Advances In Wave Sensing Using MEMS

Tim Crandle, PhD
SeaView Systems, Inc.
tcrandle@seaviewsystems.com

The Internet of Things (IoT)...

- **Worst acronym in history?**
- **The confluence of:**
  - **Readily available processing power and memory**
  - **Better sensors**
  - **Lower power consumption**
  - **Wireless communications**
- **Driving countless new applications**

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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, faster, more accurate, and power efficient.

How will land-based mass market IoT developments "spill over" and enable the internet of floating/underwater things?

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Some Problems measuring waves...

- **How accurate is accurate enough?**

Small inaccuracies can integrate into big errors...

- **Operational versus Scientific: Tradeoff between manipulating/consolidating data on-buoy for easy transmission versus thorough retrospective analysis of complete data set...**

Some Solutions...

- **Focus on wave stats rather than absolute values**
- **Work in frequency domain**
  - **It's where you go for many of the relevant representational wave statistics anyway...**
  - **Apply filters such as mean removal or noise removal (Lang 1987) to improve accuracy**
- **Add processing power on-buoy...**
  - **Opens possibilities for improved assessment/data manipulation/correction**
  - **New data manipulation innovations?**

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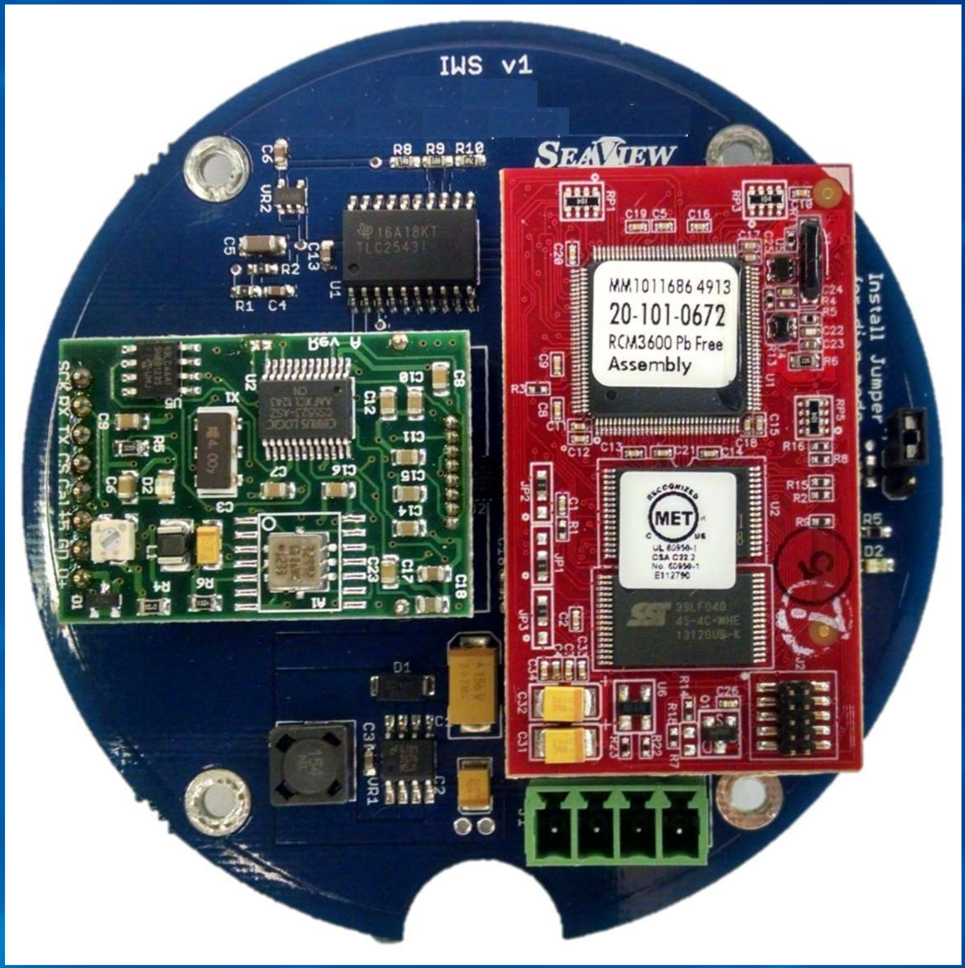
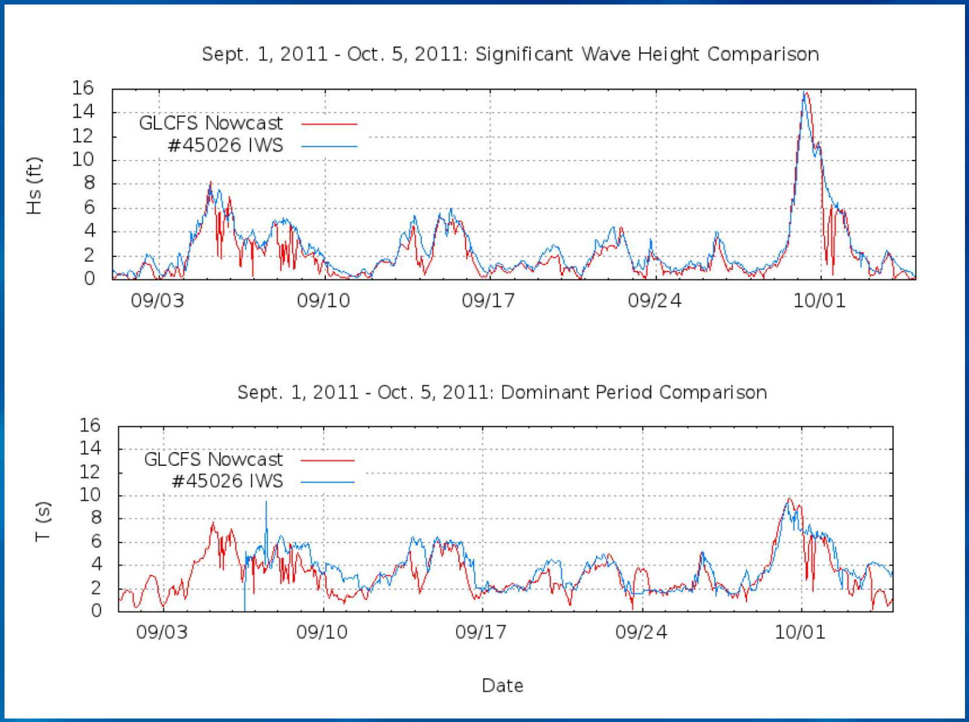
An early MEMS Wave sensor (SVS-602)



Early sensors showed this approach works

- Deployed in both Great Lakes and near shore ocean environments
- Compares well with reference sensor



Reference: Brown and Meadows, 2011

But Technology Marches Forward...

- Better sensor accuracy/more outputs
- Less power consumption
- More/cheaper processing power/memory
- Flash memory price/size drop: Now practical to include raw data logging onboard...
- Temperature compensation/other accuracy features
- New possibilities...

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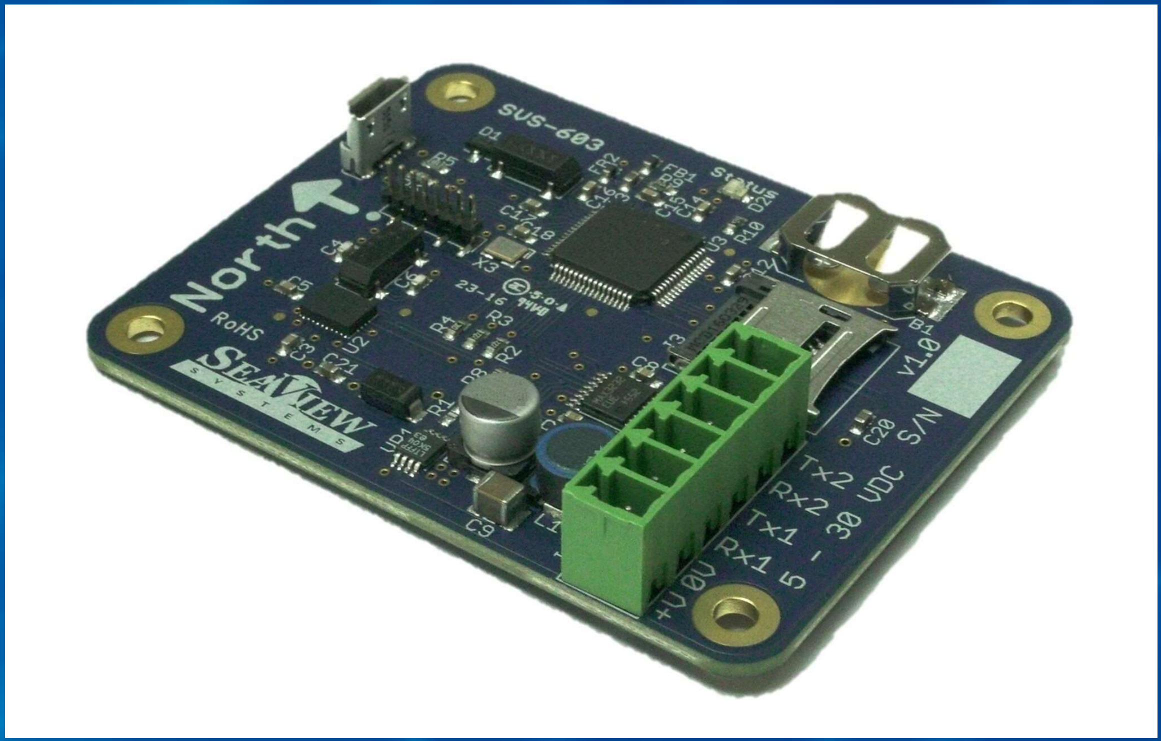
SeaView's SVS-603



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SVS-603 Features

- 14 bit sensors with full x, y, z acceleration, pitch, roll, heading, angular velocity, and magnetometer output
- Powerful on-board CPU
- Highly configurable: Serial and USB ports with separately controlled summary or detailed data streams
- On-board micro-SD card with configurable data stream
- Smaller/Lower power (130mW!)/System clock/etc...
- Dedicated GUI/Full set of algorithms

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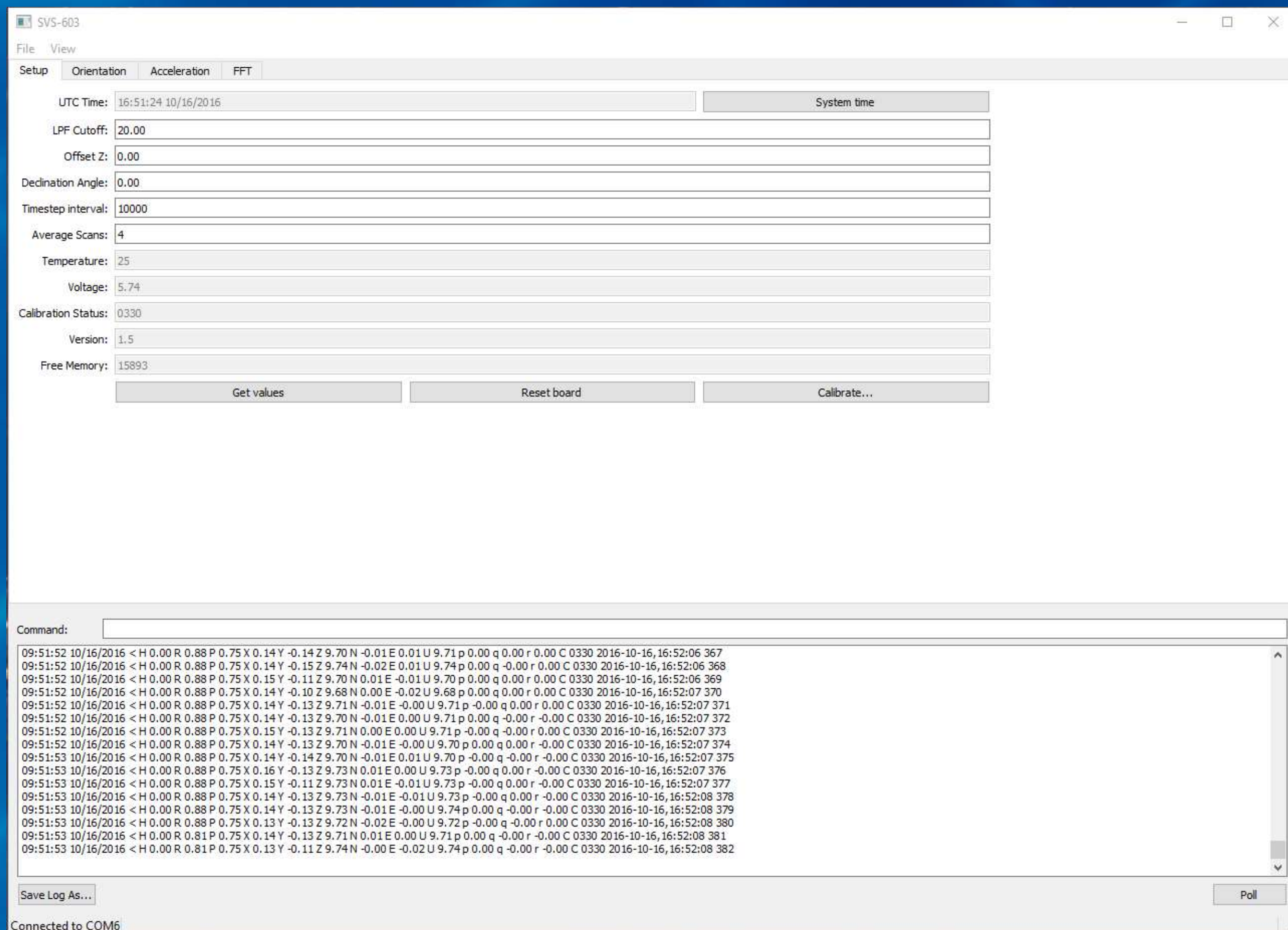
The SVS-603...

SVS-603 Graphical Display



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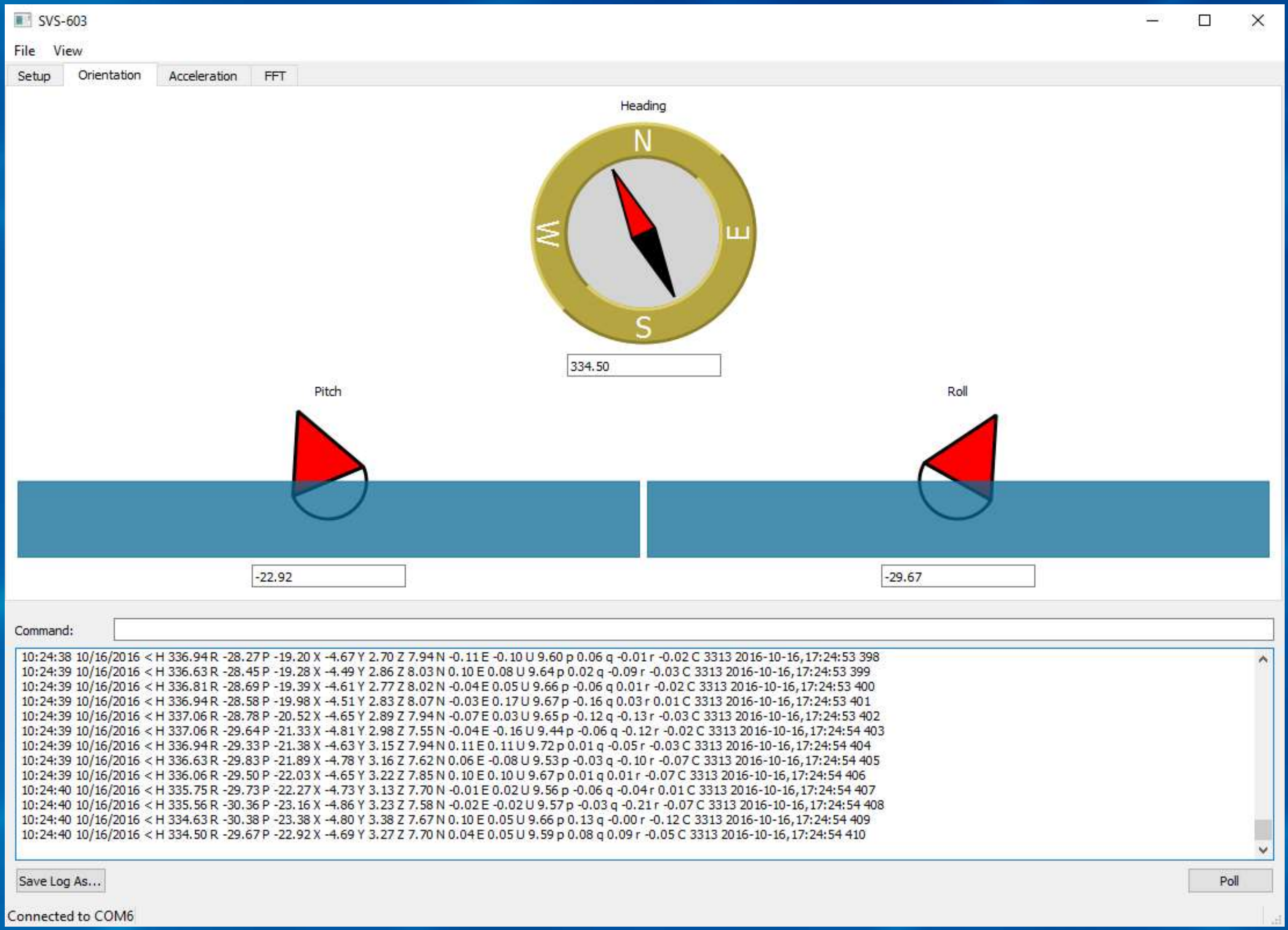
SVS-603 Graphical Display



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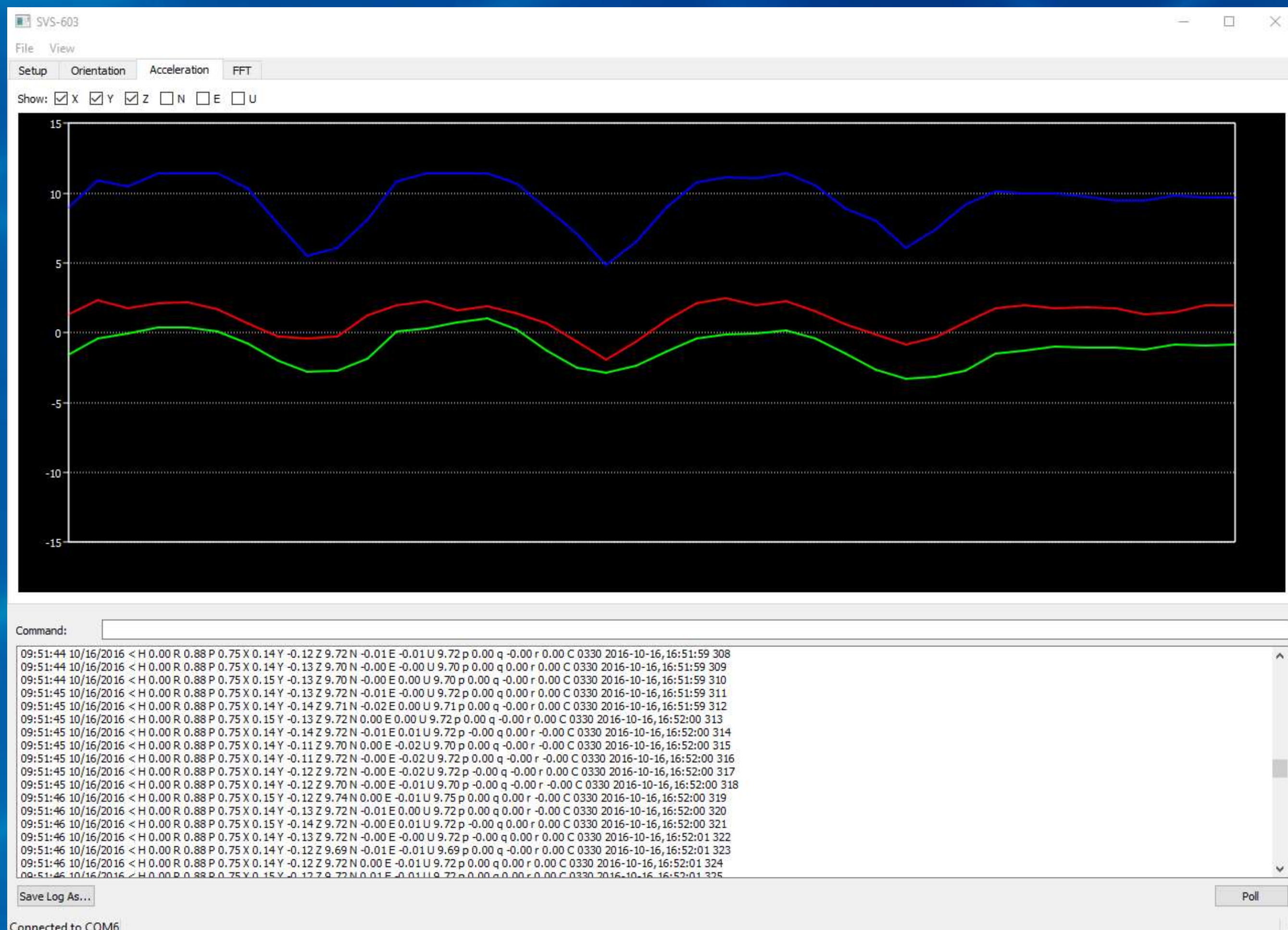
SVS-603 Graphical Display



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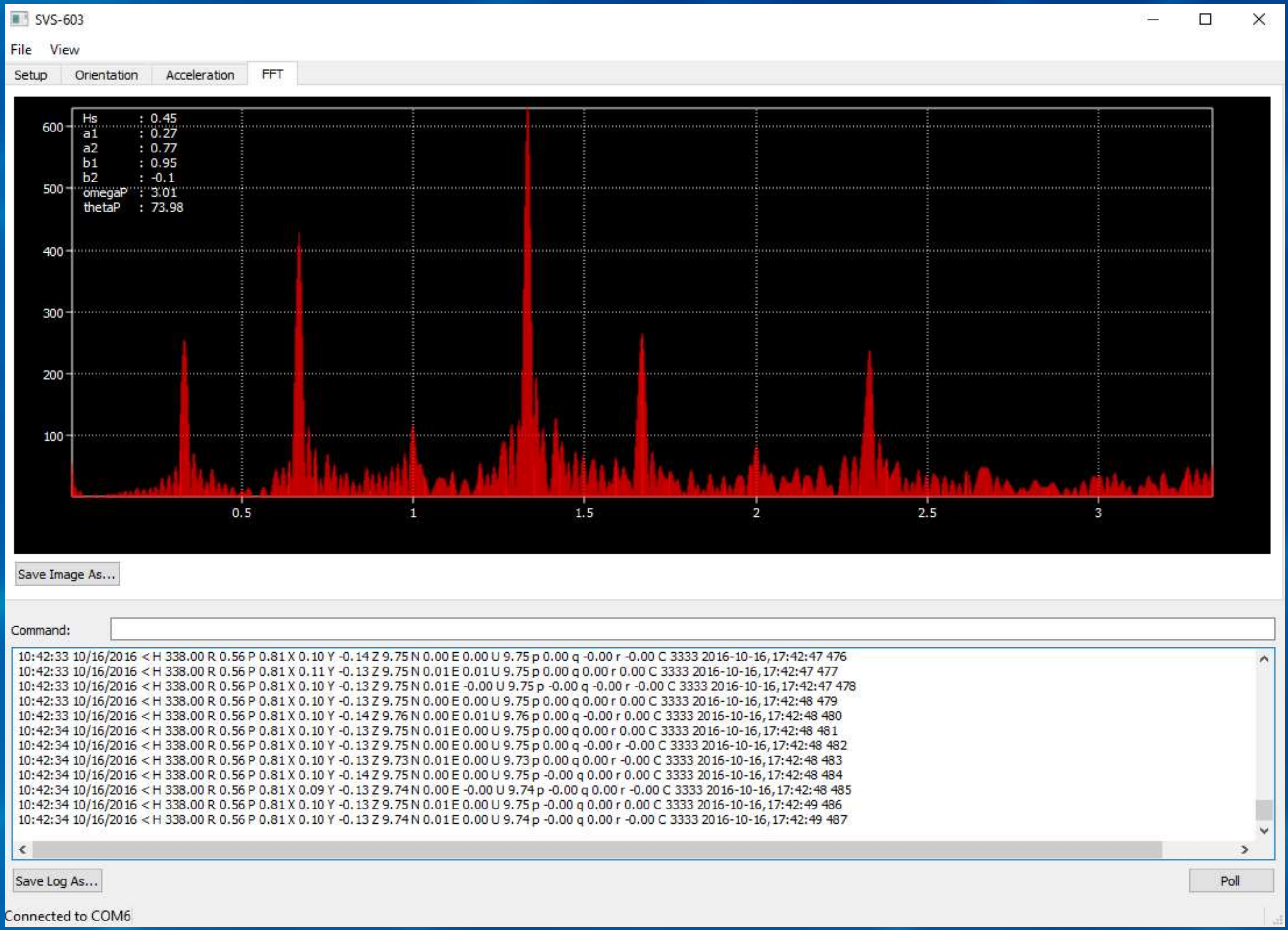
SVS-603 Graphical Display



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Buoy motion non-idealities

- **Pitch and roll perturb motion**
  - **Shifting to earth frame gets motion of interest**
- **Position away from roll center perturbs motion**
  - Fortunately if the motion of a sensor that is a fixed displacement away from the roll center is known, the motion of the roll center can be readily determined using outputs from newer sensors
    - Angular velocity (available from sensor)
    - Angular acceleration (easily calculated)
- Thanks to the aircraft applications these algorithms are well documented...

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Thank you rocket scientists!

The inverse relationships are

$$p = \dot{\phi}_g - \dot{\psi}_g \sin\theta_g - \dot{L}\cos\theta_g \cos\psi_g - (\Omega_e + \dot{\lambda})(\cos L \cos\theta_g \sin\psi_g - \sin L \sin\theta_g) \qquad \text{(V-10)}$$

$$q = \dot{\theta}_g \cos\phi_g + \dot{\psi}_g \sin\phi_g \cos\theta_g - \dot{L}(\sin\theta_g \cos\psi_g \sin\phi_g - \sin\psi_g \cos\phi_g) - (\Omega_e + \dot{\lambda})\cos L(\sin\theta_g \sin\psi_g \sin\phi_g + \cos\psi_g \cos\phi_g) - (\Omega_e + \dot{\lambda})\sin L \sin\phi_g \cos\theta_g \qquad \text{(V-11)}$$

$$r = -\dot{\theta}_g \sin\phi_g + \dot{\psi}_g \cos\phi_g \cos\theta_g - \dot{L}(\sin\theta_g \cos\psi_g \cos\phi_g + \sin\psi_g \sin\phi_g) - (\Omega_e + \dot{\lambda})\cos L(\sin\theta_g \sin\psi_g \cos\phi_g - \cos\psi_g \sin\phi_g) - (\Omega_e + \dot{\lambda})\sin L \cos\phi_g \cos\theta_g \qquad \text{(V-12)}$$

Vehicle Coordinates

Vehicle coordinates can be computed from the X,Y,Z axes velocity components and vehicle Euler angles by integrating the equations

$$\dot{x}_g = u\cos\psi_g \cos\theta_g + v(\cos\psi_g \sin\theta_g \sin\phi_g - \sin\psi_g \cos\phi_g) + w(\cos\psi_g \sin\theta_g \cos\phi_g + \sin\psi_g \sin\phi_g) \qquad \text{(V-13)}$$

$$\dot{y}_g = u\sin\psi_g \cos\theta_g + v(\sin\psi_g \sin\theta_g \sin\phi_g + \cos\psi_g \cos\phi_g) + w(\sin\psi_g \sin\theta_g \cos\phi_g - \cos\psi_g \sin\phi_g) \qquad \text{(V-14)}$$

$$\dot{z}_g = -u\sin\theta_g + v\cos\theta_g \sin\phi_g + w\cos\theta_g \cos\phi_g \qquad \text{(V-15)}$$

$$r_g = \sqrt{x_g^2 + y_g^2 + z_g^2} \qquad \text{(V-16)}$$

CASE FILE COPY

NASA SP-3070

SUMMARY OF TRANSFORMATION EQUATIONS AND EQUATIONS OF MOTION USED IN FREE-FLIGHT AND WIND-TUNNEL DATA REDUCTION AND ANALYSIS

GAINER and HOFFMAN

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION U.S.A.

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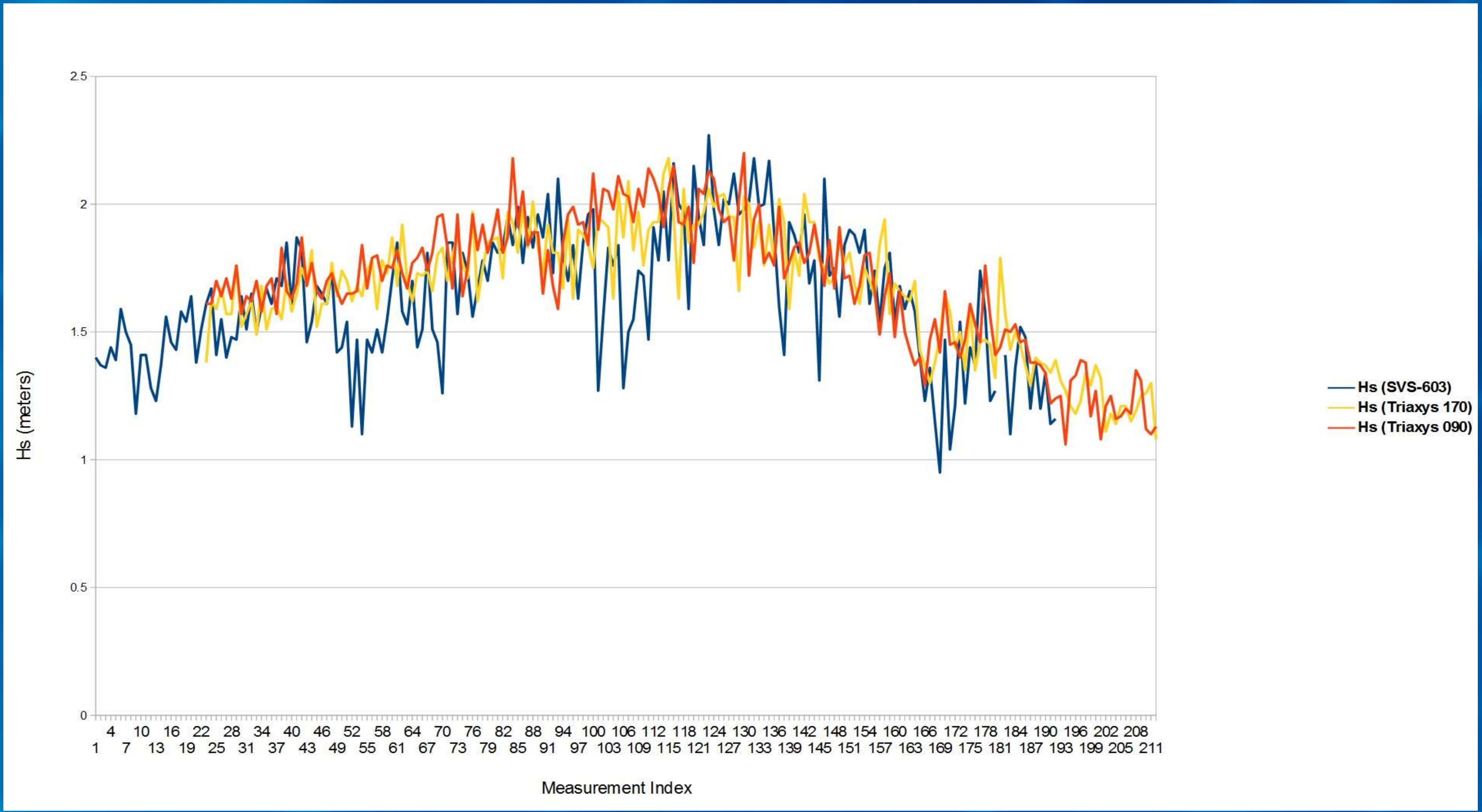
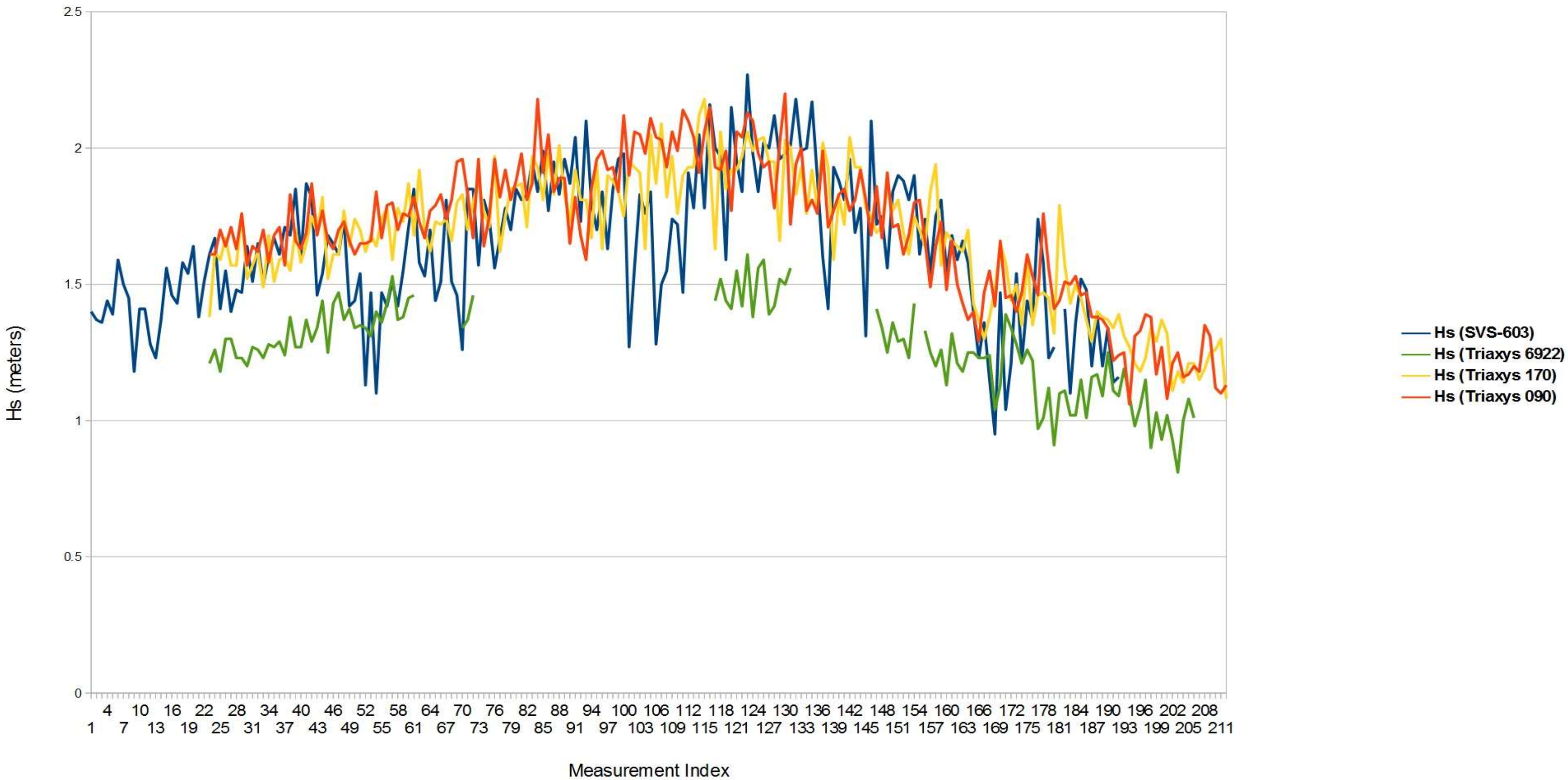
New Zealand (Cawthron Institute) deployment

Hs comparison (New Zealand)



Data courtesy of Cawthron Institute

Hs comparison (New Zealand)



Data courtesy of Cawthron Institute

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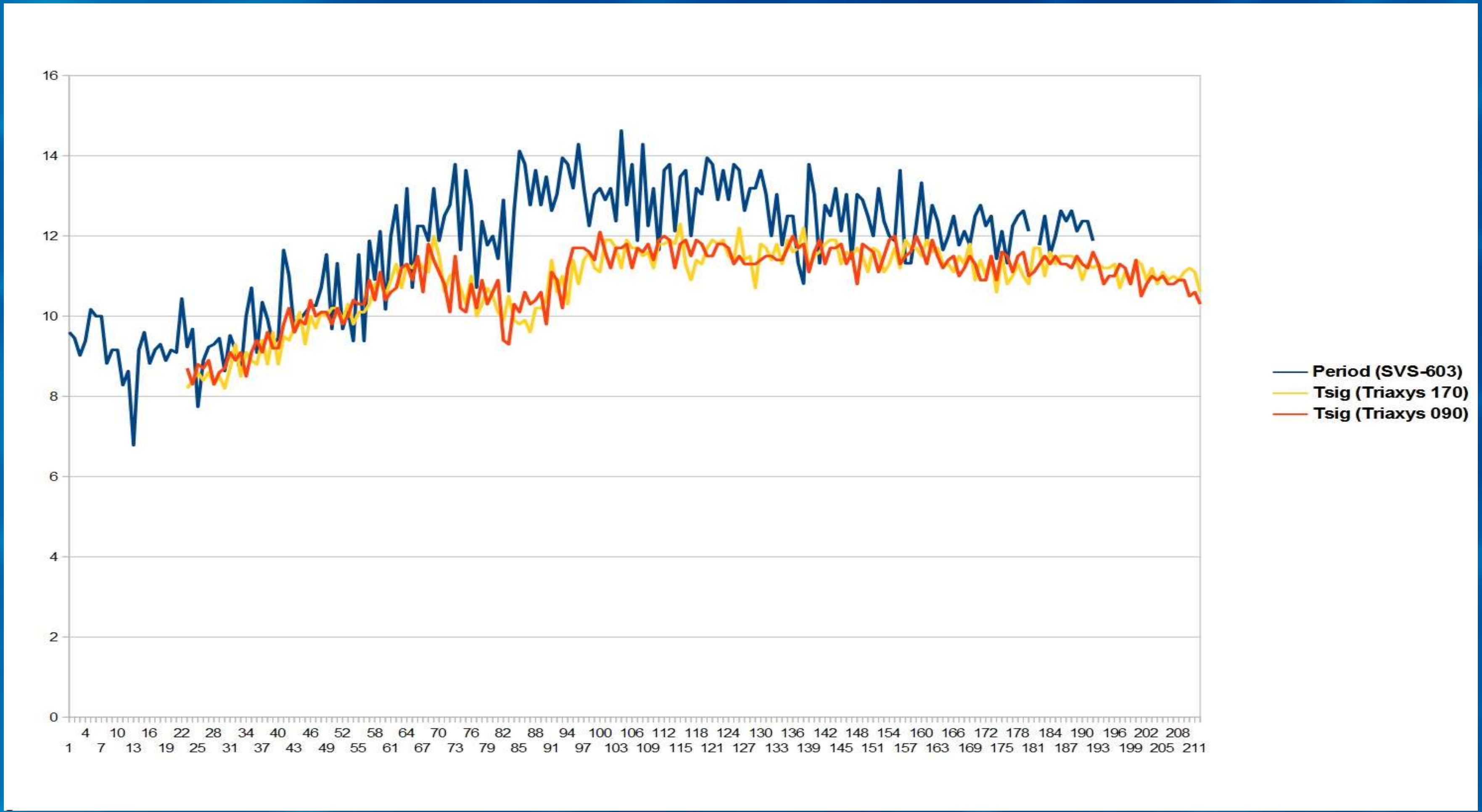
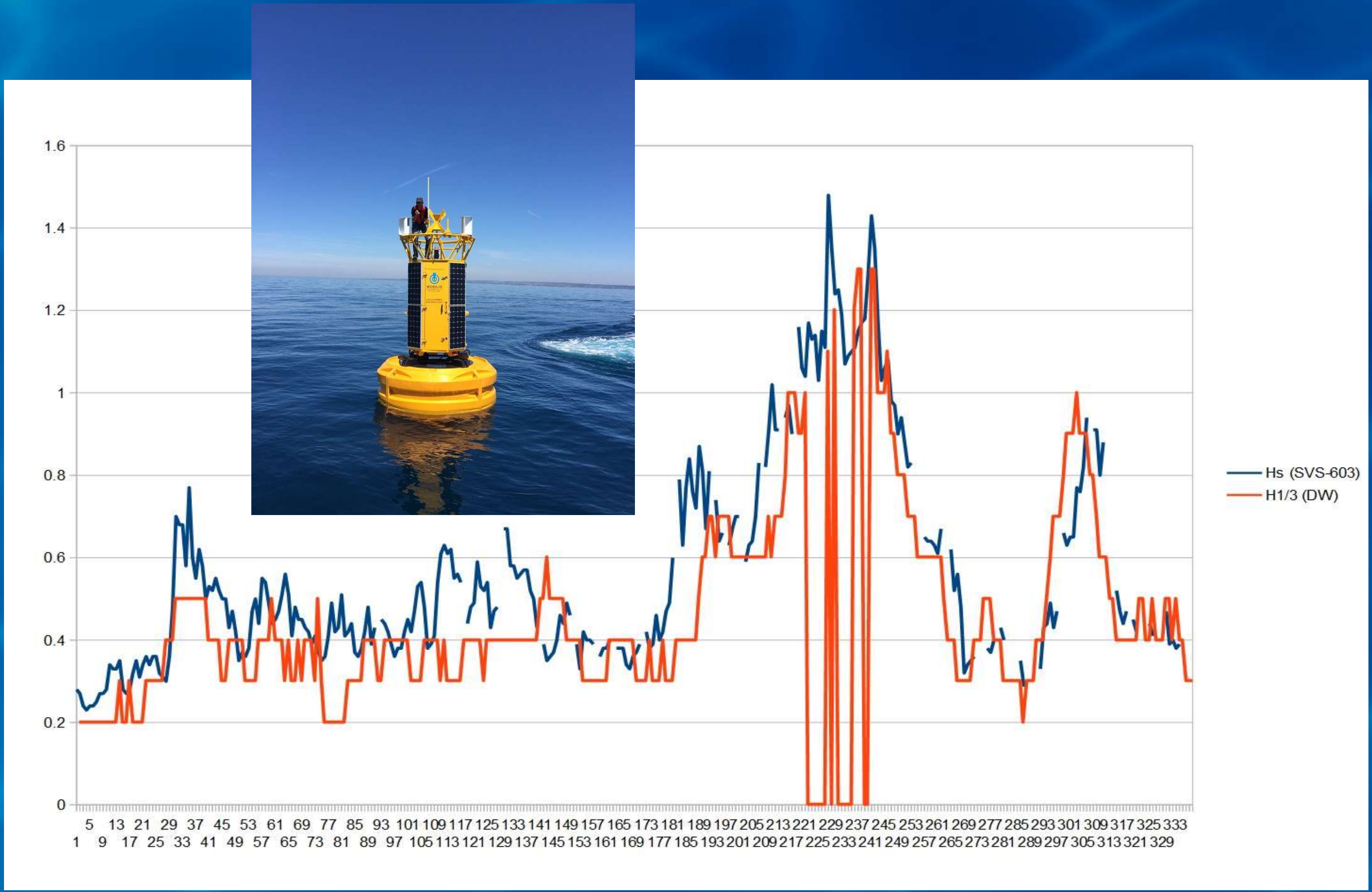
Dominant Period comparison (New Zealand)



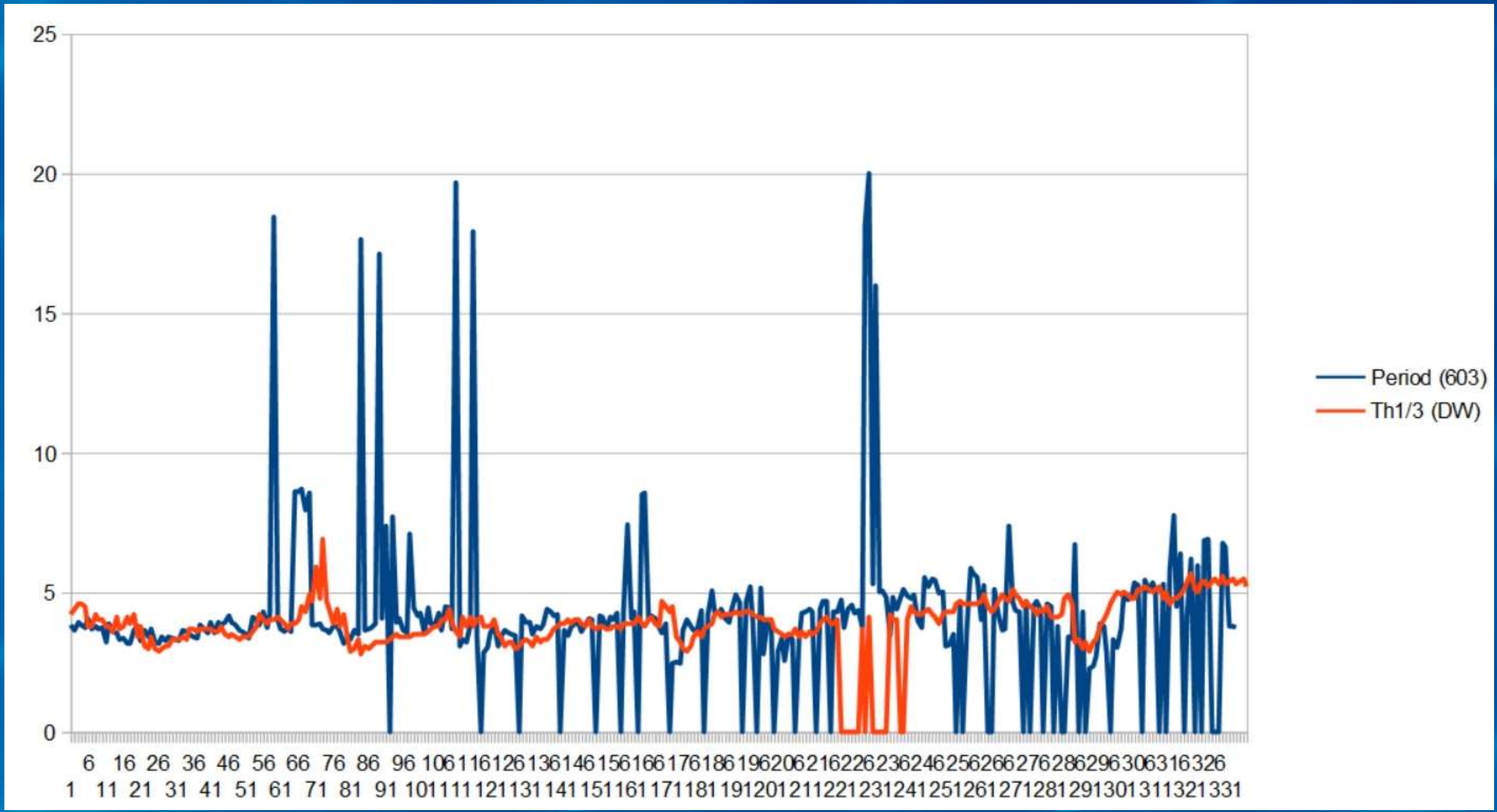
Data courtesy of Cawthron Institute

Hs comparison: Southern French coast (1.2 m above roll center)



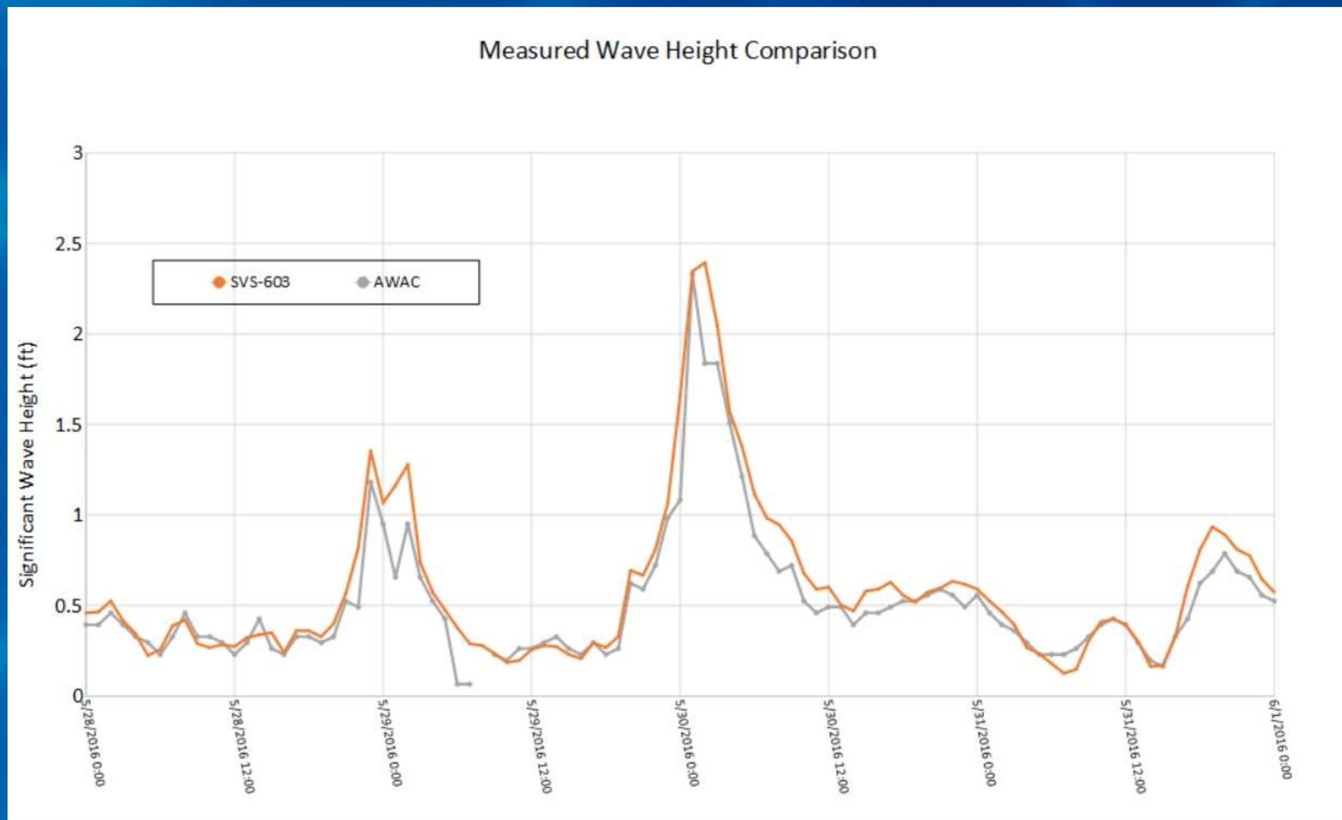
Data courtesy of Mobilis SA

Period comparison: Southern French coast (1.2 m above roll center)



Data courtesy of Mobilis SA

Hs comparison: Great Lakes deployment



Data courtesy of Limnotech

Why a dedicated GUI?

- Convenience
- Dedicated graphical standard plots...
- Easily backtest new algorithms
- Apply and assess RAO functions
- Web interface?
- Specialty applications?

- With great power comes great responsibility...

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Ongoing work...

Test on a wider range of buoy hulls

Develop methodology for fitting buoy hull response based on comparison data

Configurable RAO function

Explore algorithm improvements for non-ideal hulls/mounting position/buoy pitch/roll

Other enhancements for specialized applications

- Scheduler
- Triggering events
- More TBD...

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Thank you!

Please contact me to find out more or explore how we can support your application!

tcrandle@seaviewsystems.com