Across-shelf Versus Along-shelf Coherence Estimates of Low-frequency Pulse Transmissions on the New Jersey Continental Shelf

Jon M. Collis[1], Timothy F. Duda[2], James F. Lynch[2], Harry A. DeFerrari[3]

[1]Colorado School of Mines
Golden, CO, 80401

[2]Woods Hole Oceanographic Institution
Woods Hole, MA, 02543

[3]University of Miami
Miami, FL, 33149

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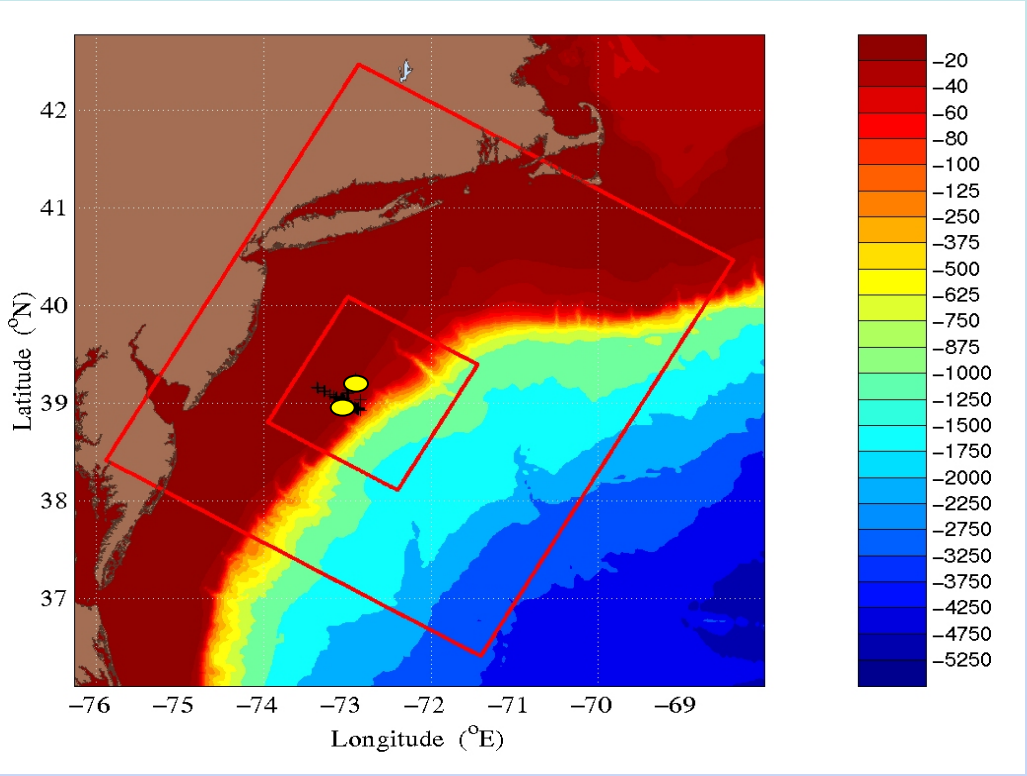
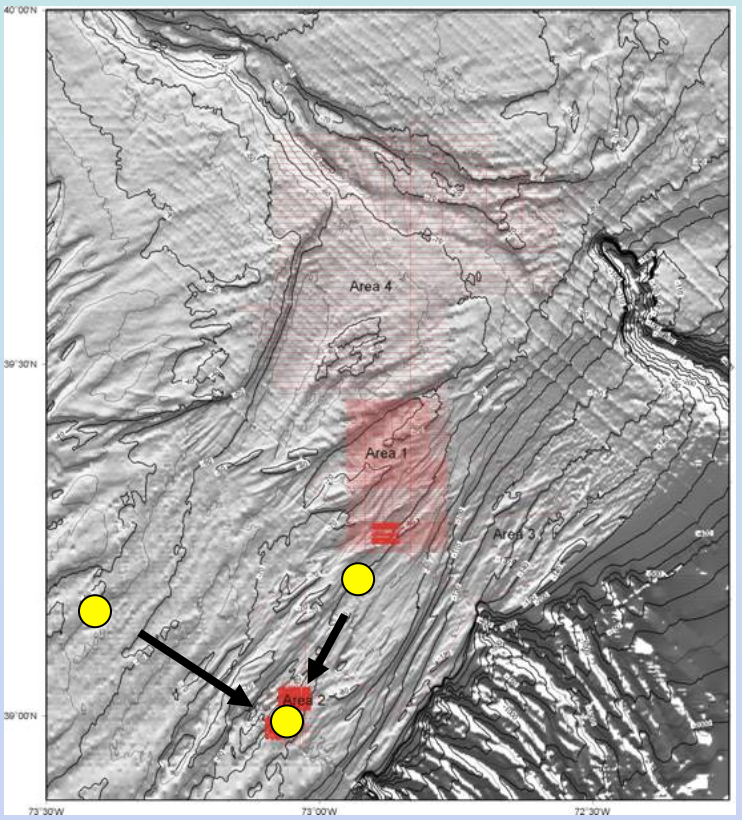
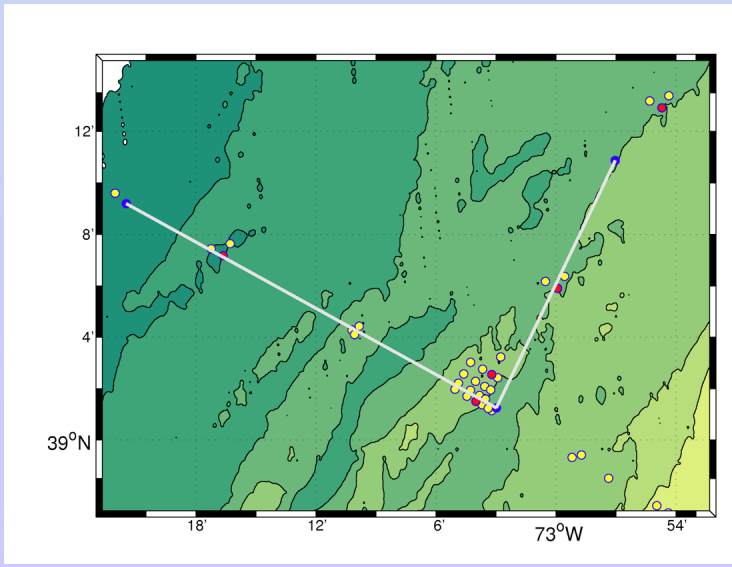
Experiment Information

- SW06 Experiment, east of New Jersey, Summer 2006
  - Fixed L-array (co-located horizontal and vertical line arrays) receiver
  - Two source paths
    - Along–shelf: 19.2 km, approximately 80 m depth, some undulation. 100, 200 Hz, M-sequence modulated broadband pulses from the University of Miami Sound Machine (MSM, thank you H. Nguyen)
    - Across-shelf: 30.1 km, 60 m depth at source to 80 m at receiver, 224, 400 Hz WHOI Sources
- Internal ocean state (waves) measured with sensors near L-array, near the source, mid-way, and elsewhere.
- Mode decomposition at the VLA shows overlapping arrivals of differing modes, and multiple arrivals of individual modes
- Periods of weak and strong internal wave activity have been treated separately, giving different coherence lengths.





- Chart of the area showing the receiver location (at the south)
- Also, paths from source locations:
  - NE (top-right)
  - NW (top-left)



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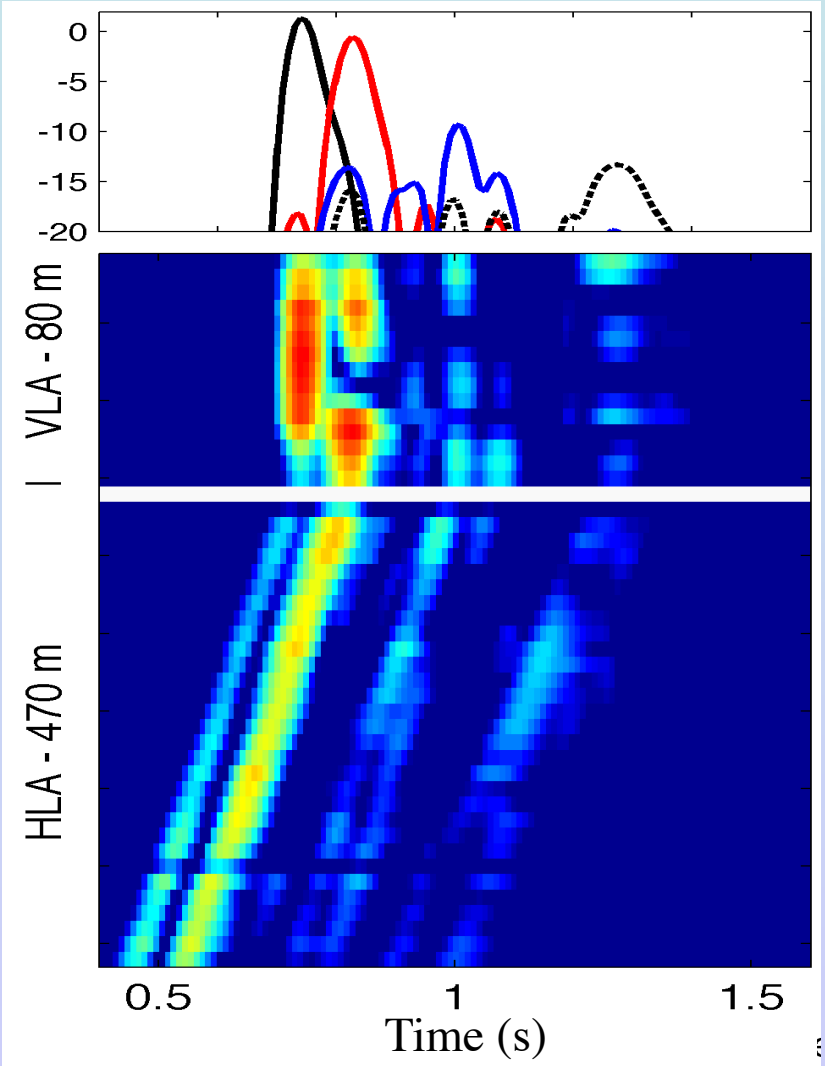
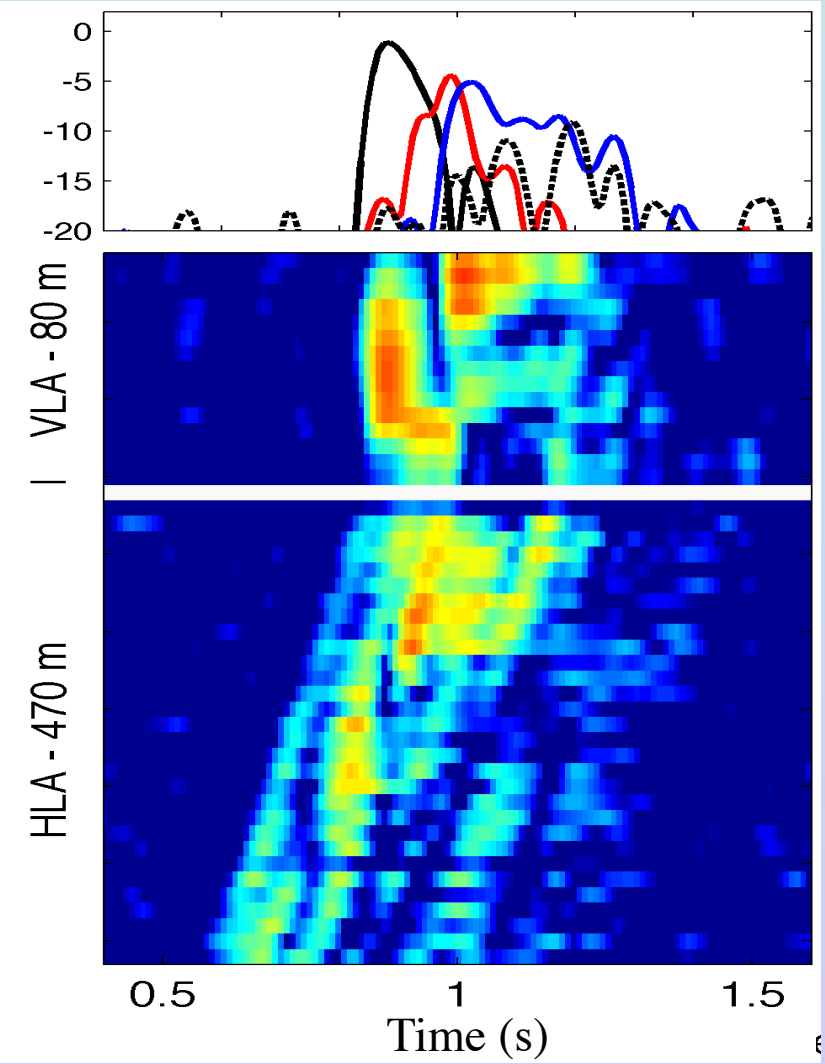
Investigating the nature of horizontal coherence using an L-shaped array

- At non-broadside geometry, mode interference can shorten coherence length
- Angle of incidence is critical to providing accurate coherence length estimates
- The results depend on the fraction of the pulse duration that is analyzed

- We developed a method to directly measure azimuthal decoherence effects of broadband low-frequency pulses (that would, e.g., be a cause of array-gain degradation of a broadside signal)
  - Use of VLA data to generate the fixed-mode field on the HLA allowed strong azimuthal variations to be identified

Arrivals: 100 Hz

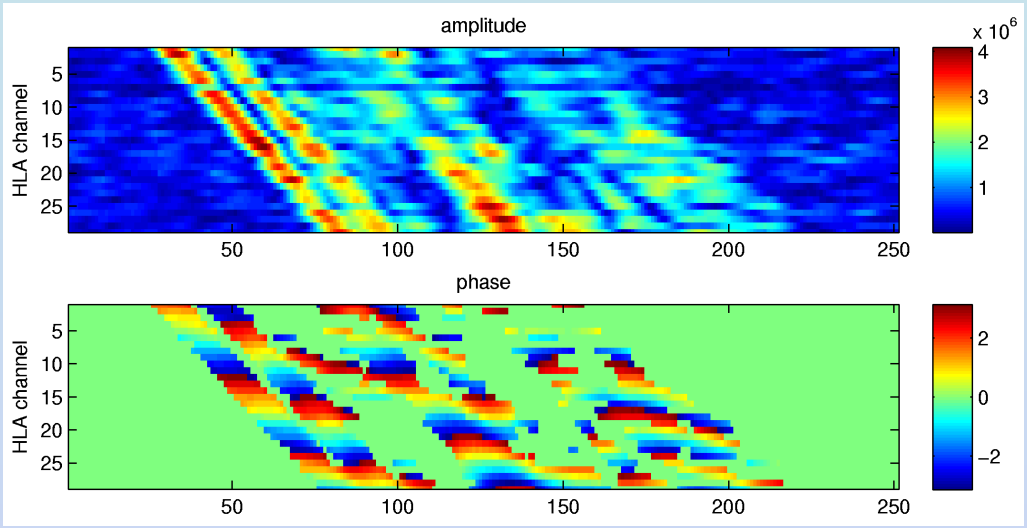


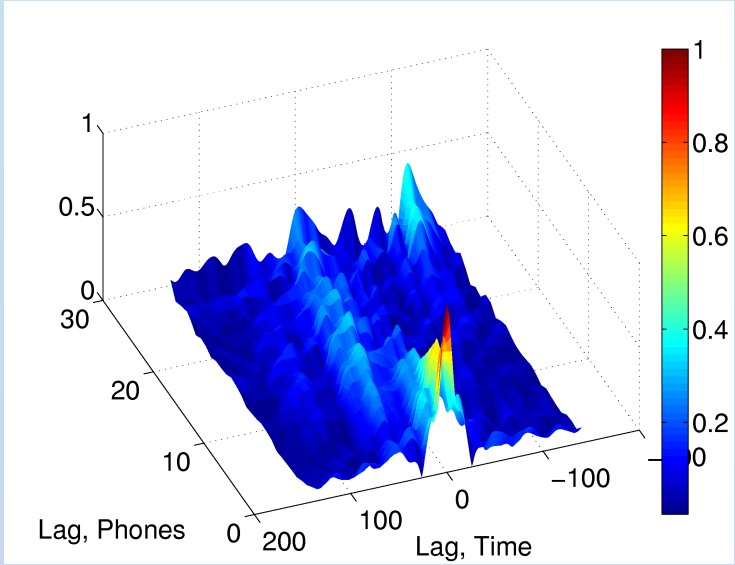


- Along HLA, long coherence length.

- Mode arrivals overlap and multiple.
- Short coherence length.

Two-Dimensional Coherence Function





• Coherence analysis uses the spatial and temporally lagged cross-correlation function:

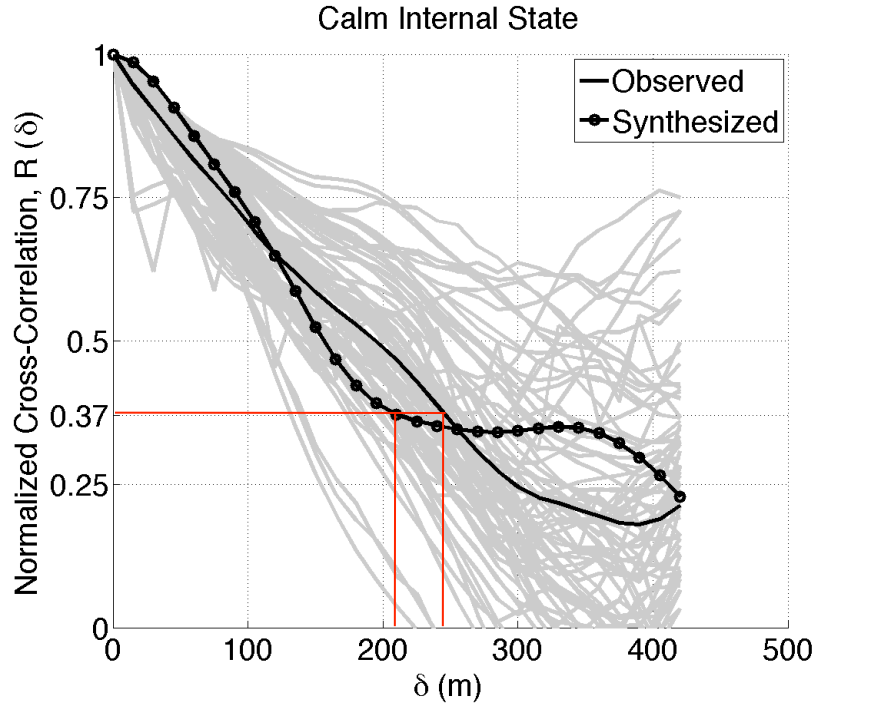
$$R(\Delta x, \Delta t) = \left\langle p(x,t)\; p^{*}(x+\Delta x, t+\Delta t) \right\rangle$$

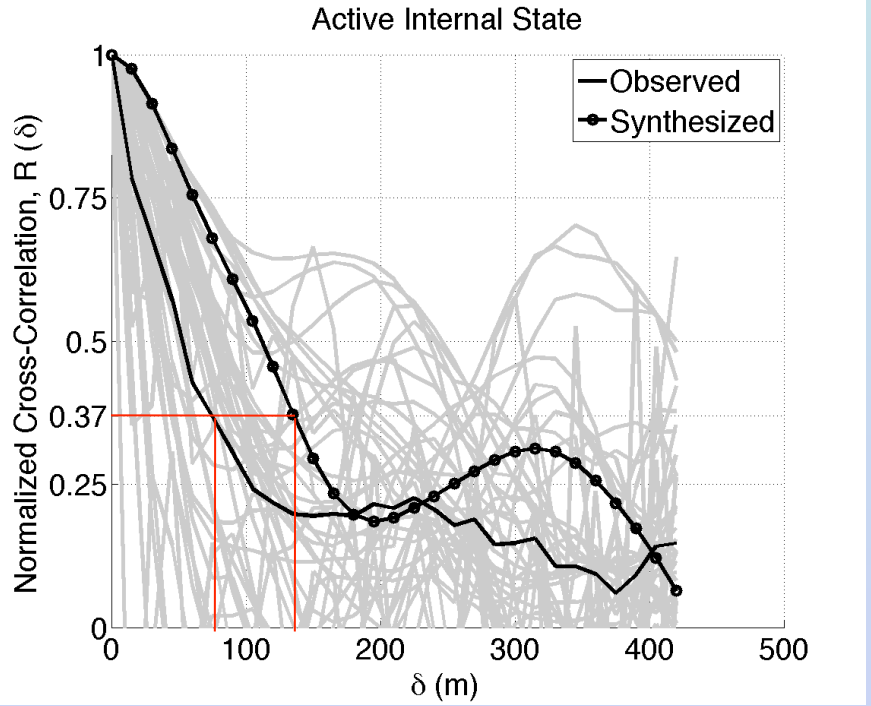
• Use beam steering to redefine time origin at each phone, set

$$\Delta t = 0$$

• We are essentially analyzing the field that is summed in conventional beamforming

Horizontally Lagged Field Coherence Function

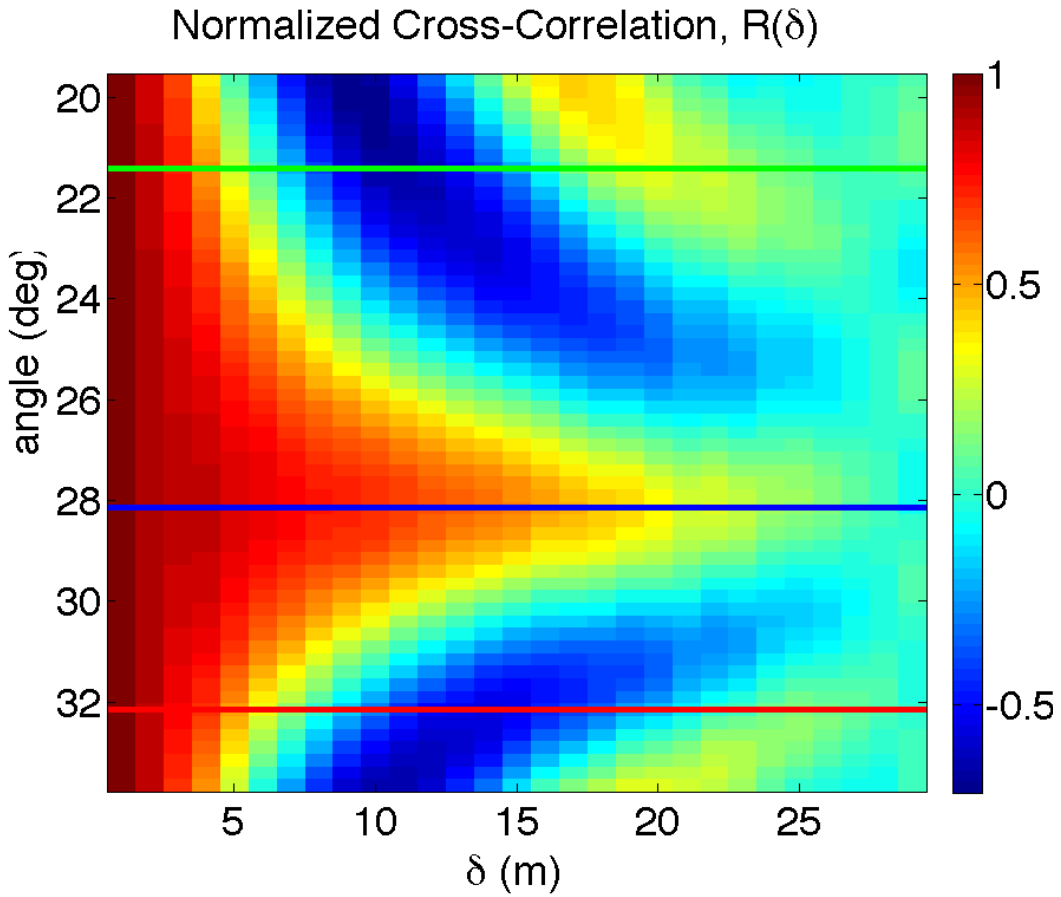




- Synthesized fixed-mode field coherence function vs. observed field coherence function
  - Equal scales: mode interference controls the scale length
  - Unequal scales: additional strong azimuthal effects

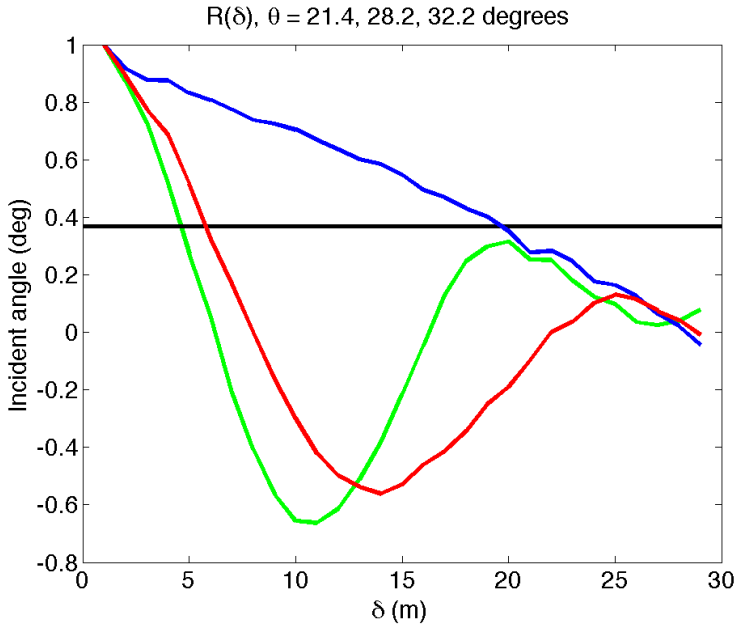
- J. M. Collis, T. F. Duda, J. F. Lynch, and H. A. DeFerrari, *Observed limiting cases of horizontal field coherence and array performance in a time-varying internal wavefield*, J. Acoust. Soc. Am., **124**, EL97 (2008).
- K. Heaney, *A normal mode projection technique for array response synthesis in range-dependent environments*, J. Acoust. Soc. Am., **126**, 1036 (2009).

Steering Angle and Angle of Incidence Variability

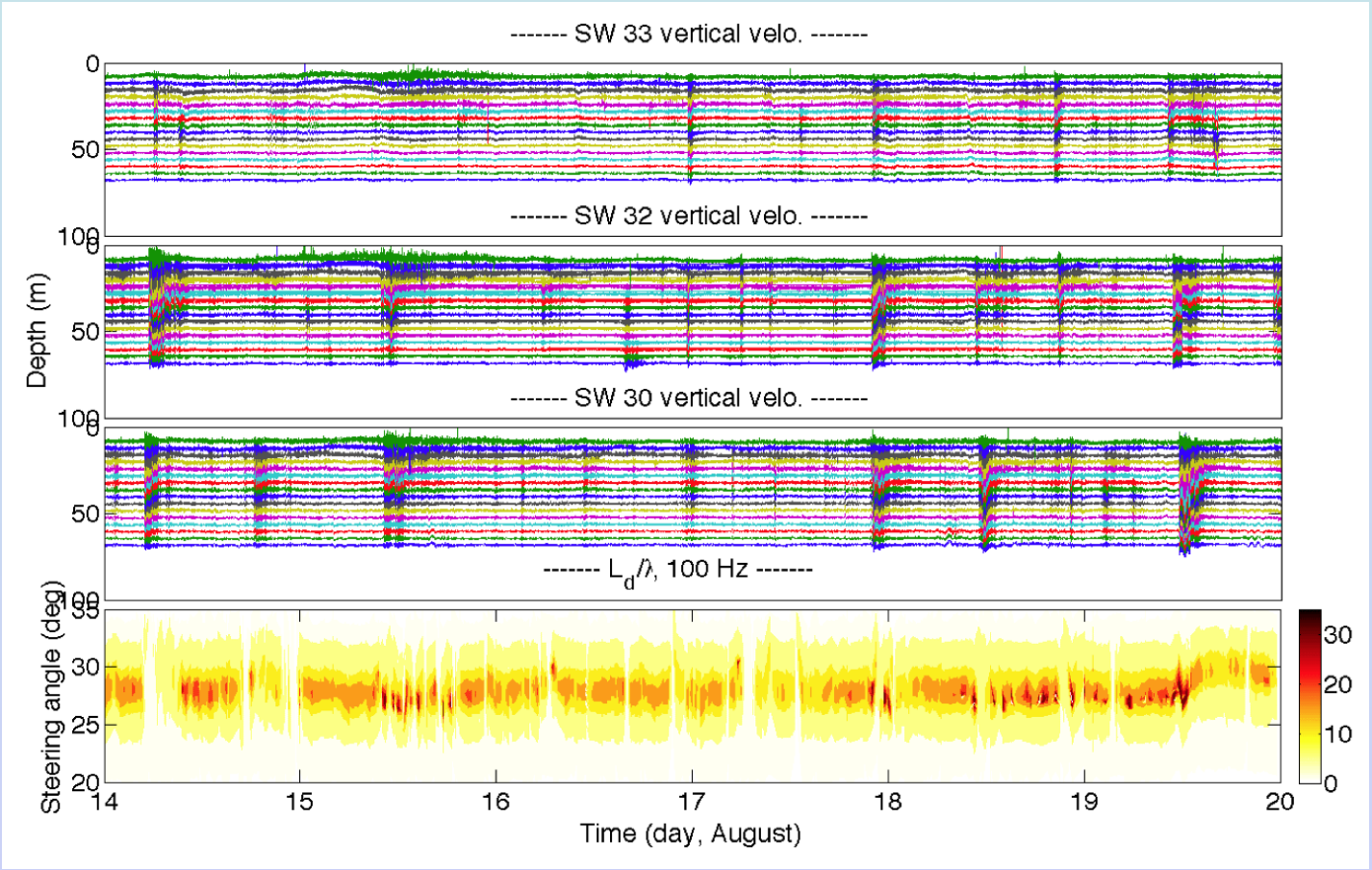


- The coherence length is dependent on the steering angle

- Fixing an angle can significantly underestimate the coherence function



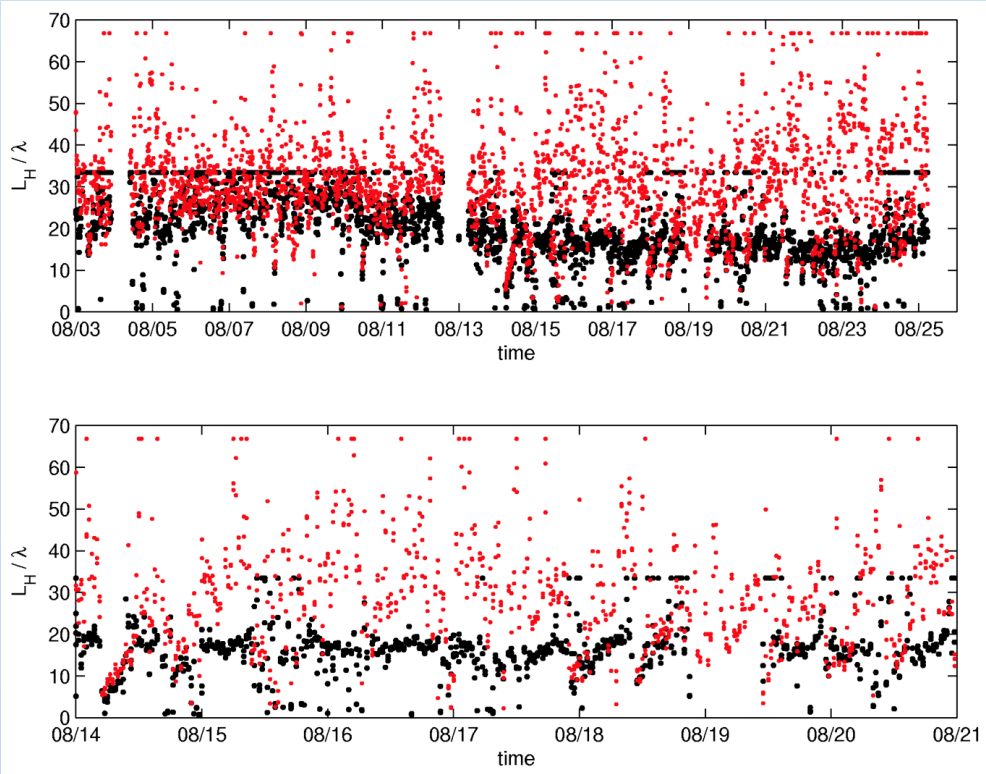
Along-Shelf Propagation: 100 Hz



- Six day period
- North to south, down the page.
- SW30 is near the receiver.

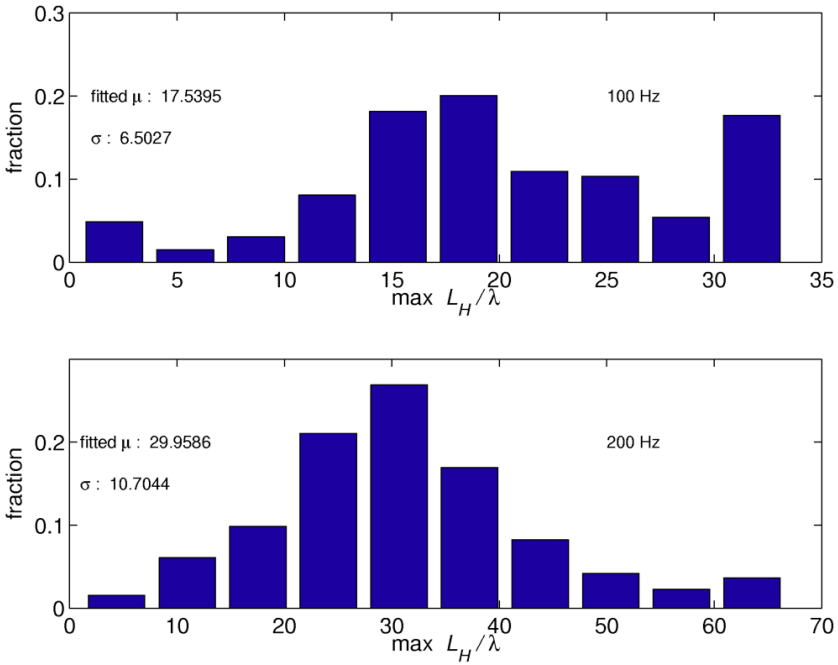
- Top three frames: ADCP vertical velocity time series
- Lower frame: coherence scale length as function of beam steering angle
- Steering angle variation related to internal waves

Along-Shelf Propagation: 100 and 200 Hz



- Coherence length vs. time
- 100-Hz results in black
- 200-Hz results in red.
- Normalized by wavelength

- The maximum value (over steering angle) for each pulse is used.
- Upper pane: entire month
- Lower pane: seven days only
  - Daily tidal variation is evident
  - 200-Hz results show greater length



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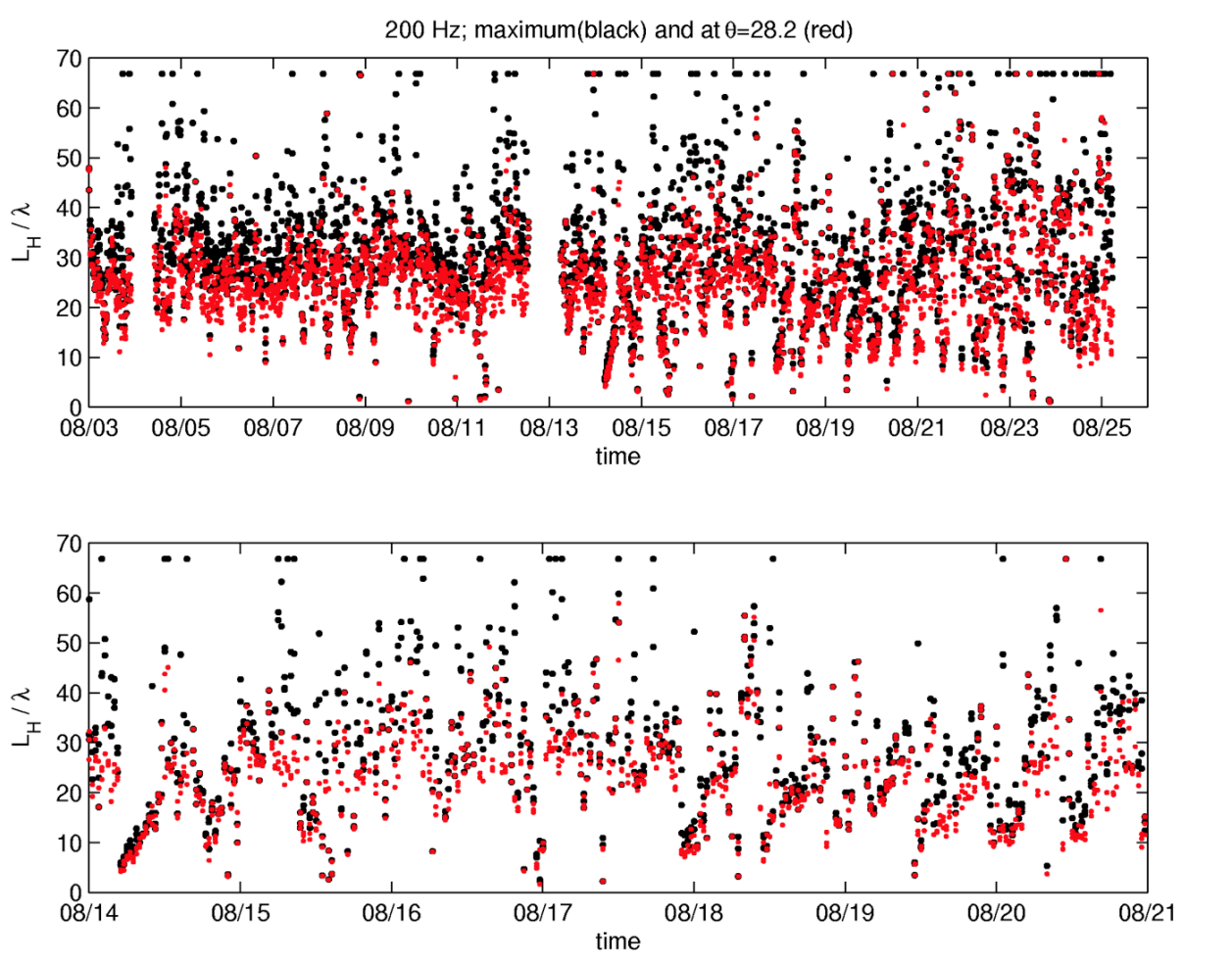
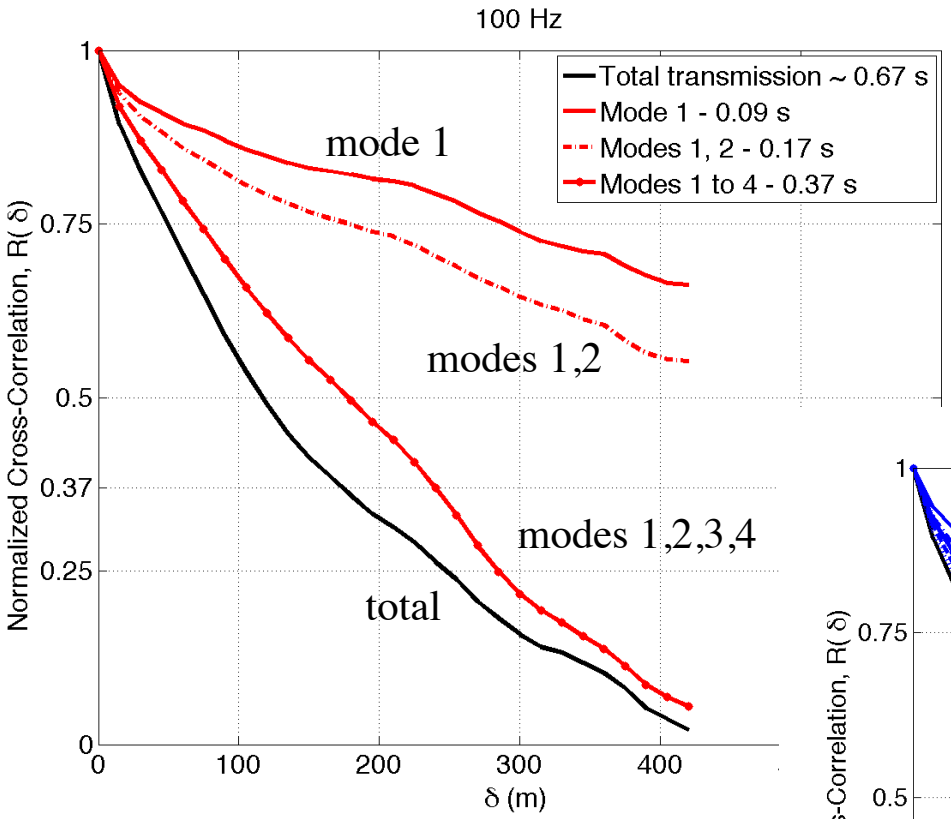


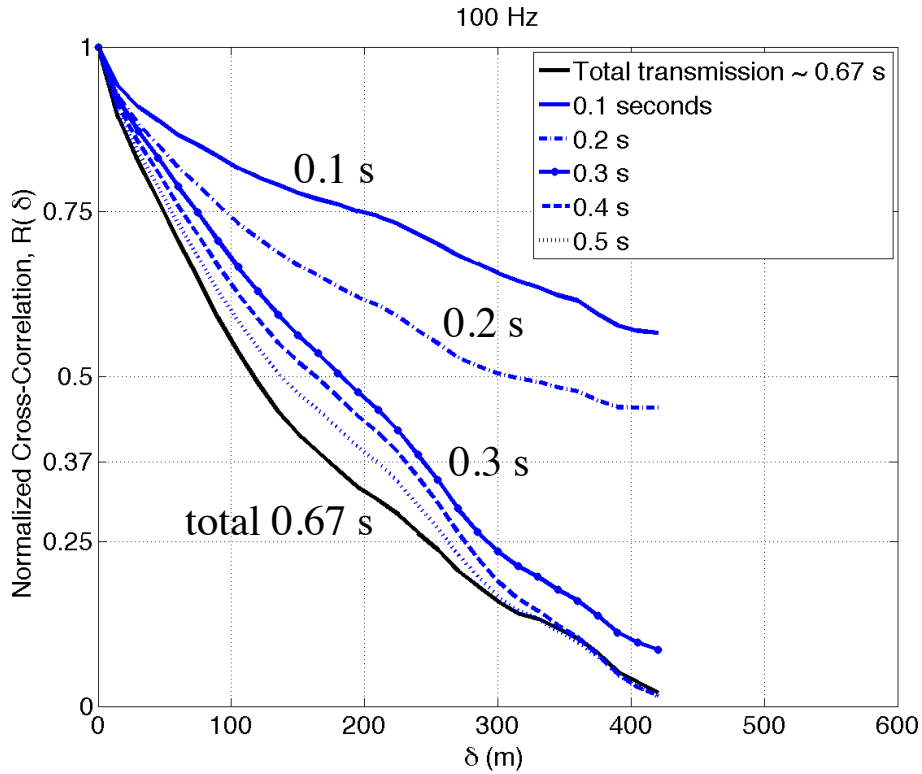
- Maximum coherence length for 200-Hz data are repeated in black
- Coherence length at fixed beam angle 28.2 degrees is shown in red.

- Lower pane: detailed view for a seven day time period.
- Almost without exception, the 'steered' value is greater

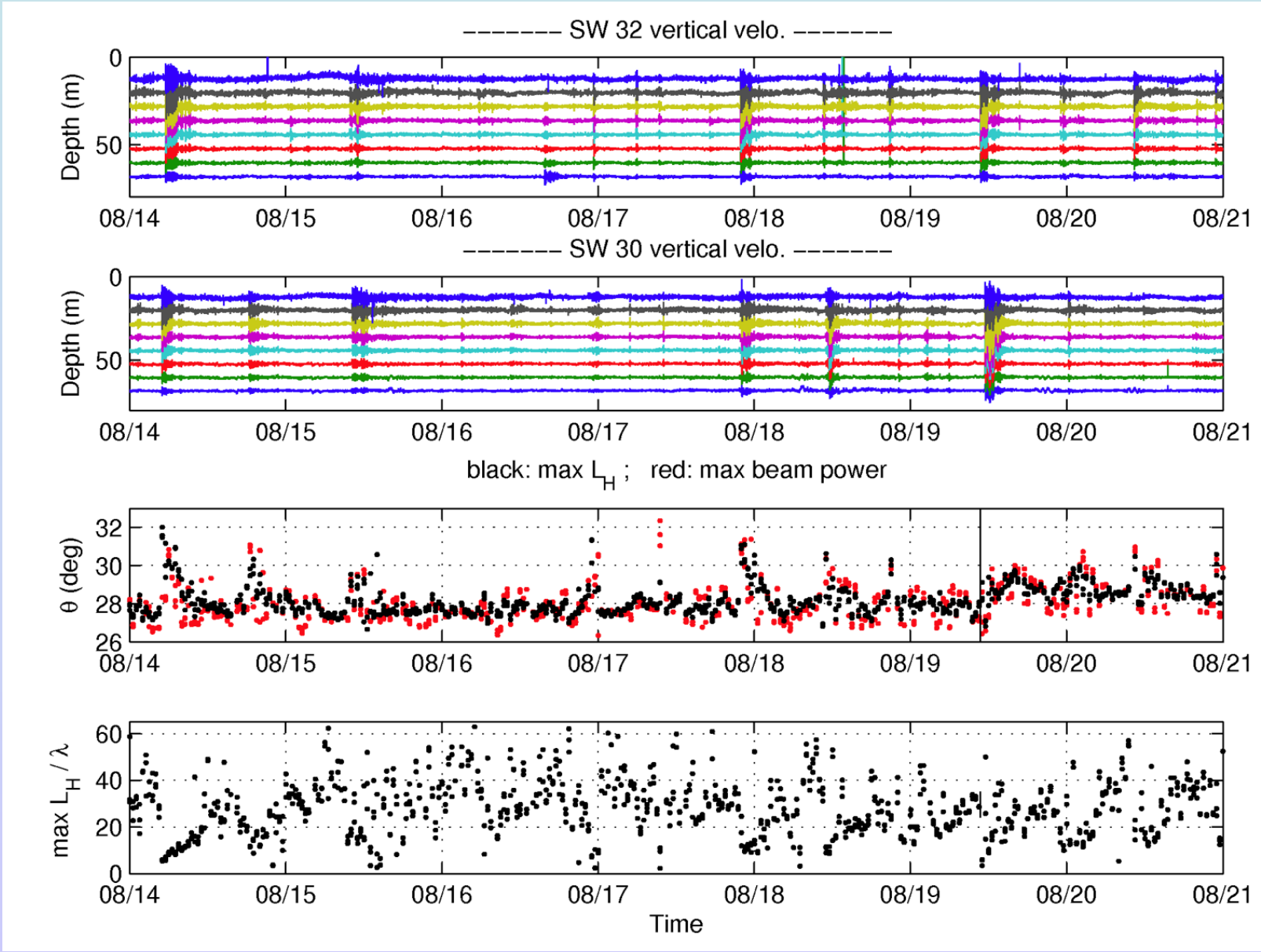
Signal Duration and Coherence Length



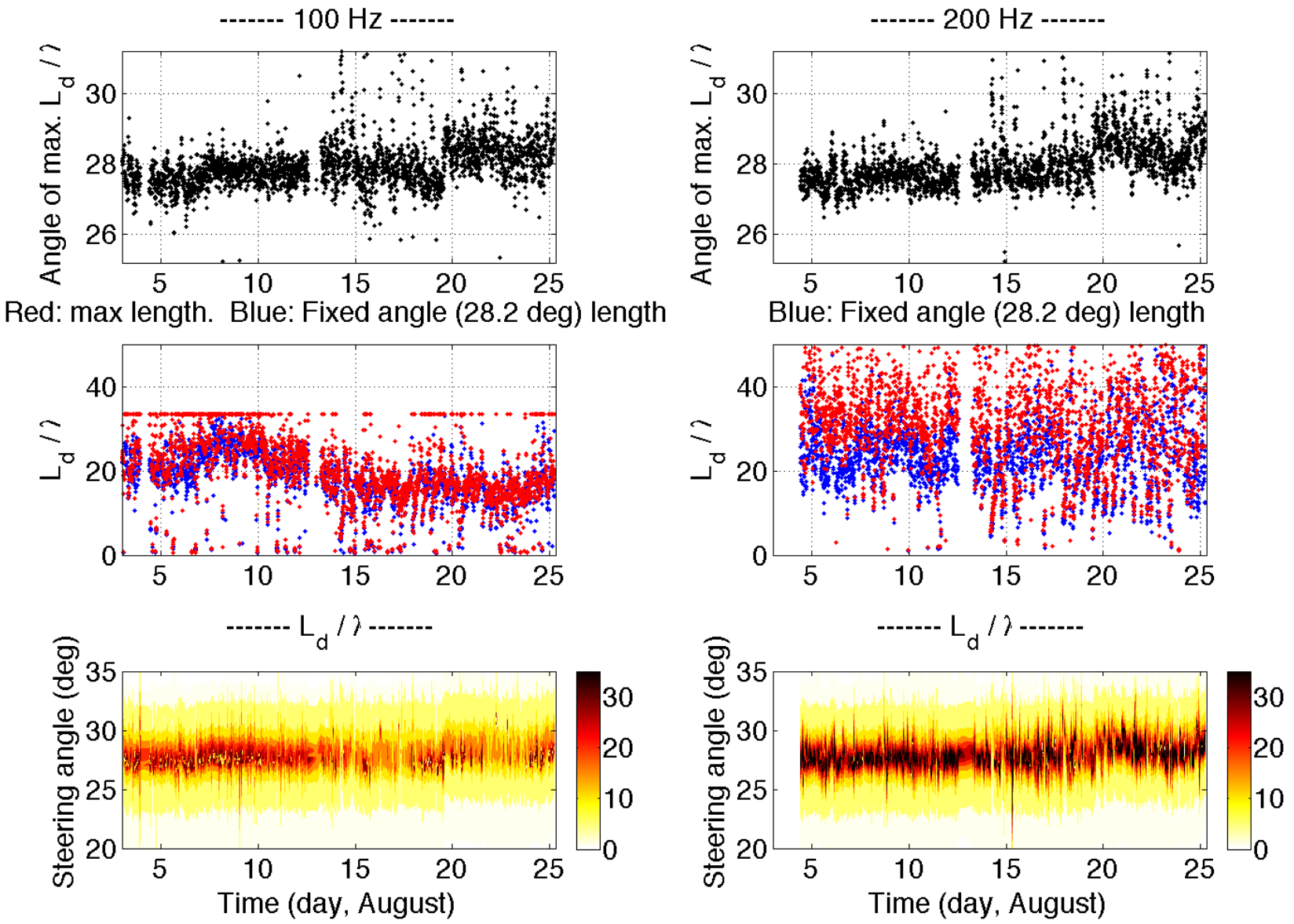
- Ensemble average estimates
- August 14 to 21



Angle Shifts (Beam Wobble)



Along-Shelf Comparisons



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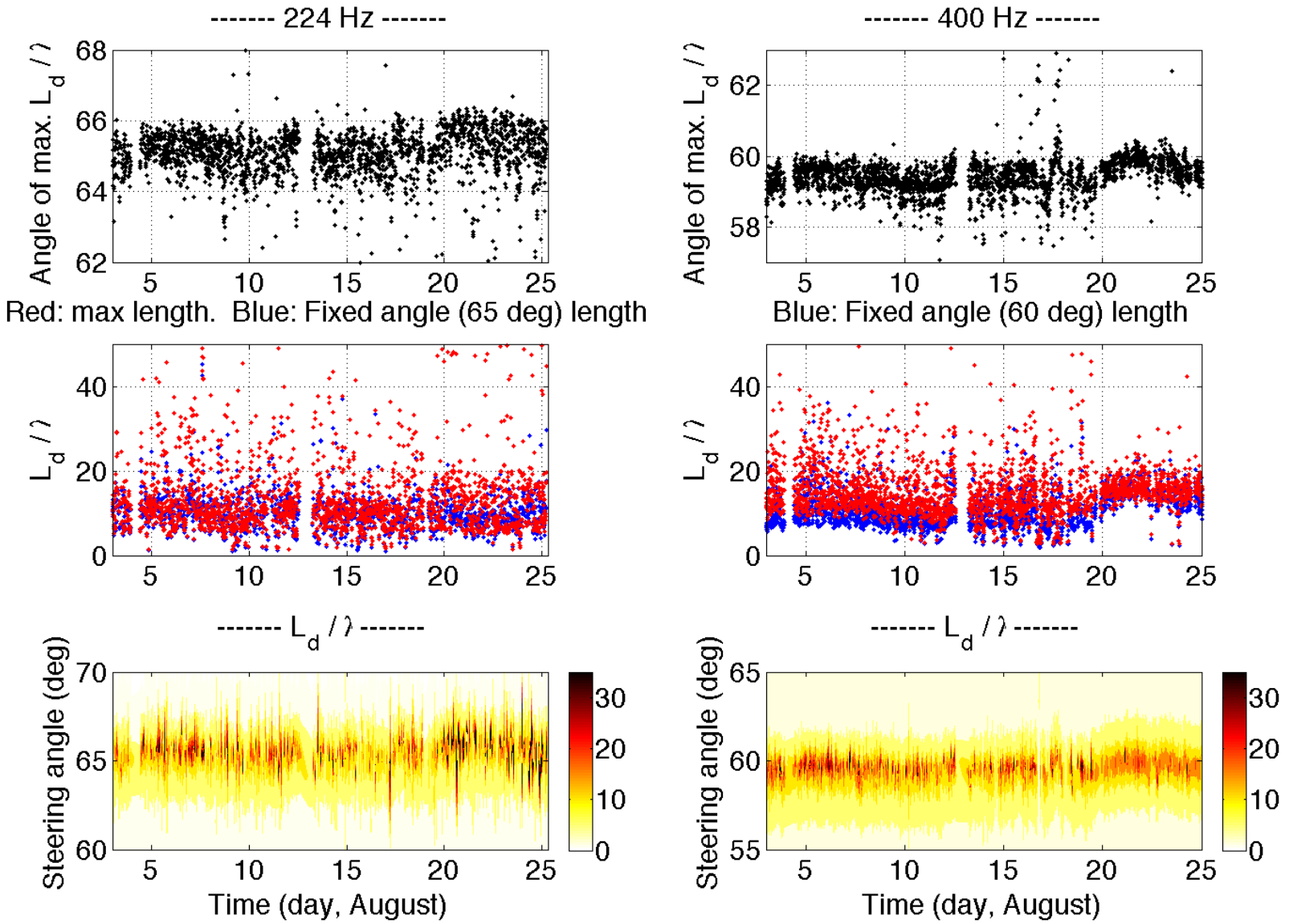
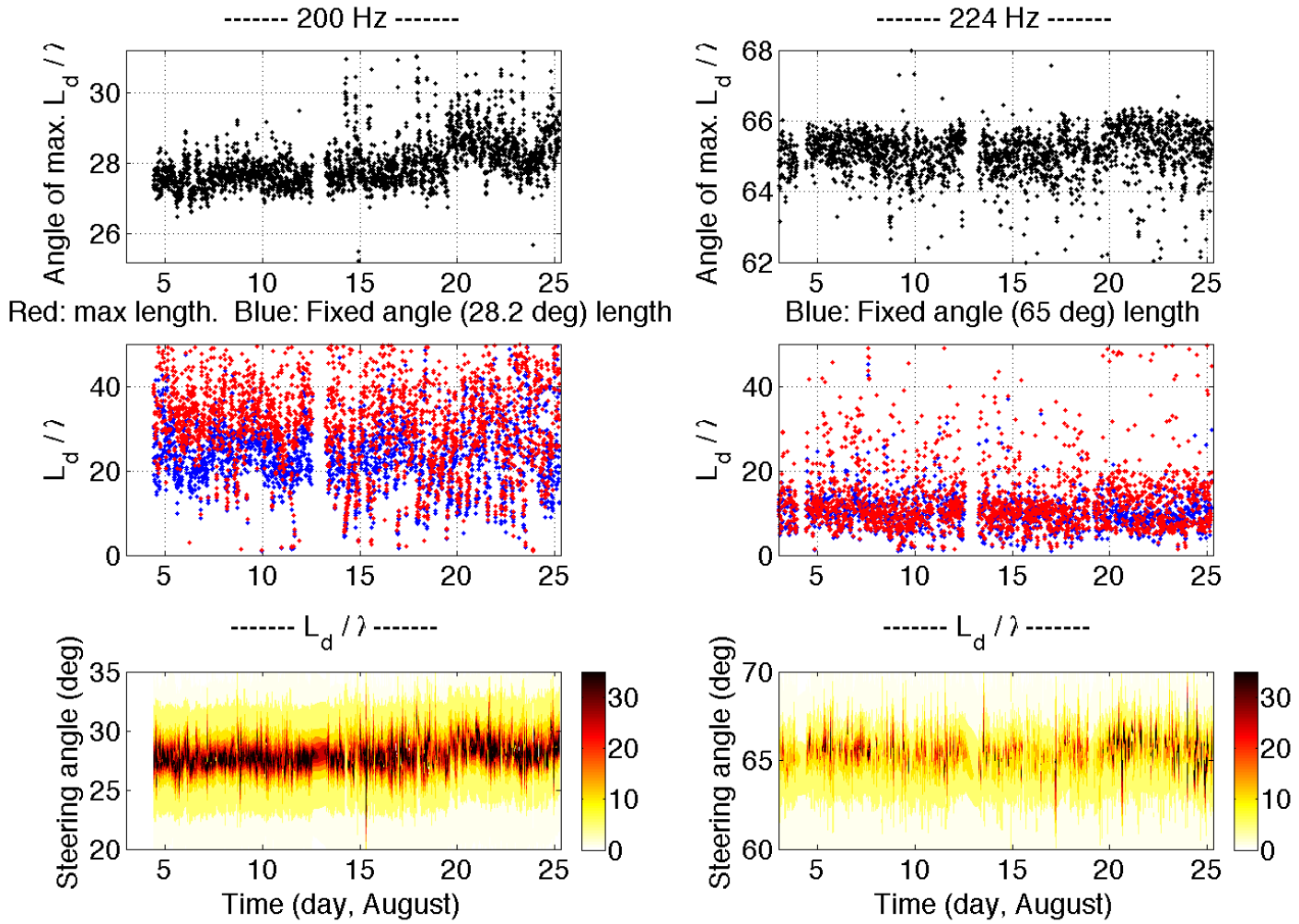


Along- versus Across-Shelf Comparisons



• Comparable wavelengths suggest propagation distance might be a better normalization

Summary of Findings

- During internal wave activity, the coherence length is reduced to a few wavelengths, projected onto a line normal to acoustic propagation (transverse line).
- At all times, coherence length assuming naïve incidence is either shorter than or equal to estimates that have been phase adjusted
- Beam steering angle critical to obtained optimized coherence length estimates
- Angle shifts correlate with internal volume effects (NLIW)
- Signal duration an important consideration
- Array may have been too short for 100 Hz signal coherence estimates, however helpful for interpreting results
- Coherence along HLA is governed by phase alteration.
  - i.e. … Coherence length for intensity is longer (not shown)
- Across-shelf coherence length is nearly double the along-shelf coherence length

Thank You

- Ying-Tsong Lin -- For his efforts in providing both the pulse compression implementations used to process encoded acoustic arrival data and the sound-speed structure data for mode filtering.

- Office of Naval Research -- without their support this research would not have been possible. Both through a Postdoctoral Fellowship Award to the first author and by sponsoring the SW06 experiment.