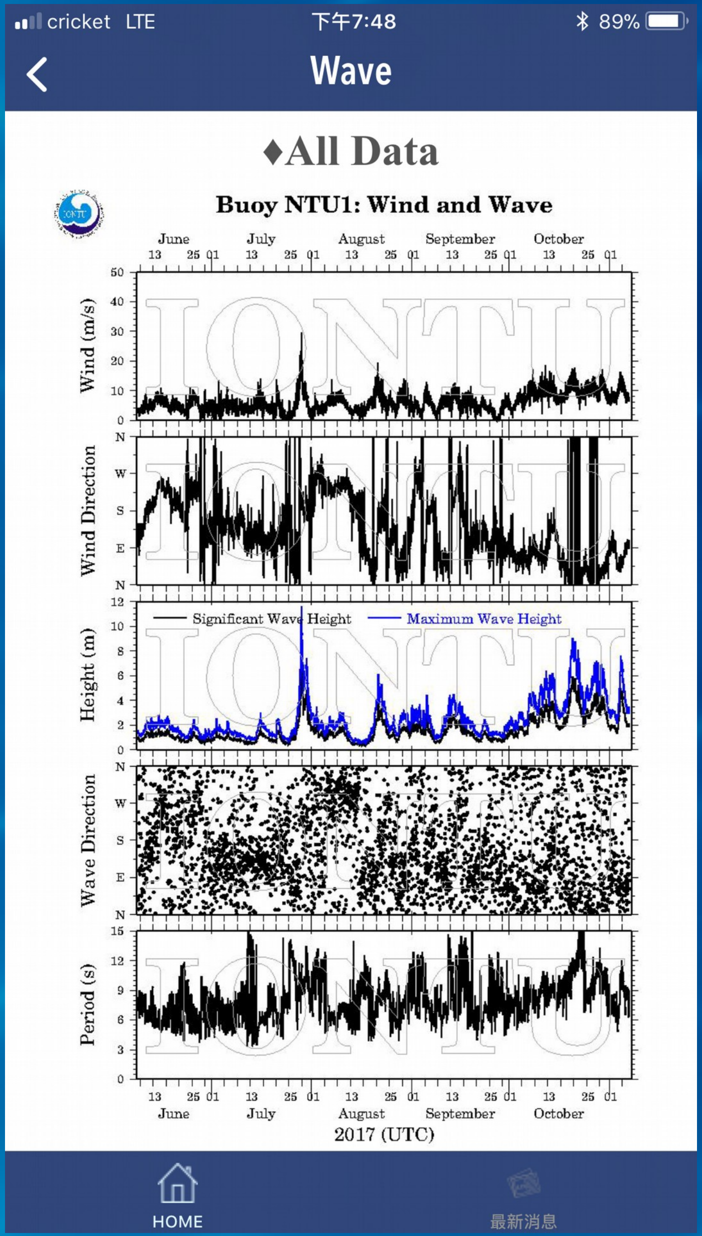






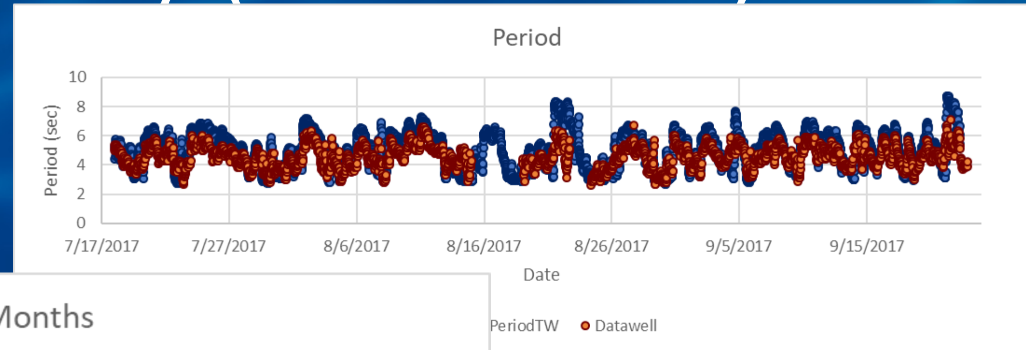
Images and data courtesy of
Paul Barter
Cawthron Institute, New Zealand

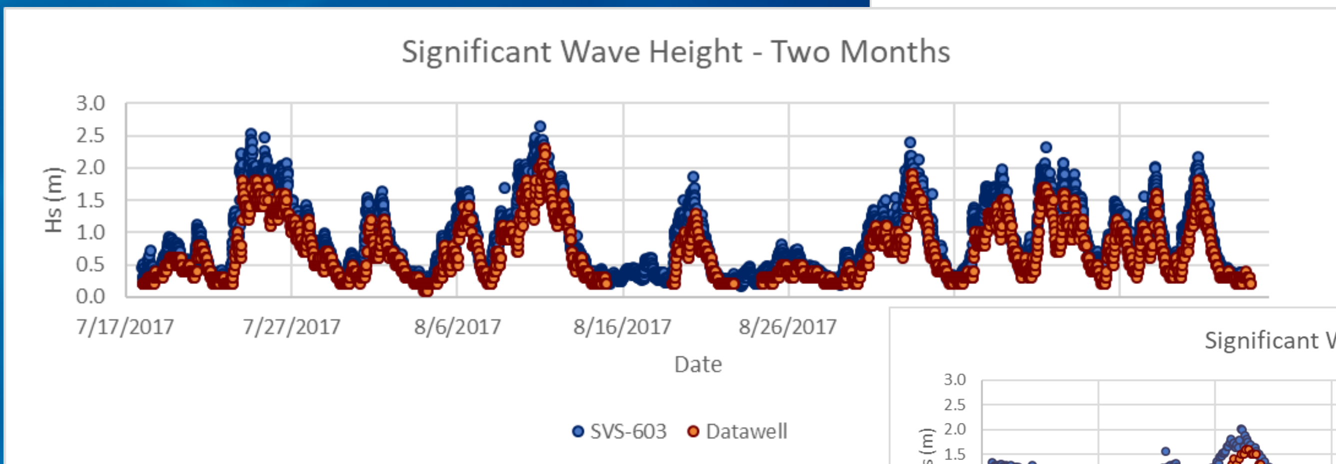
NTU Buoy (~ 2.5m Toroid)

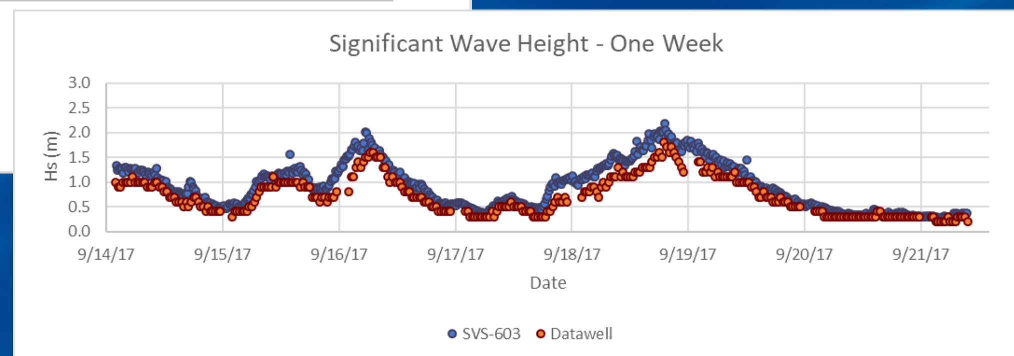


Images and data courtesy of NTU, Taiwan

Large Laboratory buoy (offset > 1m)

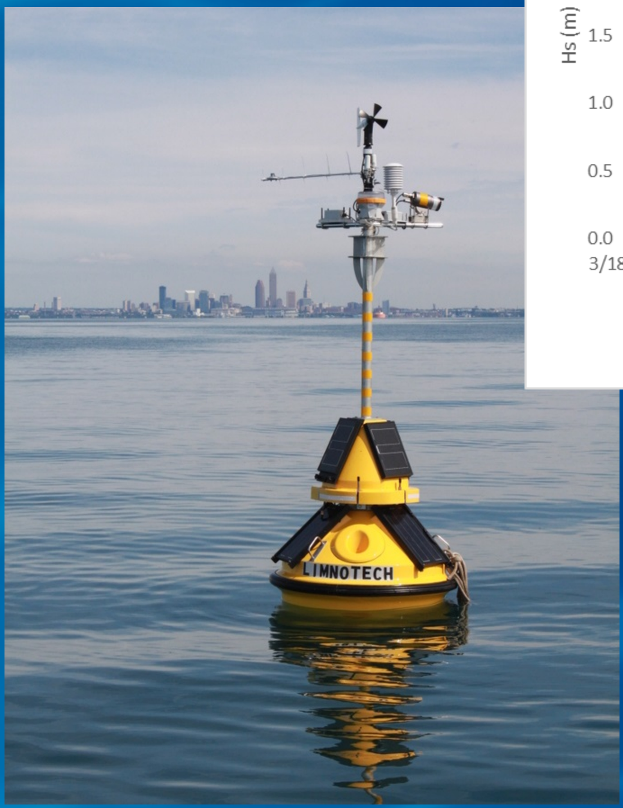


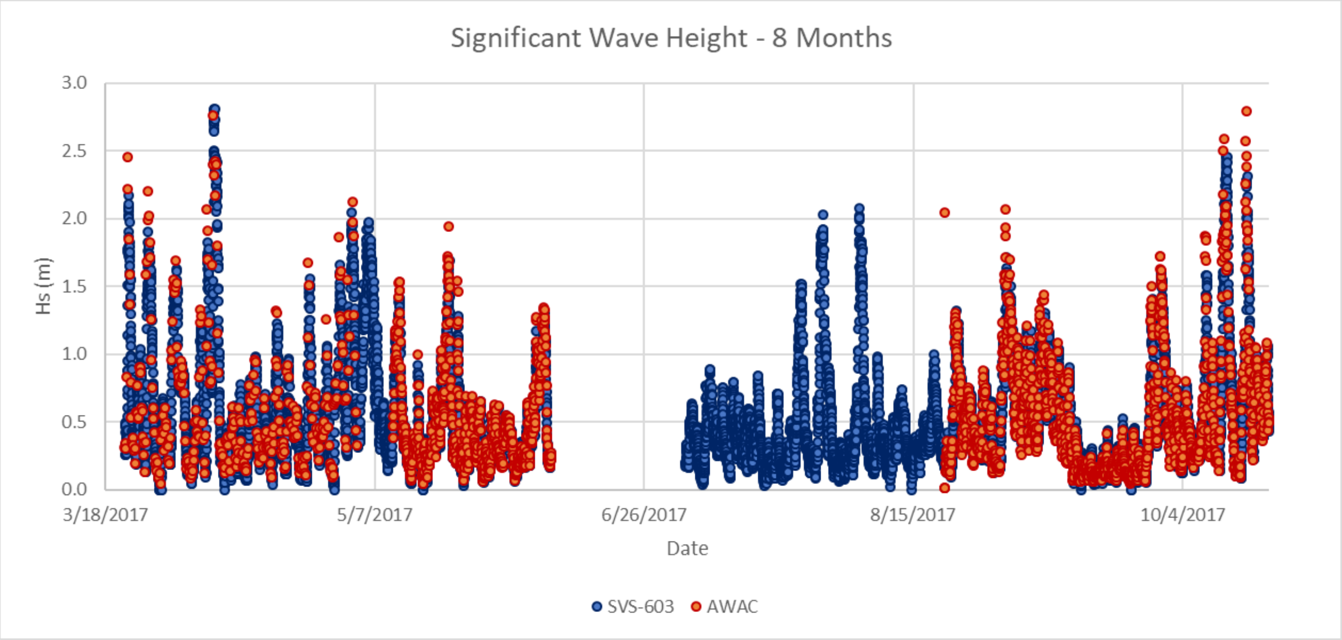




Images and data courtesy of
Mobilis SA
Aix en Provence, France

LimnoTech Cleveland Buoy (Hs)





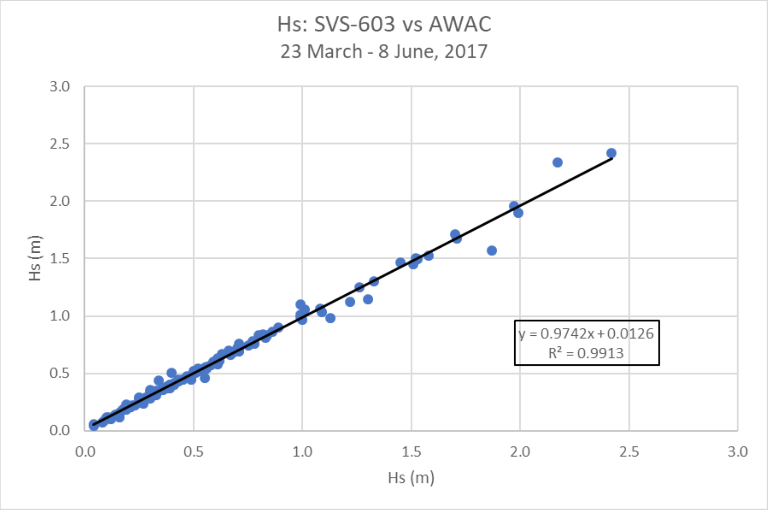


Image and data courtesy of
Edward Verhamme
LimnoTech Inc., Ann Arbor

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LimnoTech Cleveland Buoy (Period and Direction)

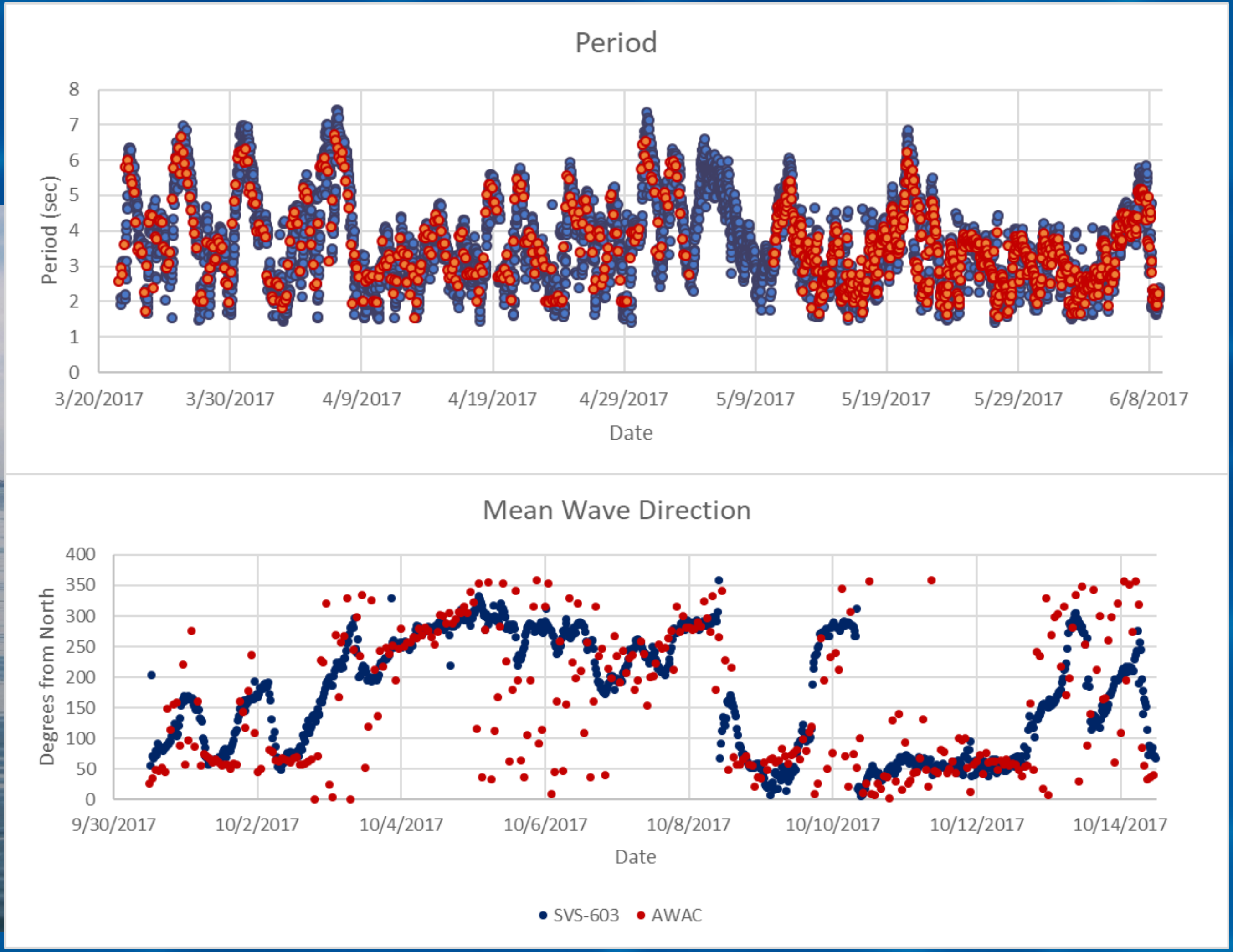

Image and data courtesy of
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LimnoTech Inc., Ann Arbor

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Error sources and correction tools

- **Error sources (partial list only!)**
  - **Compass/acceleration/tilt measurement inaccuracies**
  - **Hull and Mooring non-idealities**
    - **Incomplete buoy-to-wave coupling**
    - **Low frequency noise**
    - **Anomalous motions**
- **Correction possibilities (partial list only!!)**
  - **RAO models for imperfect wave coupling**
  - **Lang/similar filtering models for low frequency noise**

To facilitate data quality from a range of buoy hulls/moorings/deployment conditions:

Accurately characterize hulls with respect to wave coupling, low frequency noise, non-ideal motion, other effects…

Ideally isolate these effects to make sure any adjustment is moving the right lever!

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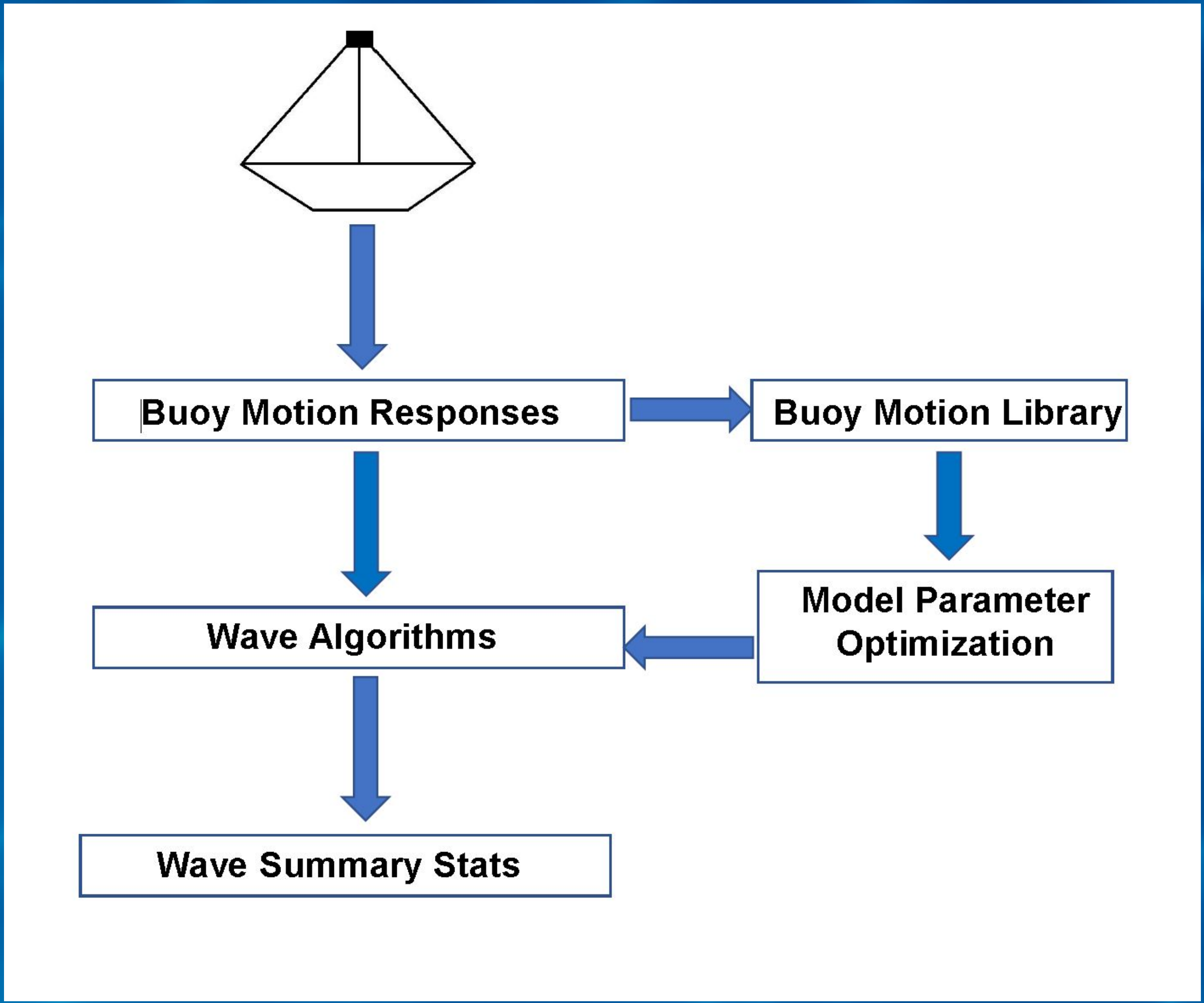
Data Flow in SVS-603



Wave Sensing Modes

- Operational
  - End user oriented outputs of "real time" interest
  - Generally tailored to low bandwidth
- Scientific
  - May involve much more data that may not be of interest to "real time" audience
  - Useful for scientific study or detailed analysis
  - Exploits on-board mass storage or high bandwidth data feed
  - Examples: Spectrum, directional spectrum, details of buoy motion, etc…

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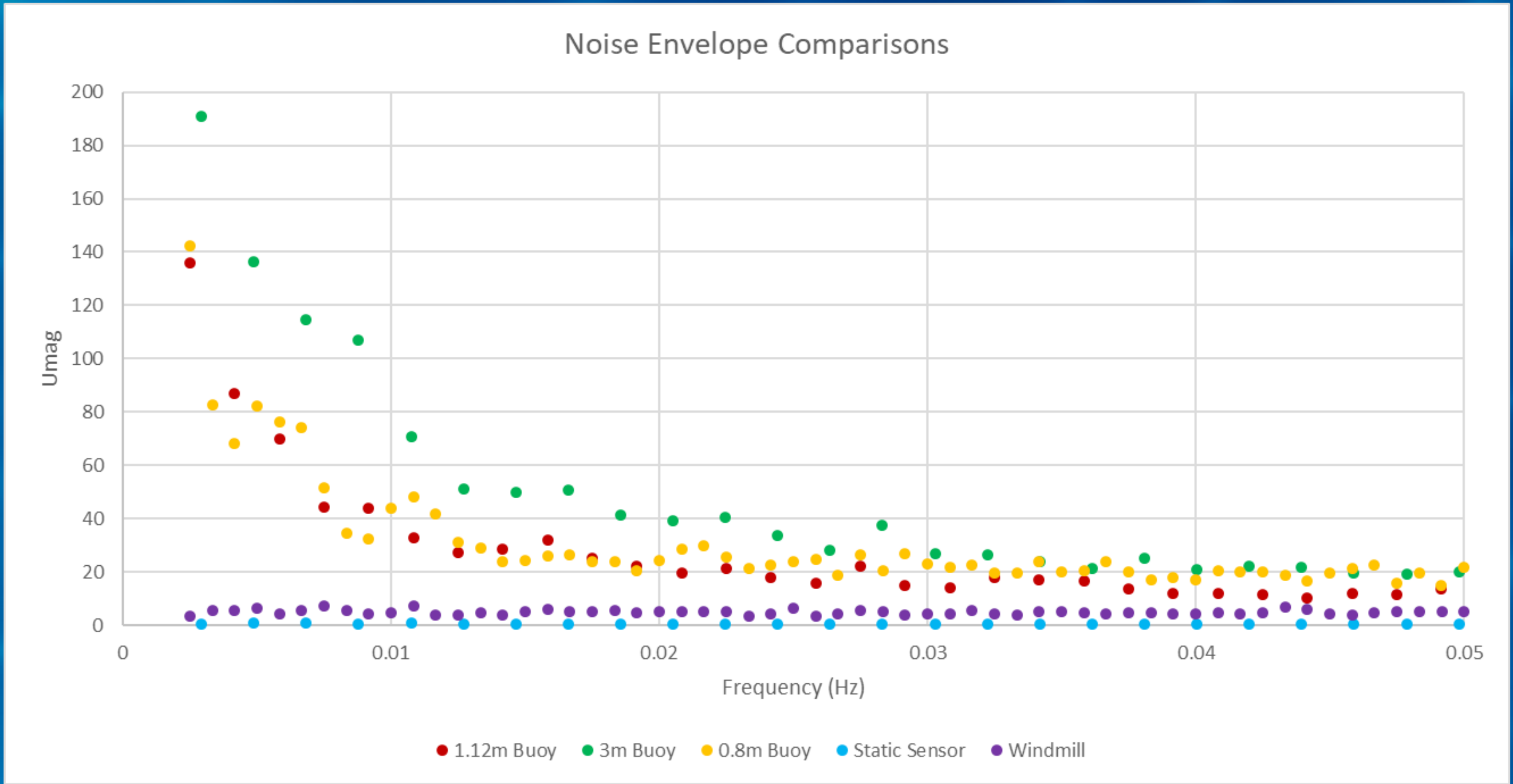
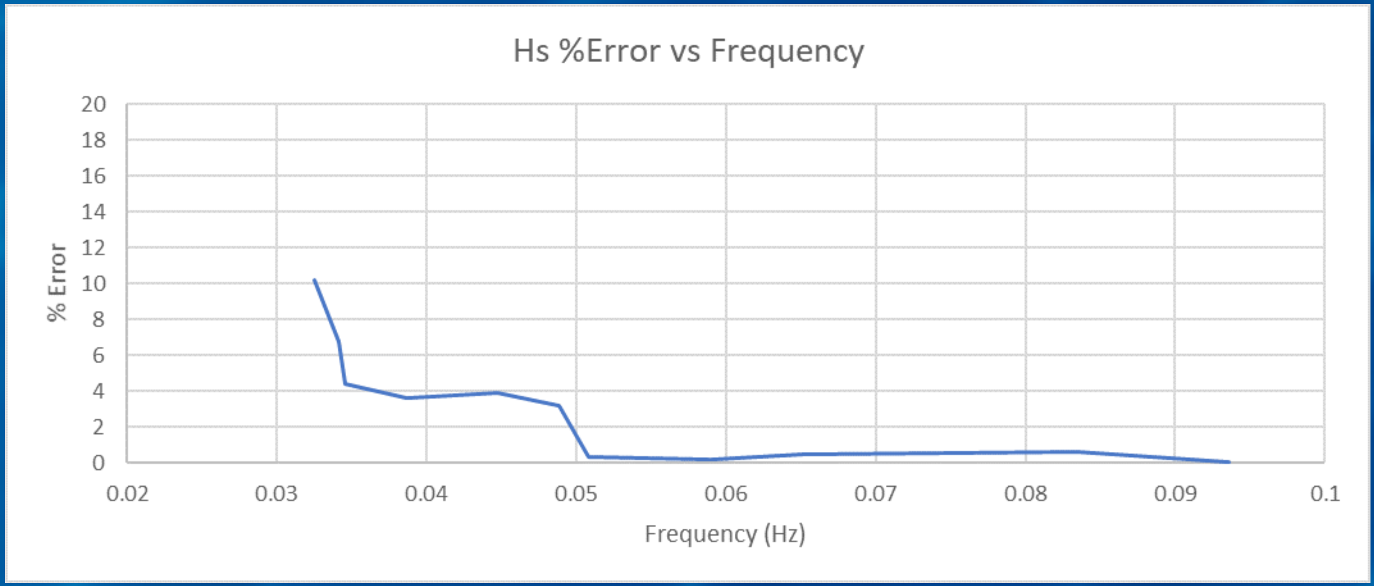
Noise Envelopes for various buoys



Sensor performance at long wavelengths



- **Accurate to within a about 4 percent at periods up to about 25 seconds…**
- **Error increases dramatically at longer periods**
-

Buoy Noise following Lang analysis

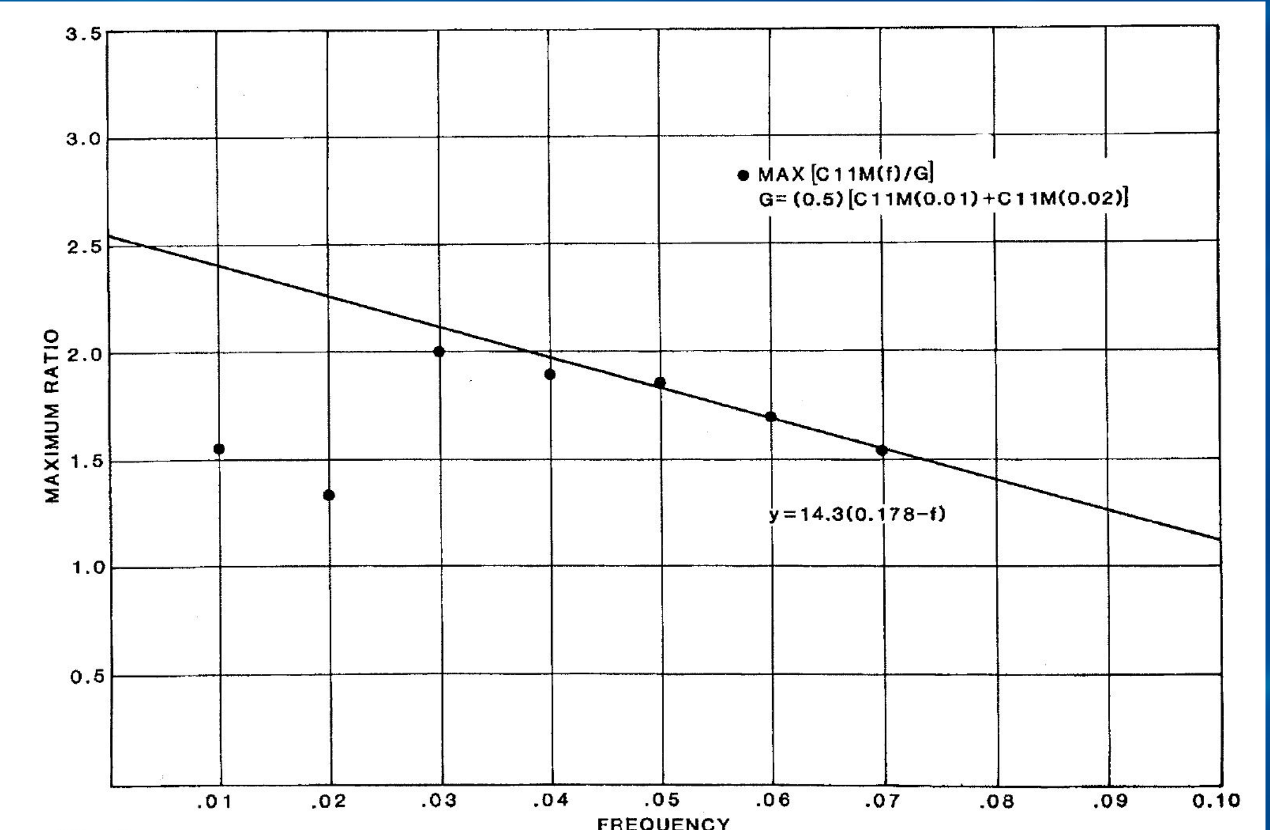
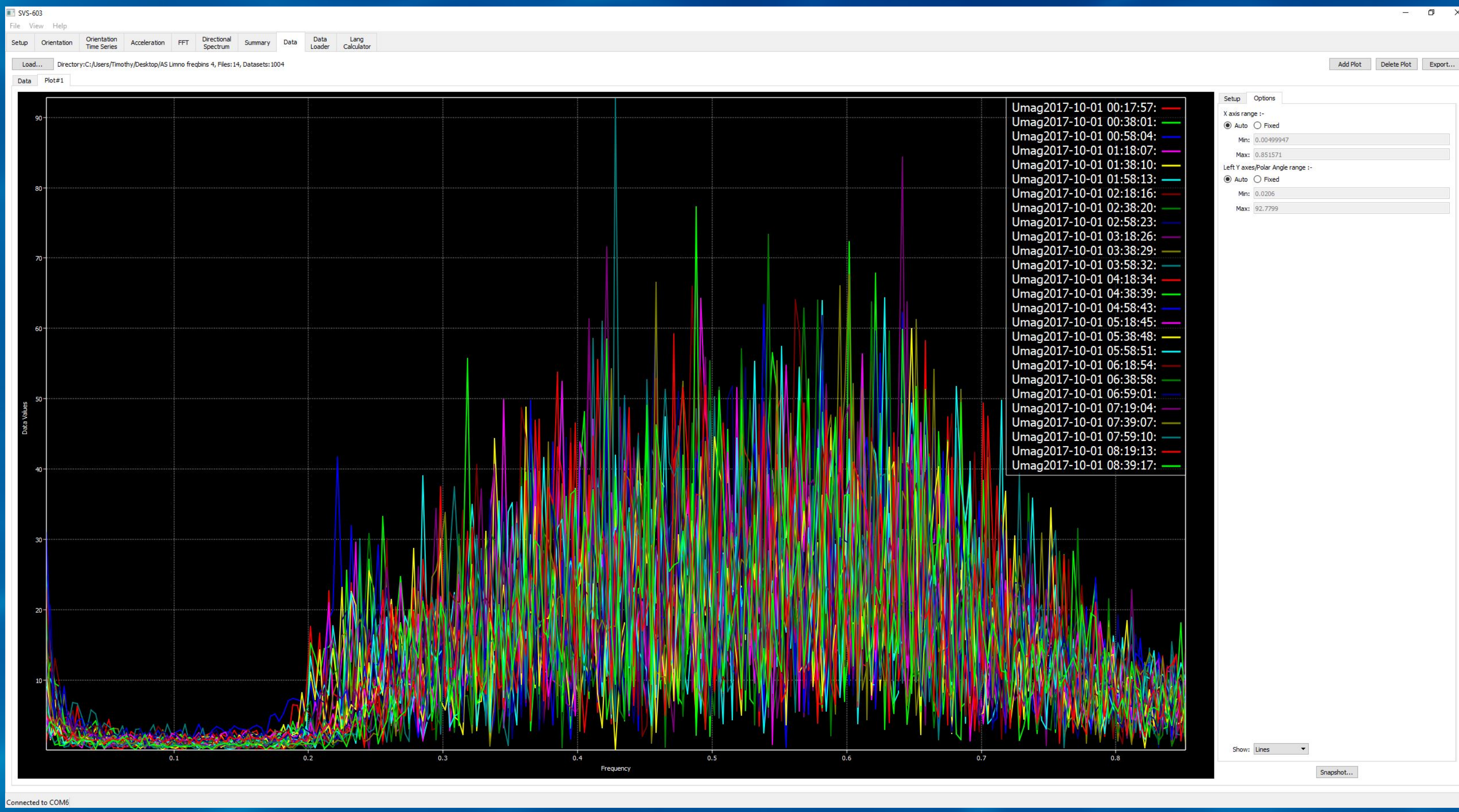


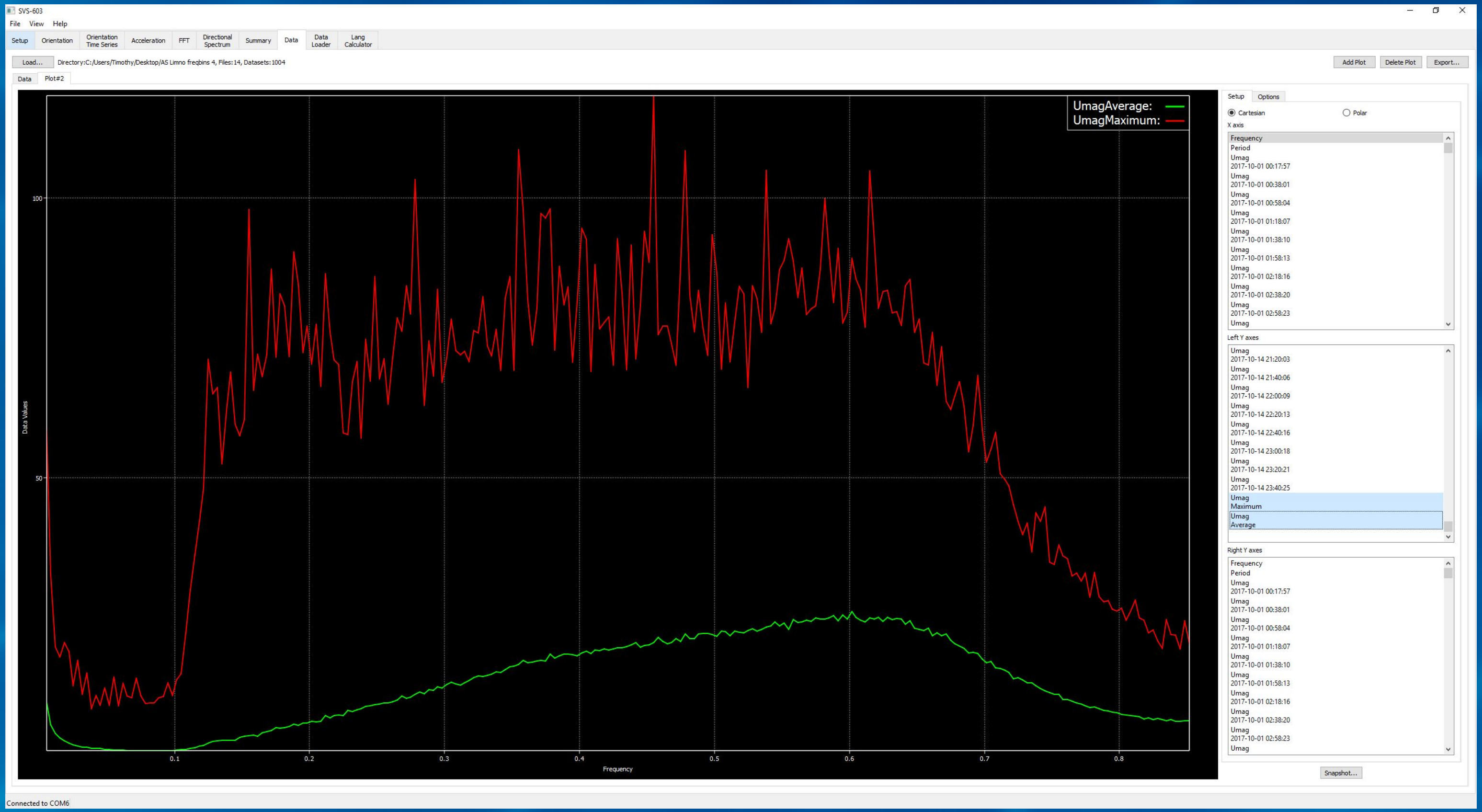
Figure 2.

Source: NDBC Technical Document 96-01
Nondirectional and Directional Wave Data Analysis Procedures
Stennis Space Center
January 1996

Ensemble spectra in SVS-603 software environment



Spectral Data for Max and Average w/in SVS-603 software environment



Limits at long period end of spectrum

- **Buoy hull noise seems to be somewhat similar in magnitude across a variety of hulls**
- **Current sensor technology appears to perform reasonably well in range of periods out to 20 to 25 sec.**
- **This makes noise filtering (Lang or other) appear to be a key consideration for good long period results (and possibly key in determining Hs)**

- **Mass data storage seems likely to offer the tools to assess a range of hulls/deployment situations as new models come to light**

- **Next step: full custom "push-button" noise function...**

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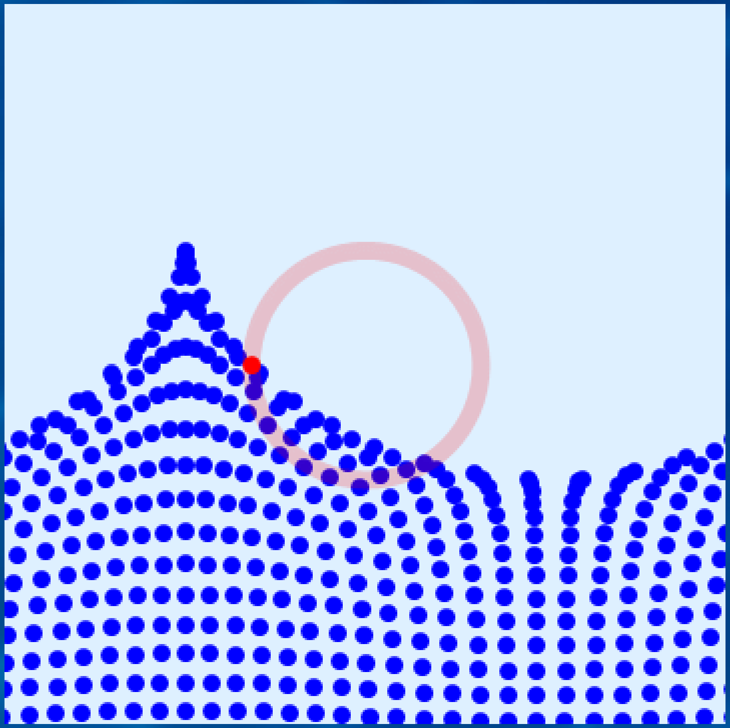
Buoy Wave Response (Idealized)



Wave Motion Idealized

- In simplified single frequency case, motion in aerial view is along a straight line
- We expect non-circular “orbital motion” but horizontal displacement is desirable
-
- Can examinations of this motion provide a means for qualifying buoy motion?

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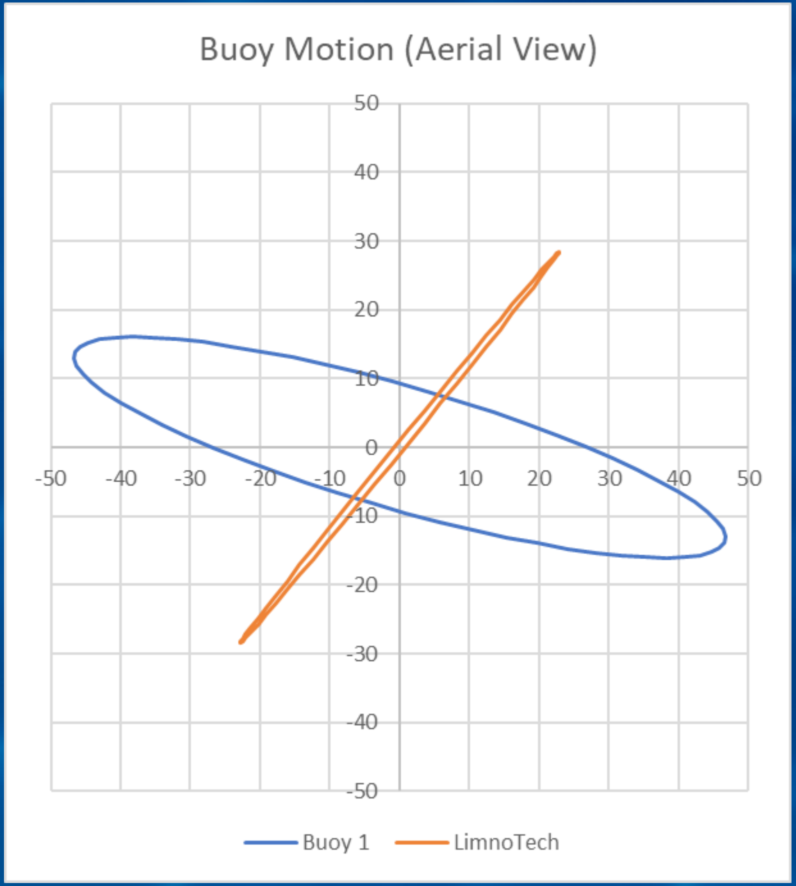
Buoy motion (aerial view)

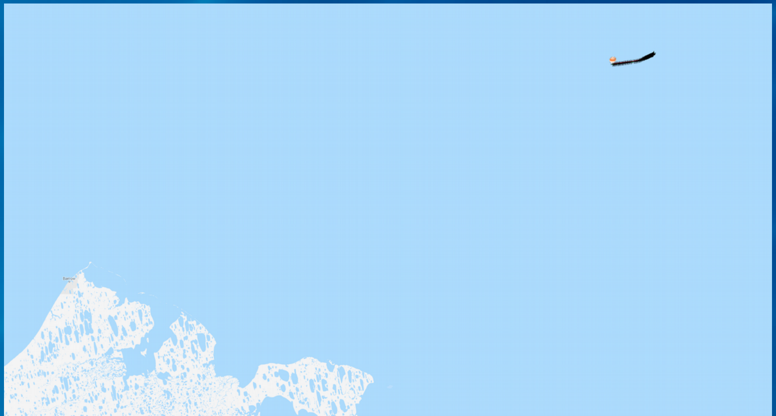


Making use of buoy motion details

- **Diagnostic**
  - **Offers the possibility of qualifying buoy motion in general and specific cycles in particular**
  - **Can be used as a confidence factor for individual data points and a indicator of buoy motion "quality"**
- **Algorithmic (Future)**
  - **Studies of large sample sets of complete buoy motion may provide basis for improved algorithms that exploit tilt, angular velocity, to overcome "non-ideal" buoy motion, hull noise, and mooring effects**
  - **Goal: To seamlessly select models/parameters suited to a particular buoy, location, mooring, etc. based on measured data set…**

When is a wave sensing buoy not a wave sensing buoy?

When it is an ice floe!



Images and data courtesy of
Mark Johnson
University of Alaska Fairbanks

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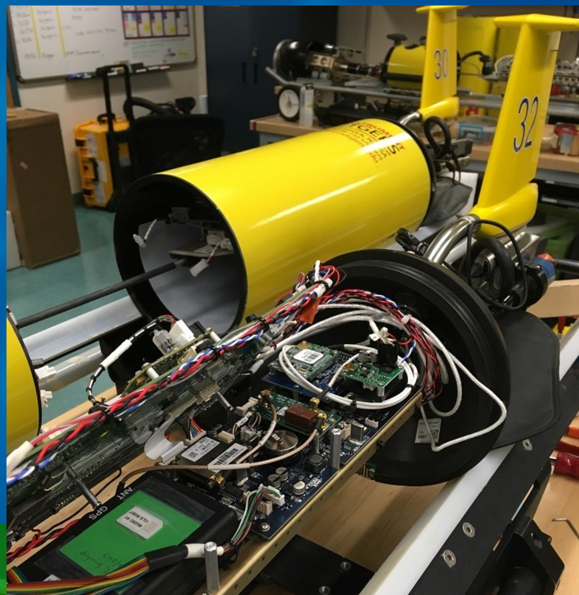
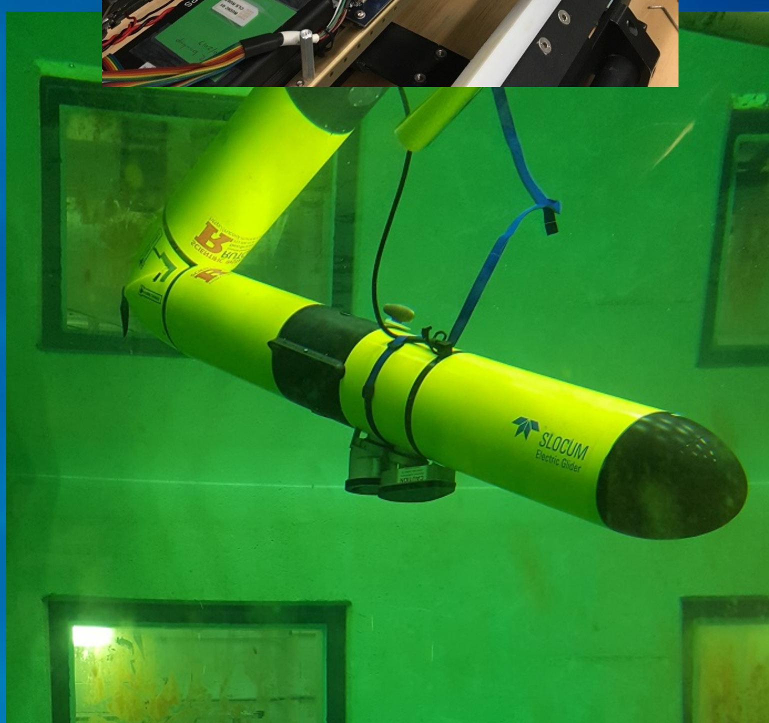
When it is an autonomous vehicle!





Images and data courtesy of
Center for Ocean Observing Leadership
Rutgers University

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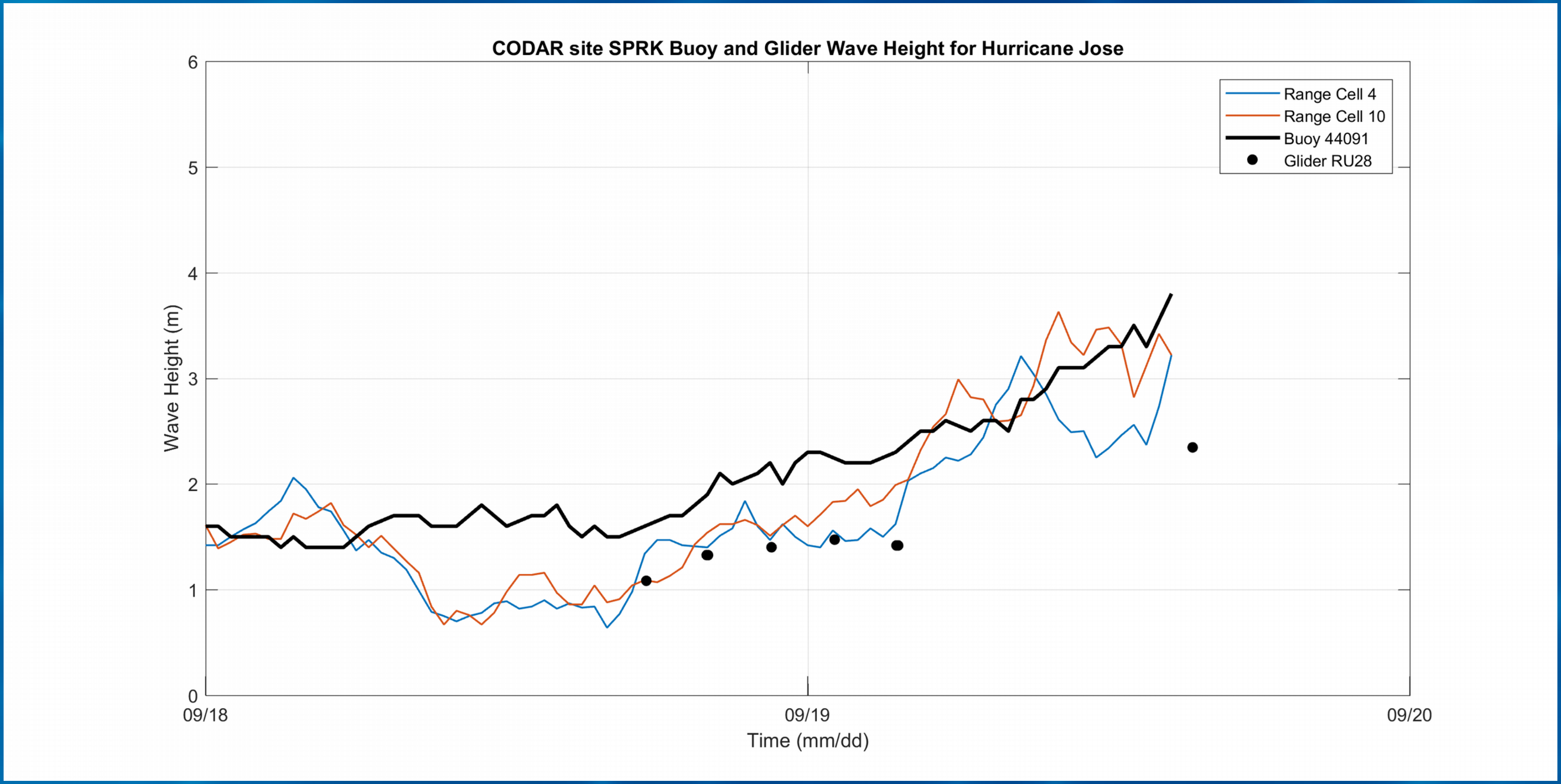
Autonomous vehicle versus reference measurements



(Preliminary!) Conclusions and Directions for Future Work

- More exploration of noise considerations using mass data sets from deployed buoys
- Push-button tailored noise filter implementation based on individual buoy measurements
- Figures of merit to discriminate buoy motion quality as a confidence indicator for individual data samples
- Models that exploit rich set of sensor variables including tilt, angular velocity as supplements for non-ideal buoy motion situations
- More and more and more...

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