

Welcome to the Currents and Turbulence Measurements Workshop

- Bret Webb, PhD, PE, DCE – University of South Alabama
 - Civil Engineering Lab Facilities, Flume and Wave Basin
- Jeremy Hancyk – Rockland Scientific
 - Microstructure turbulence measurement instrumentation
 - Integrated with Vector in Flume
- Chris Kontoes – NortekUSA
 - Aquadopp HR Profiler in Wave Basin
- Mike Cook, PhD – NortekUSA
 - Vectrino Profiler in Flume

Agenda



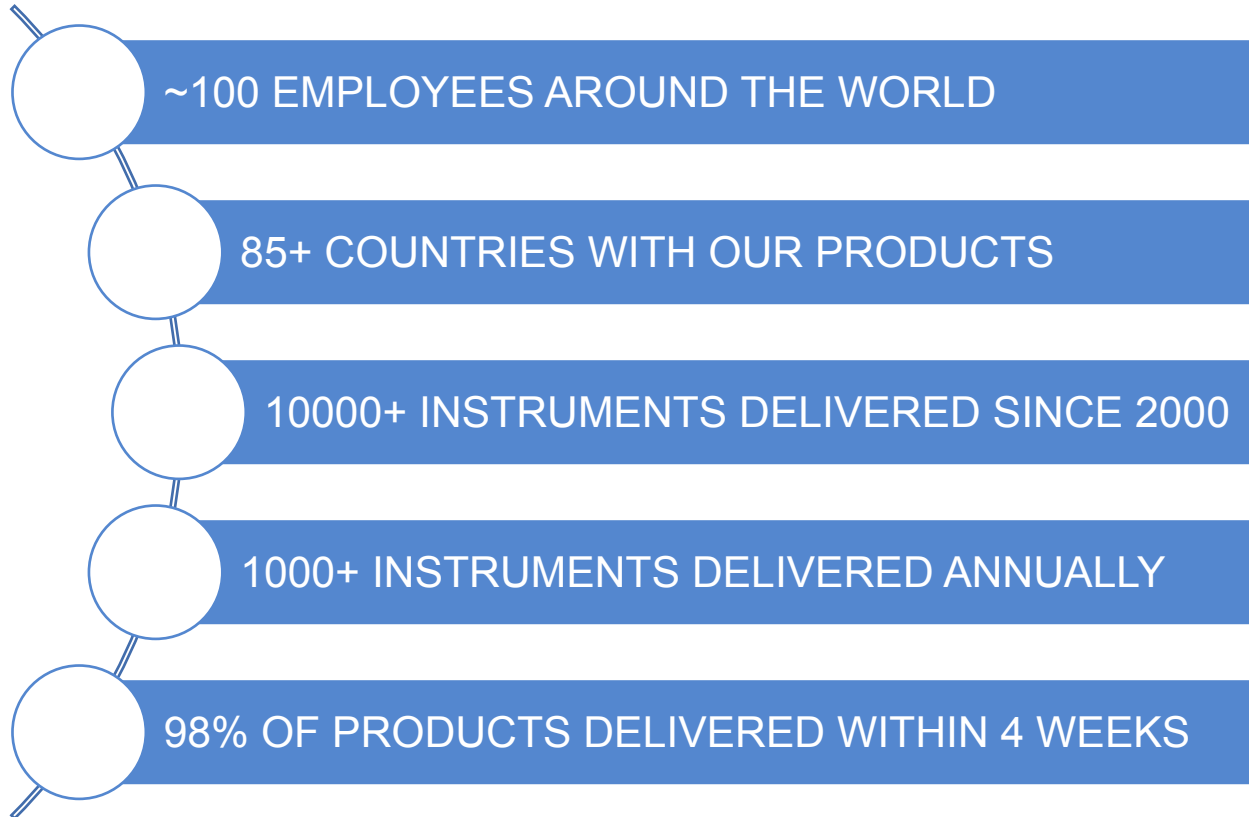
TRUE INNOVATION MAKES A DIFFERENCE

9:30-9:45	Welcome and Introductions
9:45-11:00	Explanation of the facilities & technologies
11:00-12:00	Break into two groups (Wave Basin and Flume)
12:00-1:30	Catered lunch
1:30-2:30	Break into two groups (go to new station)
2:30-3:30	Time for hands-on and applications questions
3:30-4:30	General data review and questions (snack)
4:30-5:00	Closing

Who is Nortek?



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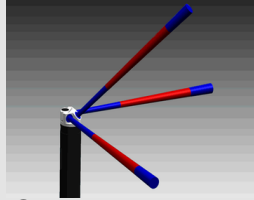
More about Nortek



TRUE INNOVATION MAKES A DIFFERENCE



Velocimeters



Current Meters



Current Profilers



Wave Systems



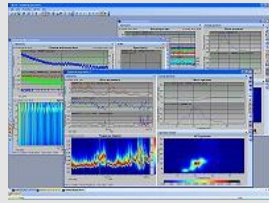
External sensors



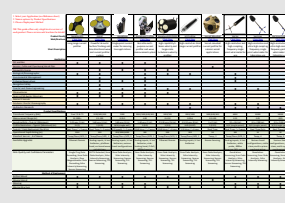
Online Systems



Vessel Mounted Profilers



Software



Quick Guide

Goal of the Workshop

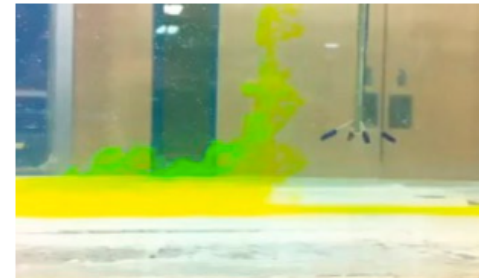
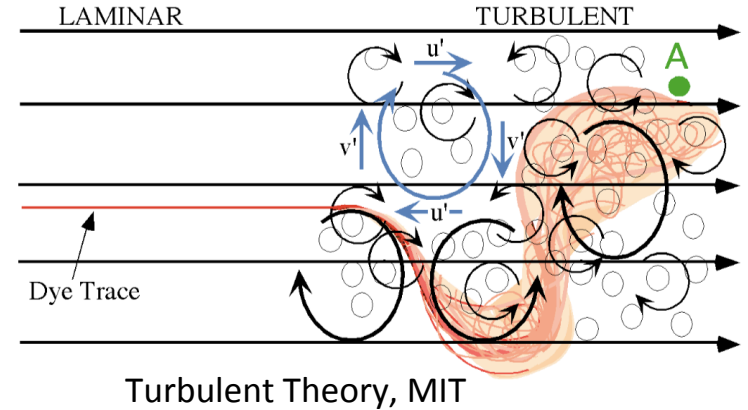


TRUE INNOVATION MAKES A DIFFERENCE

- Present concepts of turbulence and velocity measurements
- Provide background information on how instruments work
 - Basic Acoustic Principles
 - Describe Pulse Coherent Processing
 - Why is Pulse Coherent Processing important
- Instruments used in workshop
 - Vectrino Profiler
 - Vector, integrated with Rockland Sensors
 - Aquadopp HR Profiler
- Data outputs and quality considerations

Turbulence and Velocity (1)

- What is turbulence?
 - Flow regime characterized by chaotic property changes
 - Important factor for mixing, transport, energy dissipation
 - Detailed data analysis can be applied to determine more information
 - Reynolds Stresses
 - Turbulent Kinetic Energy (TKE)
 - Many more parameters

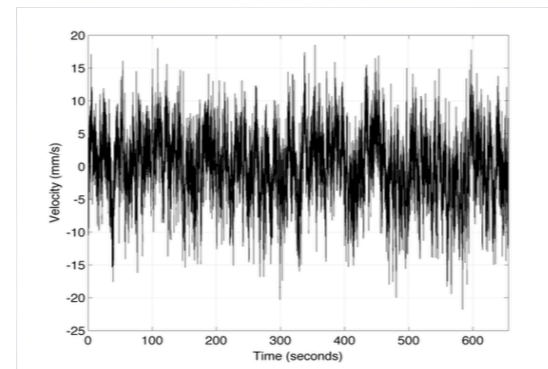
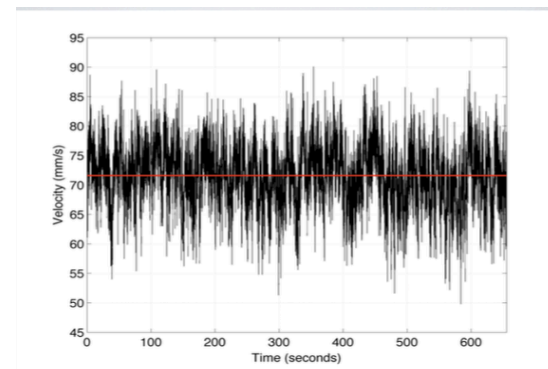


Turbulence and Velocity (2)



TRUE INNOVATION MAKES A DIFFERENCE

- Velocity Measurements
 - High resolution velocity measurements allows one to understand small scale motion
 - Also allows us to understand velocity components of the water
 - Take the mean of the times series (red line) and subtract it from the individual observations gives you small fluctuations
 - Note change in vertical scale below
- This is just the beginning...
 - Velocimeters, Current Profilers, Microstructure turbulence sensors allow for data collection and to dig deeper
 - Statistical analysis can help us understand bulk flow parameters (dissipation, stress, etc.)



- **Monostatic vs. Bistatic**
 - Monostatic – same transducer transmits and receives (current profilers)
 - Bistatic – dedicated transducers to transmit and to receive (velocimeter)
- **Point Velocity vs. Profiler**
 - Point Velocity - sampling volume at known distance from the instrument (velocimeter)
 - Bistatic; with central transmitter and separate receiver “arms”
 - Profiler measures velocities in cells or discrete layers after a blanking distance (Current Profiler)
 - Monostatic; transducers send and receive signals

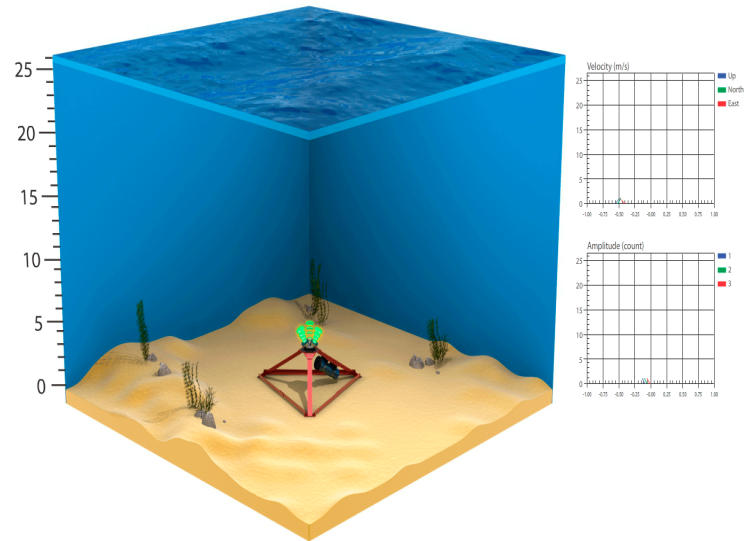
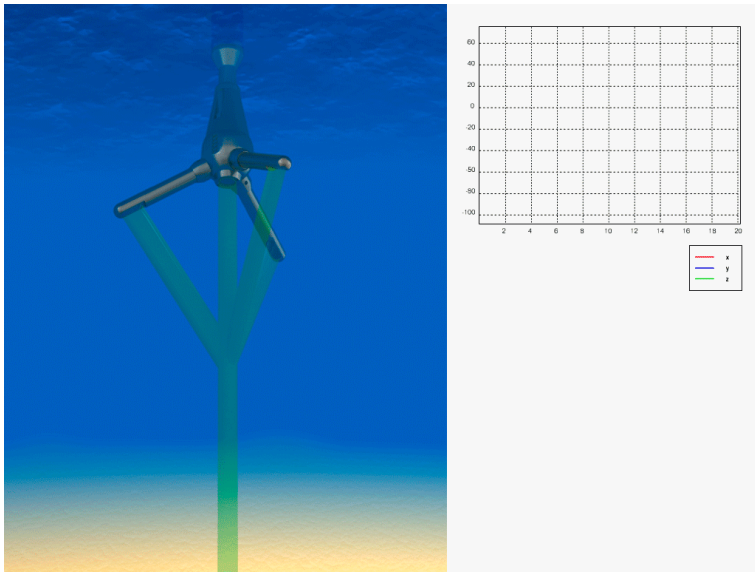
Velocimeter vs. Current Profiler



TRUE INNOVATION MAKES A DIFFERENCE

- Bistatic – Velocimeter

- Monostatic – Current Profiler

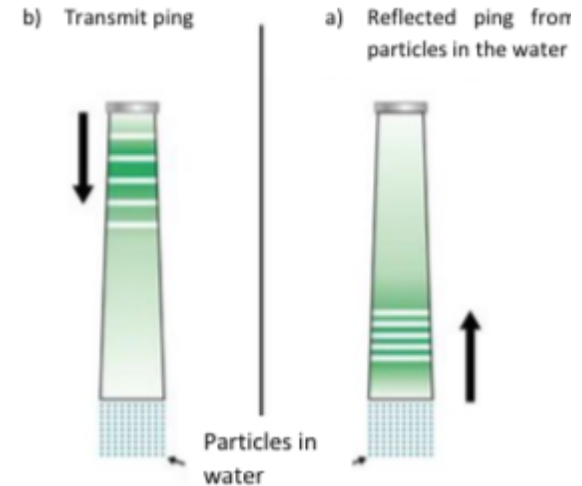
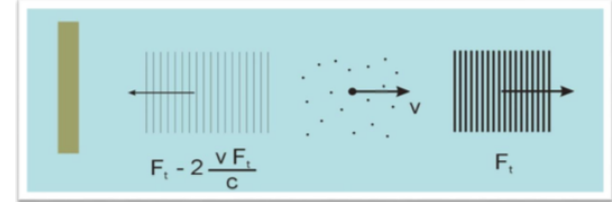


The Doppler effect (1)

- Acoustic Doppler instruments use the Doppler effect to measure current velocity by transmitting a short pulse of sound, listening to its echo and measuring the change in pitch or frequency of the echo.
- These signals reflect off small particles in the water such as bubbles, fine silt or plankton, which at the travel at same velocity as the water.

$$V = \frac{F_{Doppler}}{F_{Source}} * \frac{C}{2}$$

- V , current velocity
- $F_{Doppler}$, change in received frequency
- F_{Source} , known frequency transmitted
- V is the velocity of the water/particles
- C is the speed of sound in water



The Doppler effect (2)

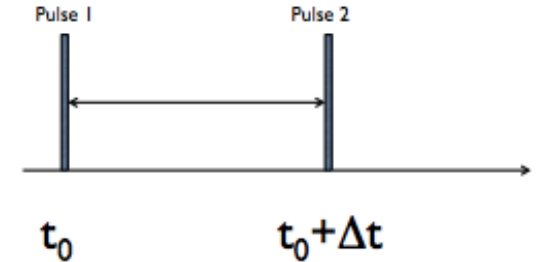


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- Multiple processing techniques to measure water velocity using the Doppler effect
 - Narrowband
 - Positive: Robust estimator, optimal range, measure close to boundary
 - Drawback: Requires data averaging, higher power consumption*
 - Broadband
 - Positive: Great single ping data, power efficient, long deployments
 - Drawback: Reduced range when compared to Narrowband
 - Pulse Coherent
 - Positive: Excellent single ping data, power efficient, long deployments
 - Drawback: Reduced range compared to Broadband, detailed setup
 - Important takeaway, Nortek uses all three processing techniques and are utilized based on application and typical monitoring goals
- The Velocimeters and Current Profilers used for the workshop utilize Pulse Coherent processing

Pulse Coherent Processing

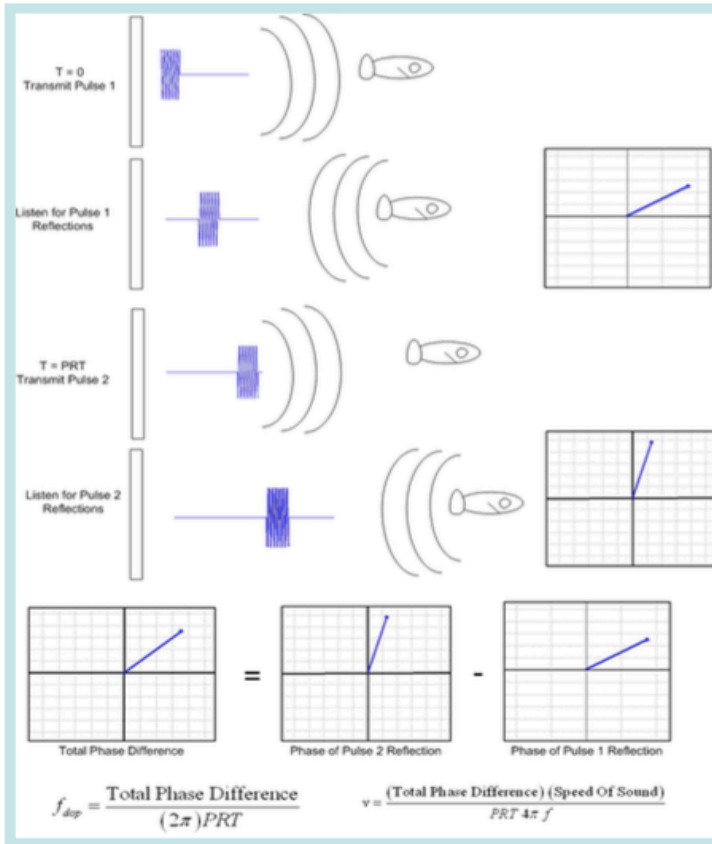
- The Doppler shift (Δf) is estimated from a change in phase between two signals ($\Delta \phi$)
 - Ping-listen-ping-listen; one ping in the water at a time
- For a given ping interval, there is a maximum measurable velocity, we call this the Velocity range
 - From the equation, the time between pulses has an impact on V_{max}
 - There are lag time tradeoffs between maximum velocity, profile range, cell size and sample rate (software)
- Most important to select good/representative velocity range (that is definitive of your monitoring location)



$\Delta t = \text{Lag, or PRT}$
(Pulse Repetition Time)

$$v_{max} = \frac{c}{4f\Delta t}$$

Pulse Coherent Processing – Practical Example



$t=0$, transmit pulse 1

$t>0$, $t<\Delta t$, listen to pulse 1

$t=\Delta t$, transmit pulse 2

$t>\Delta t$, $t<2\Delta t$, listen to pulse 2

The received signals are expressed as complex numbers (an in phase and quadrature component), making it relatively simple to calculate $\Delta\phi$.

Repeat...

Pulse Coherent Processing: Ambiguity Velocity



TRUE INNOVATION MAKES A DIFFERENCE

- Limited velocity data range due processing constraints - data beyond set range leads to phase wrapping
- ϕ (and $\Delta\phi$, phase) is unambiguously defined for $\pm\pi$
- This leads to a maximum measurable velocity, V_{\max}
- Velocities greater than V_{\max} lead to phase wrapping
 - User sets a nominal velocity range
 - Software sets the appropriate lag

$$v = \frac{c\Delta\phi}{4\pi f \Delta t}$$

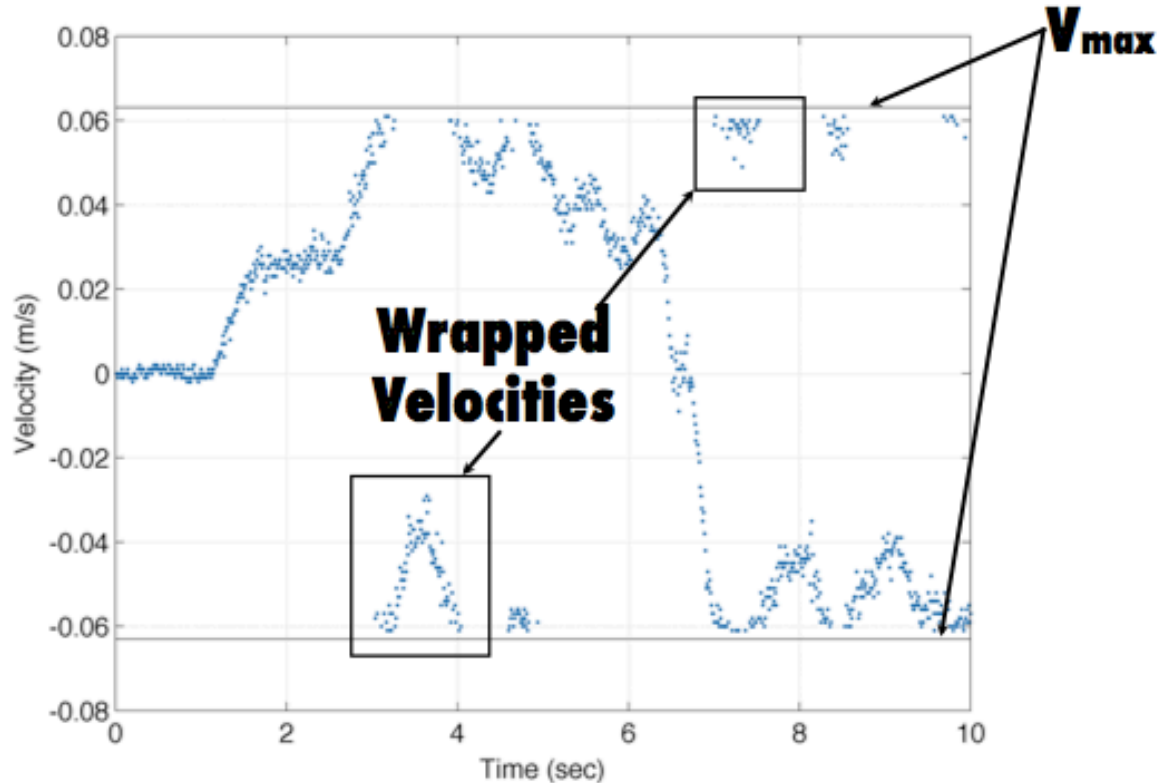
$$v_{\max} = \frac{c}{4f \Delta t}$$

f = carrier frequency (10 MHz)
c = speed of sound

Pulse Coherent Processing: Ambiguity Velocity



TRUE INNOVATION MAKES A DIFFERENCE

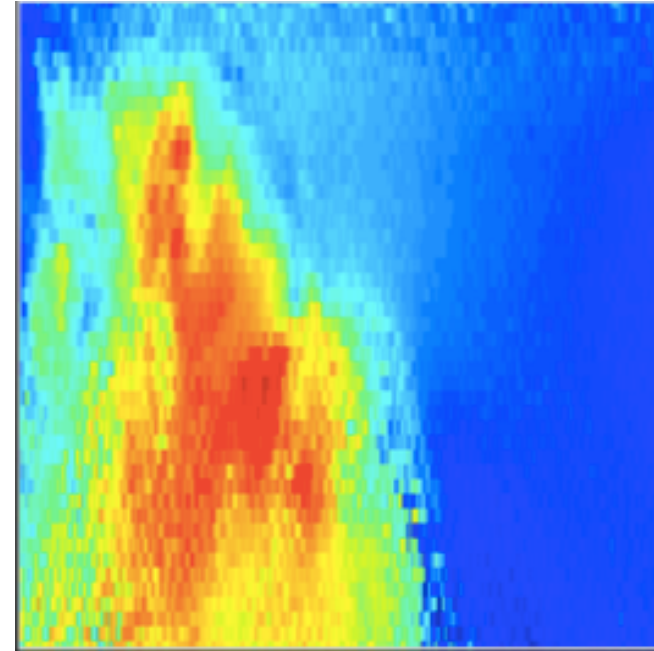


Pulse Coherent Processing (3)



TRUE INNOVATION MAKES A DIFFERENCE

- Why Pulse Coherent Processing?
 - High precision single ping velocity data
 - Typically, no averaging necessary
 - Allows for high sampling rates/high spatial resolution (mm)
 - Great for complex flows
- Considerations
 - Complex instrument – need to know your flow
 - Nortek software, simplified setup based on nominal velocity



Instruments used in workshop



TRUE INNOVATION MAKES A DIFFERENCE

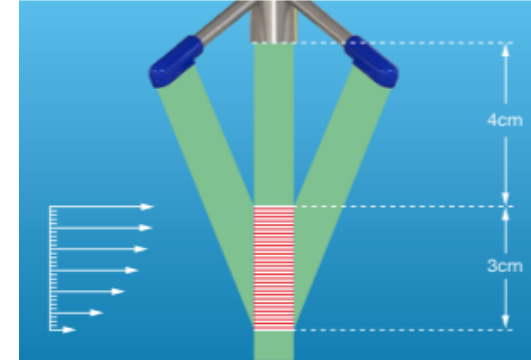
- Vectrino Profiler – Flume (Station 1)
 - 10MHz Velocimeter
 - Laboratory applications, small head, minimizes flow disturbance
- Vector, Integrated with Rockland Scientific Sensors – Flume (Station 1)
 - 6 MHz Velocimeter
 - Field rugged
- Aquadopp HR Profiler – Wave Basin (Station 2)
 - 2 MHz Current Profiler
 - Field or lab applications

Vectrino Profiler (10MHz)



TRUE INNOVATION MAKES A DIFFERENCE

- **Very Small, 4-beam head**
 - Causes less flow disturbance
 - Two independent vertical velocity estimates
- **Features**
 - Velocity range 0.1 to 3 m/s
 - Up to 100 Hz velocity measurements
 - Interleaved 10 Hz bottom distance measurements
 - Facilitates turbulence measurements
 - Synch to other Vectrino Profilers
- **Profiling**
 - User-adjustable 35 mm range, 1 mm cells
 - Allows measurement of ultra-small turbulence phenomena

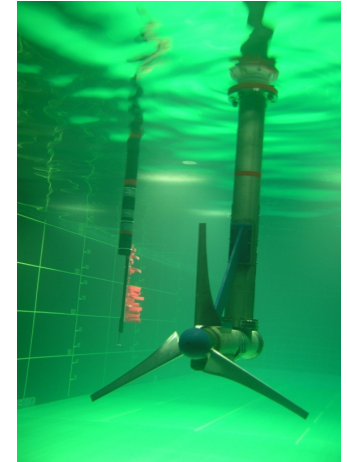
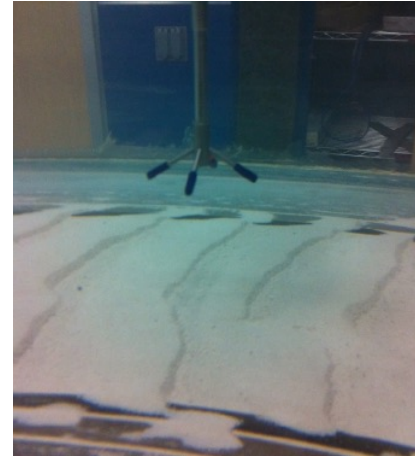


Vectrino Profiler - Applications



TRUE INNOVATION MAKES A DIFFERENCE

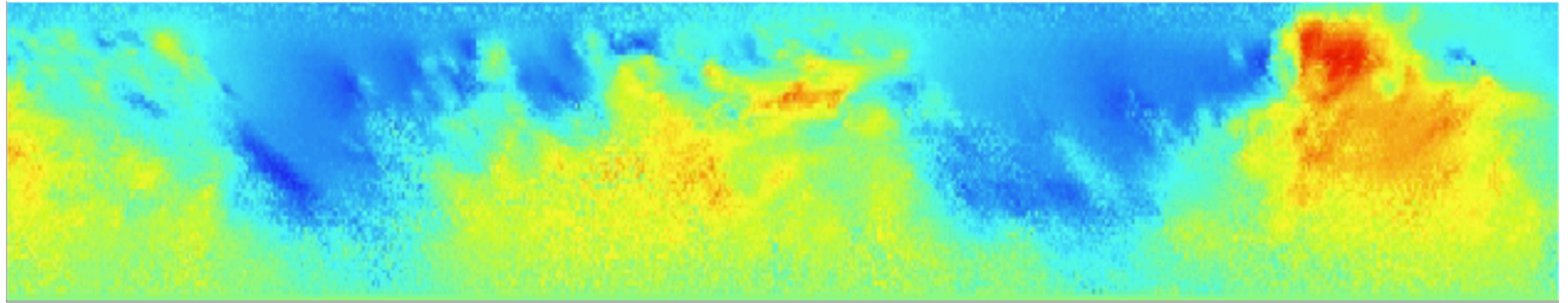
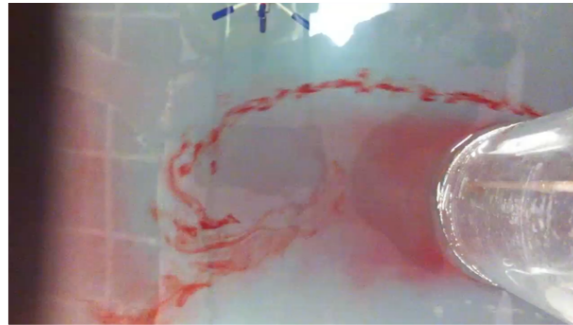
- Turbulence and mean flow in laboratories
- Turbulence and shallow flows (swash zone, shallow streams, marshes)
- Boundary layer studies
- Field studies where Vector is too large or a high sampling rate is needed



Vectrino Profiler Data Example



TRUE INNOVATION MAKES A DIFFERENCE



Vectrino – Sediment transport in a flume



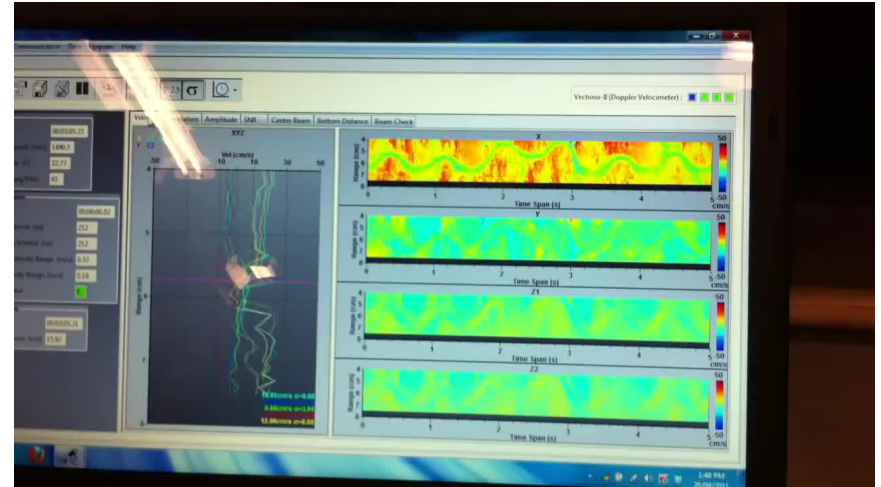
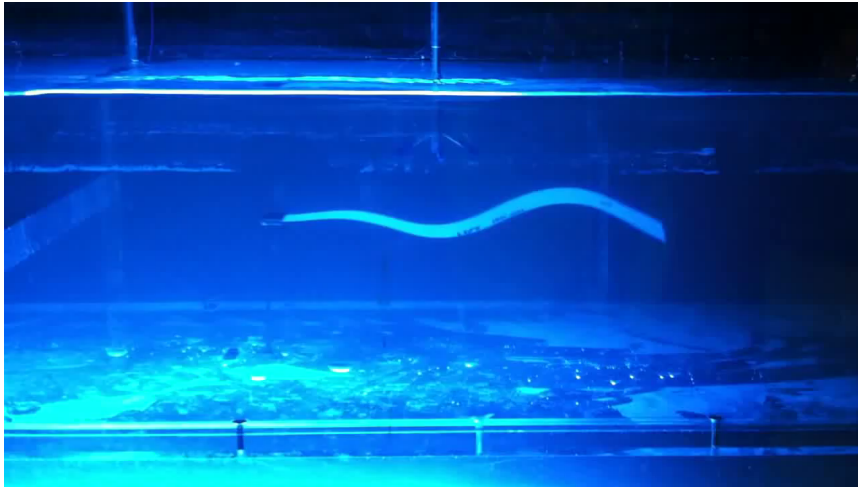
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Vectrino Profiler – Sea grass in a flume



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Vector velocimeter (6MHz)



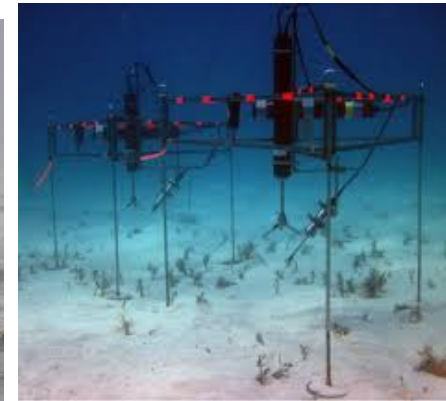
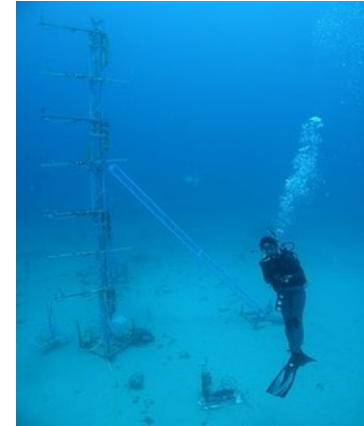
TRUE INNOVATION MAKES A DIFFERENCE

- Sample volume 15 cm from transmitter
- Velocity Range 0.01 to 7 m/s
- Flexible Configuration
 - Sampling rate up to 64 Hz (unique)
 - Option for 4000m rated housing
 - Tilt, Compass or IMU
 - Sync to other Vectors
- Analog inputs (stream data into Vector)
 - Turbidity, Fast CT, DO
- Small Size and Weight
 - 82 cm long, 1.5 kg in water
 - Makes it easy to work with

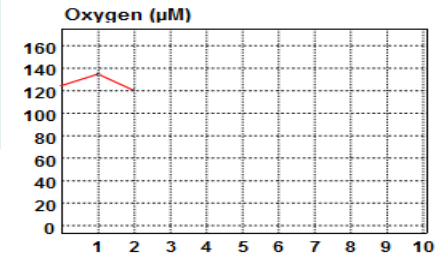
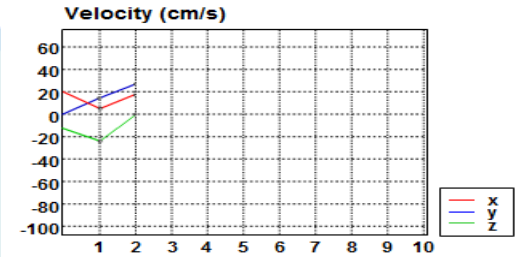
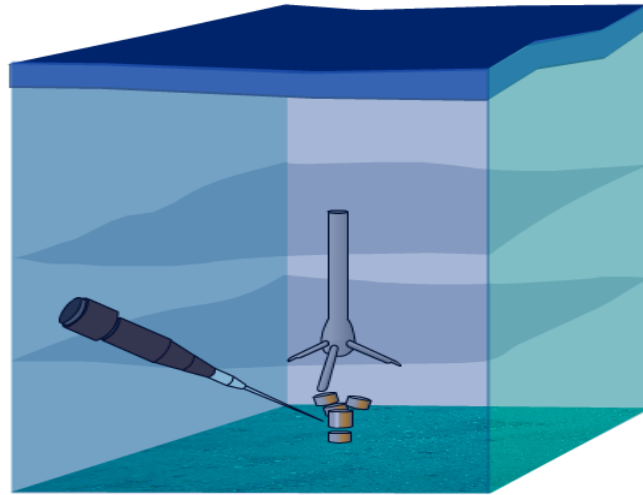
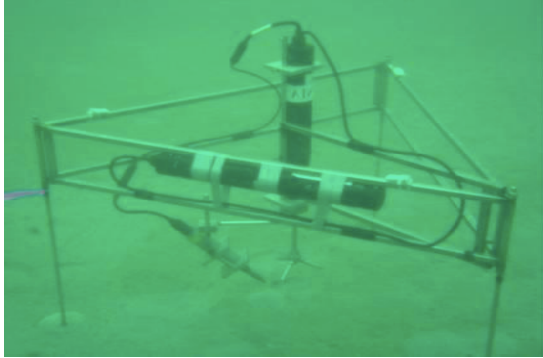


Vector - Applications

- Surf zone dynamics
- Bottom boundary flows
- Wave orbital studies
- Wave and current monitoring
- Turbulence studies
- Eddy Correlation



Vector Application - Eddy correlation

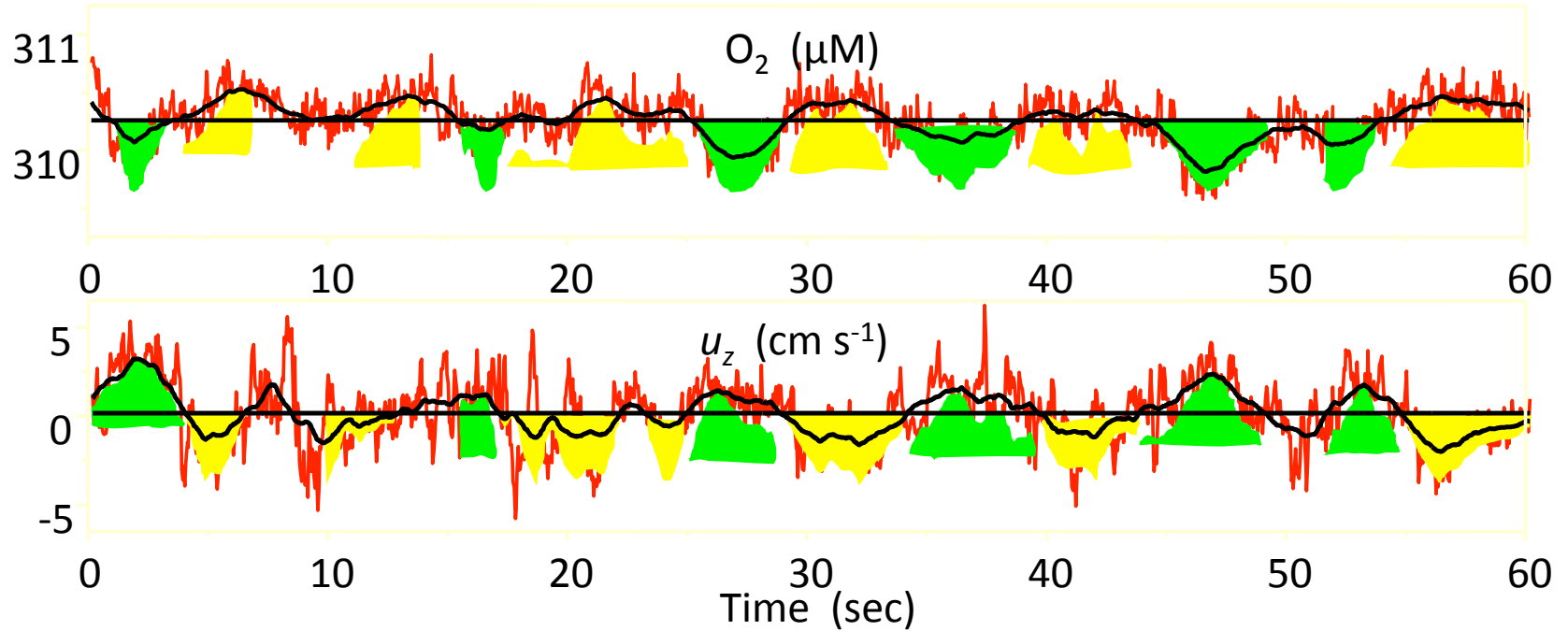


Source: Peter Berg

Vector Application - Eddy correlation



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Time averaged vertical flux

Source: Peter Berg

NORTEK ©

Aquadopp Profilers - HR



TRUE INNOVATION MAKES A DIFFERENCE

- 1MHz and 2 MHz frequencies
- 3D Velocity Profiles
- Up to 8 Hz sampling rate
- As small as 7 mm cell sizes (128 cells)
- Reduced blanking distance 5 cm
- Flexible mounting options
 - Up, down, bottom, side, buoy, surface, mooring line, etc.
 - Custom transducer heads



Sidelooking



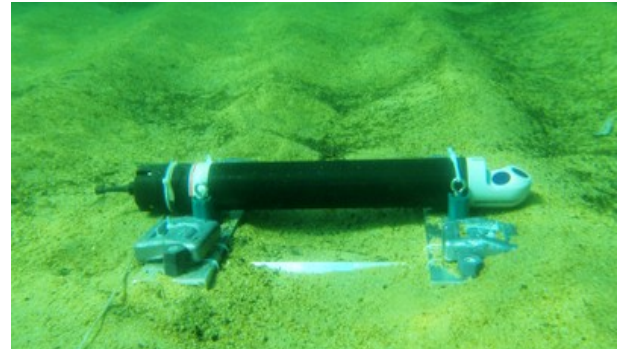
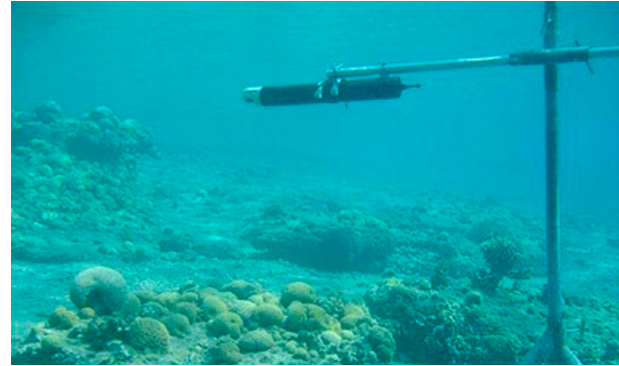
1MHz and 2MHz

Aquadopp Profilers - Applications



TRUE INNOVATION MAKES A DIFFERENCE

- 3D current information
- Boundary layer studies
- Internal waves
- Turbulence research
- Directional Waves
 - PUV method
 - Integrated pressure sensor

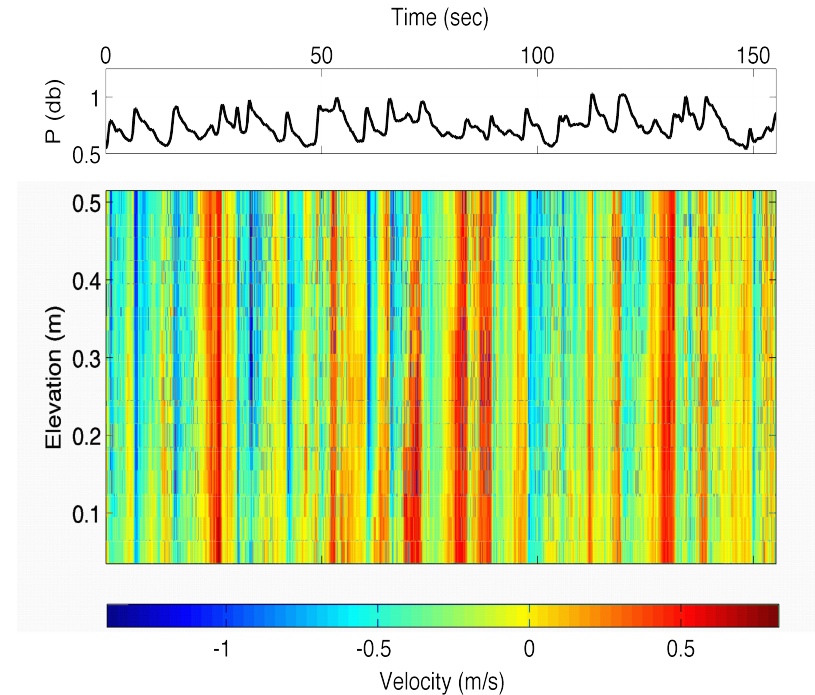
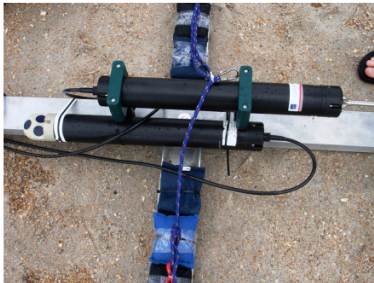


Aquadopp HR Profiler Data Example



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- Deployment of an HR Profiler off St. Augustine Beach, FL
- Dynamic conditions, with breaking waves
- High turbulence levels associated with the surf zone



Data Outputs and Quality Considerations



TRUE INNOVATION MAKES A DIFFERENCE

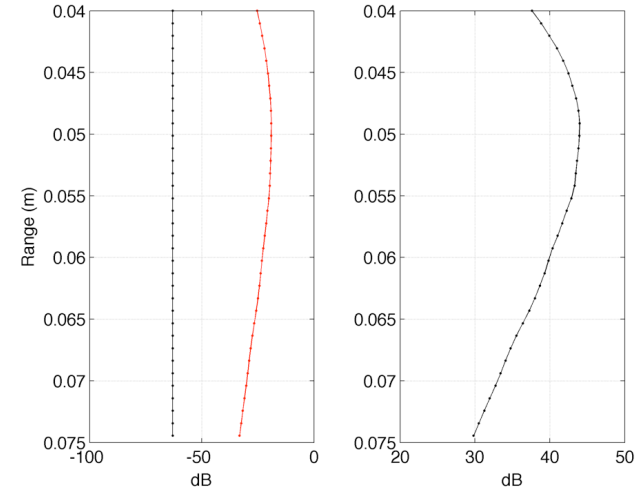
- SNR/Amplitude – Signal to Noise Ratio
 - Do we have enough scatters in the water?
- Correlation – Measure of signal quality
 - How does the Correlation data look?
- Pulse interference
 - Weak spots in the data

SNR (Signal to Noise Ratio) & Amplitude



TRUE INNOVATION MAKES A DIFFERENCE

- SNR - exactly that, expresses Amplitude (or return signal strength) relative to the instrument noise level in dB.
 - Related to amount of scatters in the water
 - More scatters - better; more signal (returned) compared to noise of instrument
 - Better measurement, minimizes influence of noise
- SNR too low?
 - May need to add scatters in the water (lab), if possible or adjust monitoring goals/expectations (field)
 - May need to check instrument power level



Data from Vectrino Profiler

- Measure of signal quality in percent, higher is better
- Mathematically correlation is reported as the norm of the normalized covariance of the return signals from pulse 1 and 2
 - Essentially, Correlation is the measure of the similarity of the two return signals
- Factors influencing Correlation
 - **SNR, Velocity Range Selection, Turbulence, Shear, Pulse Interference**

Correlation (2)

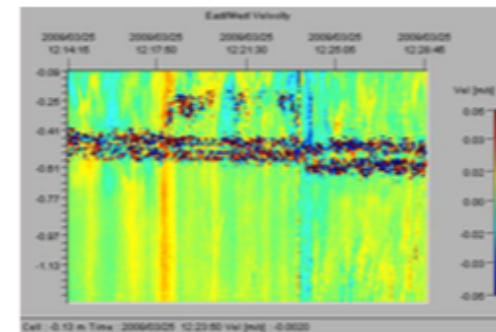
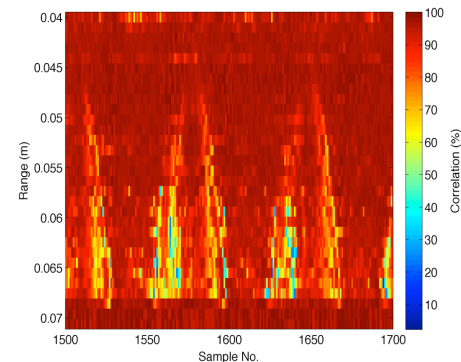
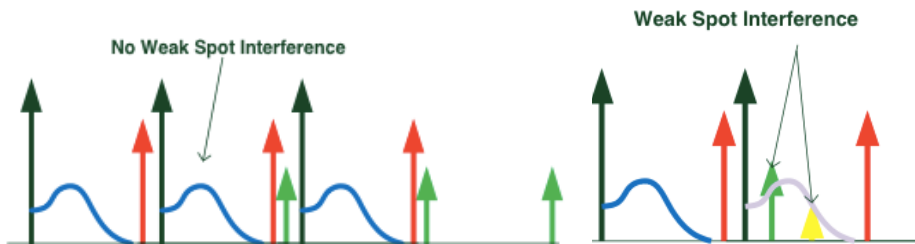


TRUE INNOVATION MAKES A DIFFERENCE

- We'd like the instrument to be sampling the same parcel of water and the same scattering particles
- If the lag is too long, particles will move out of the sample area leading to de-correlation
- Turbulence will change particle orientation, arrangement, concentration, etc. leading to de-correlation (dynamic conditions require a shorter lag, faster sampling)
- Pulse interference will cause poor correlation because there is a summation of signals being sampled
- Weak spots - Zones of poor correlation
 - Pings from previous samples interfering with existing sample
 - Adjusting velocity range can make a huge difference
 - Physical distance to boundary has an impact

Weak Spots

- Echoes from past pings can affect the present measurements
- Also referred to as pulse interference or weak spots
- These will generally show up as regions of higher amplitude and lower correlation
- Adjust nominal velocity and/or distance to boundary



Data Quality Considerations



TRUE INNOVATION MAKES A DIFFERENCE

- Pre-deployment tests are always suggested (in-situ, if possible)
 - Identifies potential problems, such as low SNR
 - Low SNR can cause a whole host of problems (decreased range, poor correlation)
 - Allows setting the appropriate V_{\max}
 - Minimizes potential for weak spots
 - Minimizes potential for phase wrapping
 - Make sure that you have the correct sampling interval
- Post data collection evaluation
 - Start with SNR, then correlation
 - Consider site and deployment conditions and mounting
- Potential corrections
 - Phase Wrapping (Beam Velocity)
 - Data filtering/screening – look at median and estimate of standard deviation, discard data 3-4 times the spread
- Good instrument setup goes a long way for quality data (see first bullet)

- Pulse Coherent processing in Velocimeters and Current Profilers is a very powerful tool
- Allows for the following:
 - High precision single ping velocity data
 - High temporal and spatial sampling
 - Small cell/bin sizes (mm scale)
- Instrument Setup
 - Complex instrument – need to know your site and instrument
 - Nortek software, simplified setup makes things a bit easier
 - Work through scenarios
- Need help? We have resources for you
 - Many technical documents
 - Nortek Forum (<http://www.nortek-as.com/en/knowledge-center/forum>)

Questions?



TRUE INNOVATION MAKES A DIFFERENCE

Thank you for your attendance!

Questions?

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What's NEW - Current profilers



TRUE INNOVATION MAKES A DIFFERENCE

- **Powerful AD2CP Platform** (US Patent 7,911,880)
 - Ethernet comms – fast download speed
 - Dual processor – multiple tasks at same time
- **Most Capable Turbulence Measuring ADCP Ever**
 - Direct measurement of vertical velocity—critical for turbulence measurements
 - Ping rates up to 16Hz
 - 30m/70 m range
 - Cell sizes as small as 0.2/0.5m
- **Proper Broadband Processing**
 - Frequency-based coding – very low noise velocity measurement



Signature500
Signature1000

NEW Current Profilers – Signature55



TRUE INNOVATION MAKES A DIFFERENCE

- **Powerful AD2CP Platform** (US Patent 7,911,880)
 - Ethernet comms – fast download speed
 - Dual processor – multiple tasks at same time
- Profiling range to 1000m
- Cell Sizes 5-20m
- Proper Broadband Processing
 - Frequency-based coding – very low noise velocity measurement



Signature
Series