

Development and field measurements with multi-frequency pulse-coherent Doppler systems... "Garage Doppler Development with a big garage"

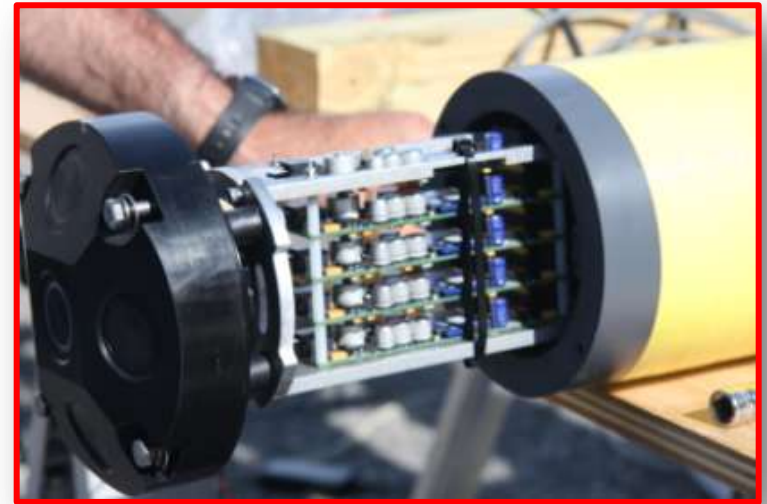


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Woods Hole Oceanographic Institution

Motivation: For turbulence and sediment transport

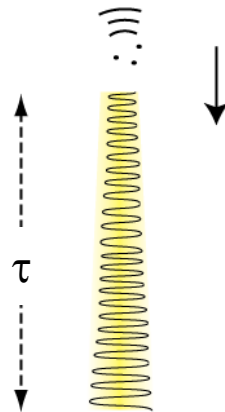
- High resolution: 0.5 -1 cm ,
- High sampling rate: 15- 30 hz,
- Accurate: 1 to 3 mm/s,
- Profiling: 1 – 2 m

1. Compare incoherent to pulse-coherent
2. Pulse Coherent Range Velocity Ambiguity
3. Multi-frequency Processing
4. Geometric Configurations
 Monostatic vs. Bistatic profiling
5. Data Examples:
 Hudson Estuary, Shipboard
 Louisiana Mud MURI 2010 / AquadopHR



In-coherent

(Auto-Correlation Method)



- $\tau = 130 \mu\text{s}$
- $L = C\tau/2 = 10 \text{ cm}$
- $\sigma_w = 1.4 C / 4\pi f_0 \tau = 64 \text{ cm/s}$
- $N_{\text{avg}} = 30 (1 \text{ s});$
 $\sigma_w = 11.5 \text{ cm/s}$
- $N_{\text{avg}} = 30 (60 \text{ s});$
 $\sigma_w = 1.5 \text{ cm/s}$

Low Velocity Variance requires long pulses (poor spatial resolution) and long averaging (low temporal resolution ~ 60 s)

Pulse-coherent



Can have Low Velocity Variance with short pulses (good spatial resolution) and short averaging (high temporal resolution ~ 1 to 30 Hz)

$L = 1 \text{ cm}$
(set by SNR and correlation)

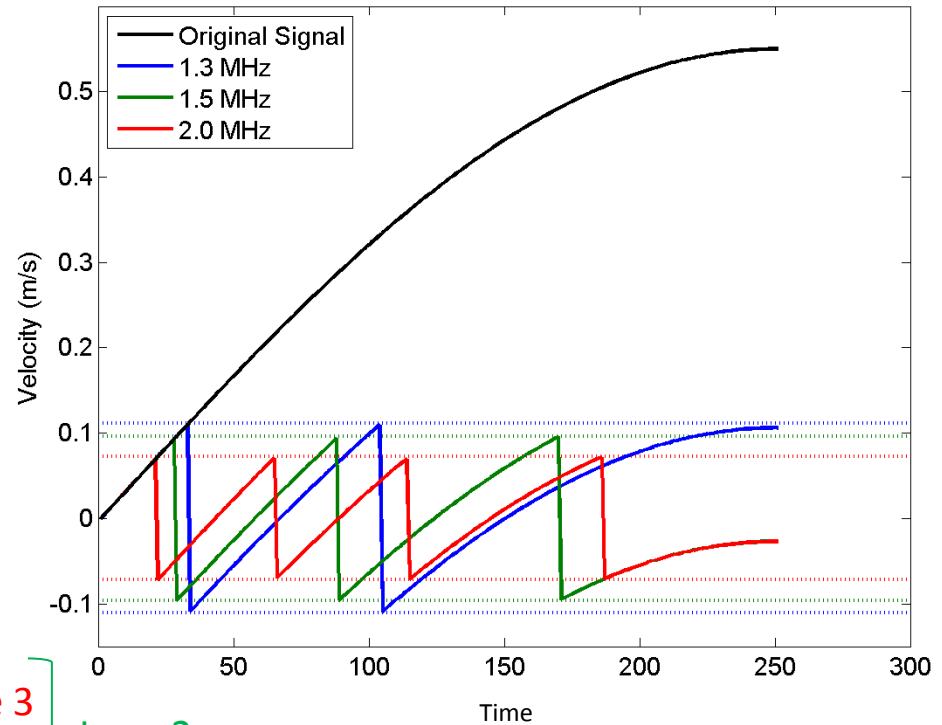
- $\tau_{\text{pp}} = 2 \text{ ms}$
- $L_{\text{pp}} = C\tau_{\text{pp}}/2 = 1.5 \text{ m}$
- $\sigma_w \sim C / f_0 \tau_{\text{pp}} = 7 \text{ mm/s} * 1/\sqrt{16} = 2 \text{ mm/s}$

But my drawing shows two pulses in the water column = BIG TROUBLE!!!

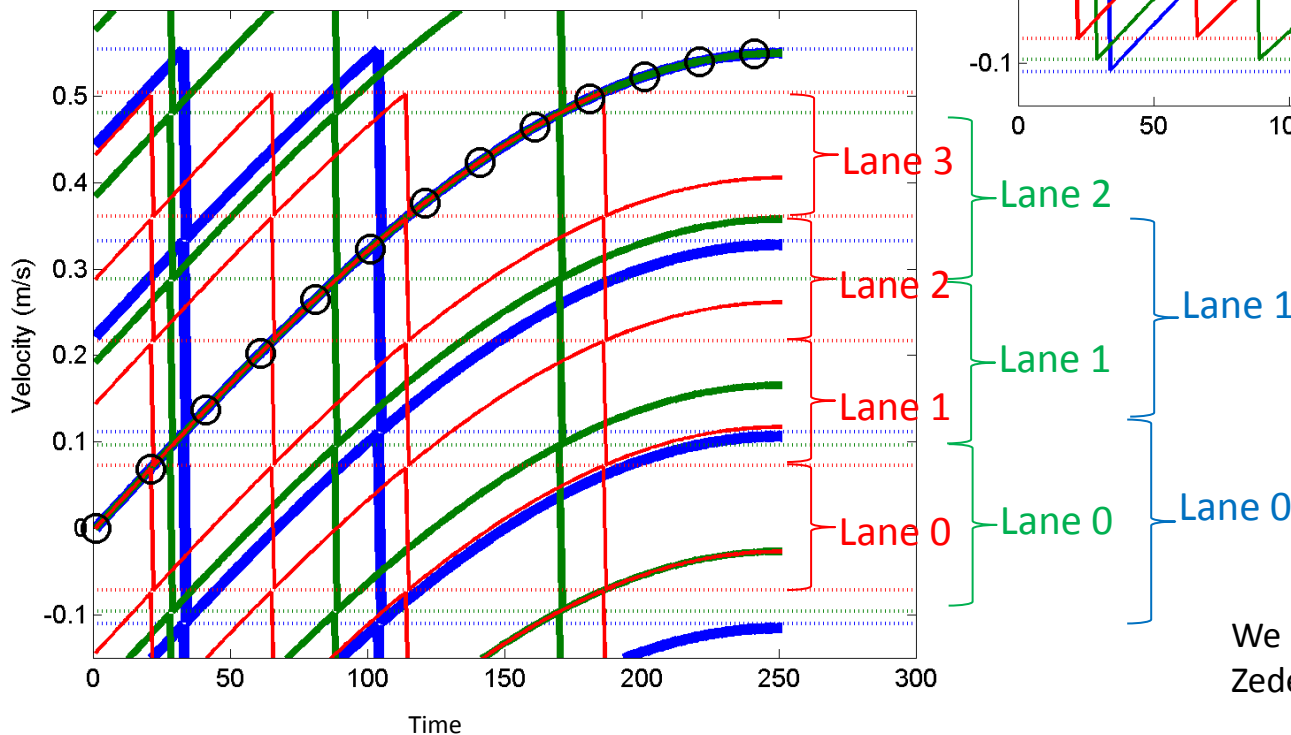
Multi-Frequency Pulse Coherent Doppler Inverse Algorithm

Each Frequency aliases at slightly different velocity (7, 9.5 & 11 cm/s)

Measured Aliased Signal



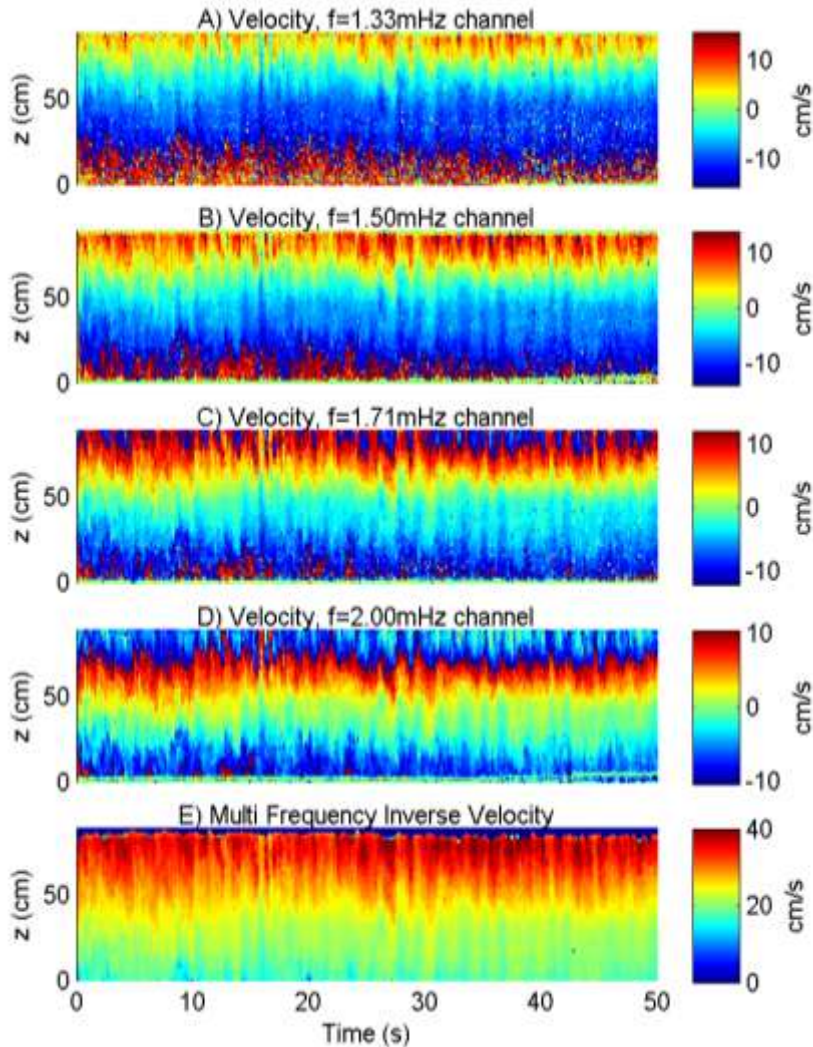
Three Frequency Inverse



Inverse: Signal from each frequency is shifted by integer number of wraps ("lanes"), and only align correctly at true value

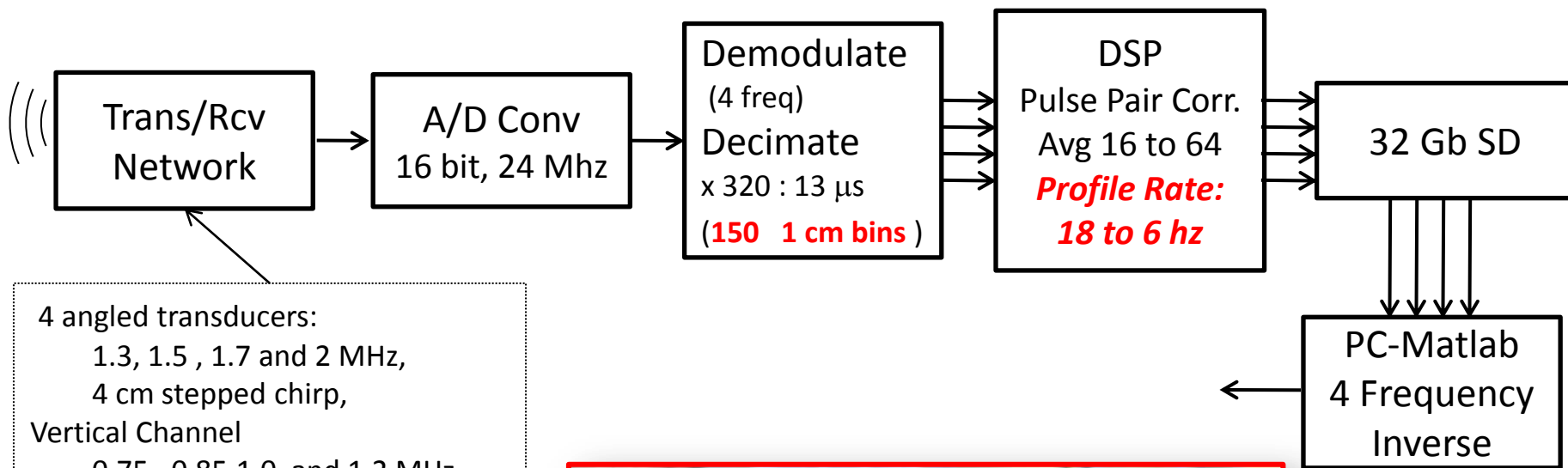
We use slightly different inverse than Zedel & Hay (IEEE Oc. Eng. 2010)

Data From Skagit Tidal Flats



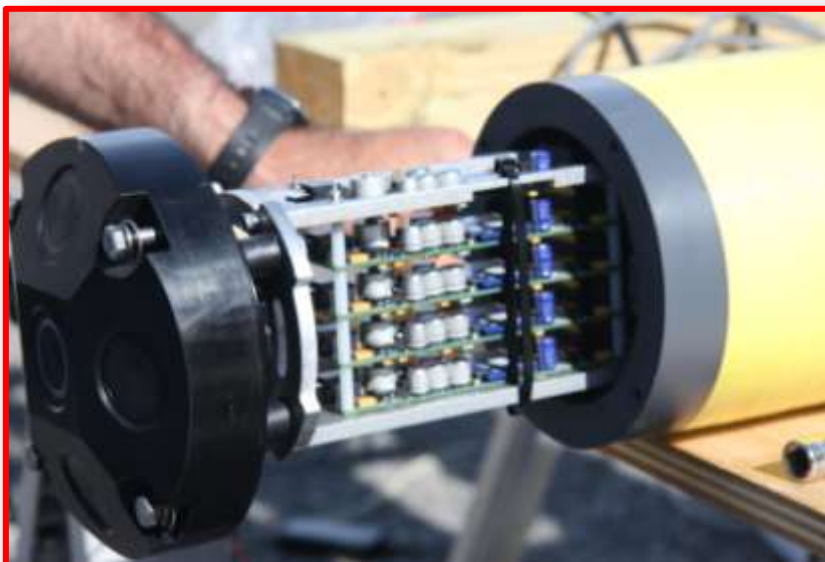
- Measured 40 cm/s along-beam velocity
- With 20° beams ~ 100 cm/s horizontal velocity, with 60 cm/s shear over 70 cm.
- Successfully de-aliased 3 wraps on 2.0 MHz channel

- Implemented with general purpose High Frequency Sonar Boards from E. Terray and T. Austin (WHOI)
 - , 1 vertical transducer, 4 20° transducers



4 angled transducers:
 1.3, 1.5, 1.7 and 2 MHz,
 4 cm stepped chirp,
 Vertical Channel
 0.75, 0.85, 1.0 and 1.2 MHz
 Ping (Profiling) rate of 330 Hz (3 ms)
 before averaging

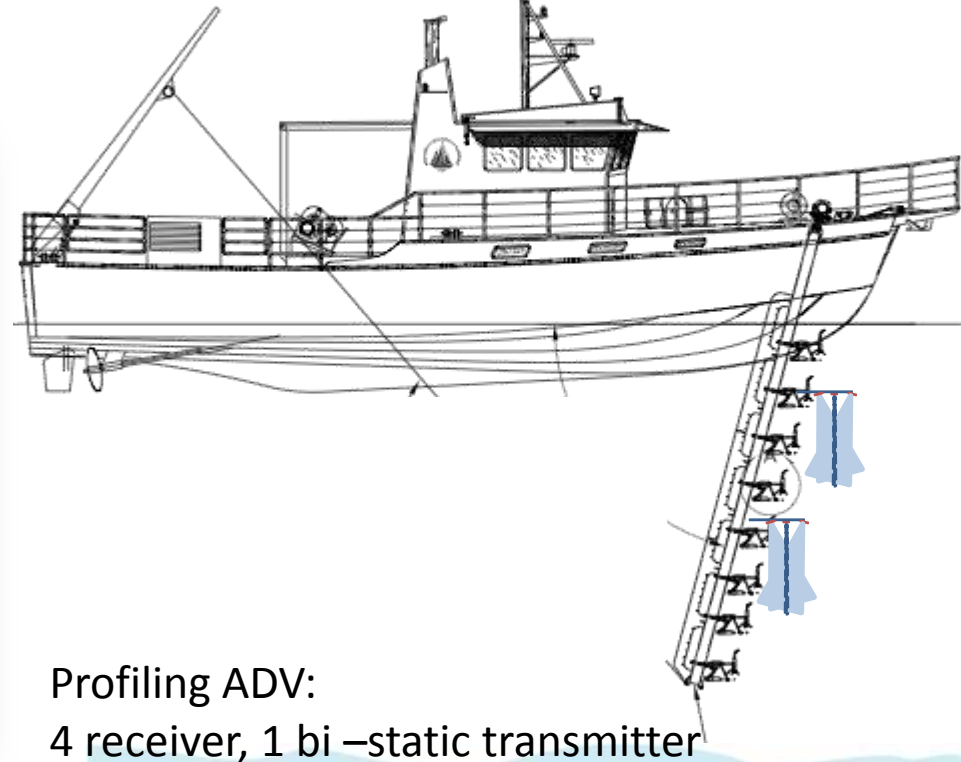
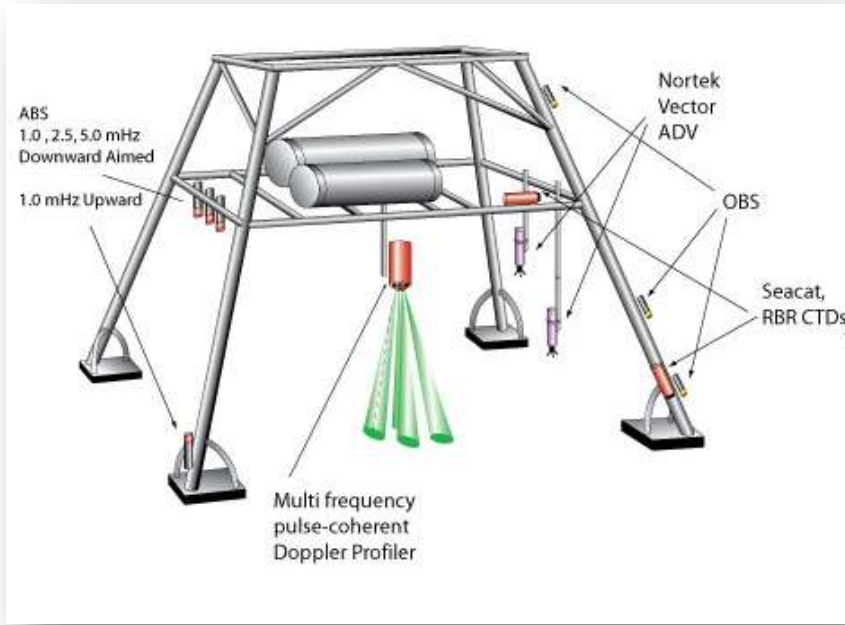
- Board concept by E Terray, T Austin as general purpose HF sonar board
- Hardware / Firmware development by Fredric Jaffre
- Doppler / Acoustic Processing and post-processing by Traykovski



One board per transducer

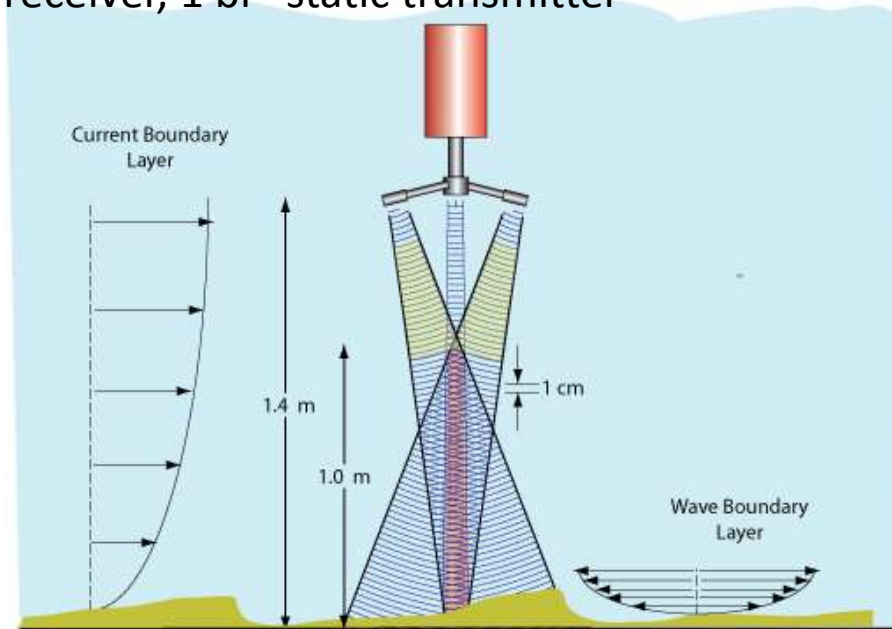
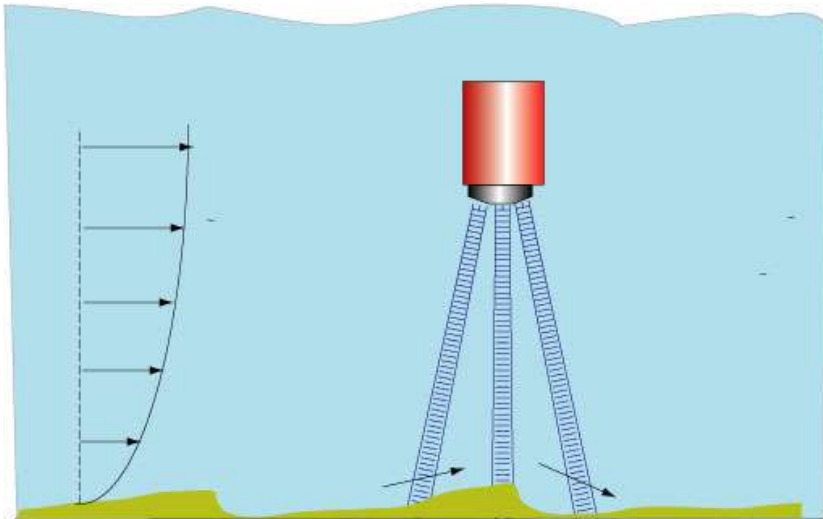
(Uses roughly 5x more power than Aquadopp= 70lbs batteries/Month)

Sampling Geometries:

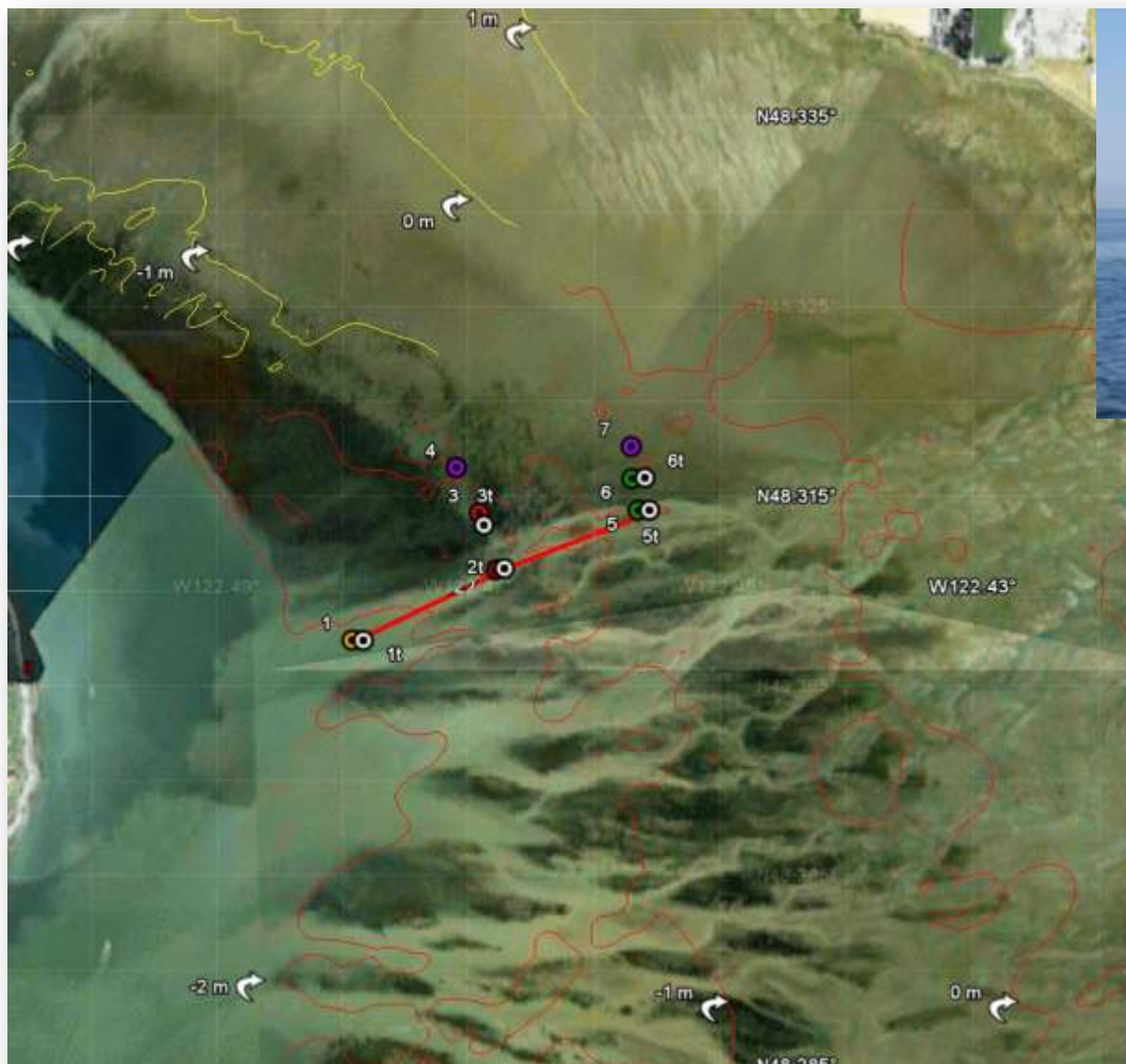


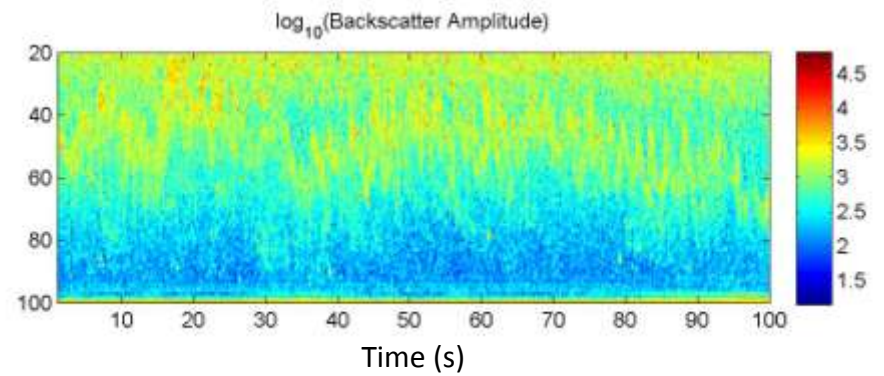
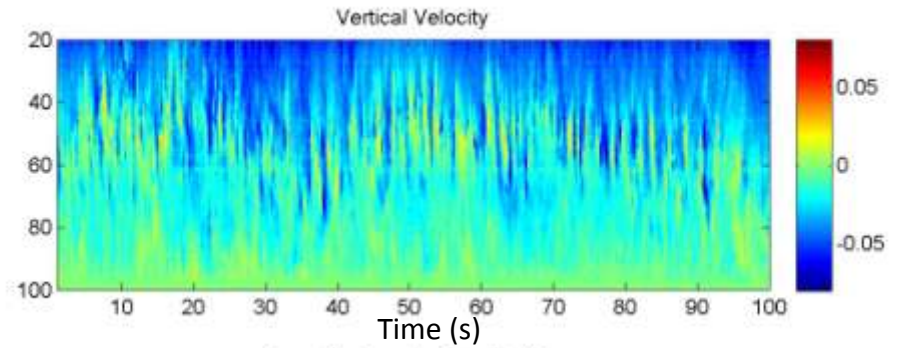
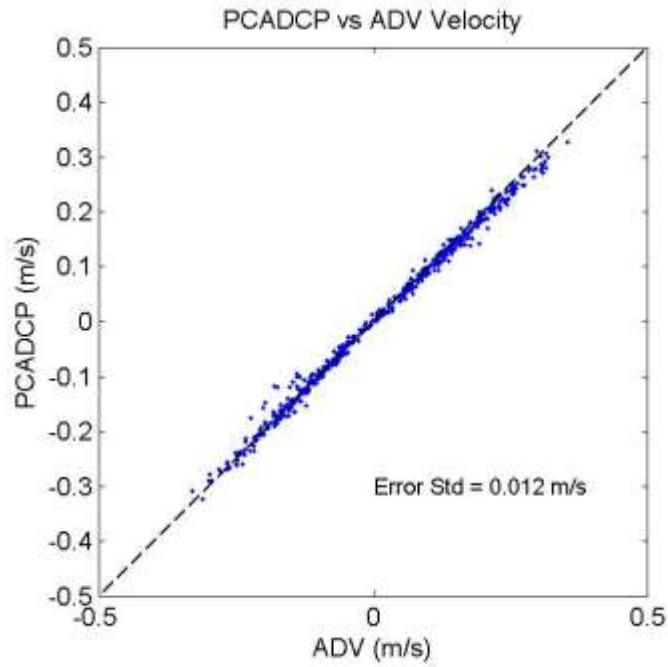
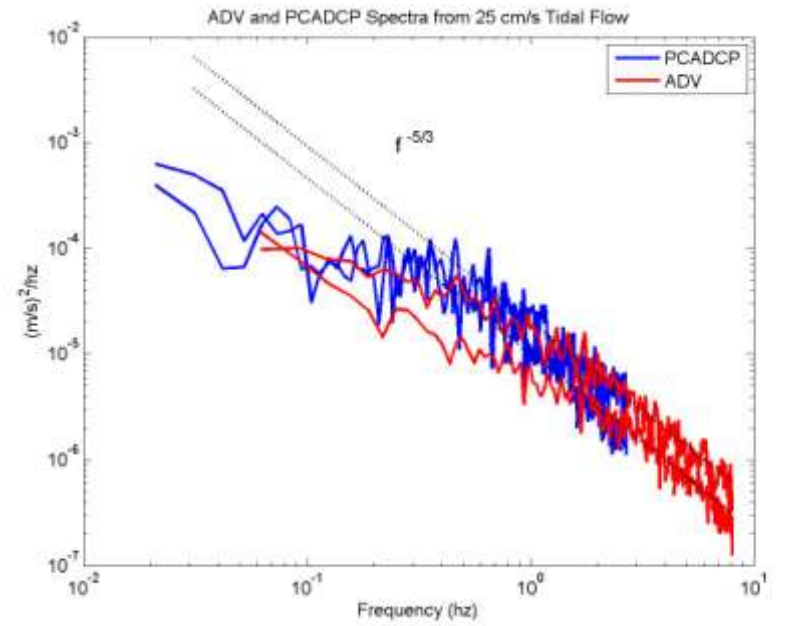
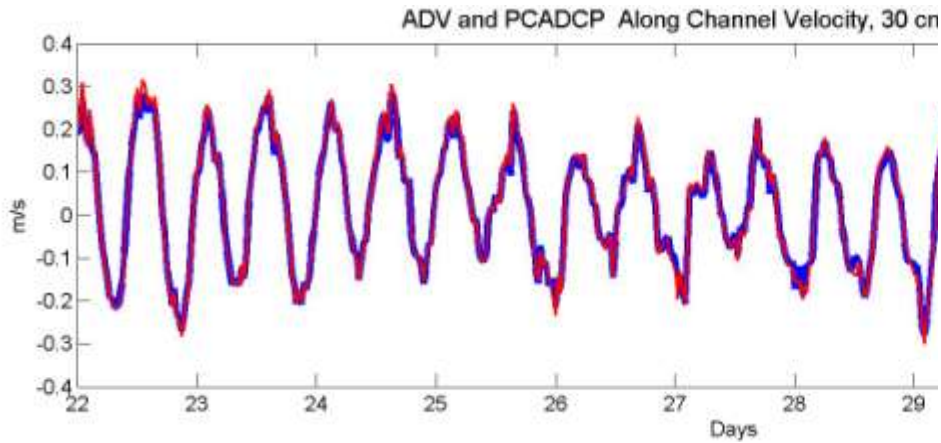
Profiling ADV:
4 receiver, 1 bi-static transmitter

ADCP: 5 beam (1 vertical) mono-static



Dynamics of Tidal Flats, ONR, Skagit River, WA



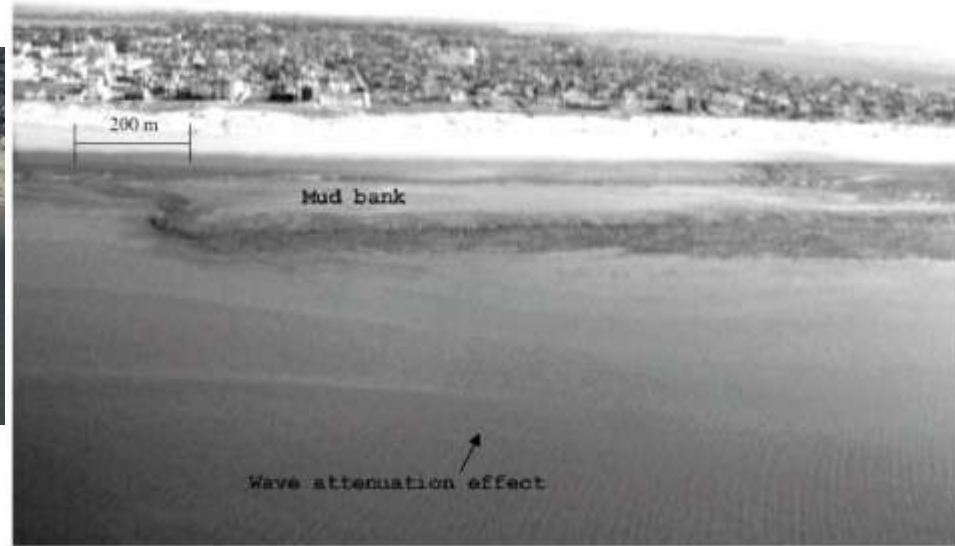


Louisiana Shelf Mud MURI (ONR)



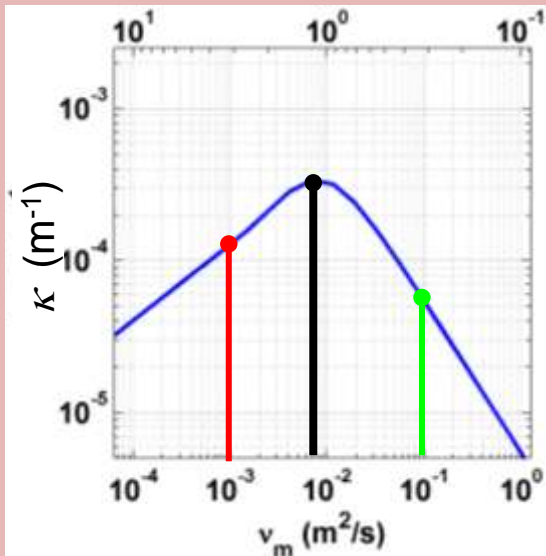
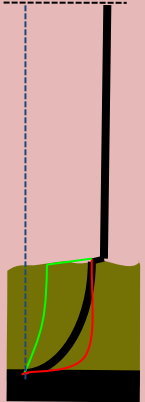
Cassino beach, Brazil:

K. T. Holland et al., Continental Shelf Research, 2009

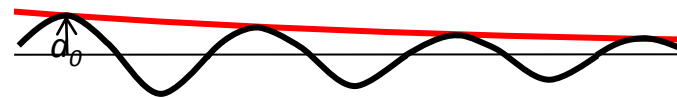


L. Calliari et al, Journ. of Coastal res., 2000

Velocity Profile



$$\eta = a_0 \exp(-2\kappa x)$$

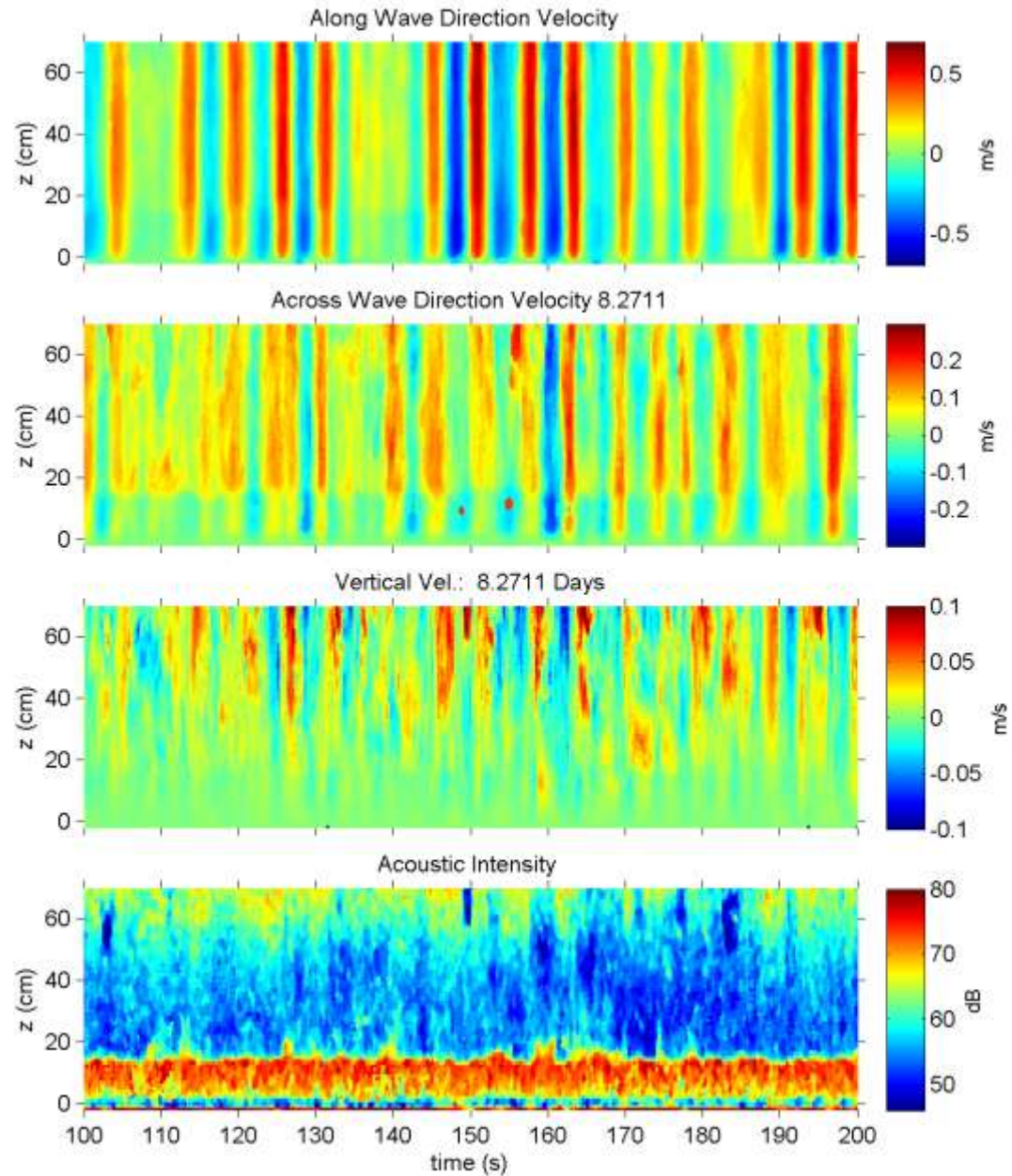
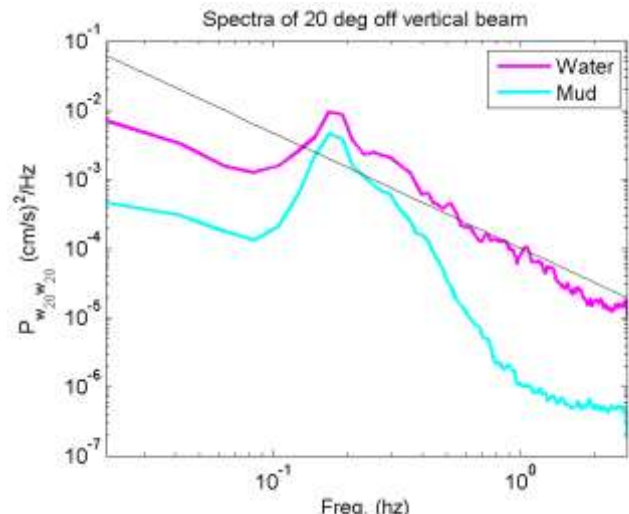
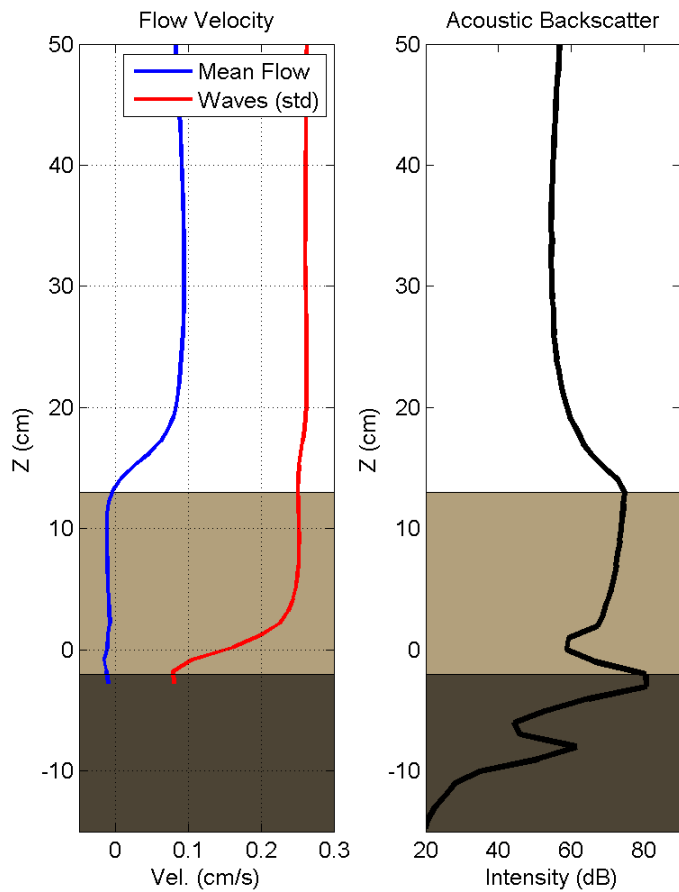


What are the Dissipation Mechanisms?

Energy from surface waves Transmitted into mud and dissipated

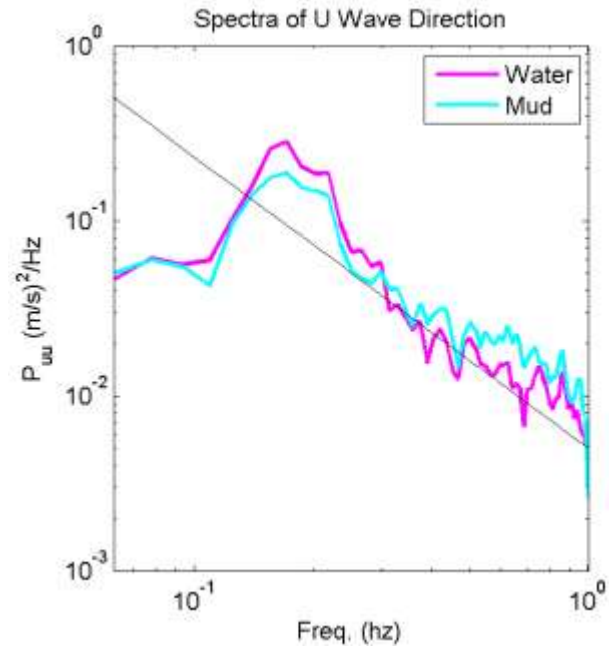
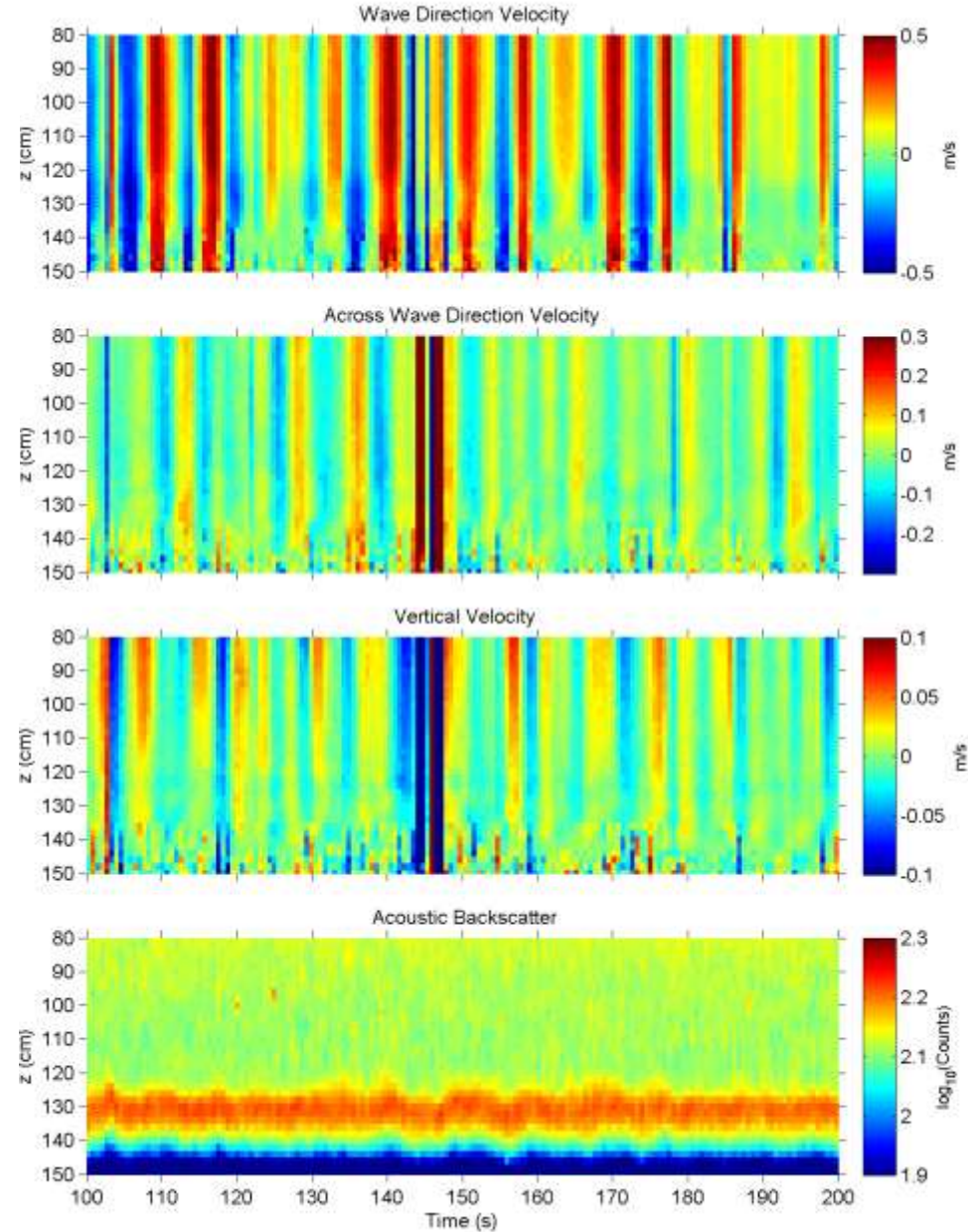
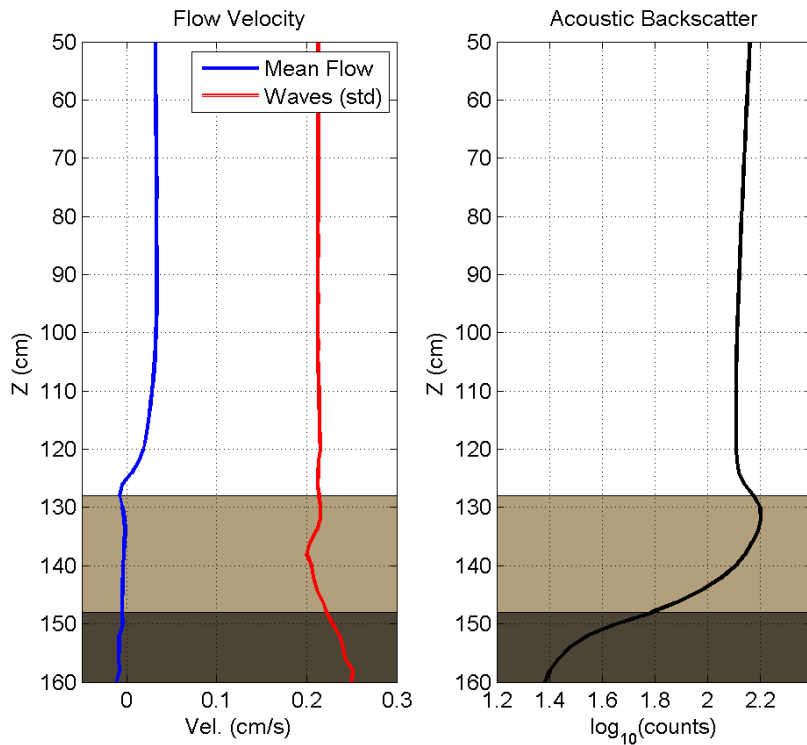


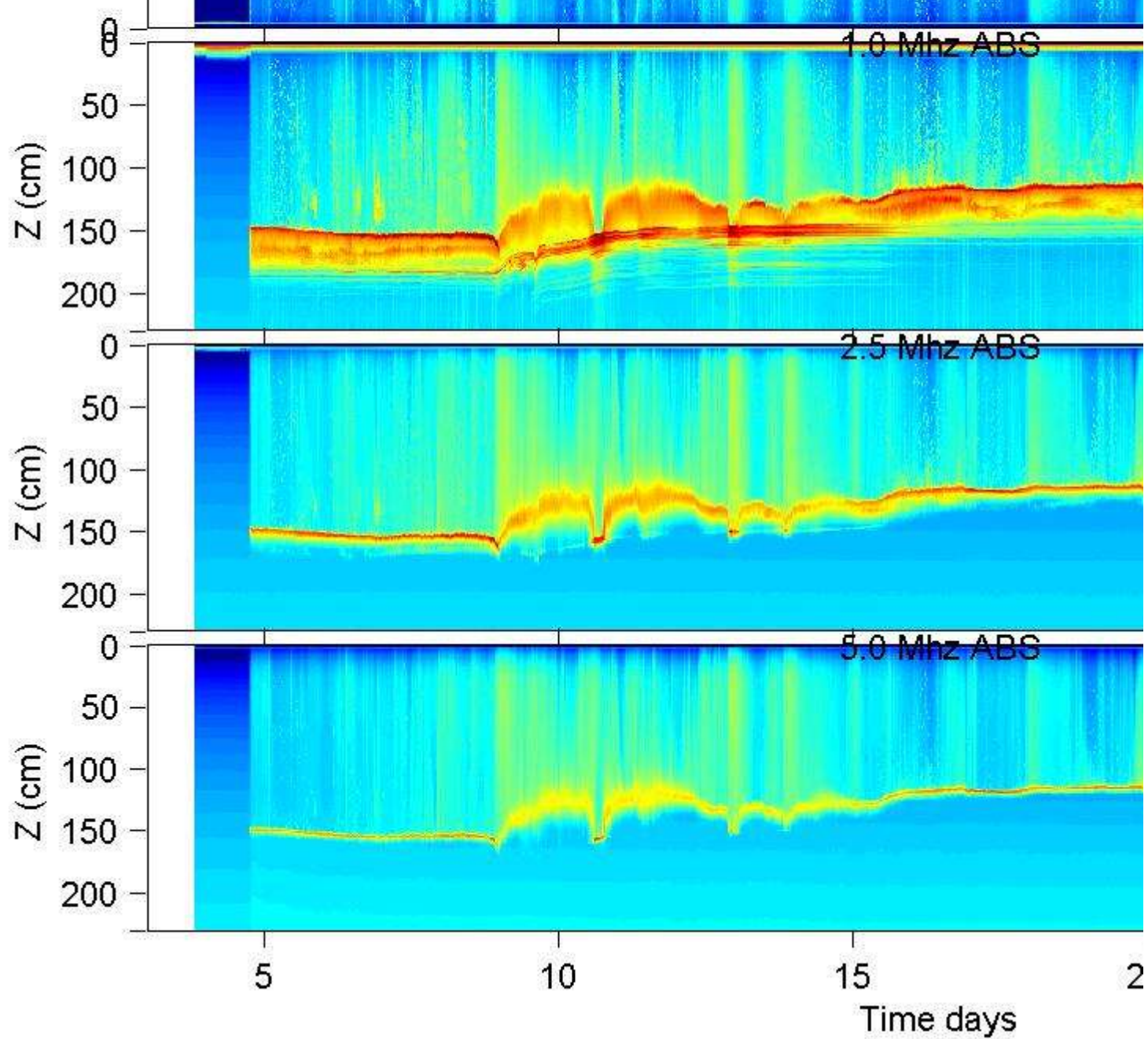
WHOI PC-ADCP



Nortek AquaDopHR

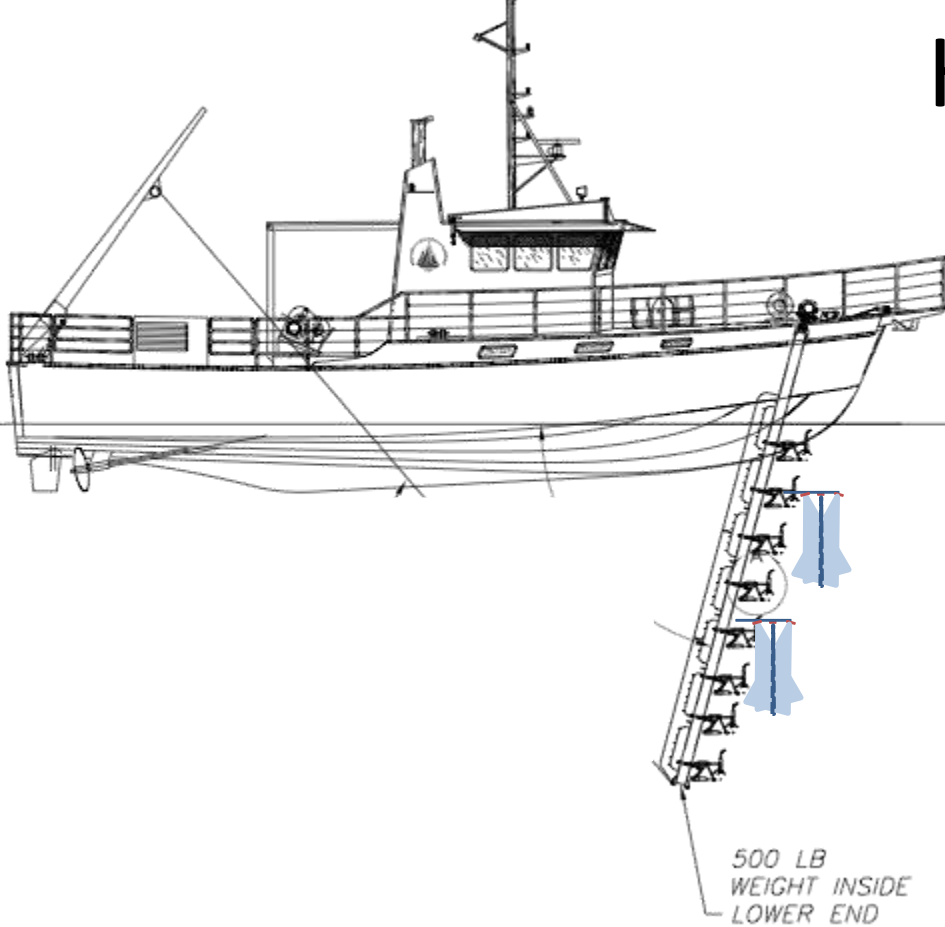
Also tried RDI mode 11



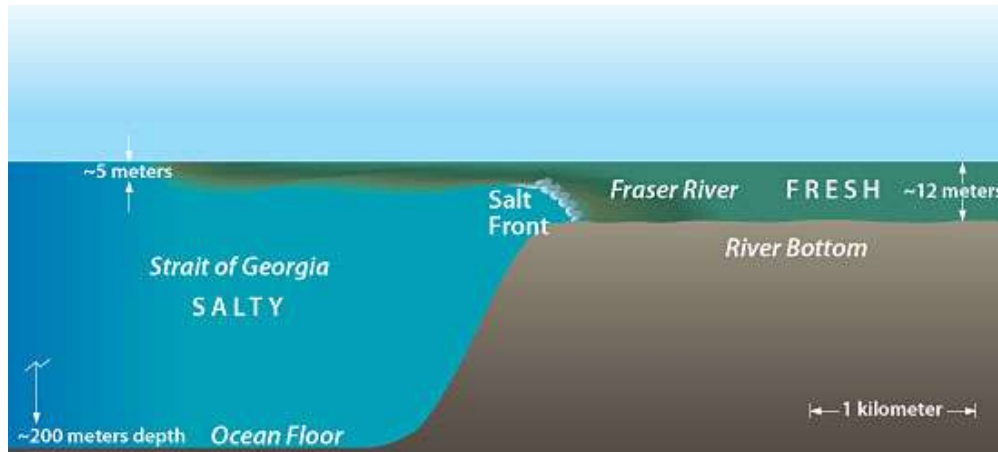
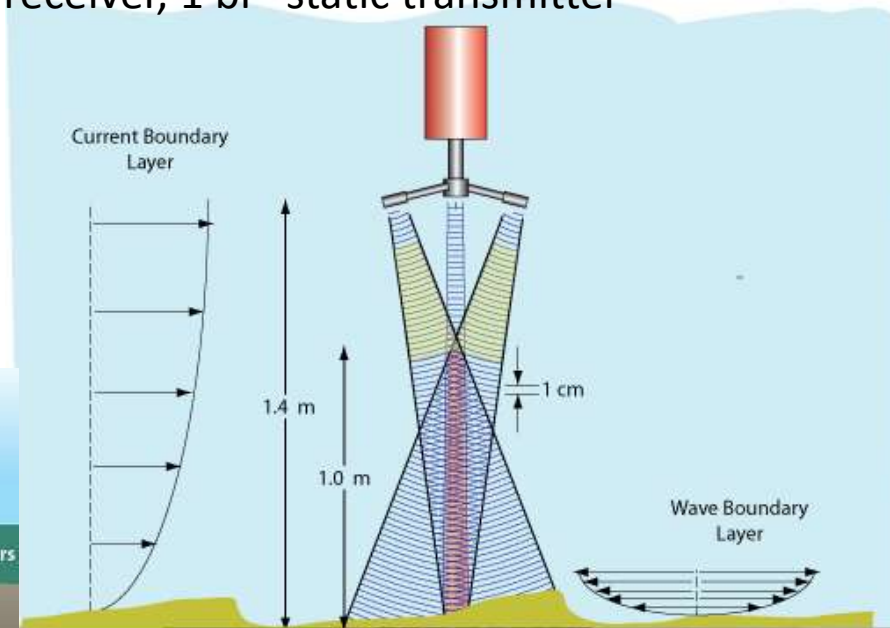


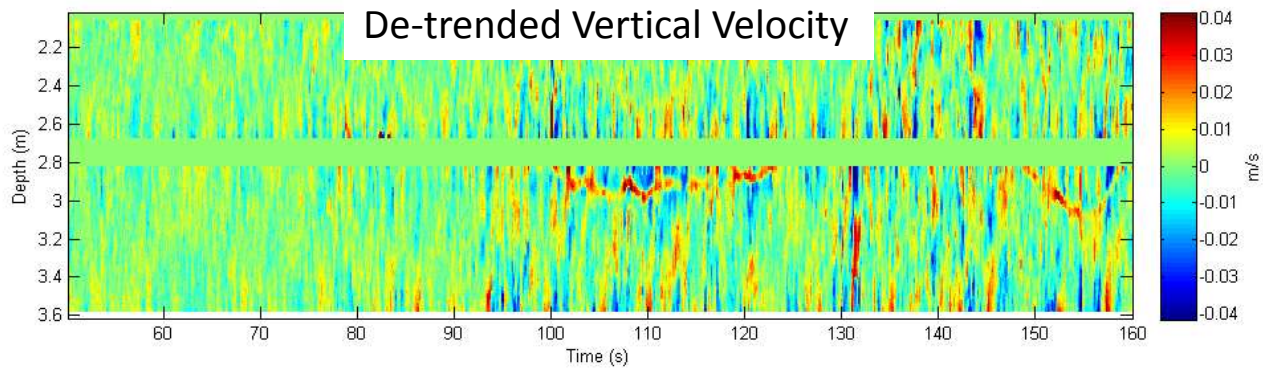
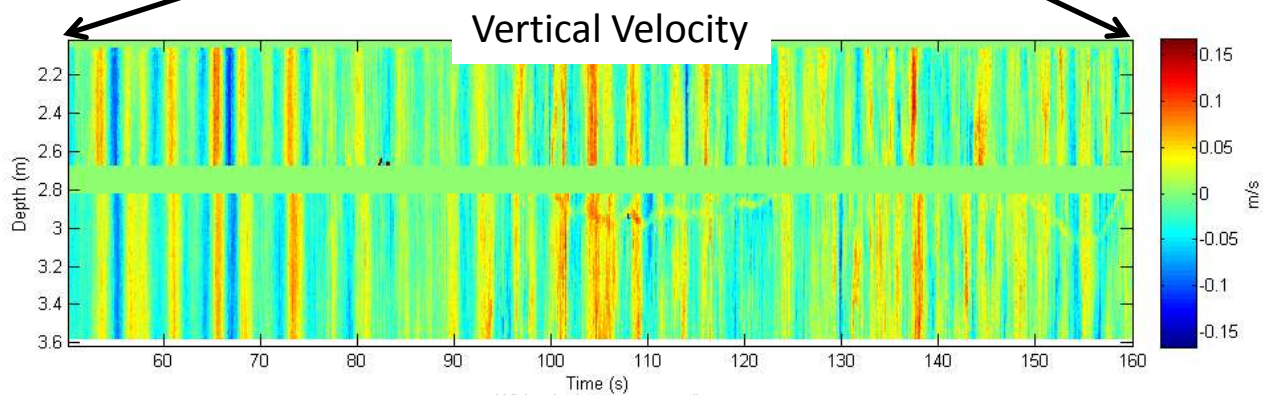
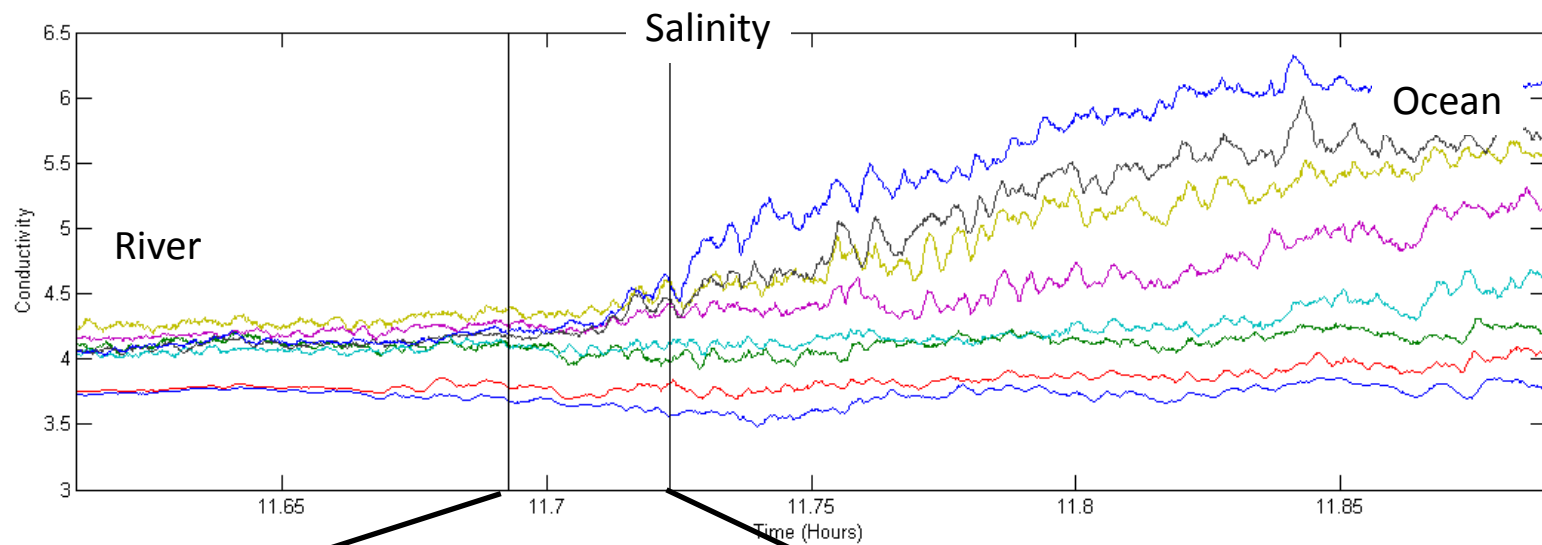
Hudson River Estuary

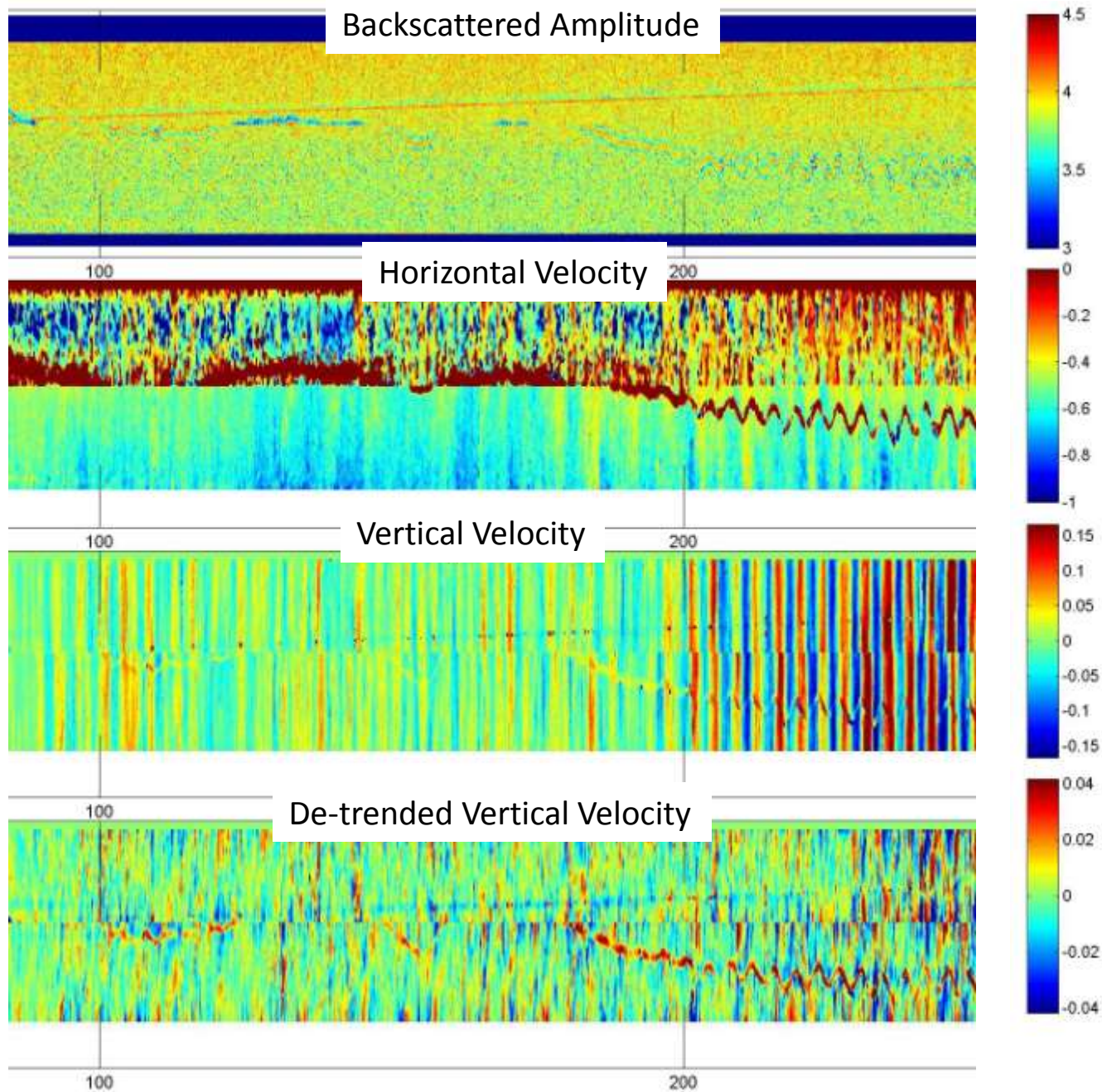
“MAST” Mounted,
with Geyer & Scully



Profiling ADV:
4 receiver, 1 bi-static transmitter







Conclusions

- Pulse Coherent Doppler has been known to offer high resolution, fast sampling accurate velocity profiles, but has been limited by Range-Velocity ambiguity
 - New multi-frequency de-aliasing techniques offer a powerful technique to overcome this.
- Bistatic Geometry (Large Profiling ADV) can produce almost “ADV / Vector” turbulence resolving data with 1-2 m long profiles similar to AquadopHR
 - Sampling volume is larger
 - Horizontal velocities are lower quality due to geometry
 - Ideally suited for boundary limited measurements
- Hopefully Nortek will implement / market these technologies soon (Nortek Scientific), because it is hard for us!
 - Small Profiling Vectrino