Directional Wave Measurements from Subsurface Buoys:

An Oceanographic and Engineering Experiment in Lunenburg Bay

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Wave Measurement Problem

Solution: Mount ADCP on subsurface buoy

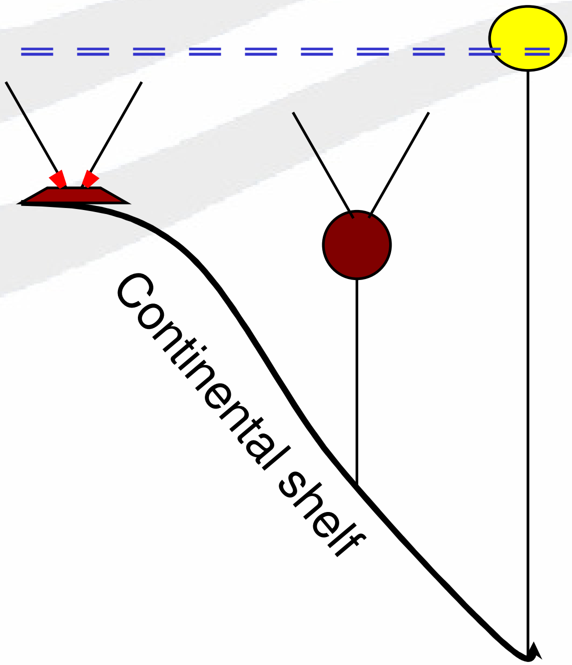
ADCP:

Pros –

Measures currents & waves
Can survive large storms
No surface expression

Cons –

Limited to shallow coast
(~50 m max deployment)



Wave Buoy:

Pros –

Can be deployed in deep water

Cons –

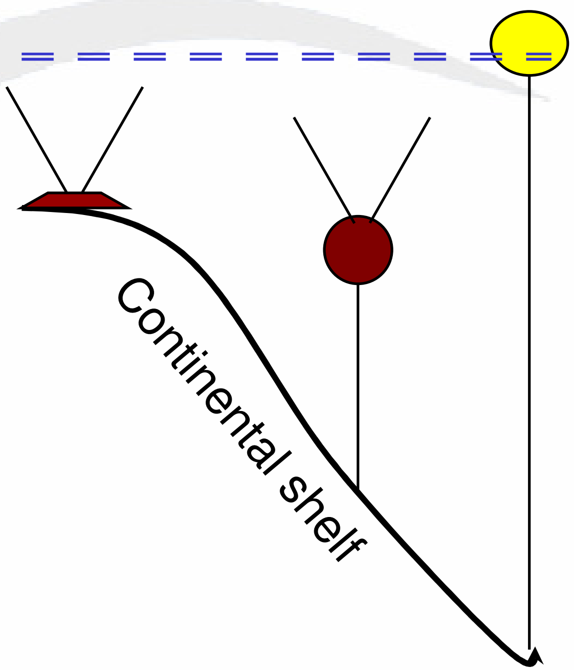
Does not measure currents
Can be damaged in storms
Prone to vandalism and collision

Wave Measurement Problem

Solution: Mount ADCP on subsurface buoy

Applications:

- Offshore boundary conditions for wave models
- Wave transformation over bathymetry
- Oil platform site surveys
- Arctic & ice-covered regions
- Ocean observing systems
- West coast & other steep shelf coasts



Wave Measurement Problem

Solution: Mount ADCP on subsurface buoy

Challenge:

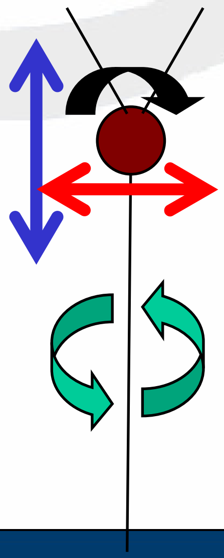
- Current profiles – no problem!
- Directional wave estimates – problem!
- Subsurface buoy moves during wave burst

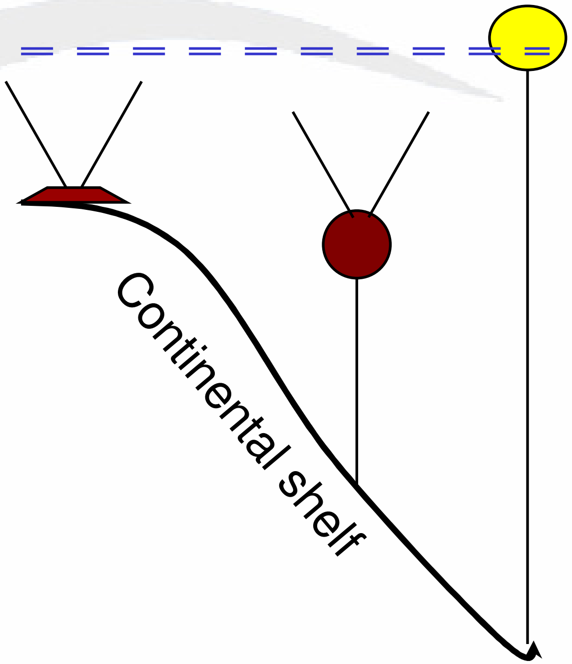
Heave

Surge

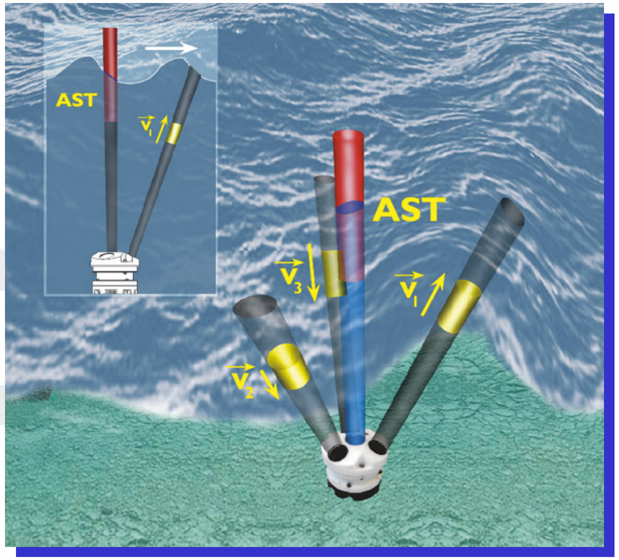
Rotation

Tilt





Wave Measurement Problem



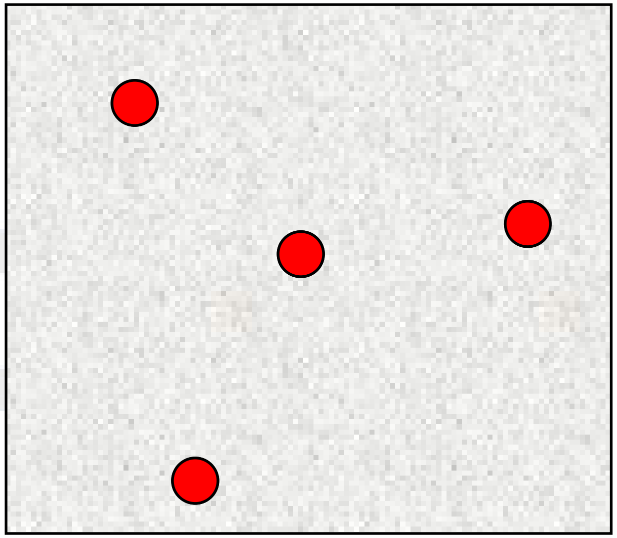
Current Profiles:

- Moving buoy is no problem
- ADCP measures tilt & heading
- Averaging is used to obtain mean velocity profile

Directional Wave Measurements:

- ADCP uses “array” style methods for directional measurements
- Maximum Likelihood Method (MLM) requires stationary array over burst length

Wave Measurement Problem



Current Profiles:

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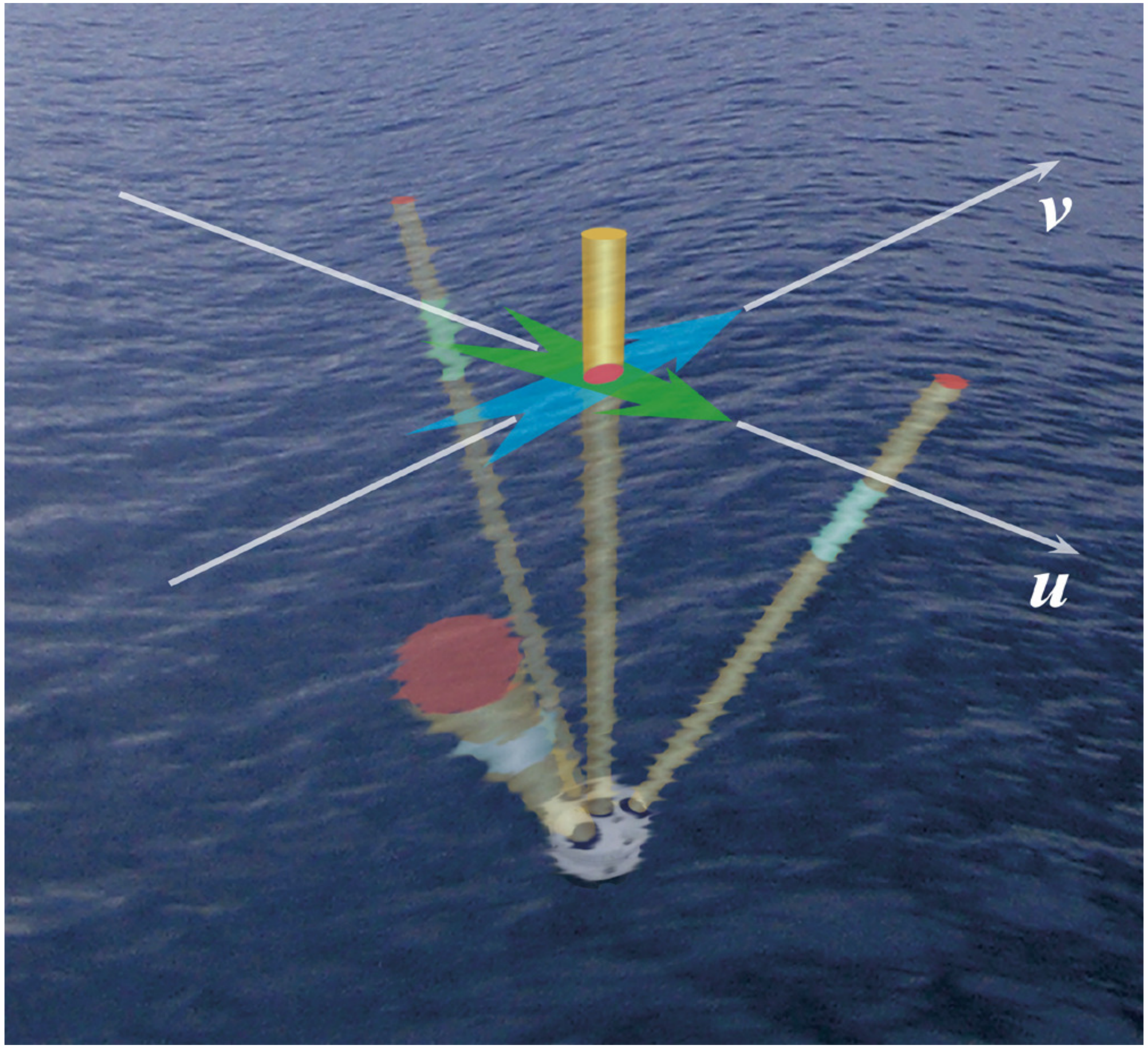
Directional Wave Measurements:

- ADCP uses “array” style method for directional measurements
- Maximum Likelihood Method (MLM) requires stationary array over burst length
- If surface array surges or rotates during the wave burst, the MLM will not work

Nortek developed the SUV method for directional wave measurements on moving platforms, such as subsurface buoy.

SUV method for buoy



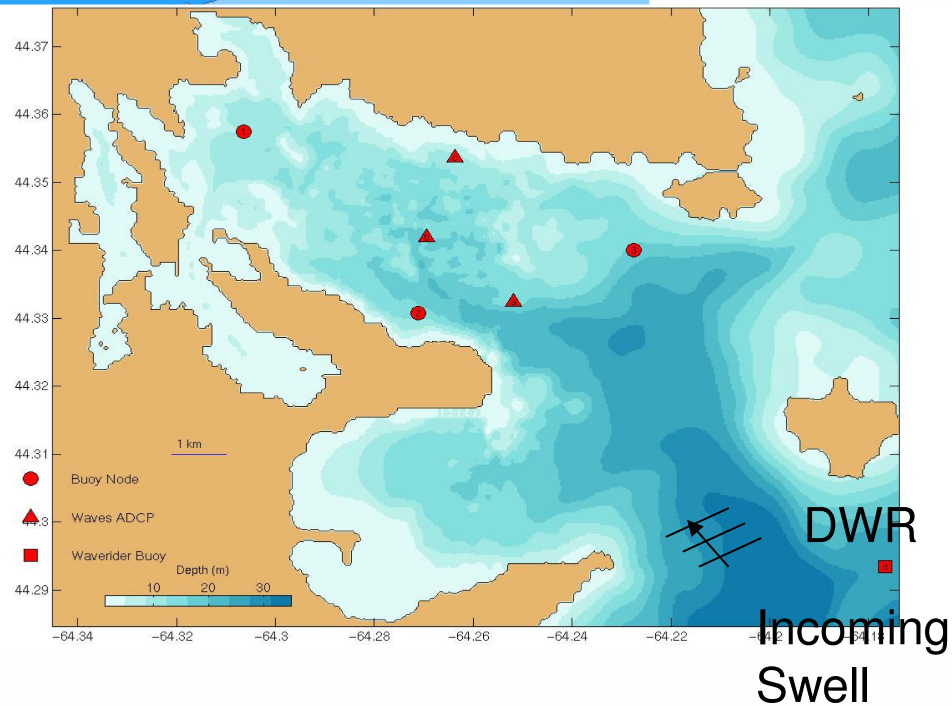
Height & Period:

- **Acoustic Surface Tracking (AST)**
- **Pressure** (secondary)

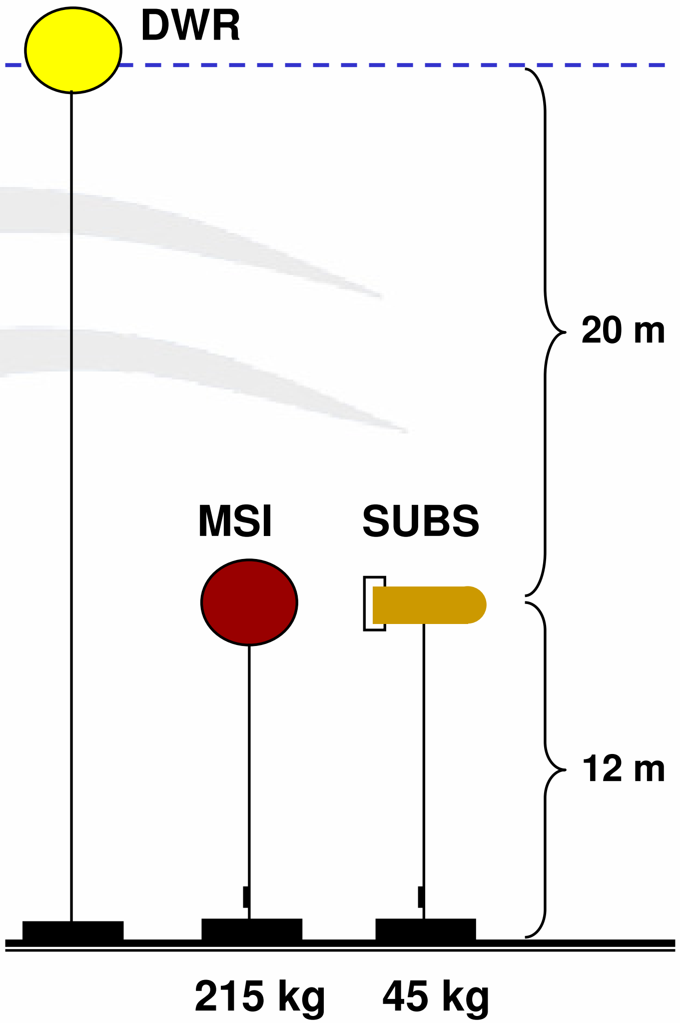
Direction:

- **Measure along beam velocity**
- **Measure AWAC attitude (heading and tilt)**
- **Coordinate transform from *Beam* to *U* and *V***
- **Form a triplet with *U, V,* and AST**

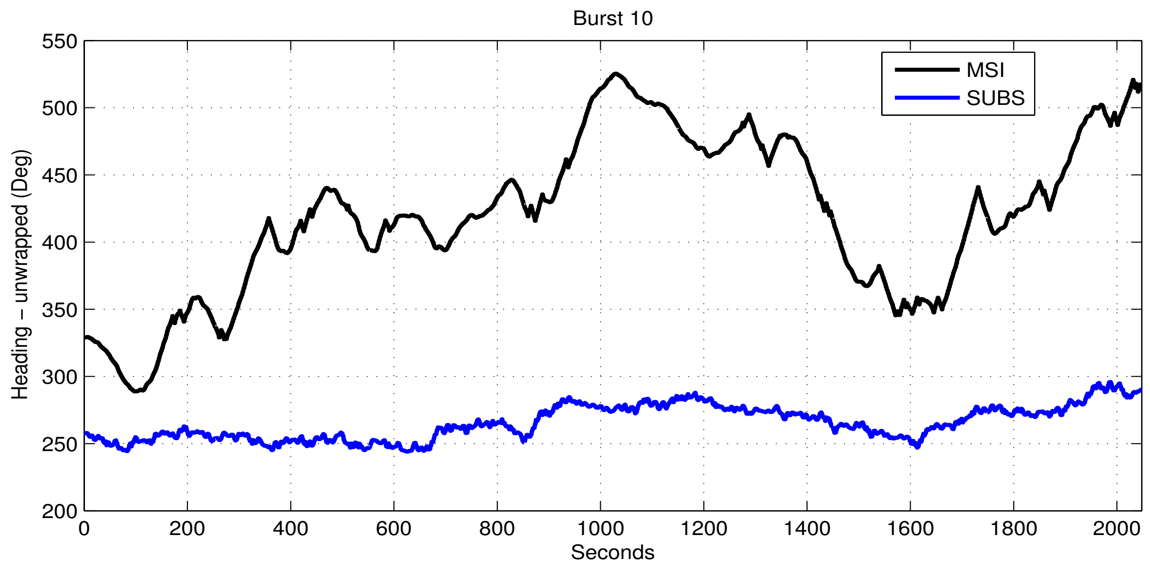
Lunenburg Bay, Nova Scotia



Lunenburg Wave Experiment



AWAC Heading



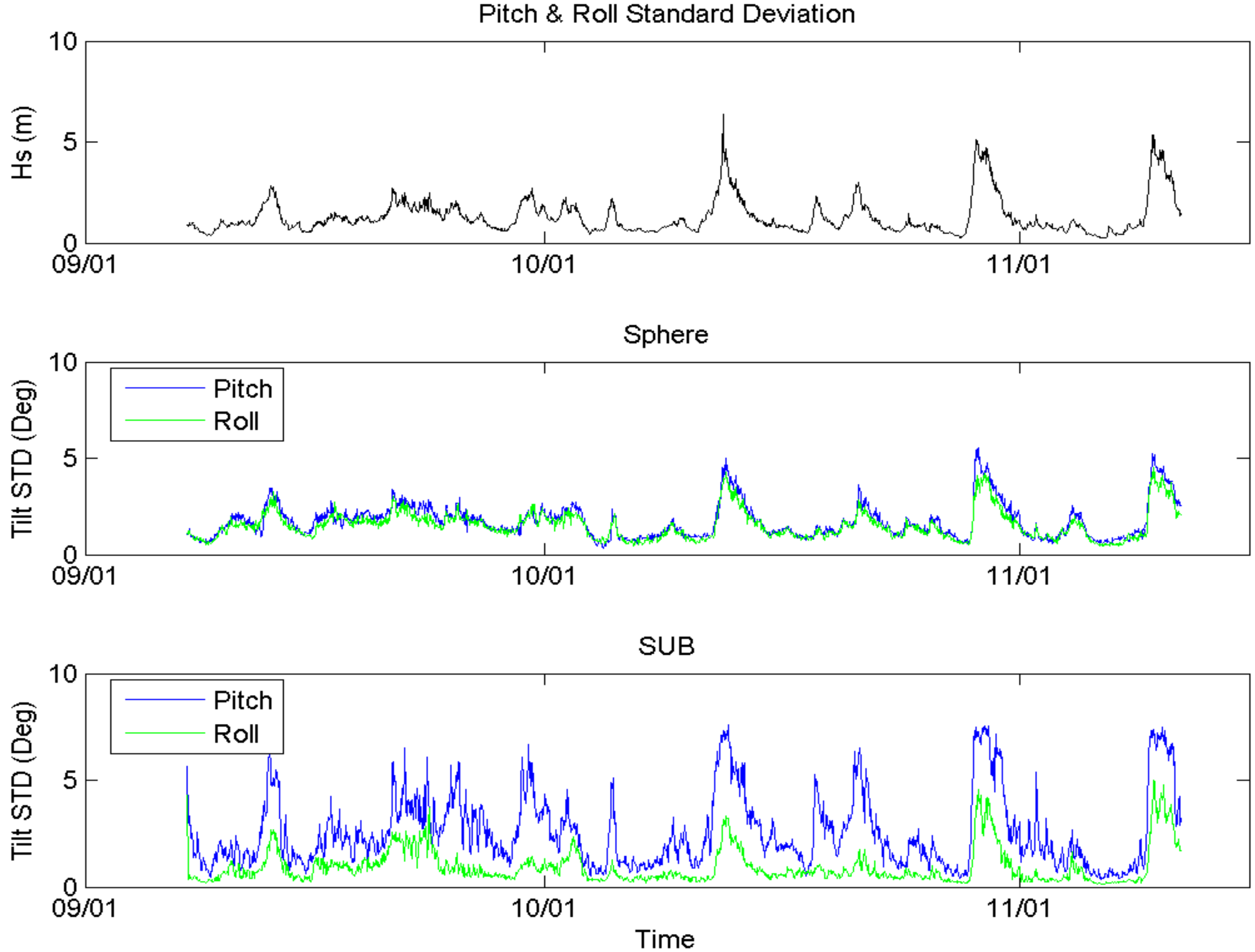
MSI:

- Makes full rotation within a measurement duration (17 min).
- AWAC compass can keep up with rotation – not too rapid.

SUBS:

- Does not rotate much during measurement duration (17 min).
- Does not rotate 180° due to wave orbital velocity.

AWAC Tilt



MSI:

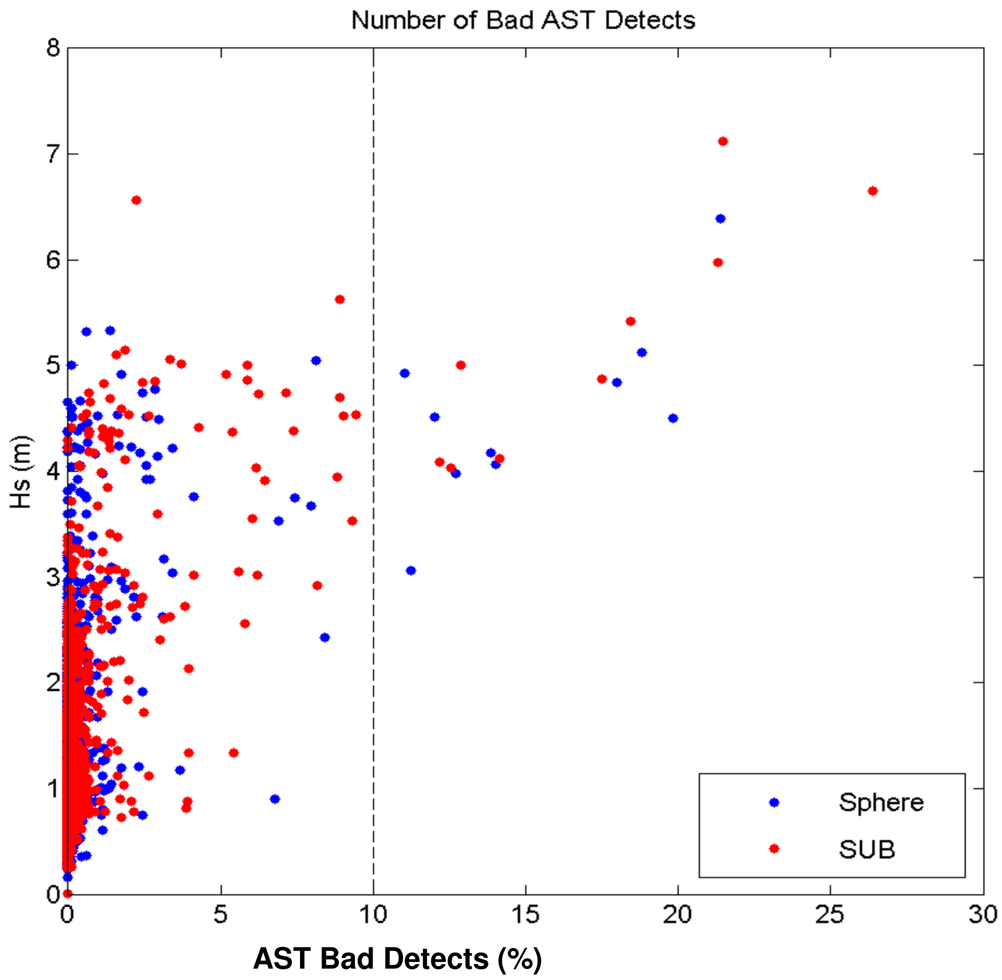
- Pitch & roll are similar
- Typical tilt standard deviation is 2-5°

SUBS:

- Pitch & roll are asymmetrical
- Roll is similar to MSI
- Pitch is larger, typically 3-7 °

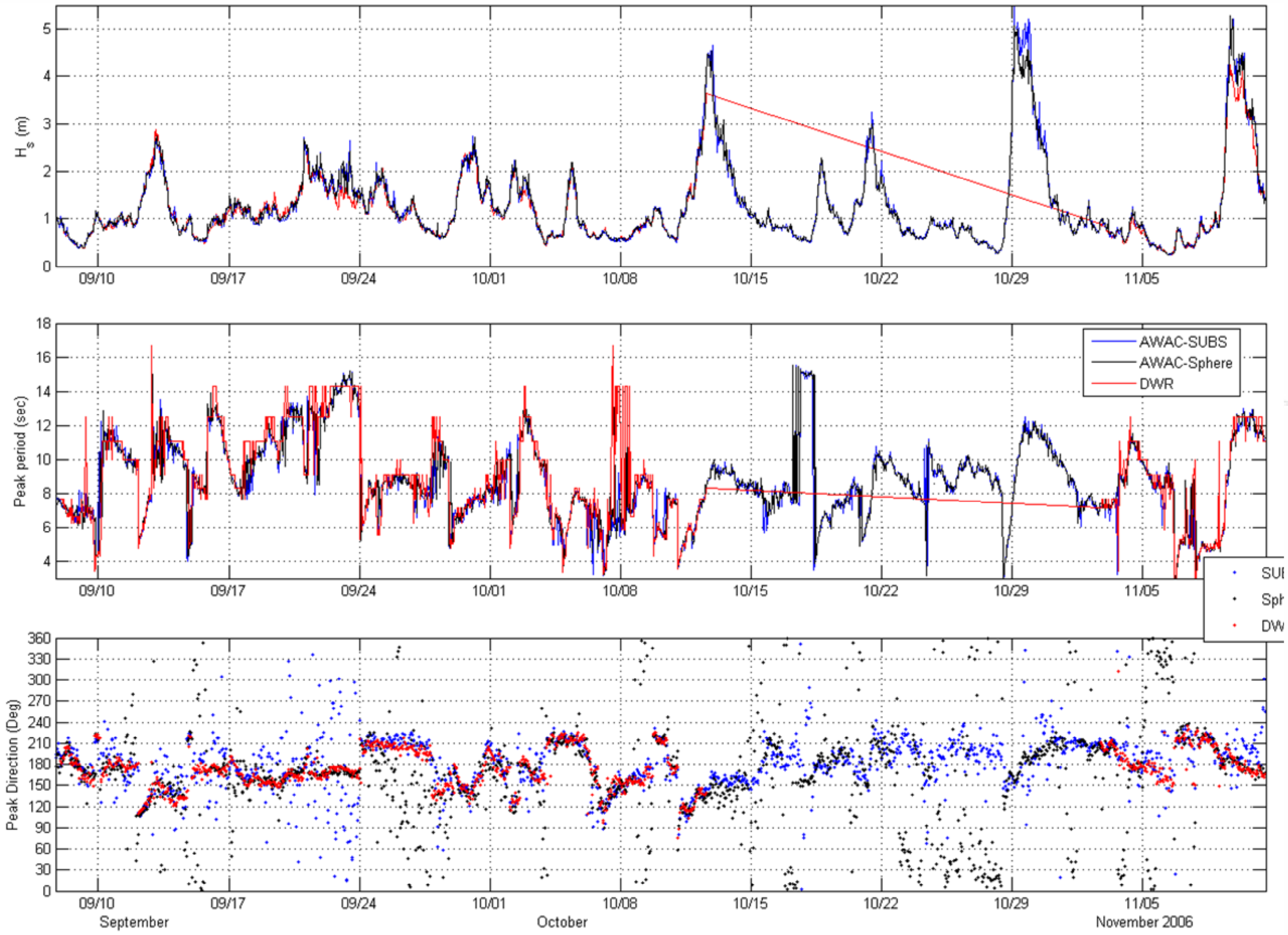
Acceleration affects tilt reading

AWAC AST Data

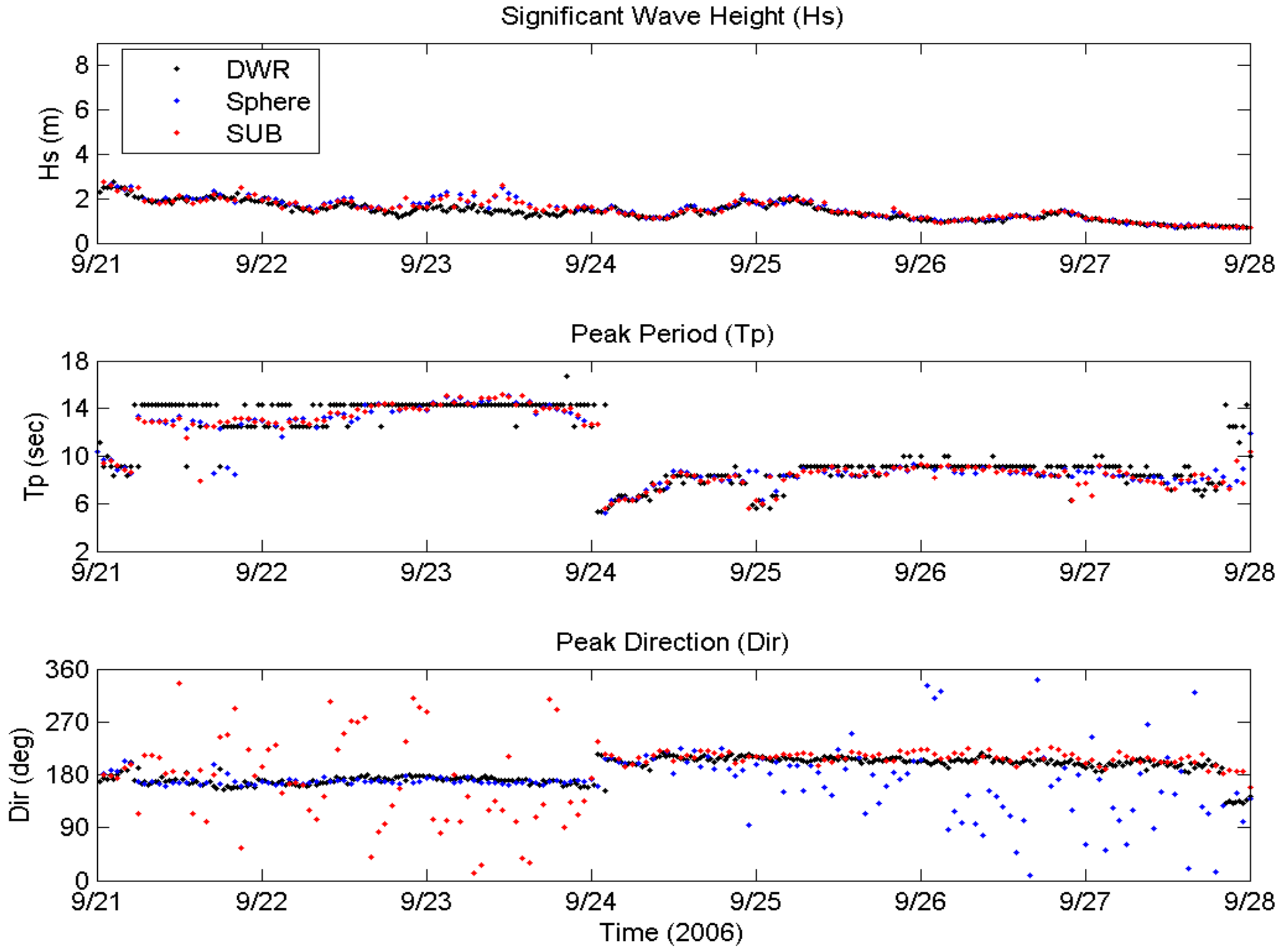


- MSI & SUBS perform similarly
- MSI: 96% AST samples have less than 1% bad detects
- SUBS: 93% AST samples have less than 1% bad detects
- Only 10 samples (out of 2 months) have more than 10% bad detects

Standard Wave Estimates



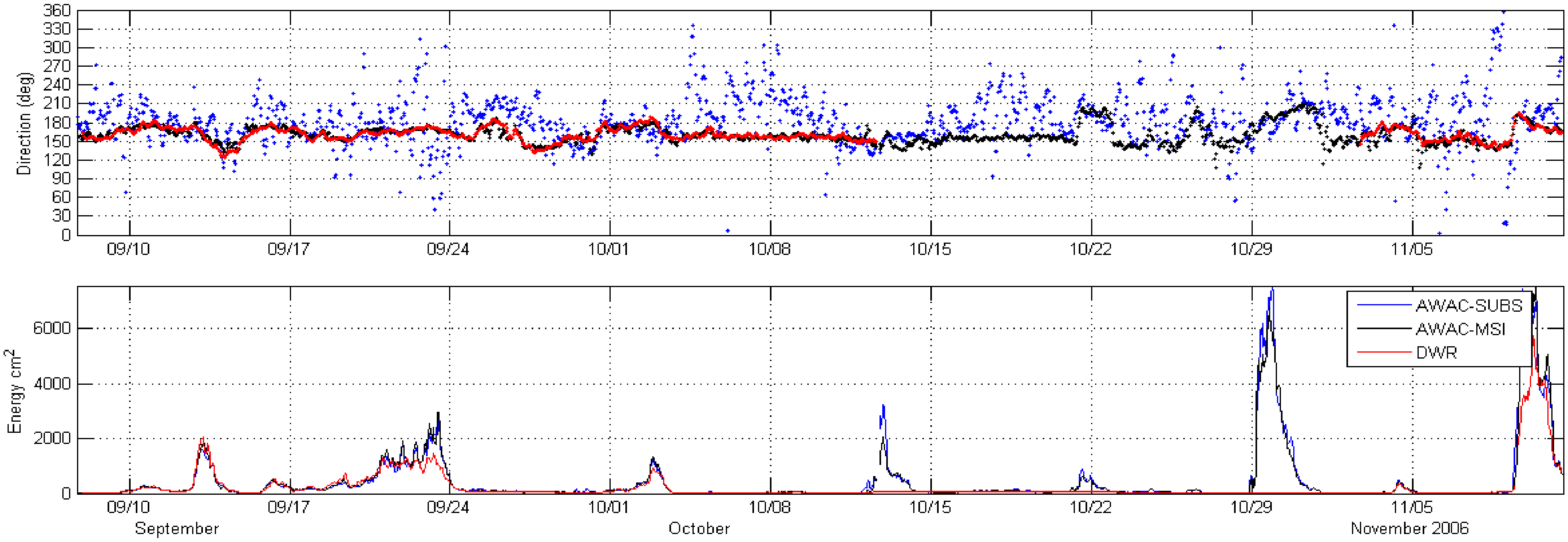
AWAC Data Zoom



Band Estimates: 10 – 33 seconds
Tilt – Direction - Energy

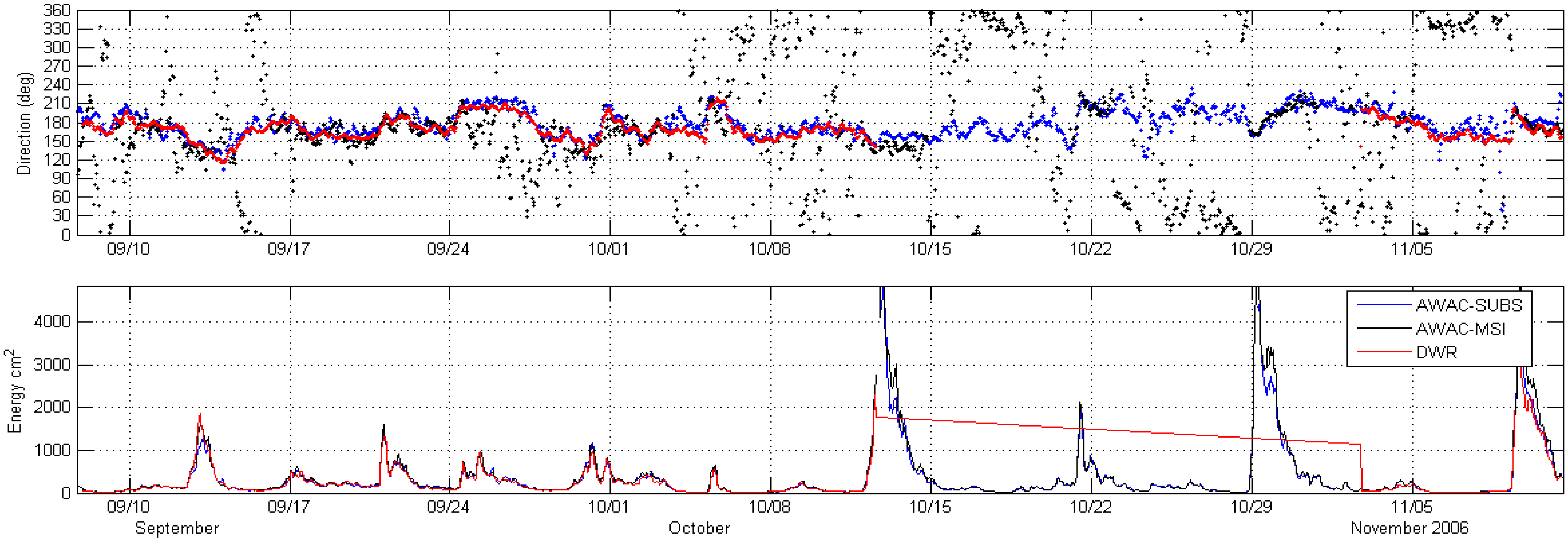
NortekUSA

Sphere better



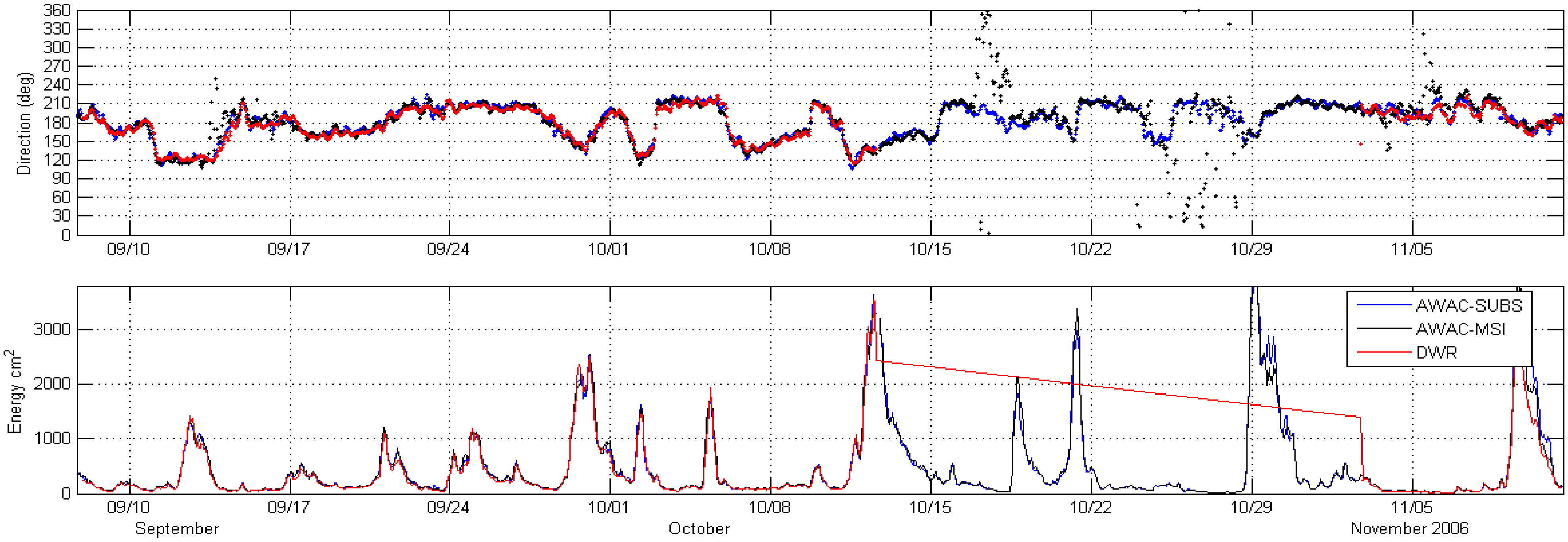
Band Estimates: 7.7 – 10 seconds
Tilt – Direction - Energy

SUBS better

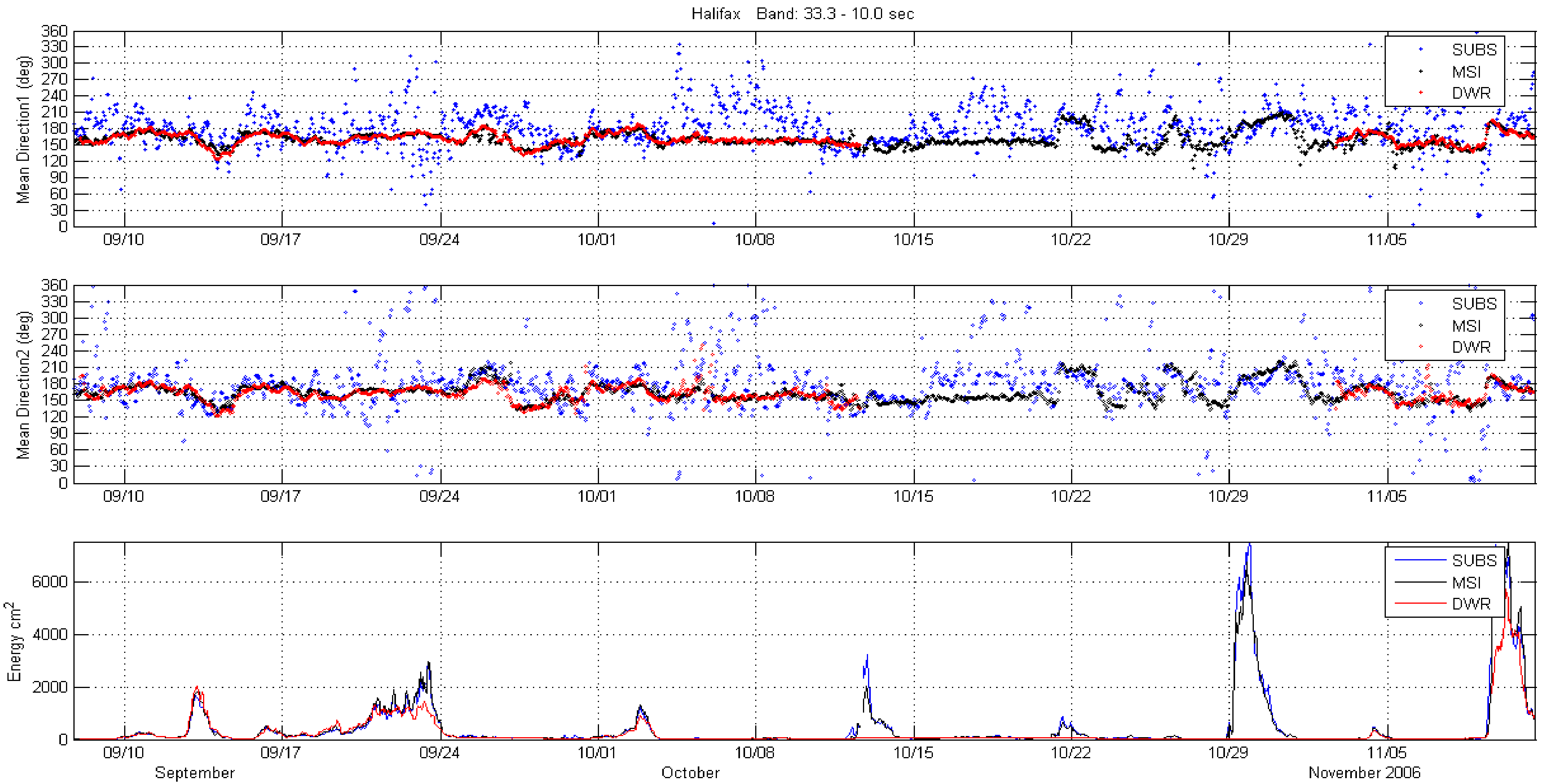


Band Estimates: 5 – 7.7 seconds
Tilt – Direction - Energy

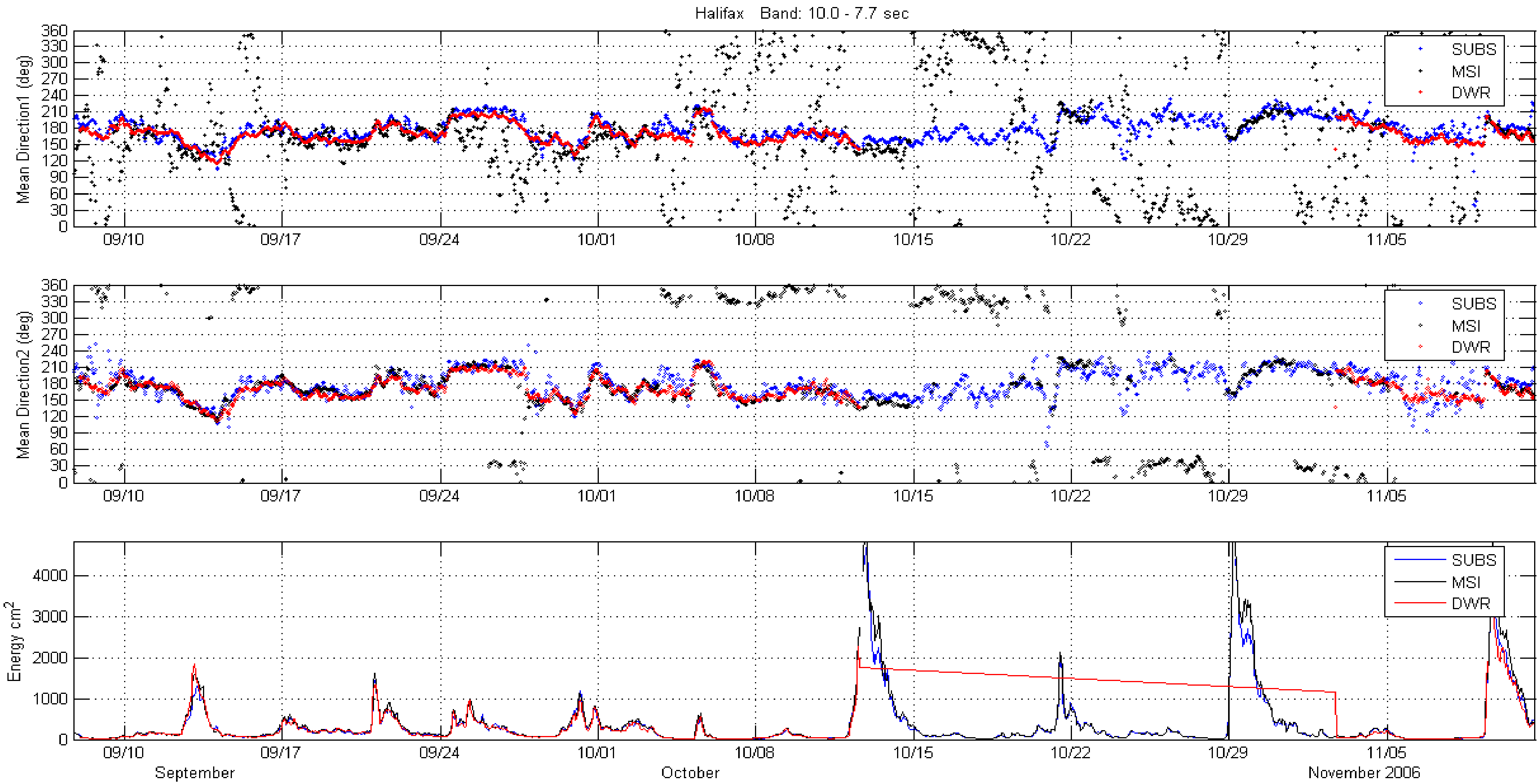
Both well



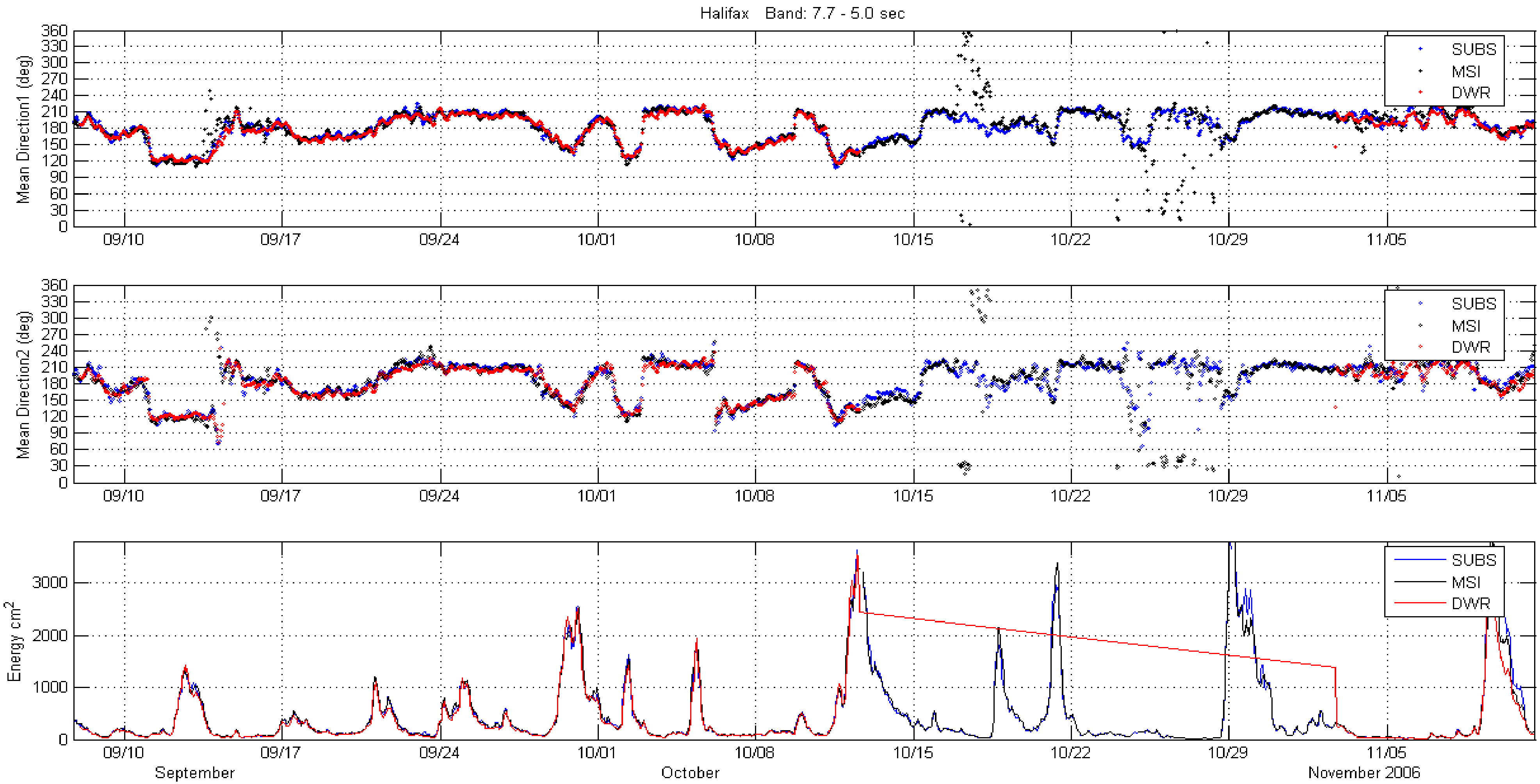
Band Estimates: 10-33 seconds
Mean Dir1 - Mean Dir 2 - Energy



Band Estimates: 7.7-10 seconds
Mean Dir1 - Mean Dir 2 - Energy



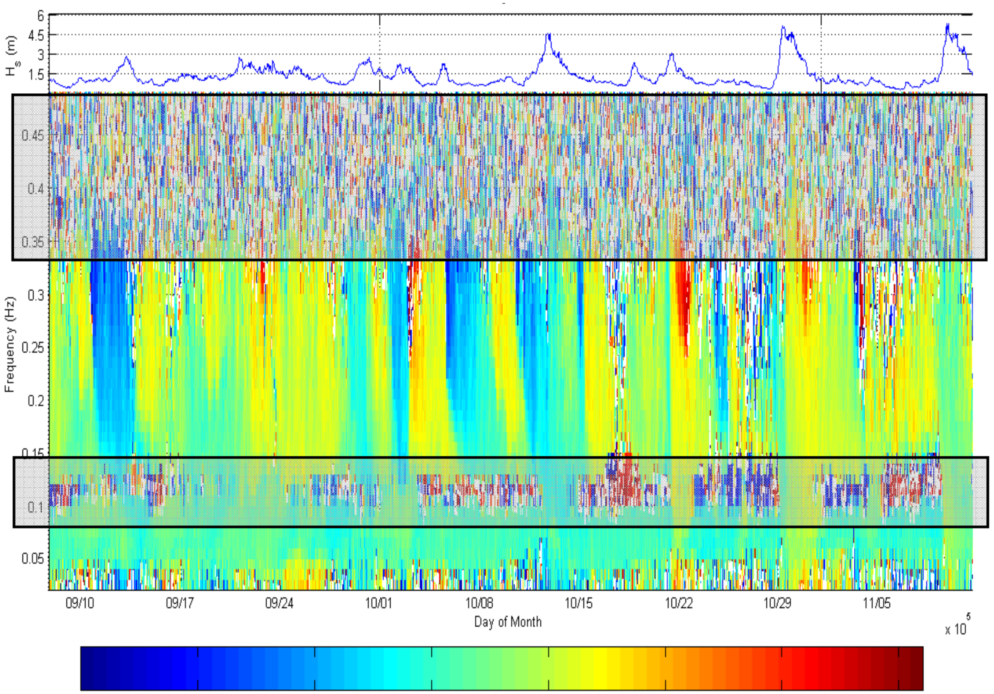
Band Estimates: 5-7.7 seconds
Mean Dir1 - Mean Dir 2 - Energy



Directional Spectrogram

Directional resolution limitation (~2.8 sec)

MSI

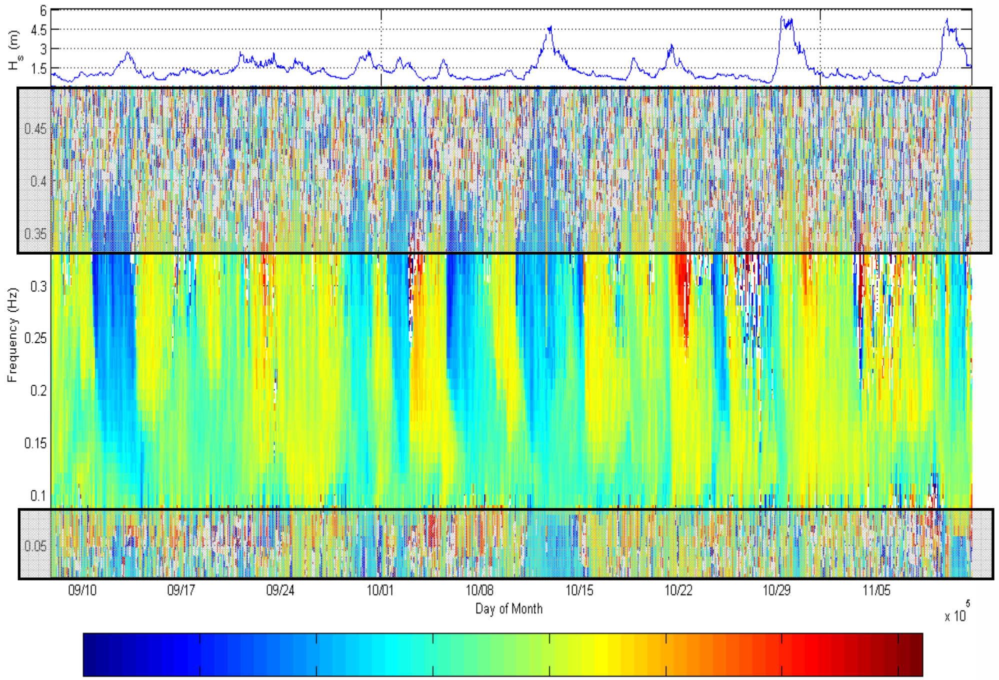


N E S W N

Direction

Poor Performance 8 - 10 sec

SUBS

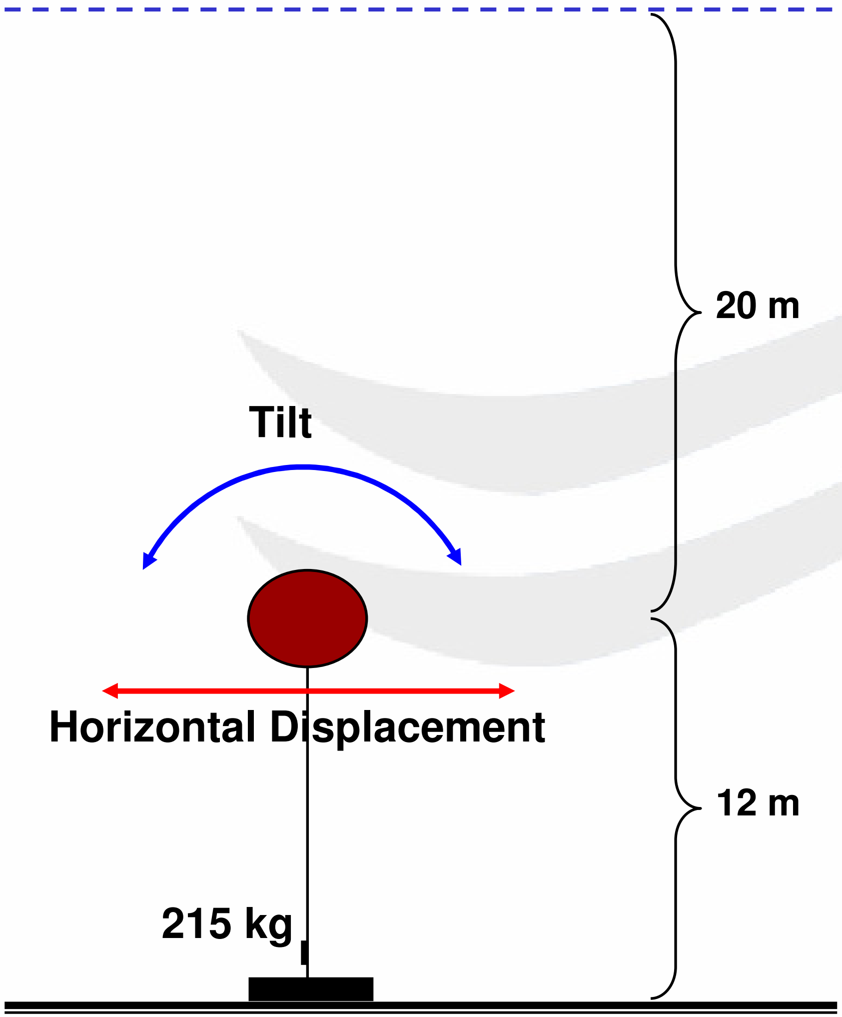


N E S W N

Direction

Poor Performance 10 - 30 sec

Buoy Motion: Sphere



Mooring system has its own frequency response.

”Inverted pendulum” Dependent upon buoyancy and length of mooring.

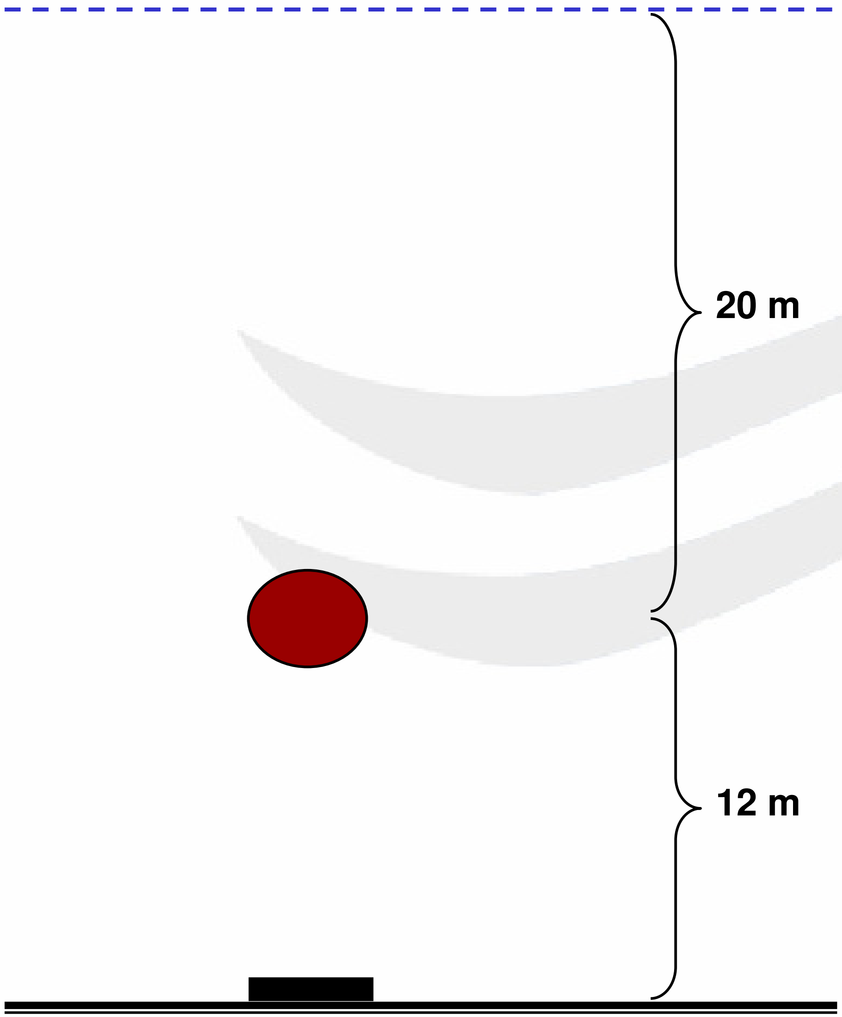
Horizontal motion creates a perceived velocity in the measurement cell.

More pronouced when low energy in band.

Tilt sensor measures a combination of tilt and horizontal acceleration.

Tilt and Horizontal displacement appear independent, i.e. uncoupled.

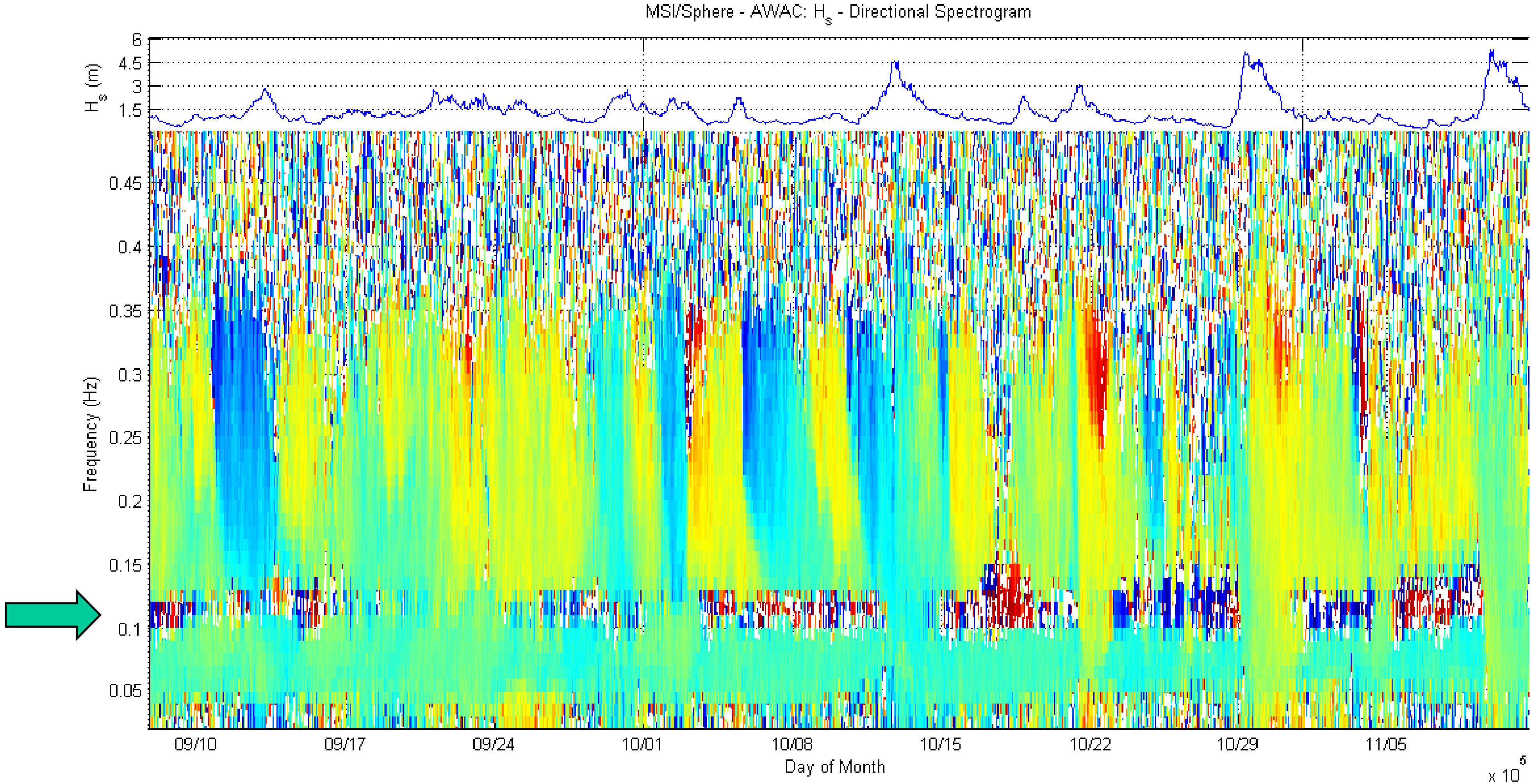
Buoy Motion: Sphere



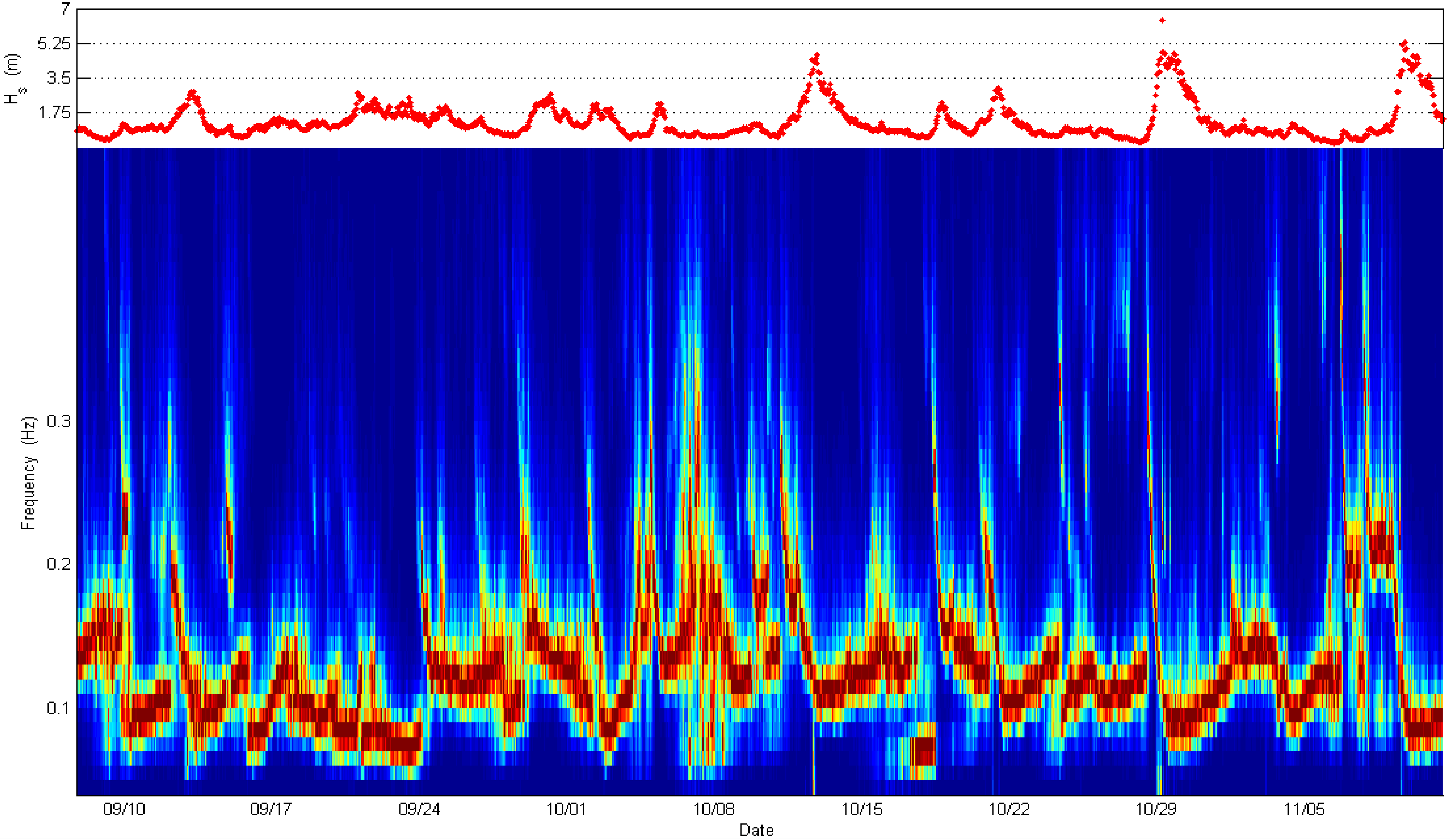
Imagine a long wave displacing the mooring and then the mooring returning to equilibrium but as an underdamped oscillator.

12 m mooring line with this configuration (mass, buoyancy) has natural period of 9 seconds

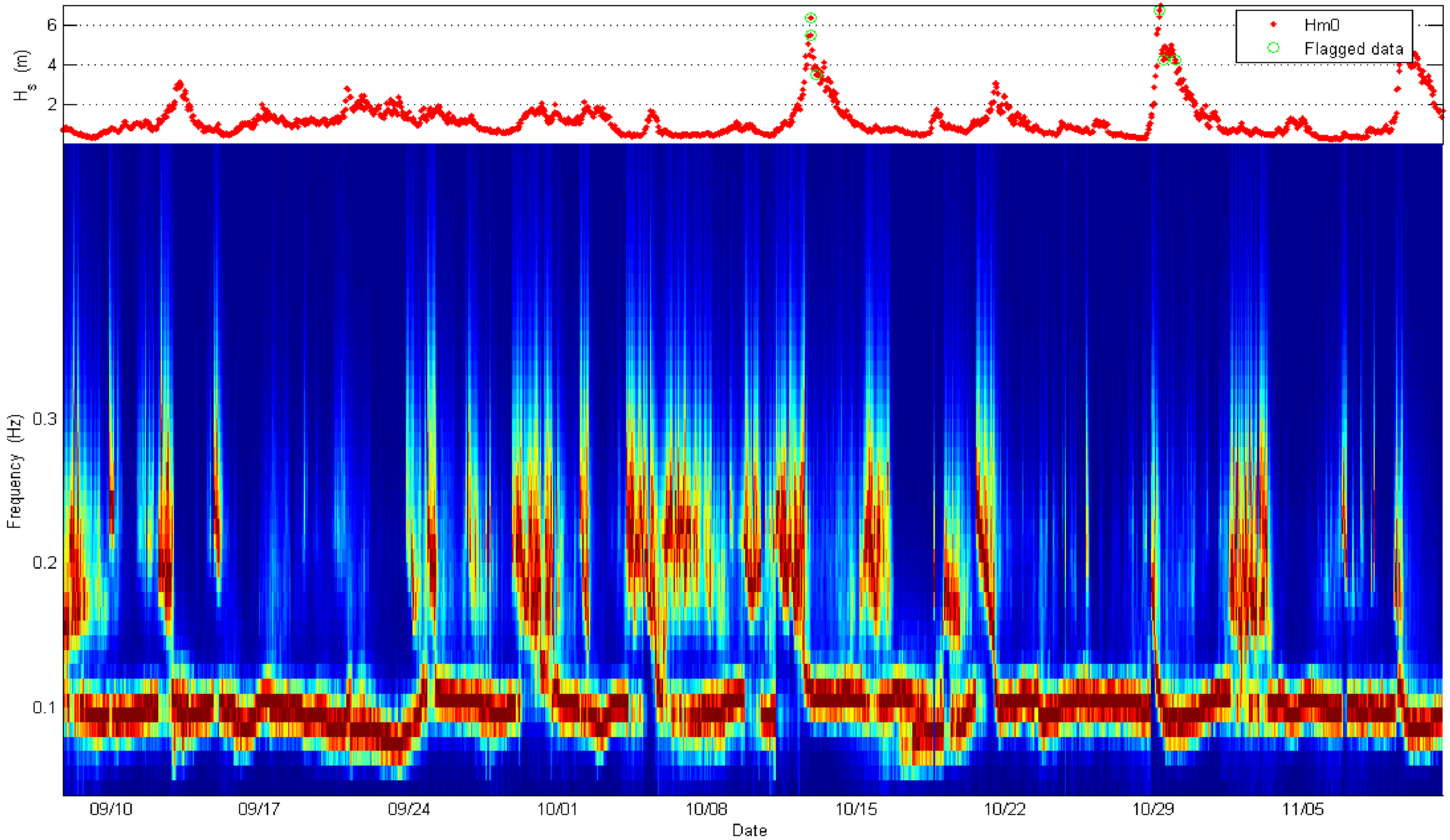
Directional Spectra - Sphere



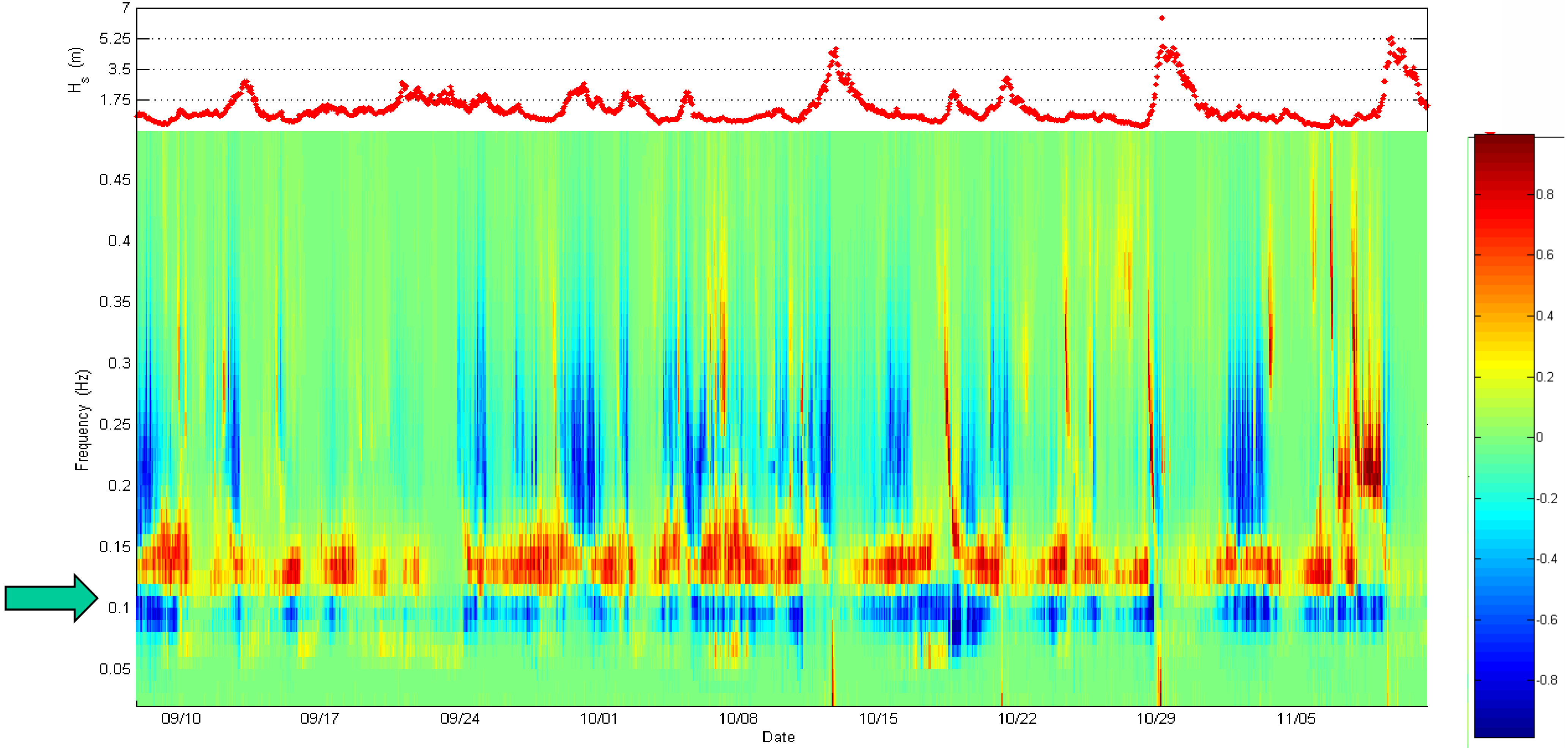
Normalized Energy Spectra: AST



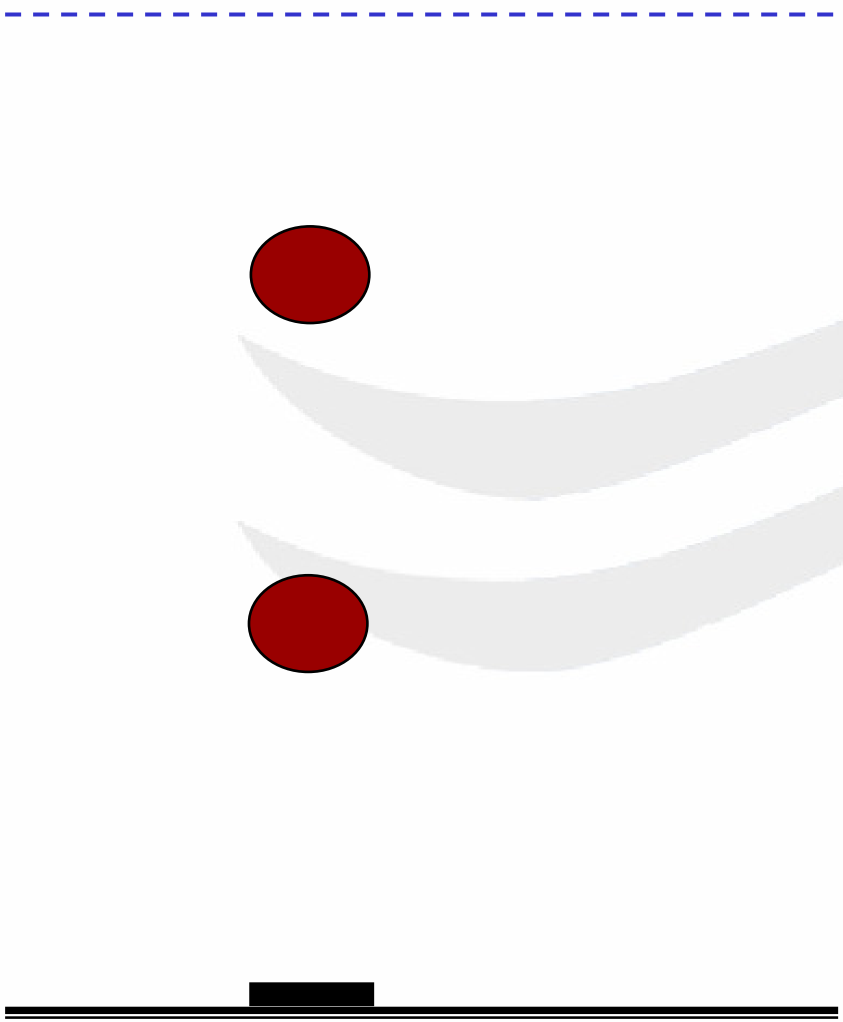
Normalized Energy Spectra: Velocity



Difference of Normalized Energy Spectra AST - Velocity



Buoy Motion: Sphere



Mooring system has its own frequency response.

12 m mooring line with this configuration has a natural period of 9 seconds.

High buoyancy & little drag caused an ”underdamped” pendulum.

How to improve mooring performance?

60 m mooring line with similar configuration has a natural period of 20 seconds.

Should use more buoyance for overdamped system.

Should use 600 kHz AWAC to deploy deeper below surface, further from wave energy (~40 m).

Summary

- Excellent example of collaborative project between government, university & multiple private companies (US & Canada)
- Safe deployment & recovery
- Everything worked
- Wave height looks good
- Wave period looks good
- Nortek SUV method works for rotating platform
- Wave direction looks good (at times)
  - MSI – poor in 8 – 10 sec band
  - SUBS – poor in 10 – 30 sec band
- Many factors affect performance
  - Buoyancy
  - Floatation shape
  - Mooring length
  - Distance below surface
- Future plans
  - Understand mooring dynamics to design a better subsurface buoy
  - Use 600 kHz AWAC to deploy further below surface in deeper water

Many thanks to BIO, Dalhousie, Open Seas & Mooring Systems