Recent Developments in Waves Measurement using Horizontal Wave Gages

David Brooks
Teledyne RD Instruments

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

TALK OUTLINE

1. Introduction – about me.
2. About Teledyne RD Instruments
3. Overview of Waves and H-Waves
4. Benefits of H-ADCP as a Wave Gage
5. Wide-Band vs. Narrow-Band Broadband
6. Depth Considerations
7. Directional Noise Floor
8. Application notes on Hyberbolic Trig Functions
9. Future Areas for Development
10. Questions

INTRODUCTION

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

INTRODUCTION

- David Brooks, from Teledyne RD Instruments.
- Lead Software Engineer on WavesMon.
- Email: dbrooks@teledyne.com
- Phone: (858)842-2766
- B.S. in Physics, SUNY Stony Brook
- 20+ years professional programming experience. Specialization in 3D Graphics.
- Principal researchers: Brandon Strong and Blair Brumley.
- I am a programmer, not an Oceanographer – so go easy on me ☺

TELEDYNE RD INSTRUMENTS
A Teledyne Technologies Company

TELEDYNE RD INSTRUMENTS

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

TELEDYNE RD INSTRUMENTS

- Founded in 1981 as RD Instruments
- Purchased in 2005 by Teledyne
- TRDI Facility: San Diego, California
- International offices: France, China
- 200+ staff
- 10,000+ ADCP’s sold! Huge mark for the world of ADCP’s.
- ISO9001-2000 certified. Helps ensure that our products are properly QC’d, and our processes are continually improving.
- Dedicated Waves Program in place since 90’s. Would like to grow this program, but we need to grow the business side as well.

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

OVERVIEW

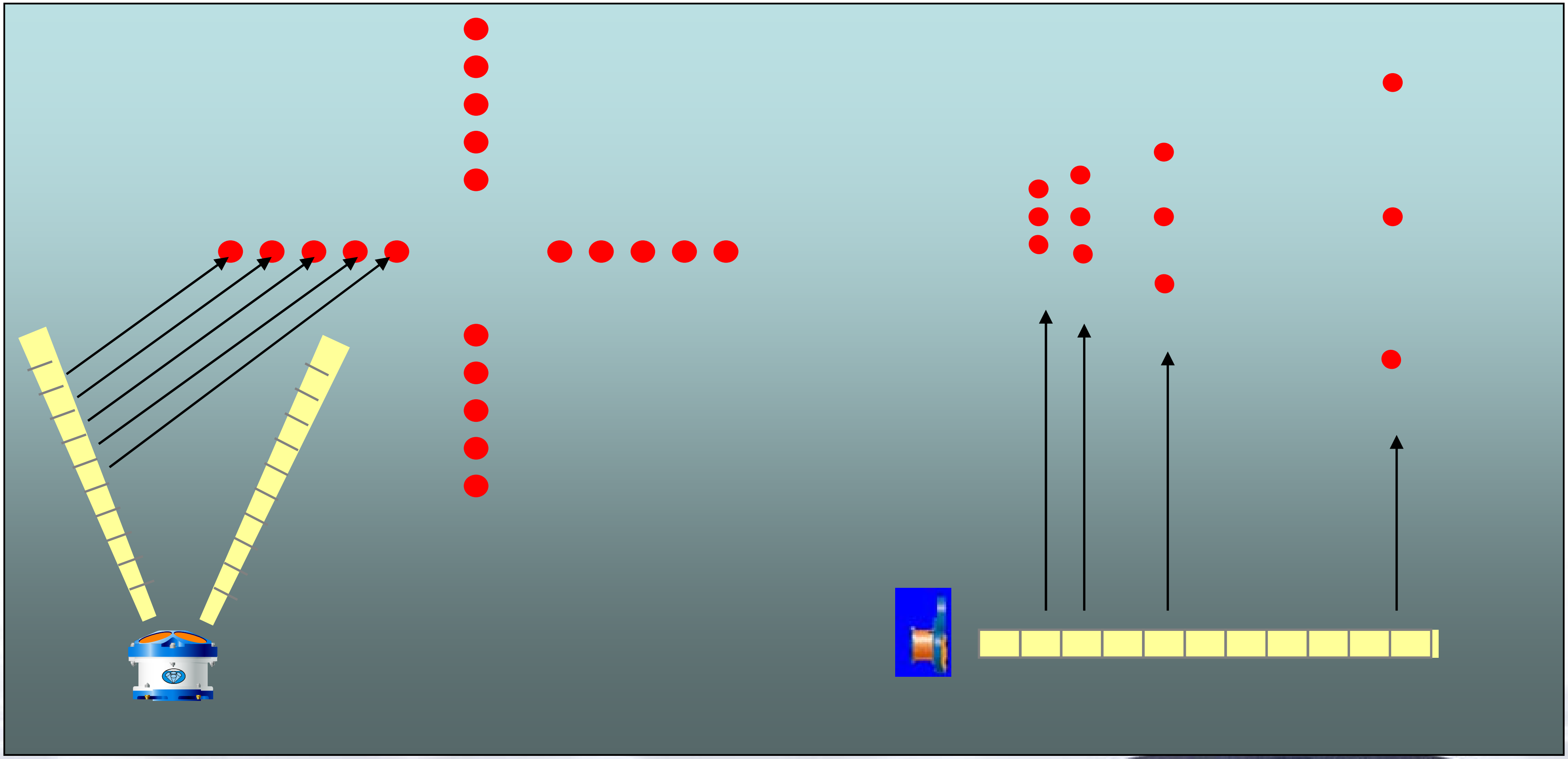
TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

OVERVIEW

- **TRDI has a long-standing development effort in Waves Measurement, including patented waves algorithms for both Vertical and Horizontal systems.**
- **Original development was on Vertical systems in 90's.**
- **Expanded into H-Waves in 2004.**
- **Teledyne has just gone through a development effort to tweak, tune, and improve our overall Horizontal Waves Processing package based on several years of data and analysis.**
- **I wanted to present some of our findings here, along with the benefits of H-ADCP's.**

(chart on ADCP vs. H-ADCP…)

OVERVIEW



TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

H-ADCP Wave Gages Benefits

H-ADCP Wave Gages Benefits

- Deploying instruments on the ocean floor can be problematic.
- Where real-time feedback is needed your current options are Fixed Cable, NEMO, Radar, Buoy, etc.
- Fixed Cable has issues in that the ocean floor is shifting while the PC is not. This leads to chafing, stretching, and breaking of cable. Cable is expensive to purchase, install, and replace.
- NEMO helps, but is limited by battery lifetime, and needs recovery.

H-ADCP Wave Gages Benefits

- Mounting an HADCP to a platform or pier, is easier to maintain, has no separation issues, and limited chafing issues if installed properly.
- For off-shore applications (rigs, drill-ships, container buoy's, etc) vertical ADCP is not an option, and single-point techniques are difficult or impossible.
- H-ADCP measures currents, temperature, salinity as well – a big plus for some customers.
- Recent Legislation on Oil Platforms.

Wide-Band vs. Narrow-Band Broadband

Wideband vs. Narrowband

- When H-ADCP was created it was desired to extend the profiling range as far from the measurement platform as possible. This way the impacts of the platform could be minimized.
- Consider a center-core Drill Rig with an ADCP mounted on the core. We don't want to be measuring currents as they flow around the core, rather we want to be measuring what they would be in the absence of the Rig.
- The same goes for Waves. We want to stay out of the "shadow" of the platform.

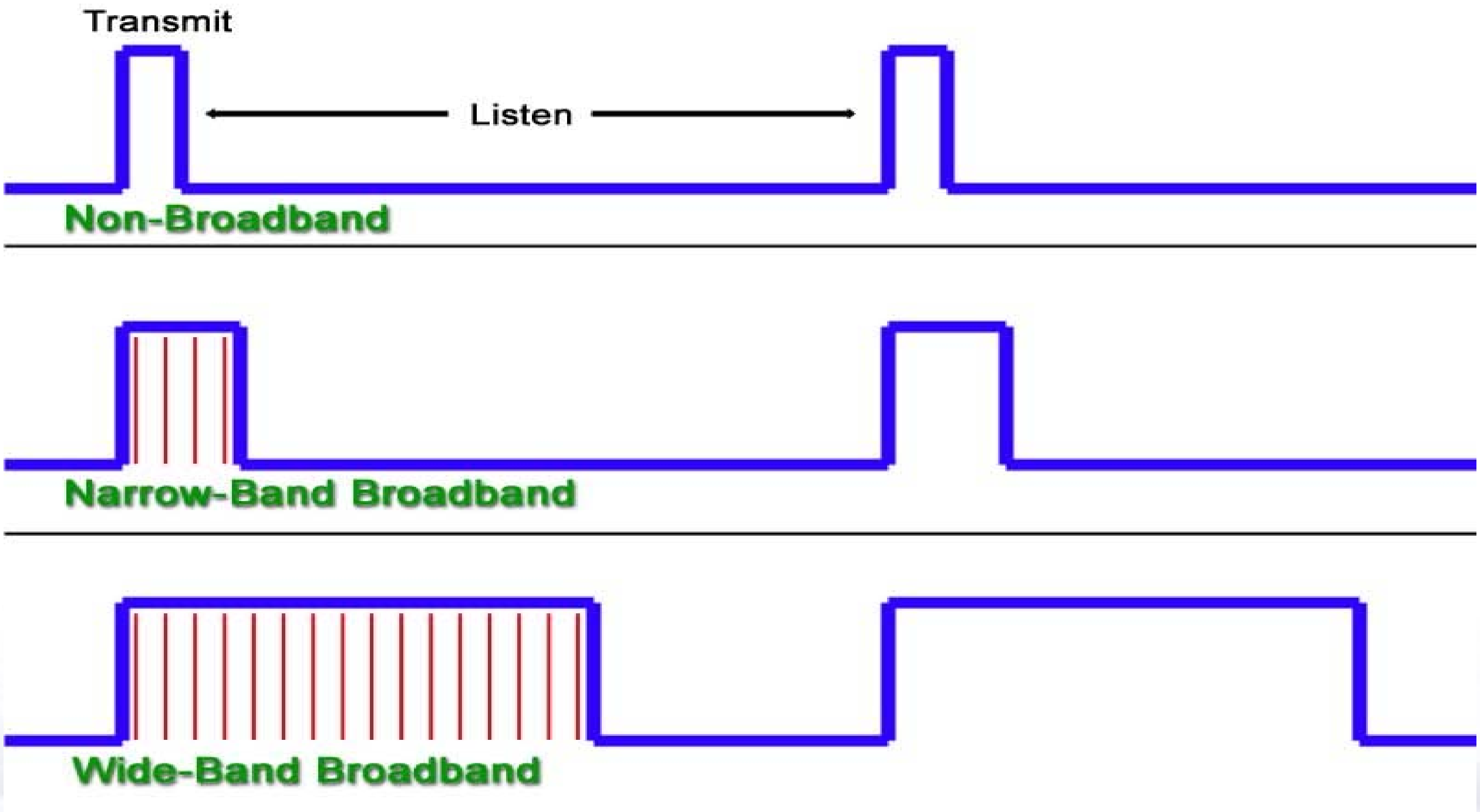
Wideband vs. Narrowband

- **Our ADCP's have two Broadband Modes.**
- **Wide-Band Broadband (WB0)**
  - **Data has a lower variance – measurement is "quieter"**
  - **Lower profiling range**
- **Narrow-Band Broadband (WB1)**
  - **Data has a higher variance – measurement is more noisy**
  - **Higher profiling range**
  - **(Still Broadband though)**

(see next chart…)

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Wideband vs. Narrowband



TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Wideband vs. Narrowband

- By using narrowband mode (WB1) we extend the profiling range by about 25%. (still Broadband though)
- This is the default for H-ADCP's (vs. Wideband mode for Vertical ADCP's).
- Waves Software was not explicitly programming H-ADCP's for Wideband mode, resulting in measurements that were much more noisy than Wideband.
- This is detrimental to the array approach which is looking for phase coherency. When the signal is buried in the noise it is much harder to find using Array Processing.
- WHAT WE CHANGED: We always program H-ADCP's for Wideband Mode!! What we give up in range can usually be made up for by strategically positioning the instrument.
- This was a nice piece of the puzzle!

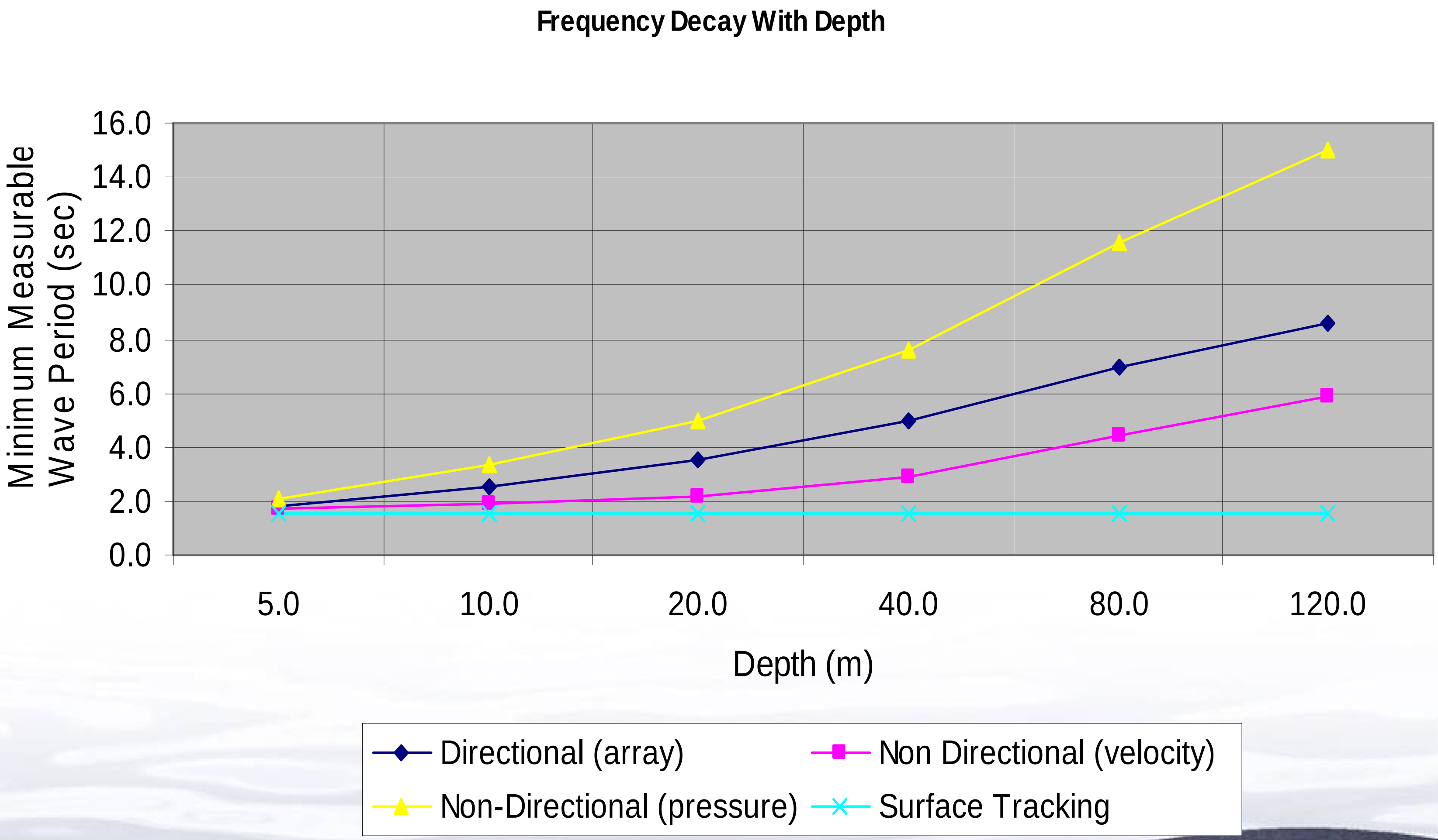
Depth Considerations

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Depth Considerations

- Wave energy attenuates exponentially with depth.
- The array approach requires orbital velocity sensor measurements to be translated to the surface.
- A velocity measurement includes both Signal and Noise. When we translate the measurements we translate the signal AND the noise. As the S/N ratio drops more noise is showing up in the higher frequencies of the spectrum.
- Because of this we need an automated way of obtaining an upper cutoff frequency based on depth of measurement.
- For vertical systems this is less of an issue because our measurement is close to the surface. For Horizontal systems our measurement is typically at instrument depth which can be anywhere from 5-30 meters (or more).

Depth Considerations



TELEDYNE RD INSTRUMENTS
A Teledyne Technologies Company

Depth Considerations

- **WHAT WE CHANGED:**
- **Mount the instrument as shallow as possible so that it is always submerged (and then some to account for beam dispersion and the maximum wave trough you expect to encounter).**
- **If you need to mount deep then try pointing the beams slightly up so you get higher in the water column towards the end of your profiling range.**
- **We automated our upper cut-off frequency calculation.**

Directional Noise Floor

Directional Noise Floor

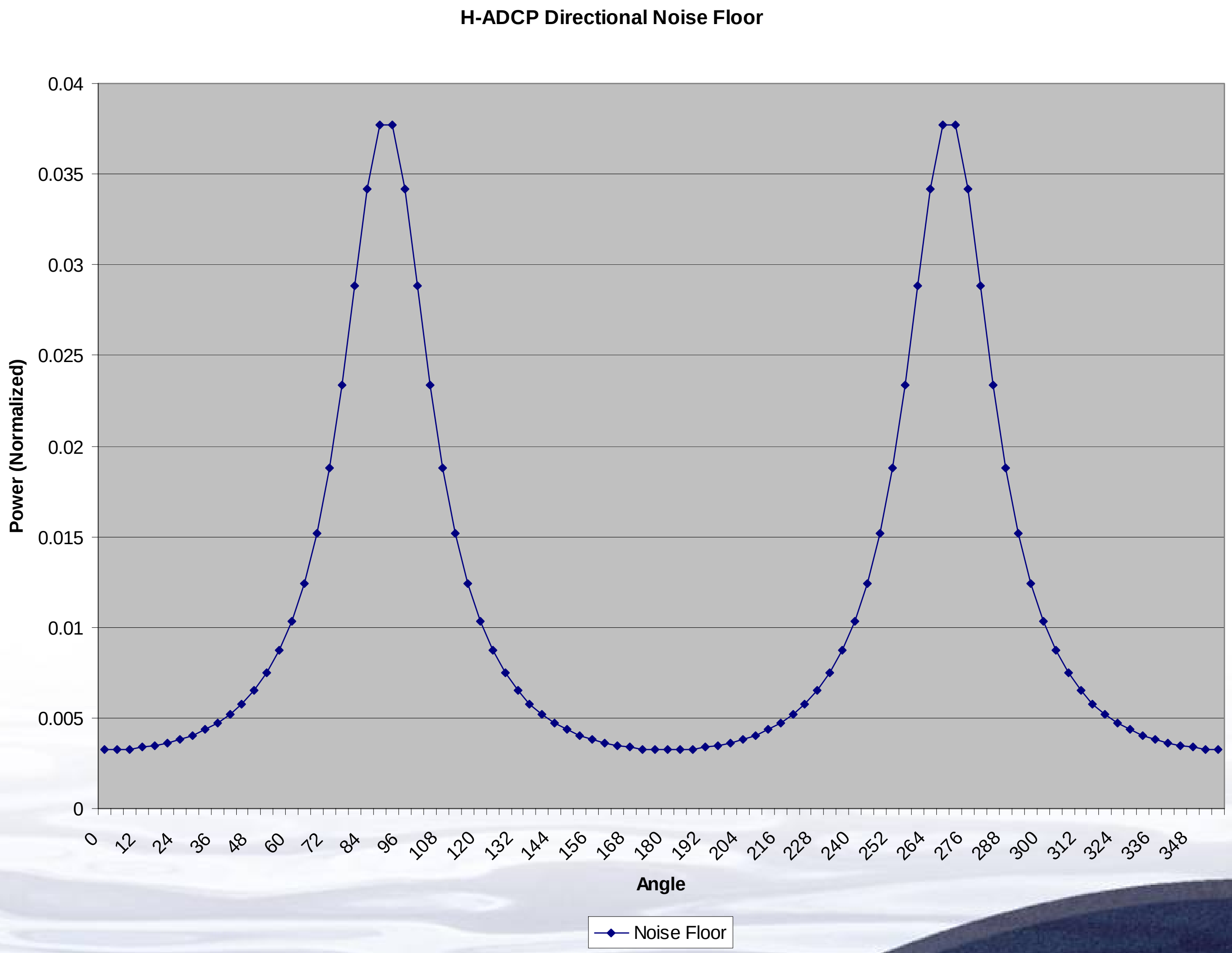
- Horizontal Wave Gages can only measure the component of the orbital velocities that are projected down the beam.
- If wave energy is propagating perpendicular to the beam then very little velocity is projected down the beam and hence very little of the wave is measured.
- At the same time the noise is isotropic – evenly spread over all directions.

Directional Noise Floor

- The anisotropic signal mixed with isotropic noise results in a directionally dependant S/N ratio.
- In our worst case scenario, the consequences of waves coming from the side is a S/N ratio that is approximately 12 times worse than it would be if the waves arrived straight on.

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Directional Noise Floor

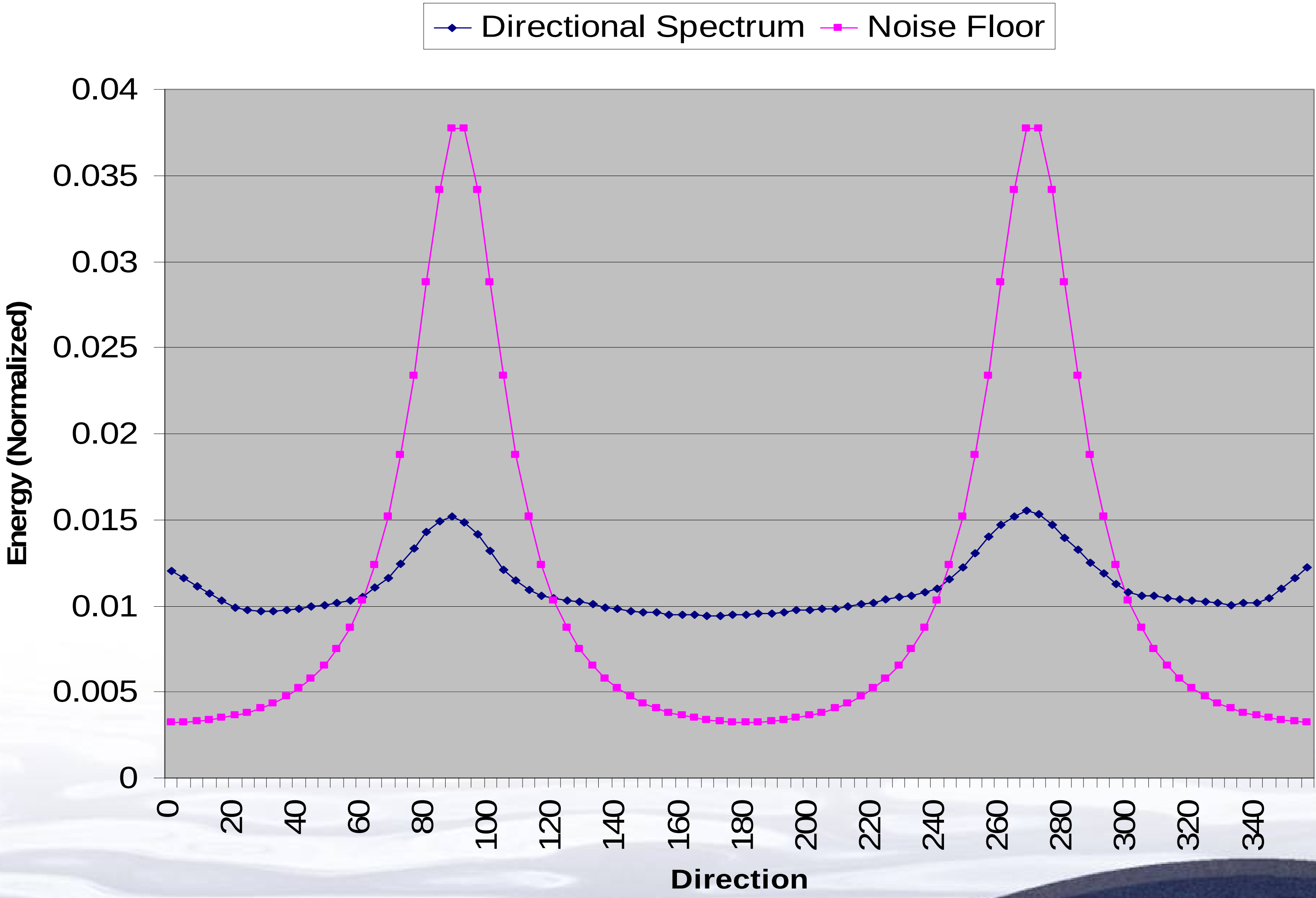


TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Directional Noise Floor

- We use the Maximum Likelihood Method (MLM) to determine directional spectra.
- This method essentially looks for where waves aren’t to quantify where they are.
- With an isotropic noise floor we can get misleading directional spectra.

Directional Noise Floor

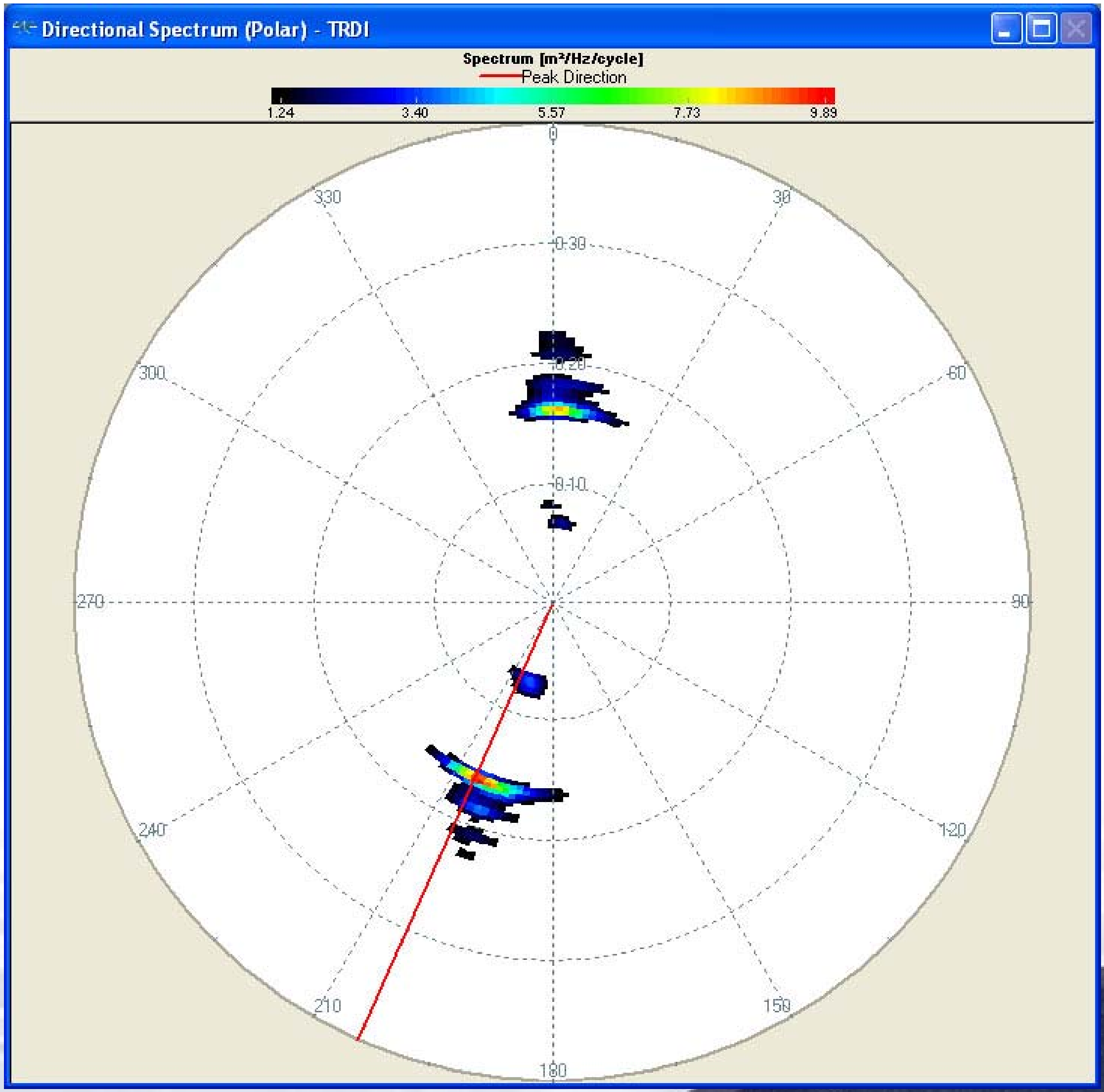


TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Directional Noise Floor

- Since we scale our directional spectra by our non-directional spectra we only run into problems when there is measurable (but not dominating the noise) non-directional energy.
- This is when we see noise floor “wings”.

Directional Noise Floor

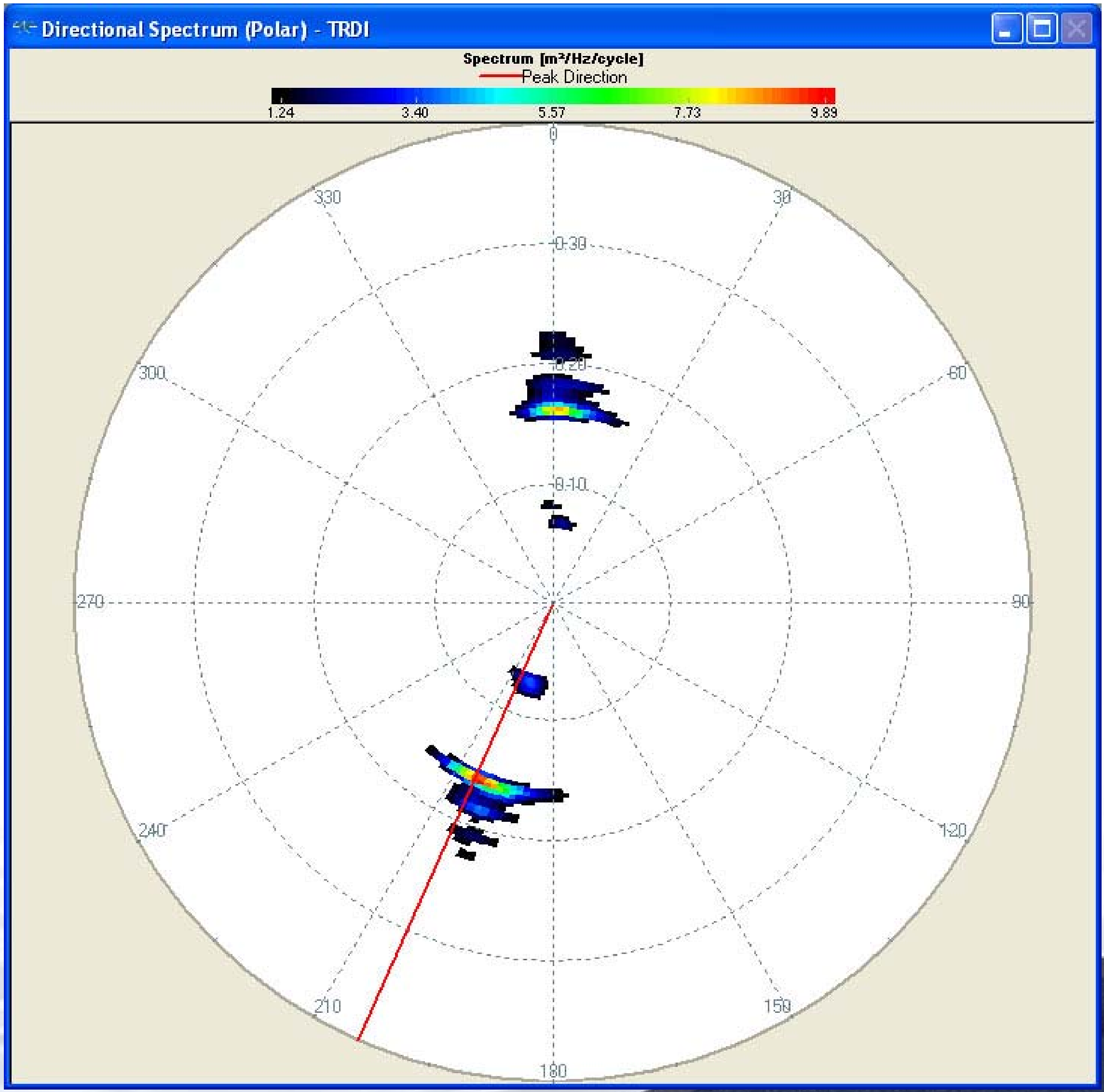


TELEDYNE RD INSTRUMENTS
A Teledyne Technologies Company

Directional Noise Floor

- If the energy in the non-directional spectra at a given frequency band is large enough then it can be the case that this frequency band is picked as the peak. In this case, unless the wave energy dominates then we will pick the noise floor "wings".
- This can result in a miscalled Dp.

Directional Noise Floor



TELEDYNE RD INSTRUMENTS
A Teledyne Technologies Company

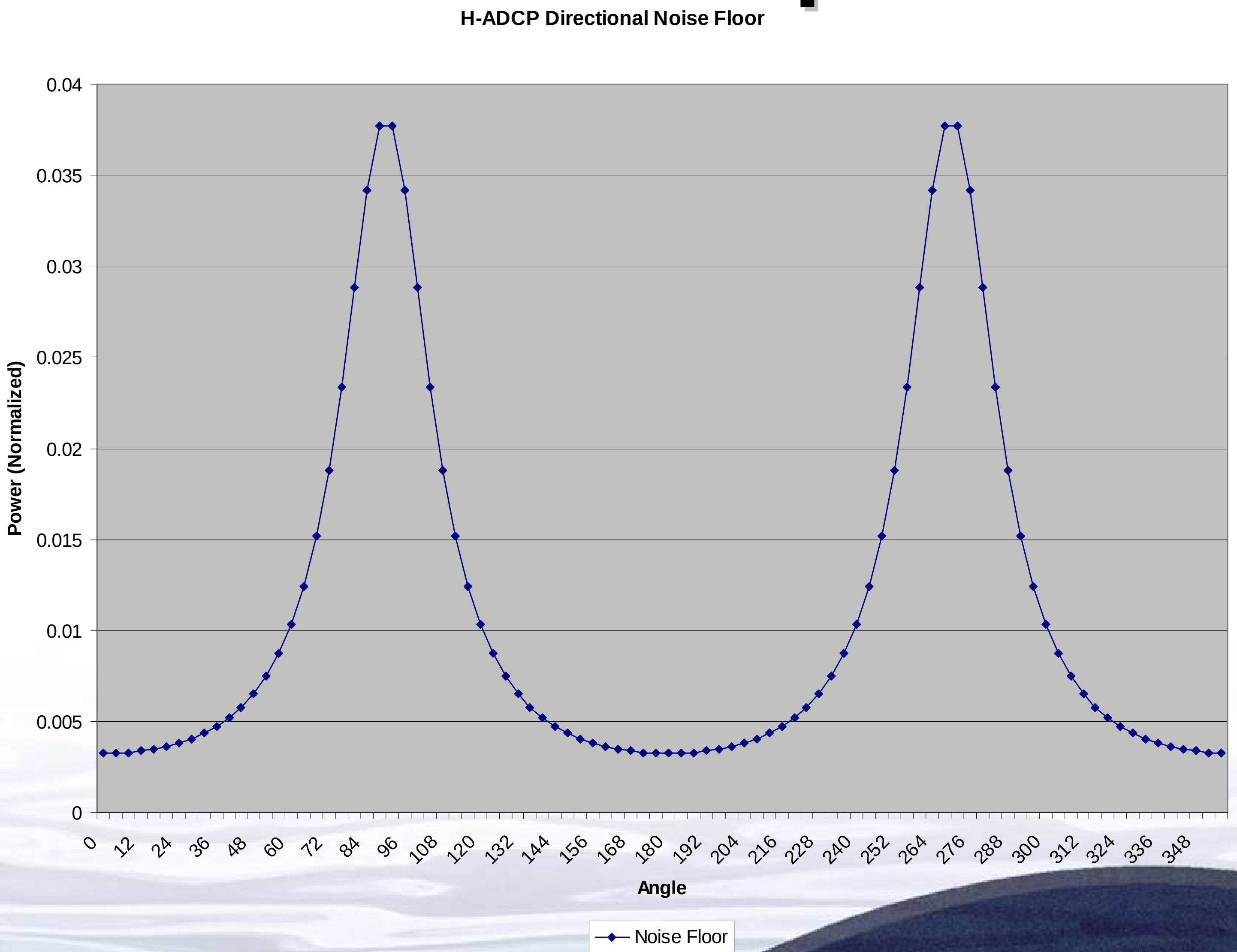
Directional Noise Floor

- WHAT WE CHANGED:
- When possible try to mount the H-ADCP so that it points into the wave energy. For instance if you are mounting it to a pier have it face the ocean, not the beach.
- Employ a directional noise floor squelching algorithm [see below].

Noise Floor Squelch

- The high-level approach is simple. We subtract the theoretical noise floor from the directional spectra, and are left with the directional spectra from the signal only.

Noise Floor Squelch

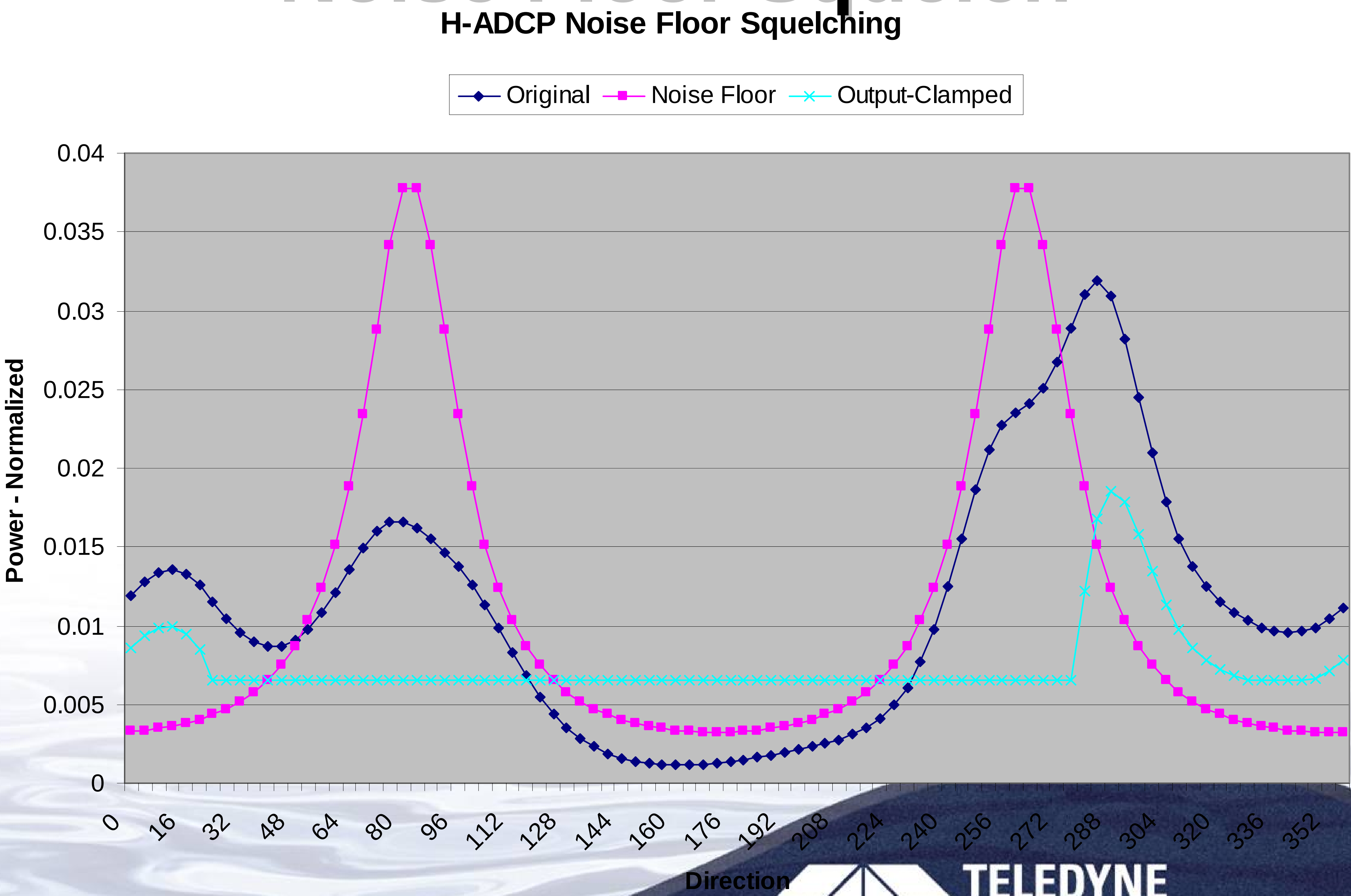


TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Noise Floor Squelch

- We employ screening criterion to make sure that only signal that is greater than the noise floor by a certain factor is left.

Noise Floor Squelch

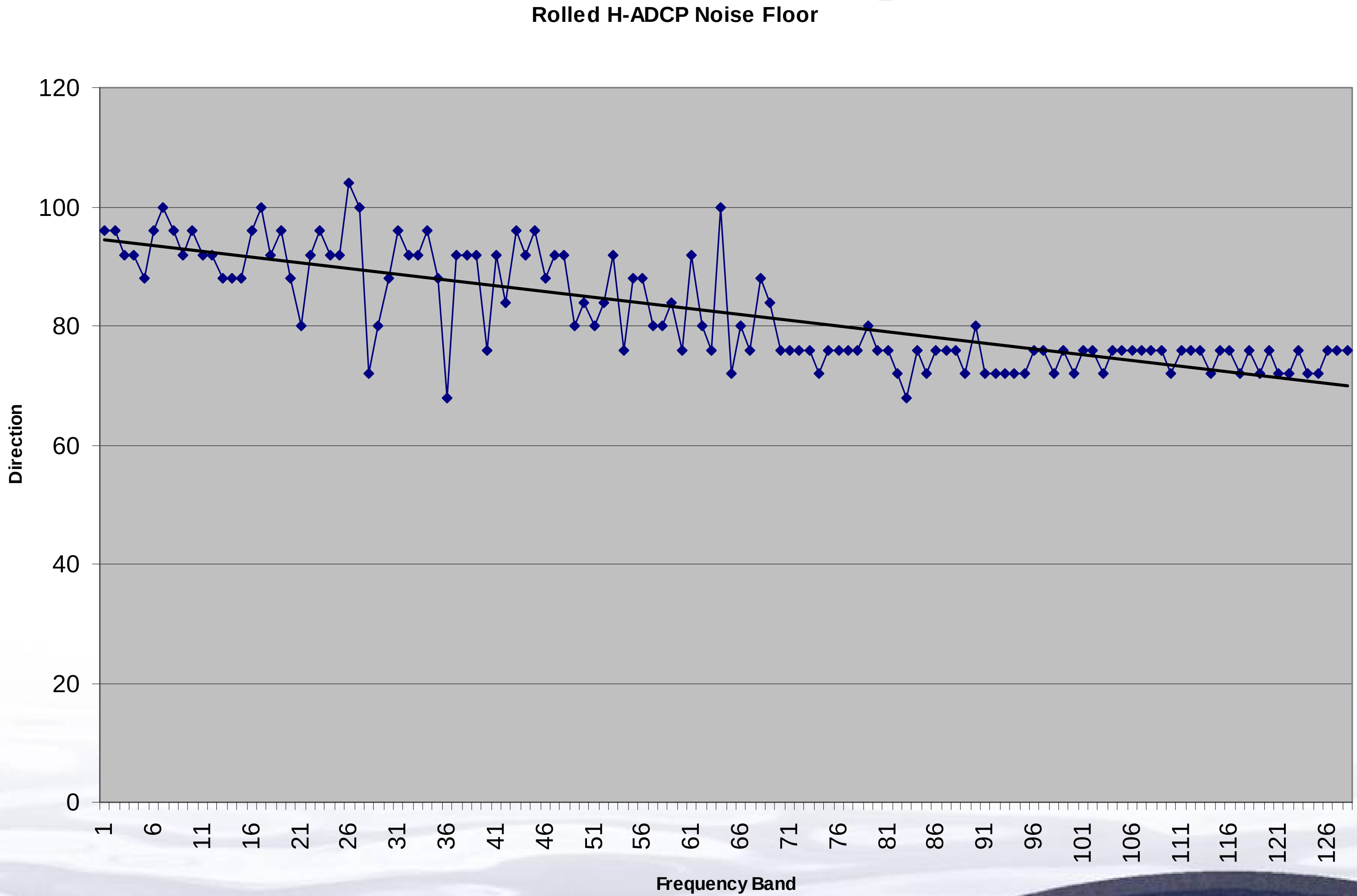


TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Noise Floor Squelch

- After analyzing results from a number of data sets we discovered that the noise floor was not always showing up where we expected it to be.
- Sometimes it would be shifted by as much as 20 degrees.
- It turns out that the noise floor is also dependant on instrument roll.
- So we have to model this as well, based on instrument roll before we subtract it out.

Noise Floor Squelch



TELEDYNE RD INSTRUMENTS
A Teledyne Technologies Company

Usage Notes on sinh()/cosh()

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Usage notes on sinh()/cosh()

- When we started to deploy instruments in deep water we discovered that the waves algorithm was slowing down significantly (exponentially) with depth.
- After some investigation we discovered that the slow-down was related to the translation of horizontal and vertical components of orbital velocity to surface displacement.

Usage notes on sinh()/cosh()

- The equations in use are of this form:

$$F = \cosh(k(h+z))/\sinh(kh)$$

- When h gets large the numerator and denominator can be on the order of 10^{250}, or greater (or even NaN or Infinity)
- What we are after – the ratio of the two, may have a small value – such as 20.

Usage notes on sinh()/cosh()

- The solution is to express the sinh() and cosh() as exponentials using:

$$\cosh(x) = (e^{x} + e^{-x})/2$$

$$\sinh(x) = (e^{x} - e^{-x})/2$$

- By factoring out terms we are left with:

$$F = (\exp(kz) + \exp(-2kh - kz))/(1 - \exp(-2kh))$$

TELEDYNE RD INSTRUMENTS
A Teledyne Technologies Company

Usage notes on sinh()/cosh()

- We are using the standard c++ double precision floating-point libraries and Microsoft VS-2005.
- It appears that the exp() routine is more robust than the sinh() and cosh() routines. It converges to a solution much more quickly.
- If you are using the hyperbolic trig functions in your routines – take close note to the magnitude of the arguments passed!!

Future areas of Development

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Future areas of Development

- **More automated Software Solutions – industrial applications are looking for highly automated, consolidated reporting of oceanographic parameters.**
  - **Dp, Hs, Tp**
  - **Navy Sea-state: 1-10**
- **Better handling of platform motion.**
- **We would like to be able to measure waves and currents from a moving boat eventually.**
- **Exporting Fourier Coefficients for Cross-Comparison.**
- **Sea and Swell Identification.**
- **Let us know what you are looking for.**

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

Conclusions

Conclusions

- **H-ADCP’s can be used from a wide array of measurement platforms.**
- **Many of these platforms represent unique mounting opportunities to H-ADCP such as Ships, Rigs, Container Buoy's, etc.**
- **H-ADCP’s record current information as well as calculating Wave Parameters, temperature, salinity, HPR, etc…**

Conclusions

- We have to take care with H-ADCP since it by default measures in Narrow-Band Broadband Mode. The new WavesMon addresses this.
- We want to mount H-ADCP's as close to the surface as possible, and pointed slightly up (2-5 degrees).
- Because of the beam geometry there is an inherently isotropic S/N ratio. This is accounted for in the new WavesMon.
- Take care of the magnitude of the arguments when using Hyperbolic Trig. functions, as you can experience significant slow-down when >50.

THANK YOU!

- Thank You for having me at Scripps Institute to talk about H-Waves!!
- David Brooks, from Teledyne RD Instruments.
- Email: dbrooks@teledyne.com
- Phone: (858)842-2766

- Questions?