Observed intensity and horizontal field coherence variability of low-frequency pulse transmissions on the continental shelf.

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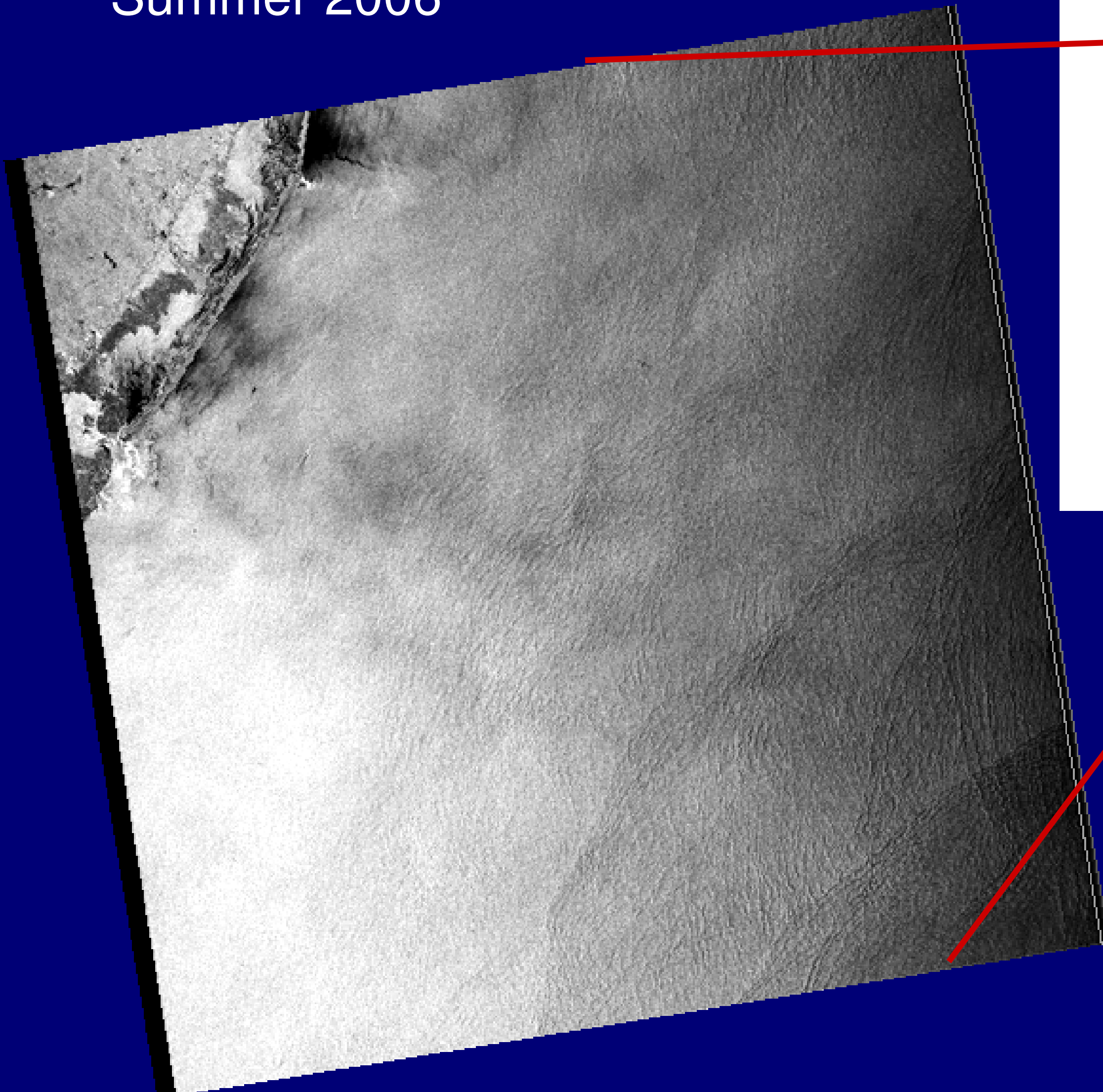
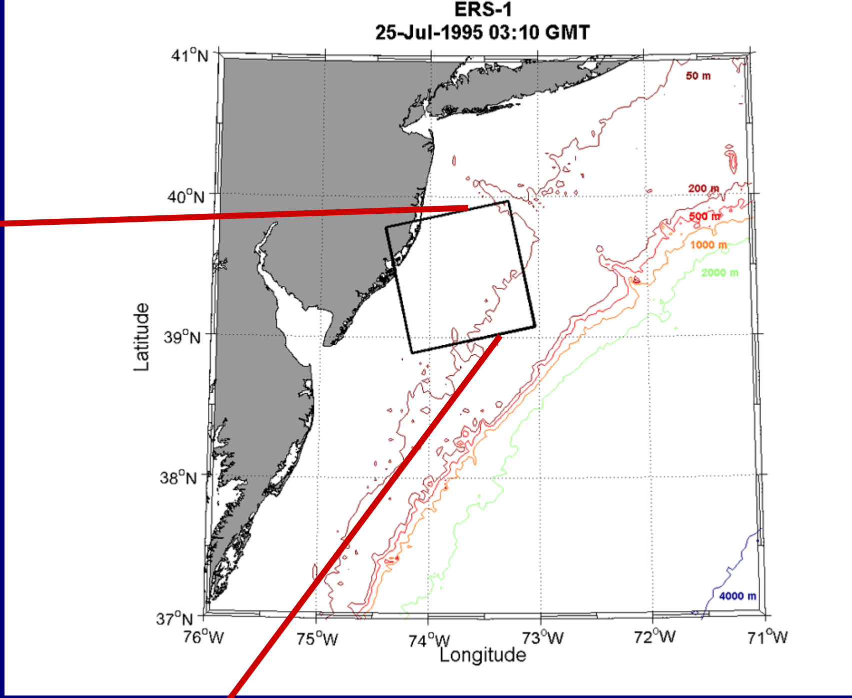
ASA Fall Meeting, 2008

* Now at Colorado School of Mines

ONR SW06 / LEAR / NLIWI Study
Summer 2006





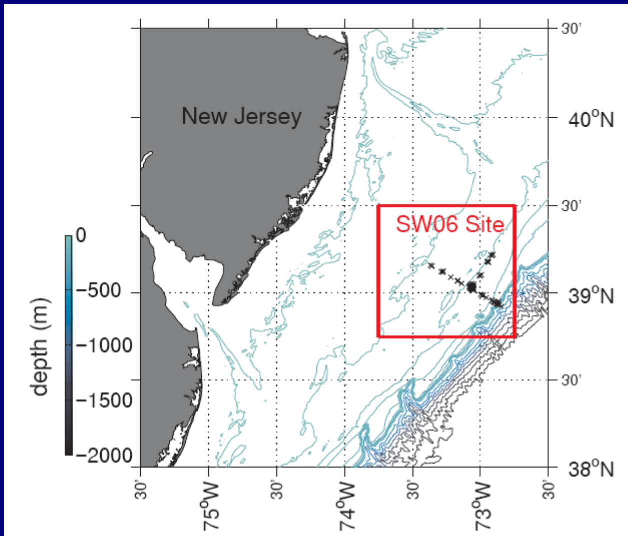


Image from Global Ocean Associates
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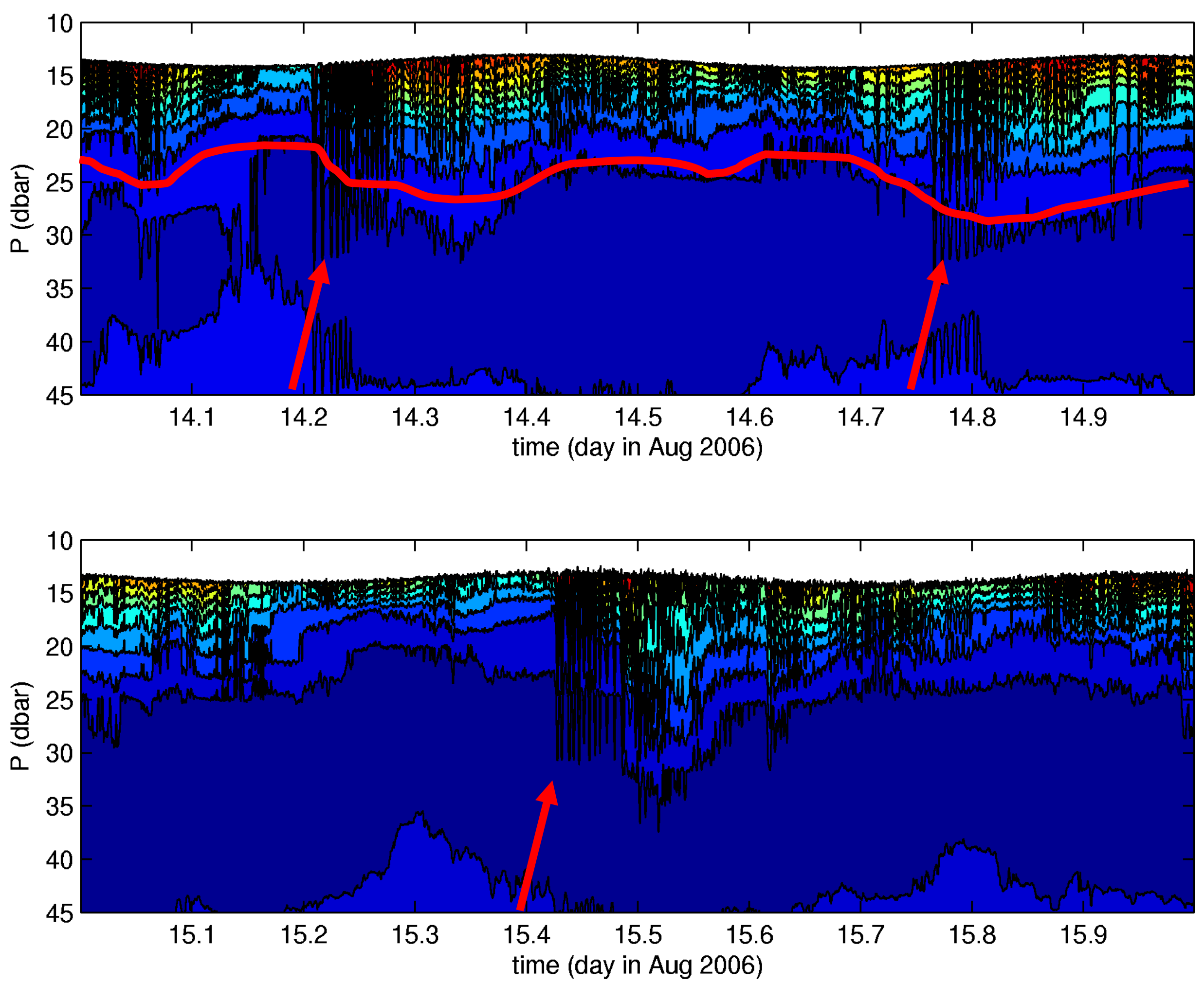
Fig: Shroyer, Moum and Nash, J. Phys. Oceanogr, in press

Character of the shoreward traveling internal tide. Time series at Central site

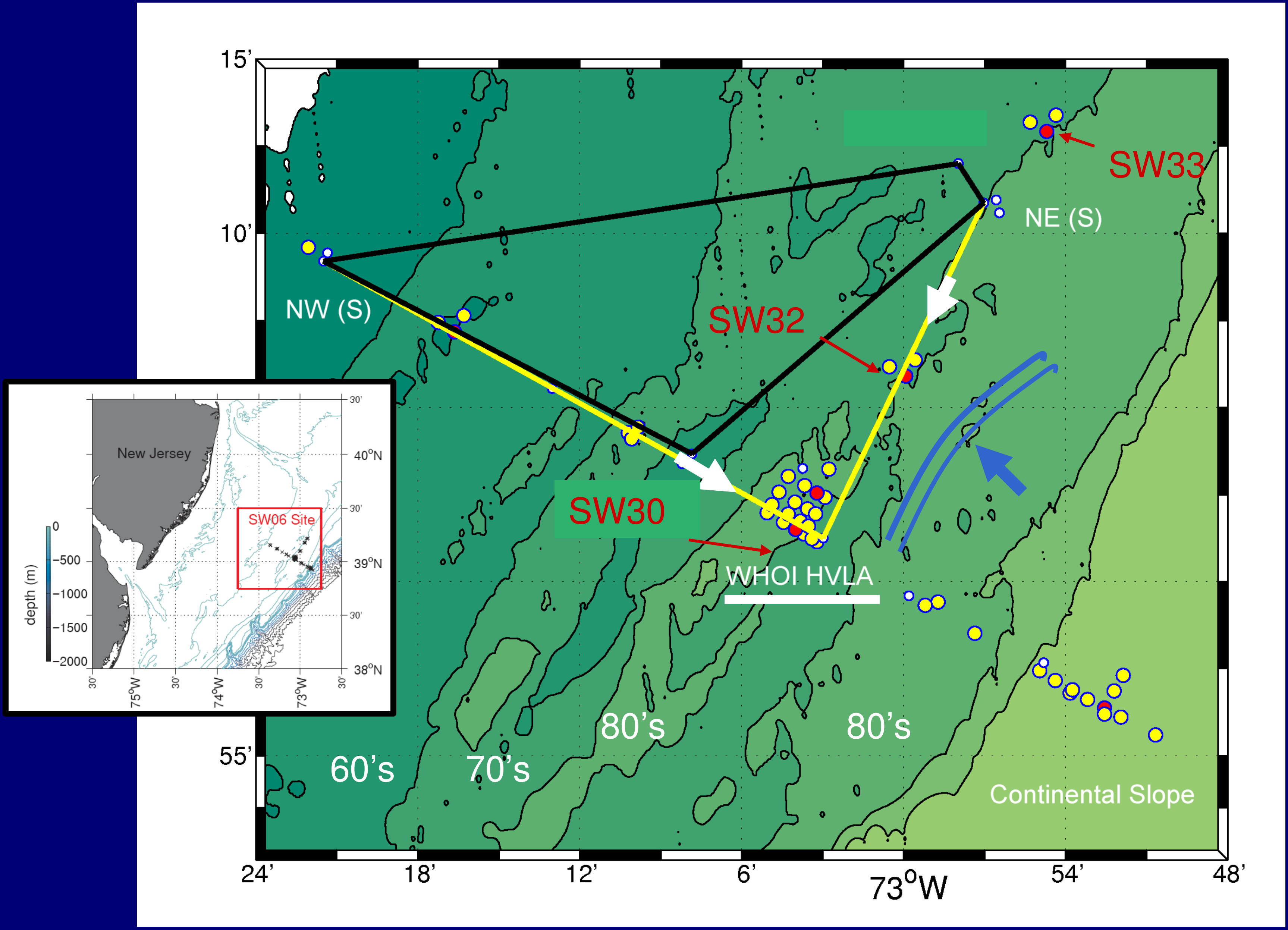
- Order 40-km wavelength
- Continually feeds energy into synchronized packets of short nonlinear internal waves



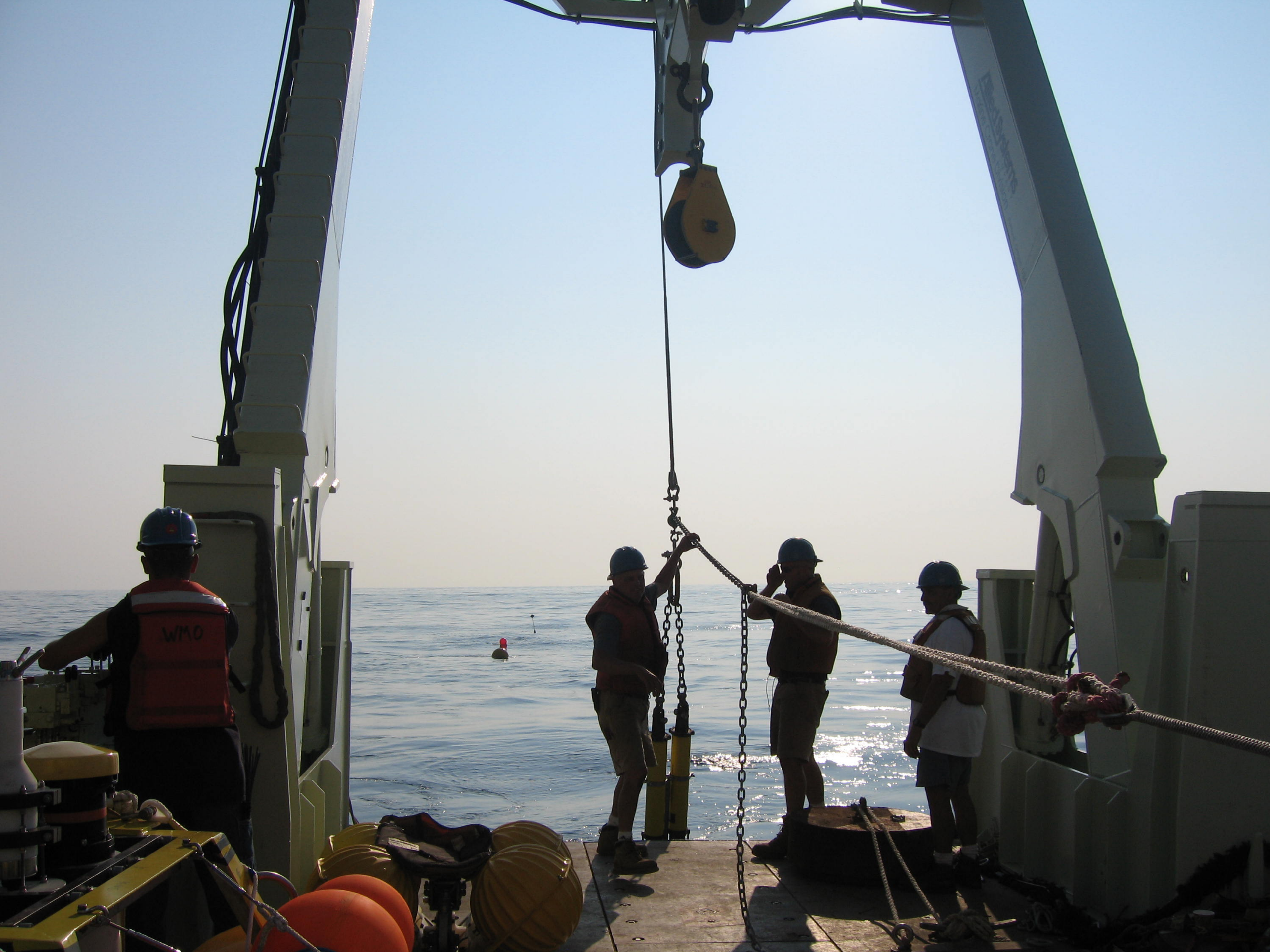
SW30 data,
Near HVLA
Isotherm depths

Aug 14, 2006

Aug 15, 2006



This talk: What is the net effect of ducting and refraction (NE sources) and mode coupling (NW sources)


WMO

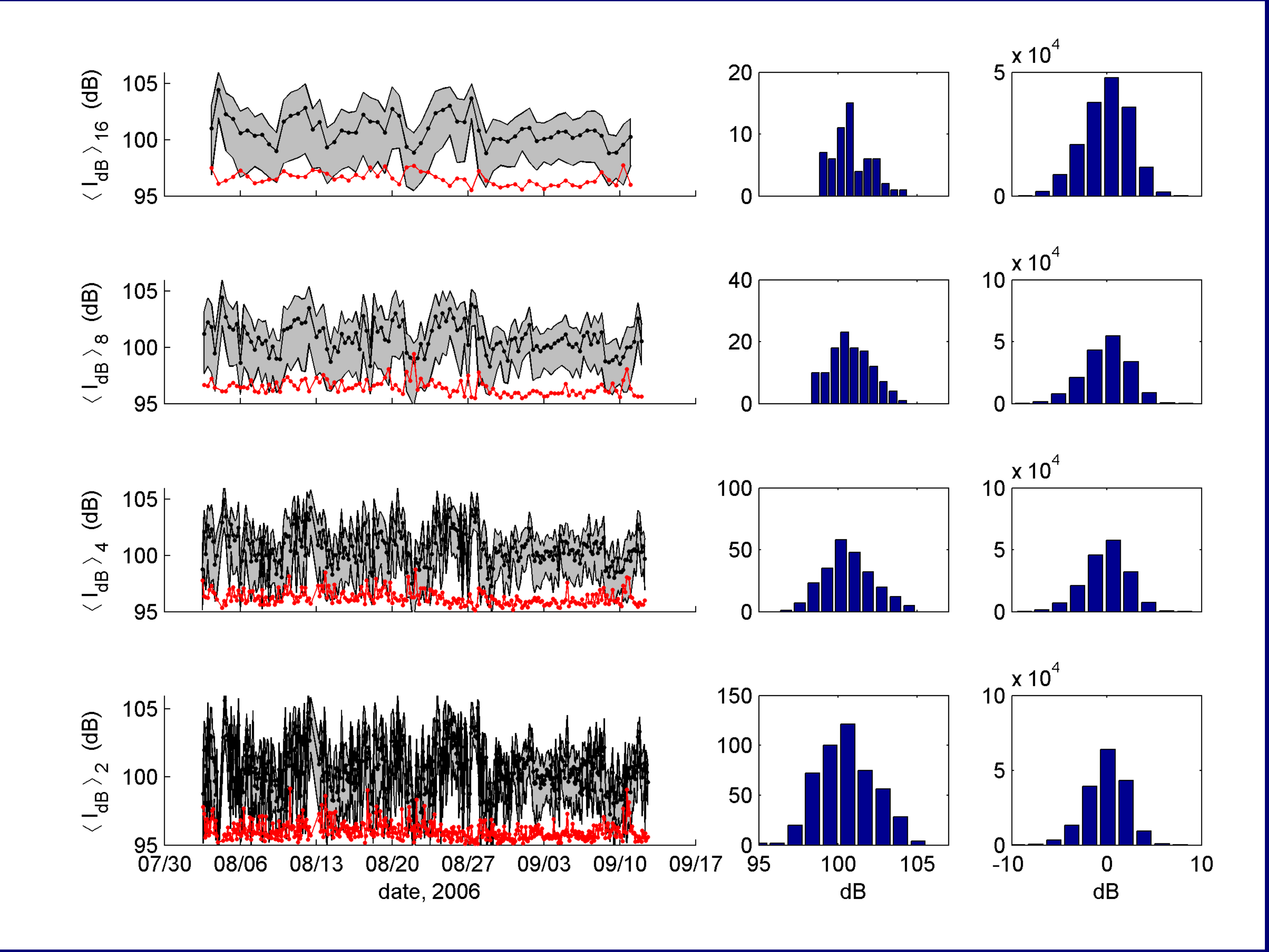
1. Temporal fluctuations at periods of minutes to hours

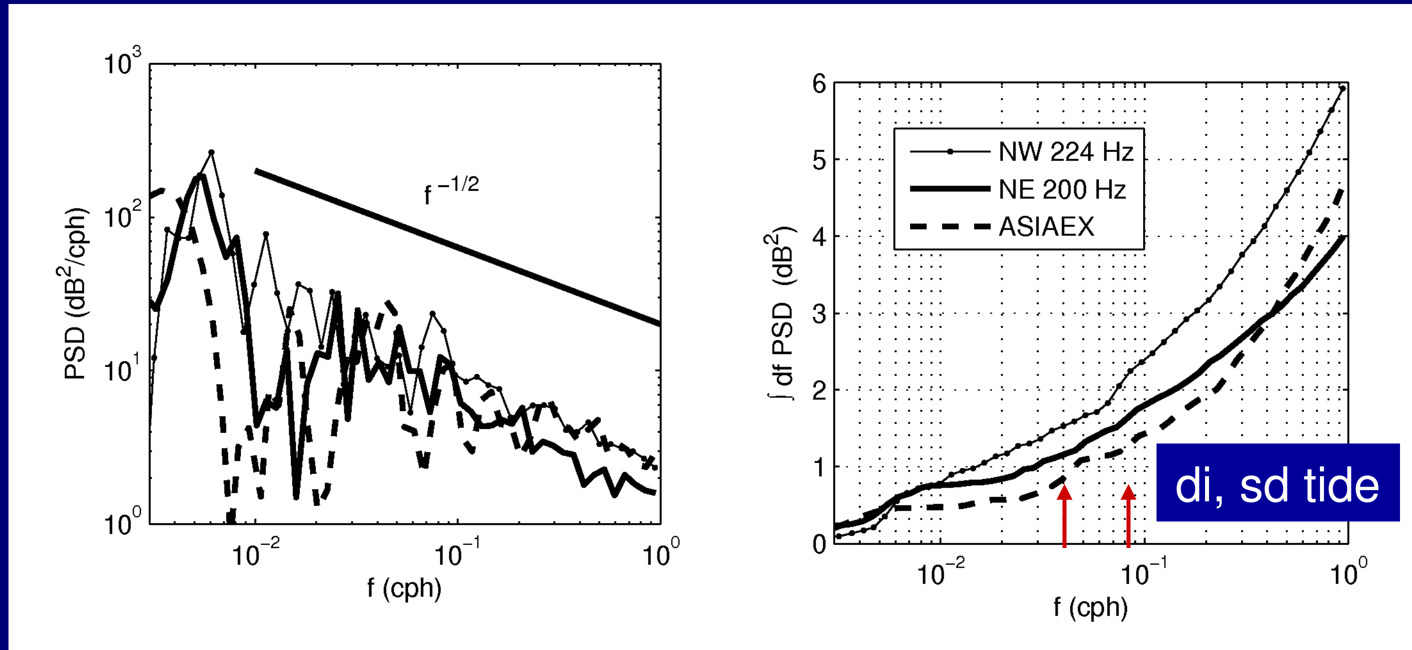
224 Hz
Cross-shelf
~ 30 km

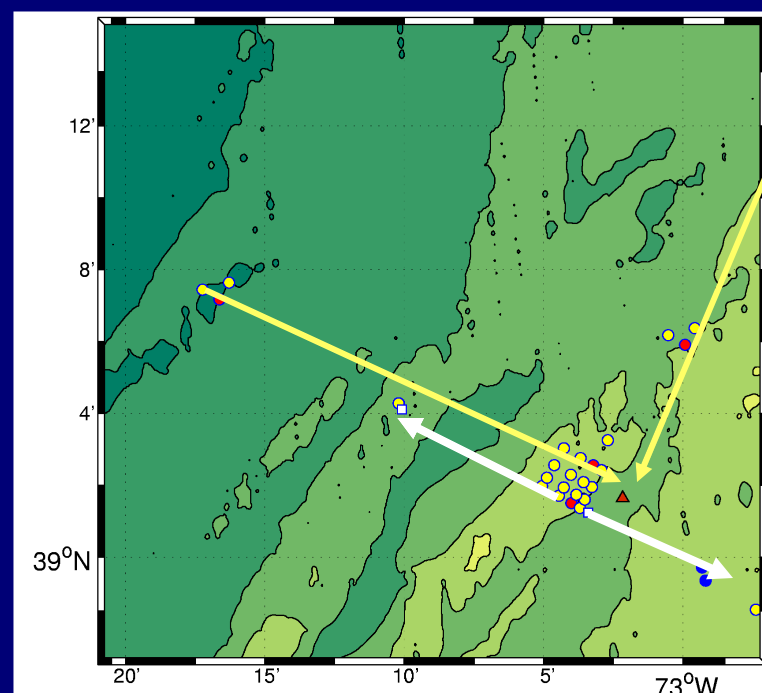
Bursts each
30 min

Receptions at
one phone

2,4,8,16-hr
averages







Gradually descending spectrum. Rises again at f >1 cph.

Note band containing most of the variance: 15 hours to 1 hr period (0.06 to 1 cph)

Gappy-date spectral methods tested and verified.

2. **<u>Horizontal variability of the acoustic field</u>** can be evaluated using

3. Array gain (or gain degradation compared with theoretical limit)
4. Coherence function $R(x) = \langle\, \Phi^*(x_0)\ \Phi(x_0+x)\,\rangle$, $\Phi = \Phi\ (t) = A(t)\ \exp(iB(t))$
5. Length scale where *R* falls to benchmark value (i.e. *exp(-1)*)
6. Characteristic length scale of coherence function

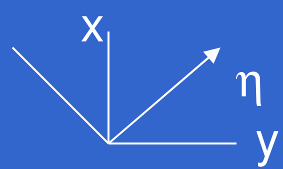
Published results obtained by analyzing a subset of the NE data

Two behaviors observed: (JASA EL Sept 2008)

4. ***Without large internal waves***: Fixed-mode (idealized field) and actual-field *R* have similar shape; coherence lengths reach their greatest values, ~240 m (16λ) ; ***Mode interference restricts coherence.***
5. ***With large internal waves***: Fixed-mode and actual-field *R* differ; Resulting coherence lengths are short: Fixed-mode: 140 m (9.3λ), Actual: 80 m (5.3λ). ***Strong azimuthal variability in the propagation restricts coherence.***

Procedure to separate azimuthal field variability: Compare actual and synthesized "Fixed-Mode" horizontal field variability.

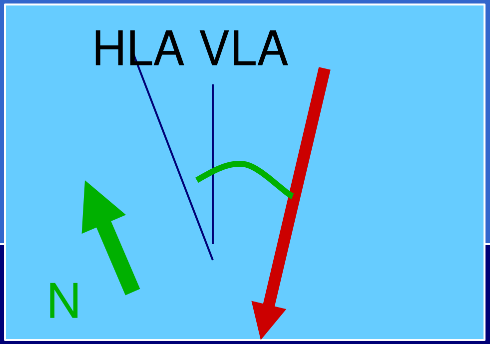
$$p_s\left(x_0, y - y_0, z_b, y, t\right) = \sum_{n=1}^{N} A_n\left(t\right)\phi_n\left(z_b\right)\exp\left(ik_n\Delta\eta\right)$$

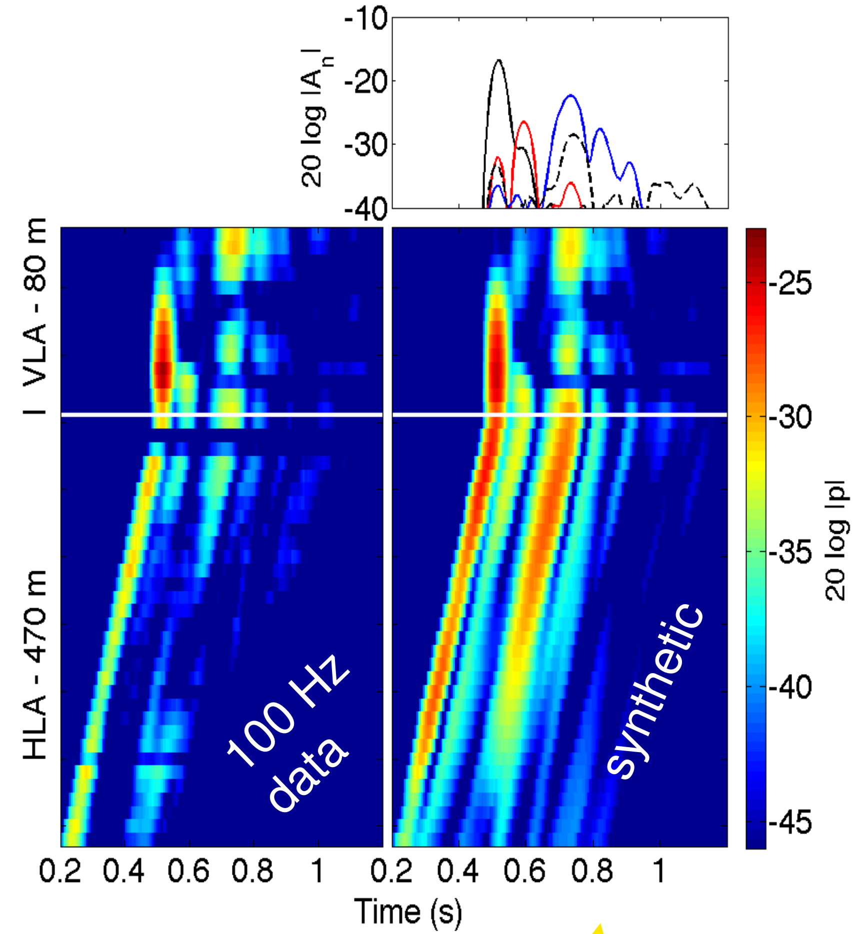


Need modes ϕ

Mode filter at VLA: $A_n(t)$

Can synthesize fixed-mode field anywhere, including interference.





Note: intensity images don't visualize coherence scale -- phase dominates

Coherence functions *R(x)*

Ensemble members (i.e. *R* curve for each pulse) and mean *R* functions, *actual and fixed-mode synth.*

(1) small IW

(2) large IW

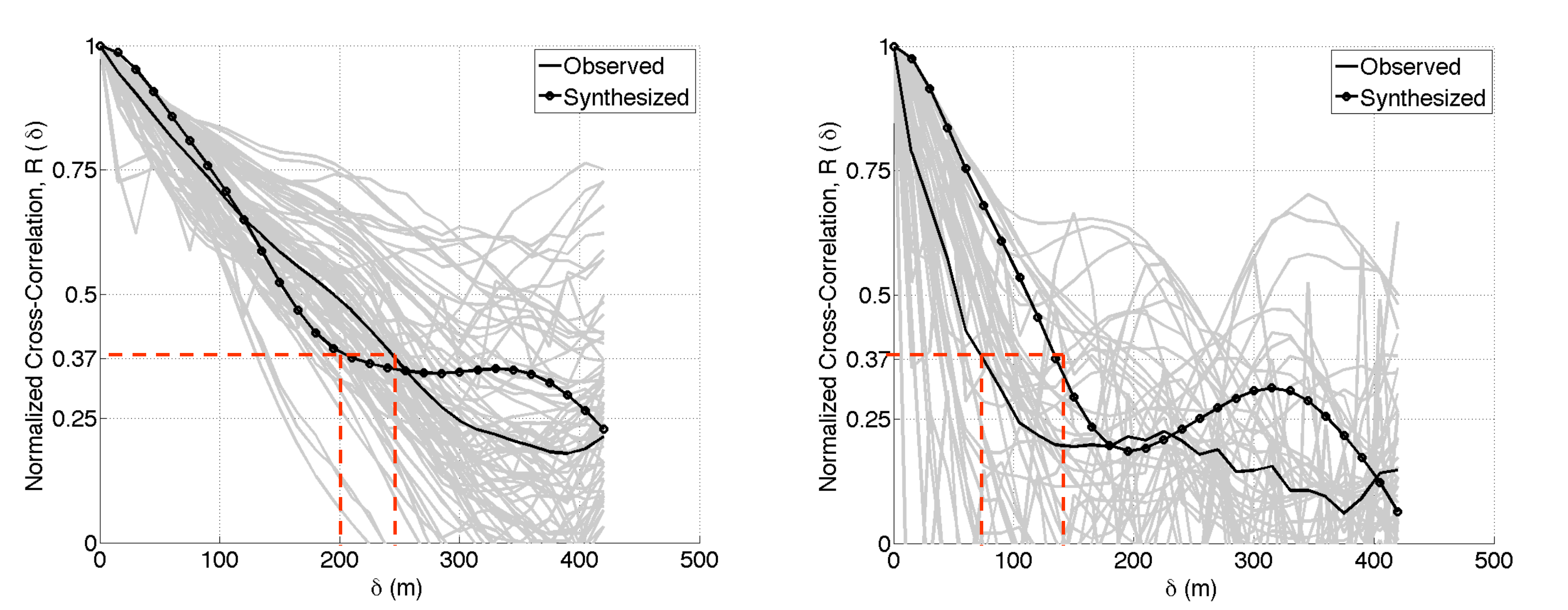
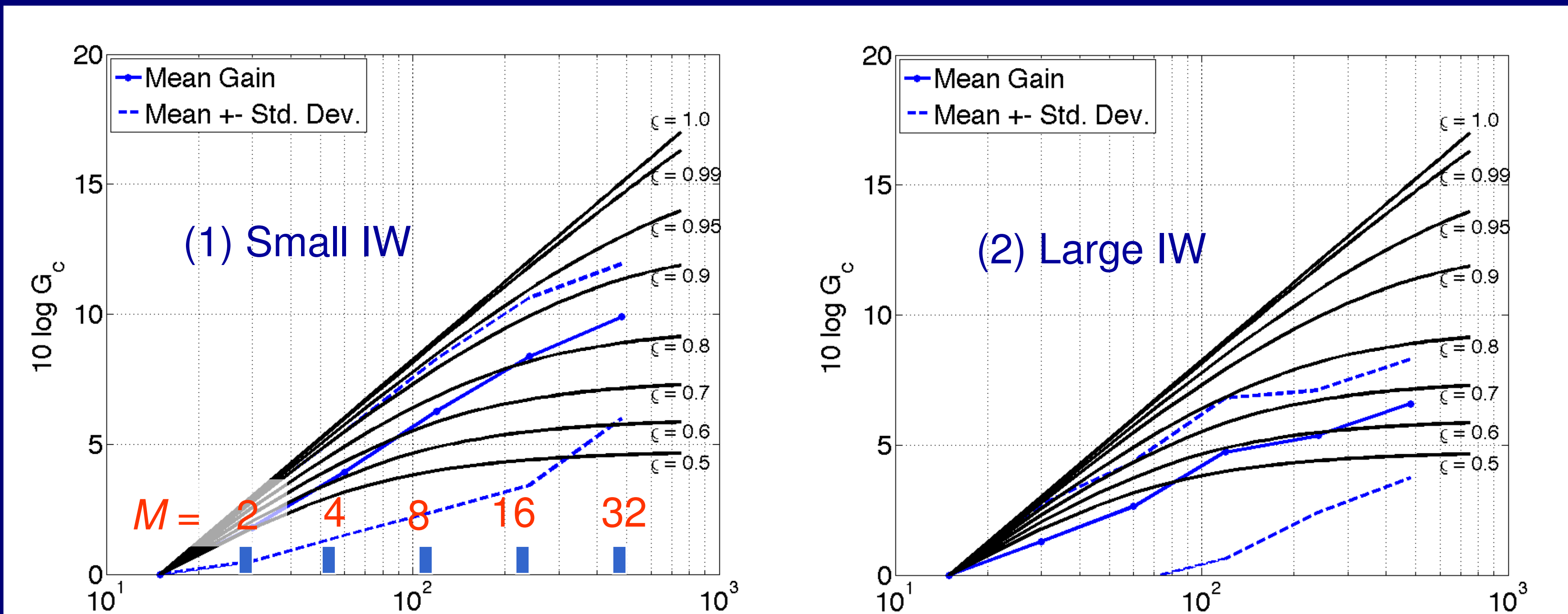


Table with correlation lengths available in the JASA-EL paper.

Array gain analysis:

Signal to noise improvement (gain, G_c) as a function of the number of equally spaced elements (M) is plotted, dB format.

$$G_c(M) = (S_M / N_M)/(S_1 / N_1)$$



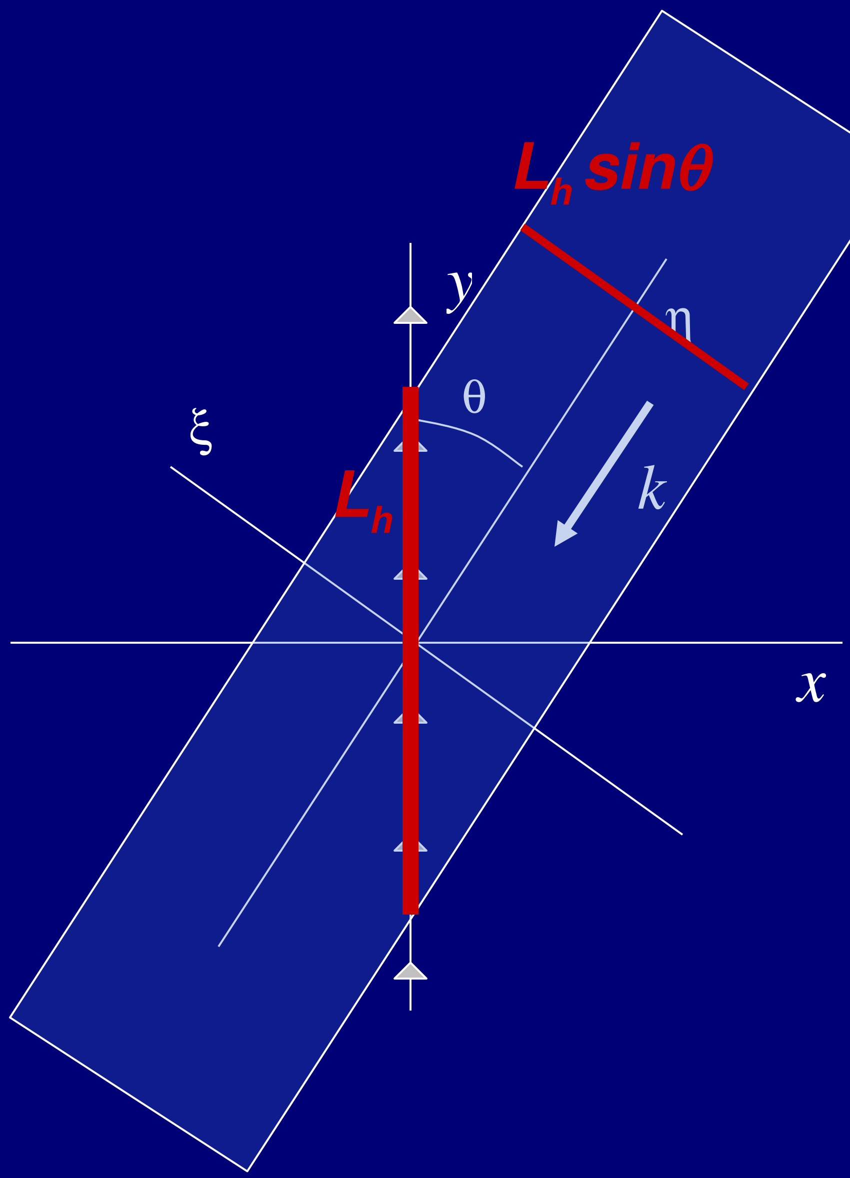
Array length (m) at $\Delta y = s = 15$ m Array length (m) at $\Delta y = s = 15$ m

Degradation below theoretical max is seen. Smooth curves show gain for various correlation parameters ρ, where

$$R(js) = \rho^j = \exp\left(-(js / H\lambda)^p\right), \quad p = 1$$

and where $H\lambda$ is correlation length.

** Note that using array shape increases gain…*



Large-IW Case .. having differing actual and fixed-mode coherence lengths …

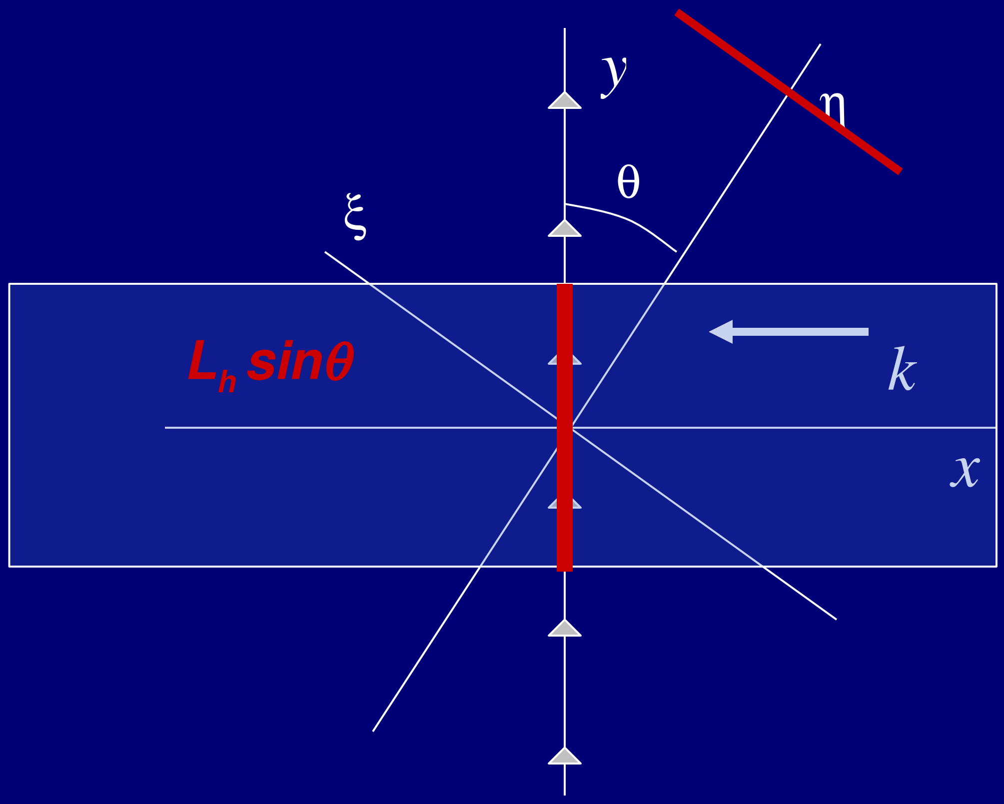
The value from actual data is shorter, ***meaning that*** mode interference caused by off-broadside incidence ***is not*** the explanation for finite *R*.

Azimuthally-varying * mode amplitudes and phases must be present, giving finite transverse coherence scale

(* azimuth re source)

L_h = 80 m

L_h sin(25 deg) = 33 m



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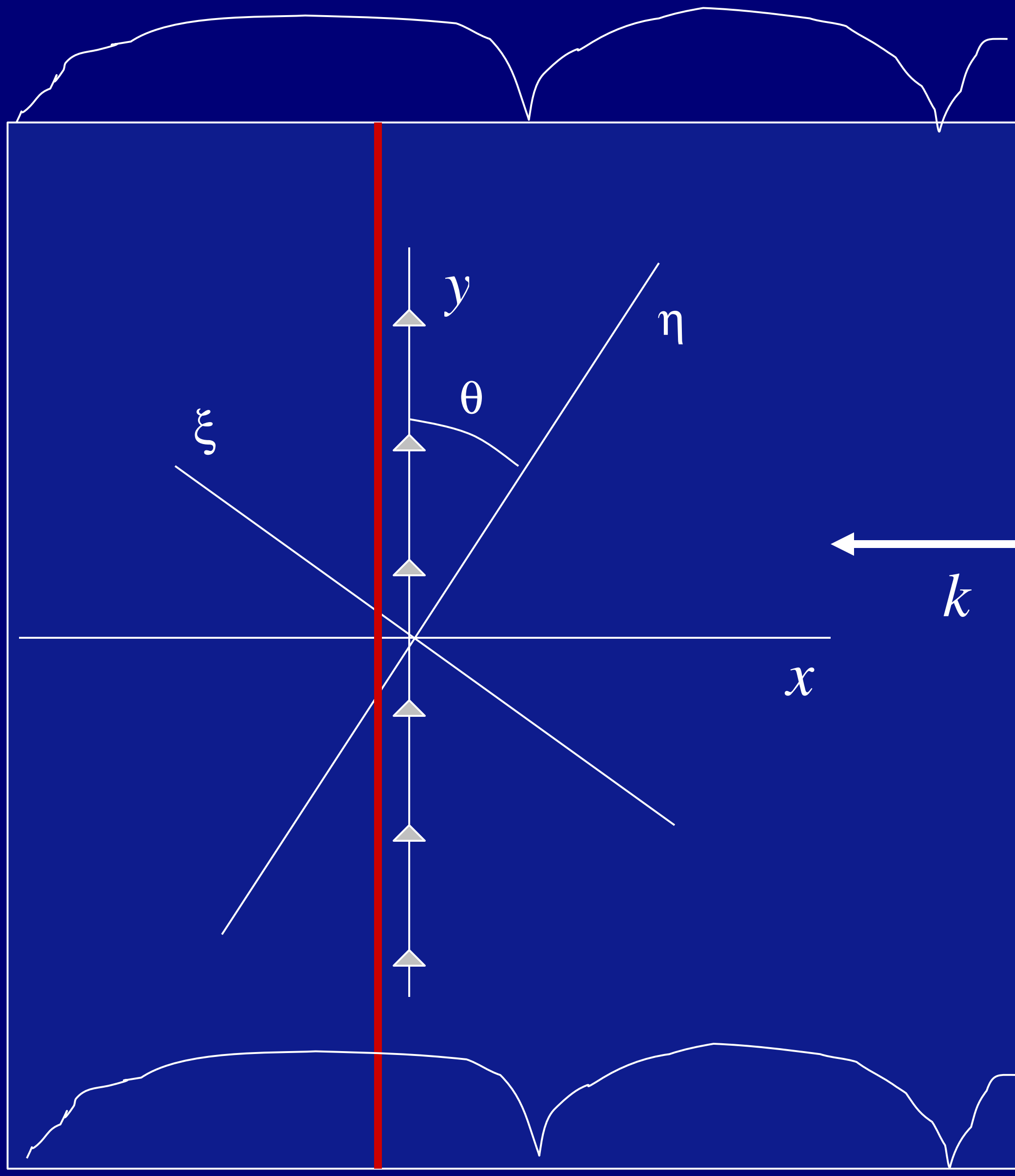
Coherence scale decreases as broadside is approached

Mode-Interference Controlled Case (small internal waves)

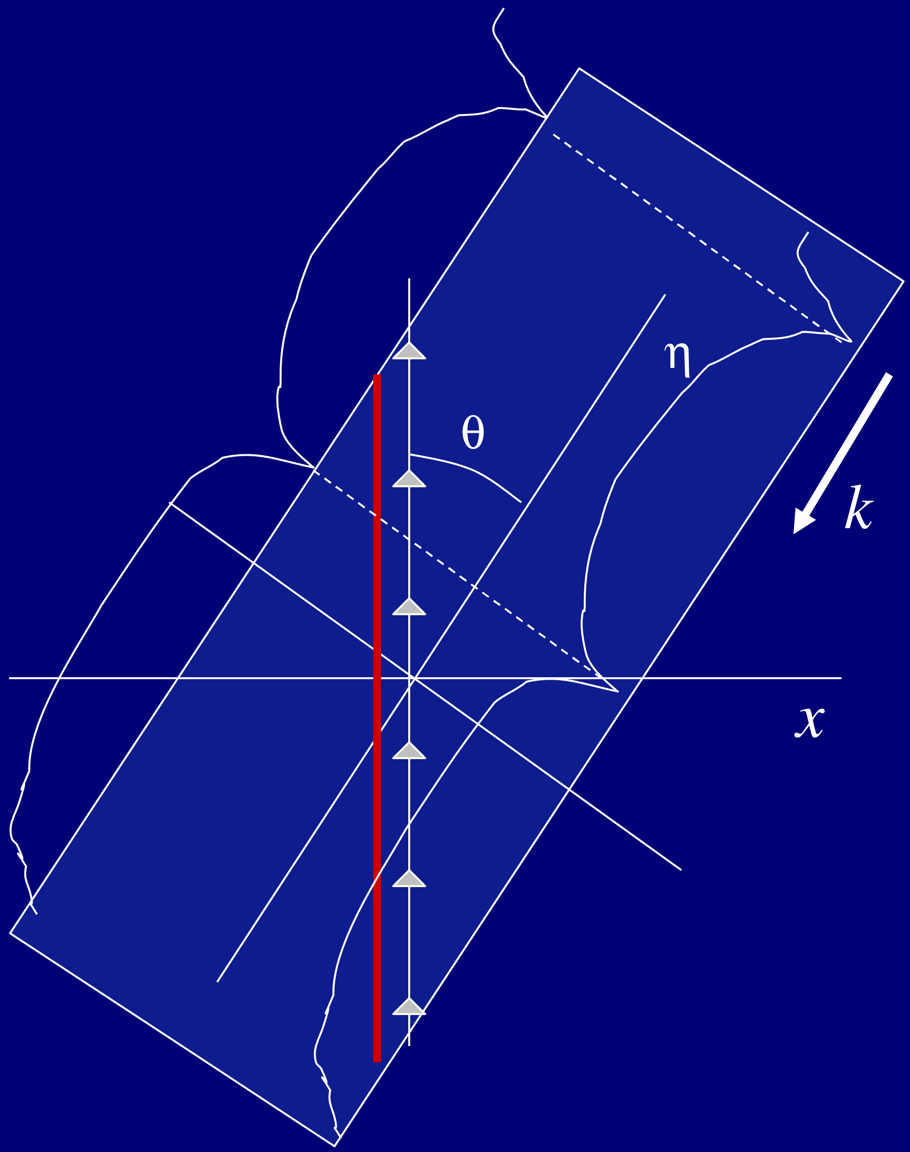
Fixed-mode and actual HLA data yield same coherence scale.



Mode-Interference Controlled Case

Long coherence length at broadside

Probable reduction of coherence length at other incidence angles, the opposite of the azimuthally-dependent propagation case

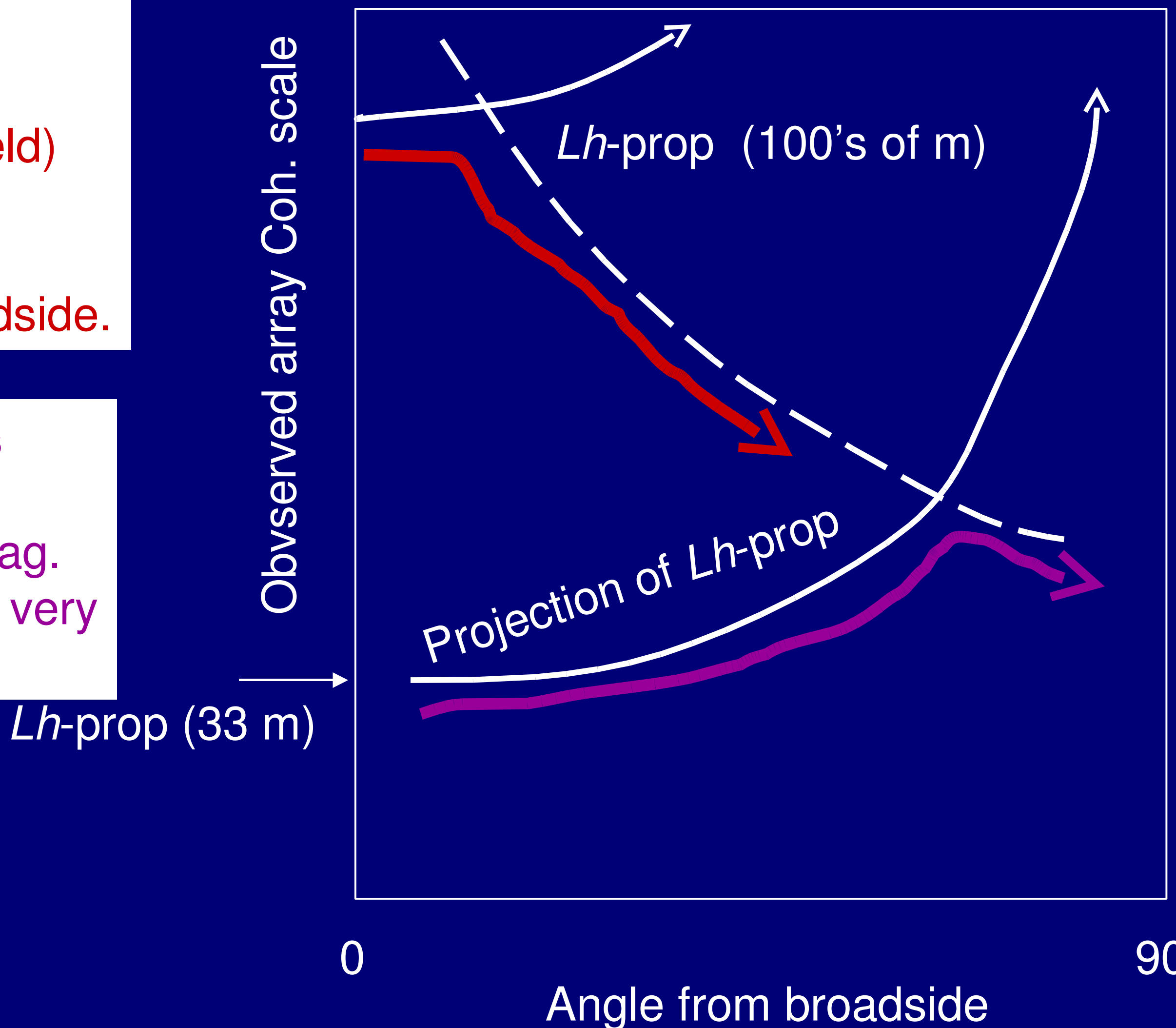


Small internal waves

Minor mode (and/or field) variation with azimuth, azimuthal effects are only important at broadside.

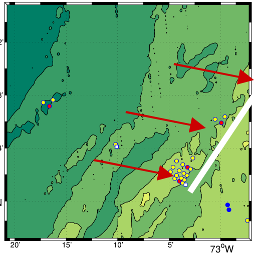
Large internal waves

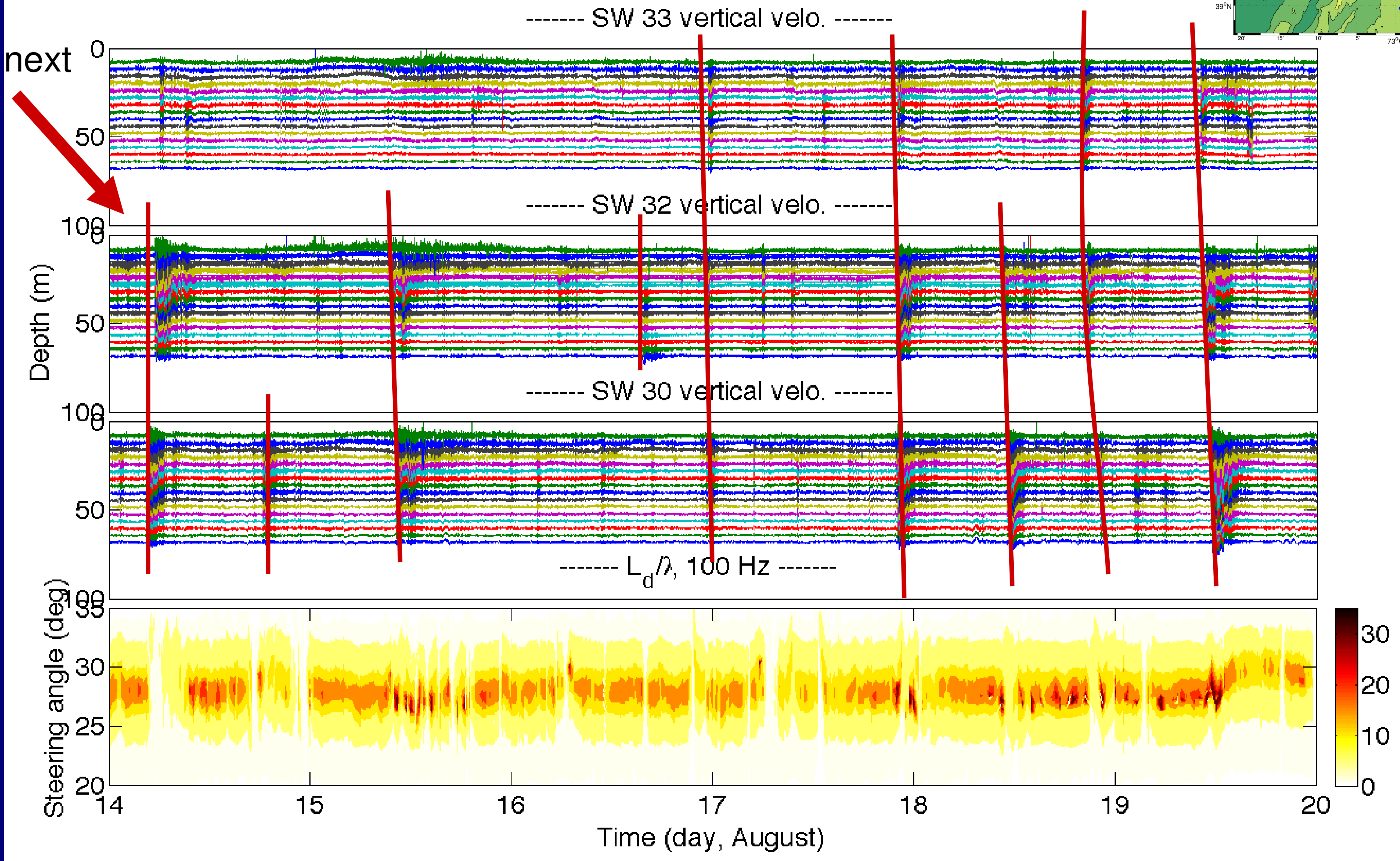
Strong azimuthal propag. limitation : *Lh*-prop is very short



[dashed line: Incidence angle-dependent mode-interference effect]

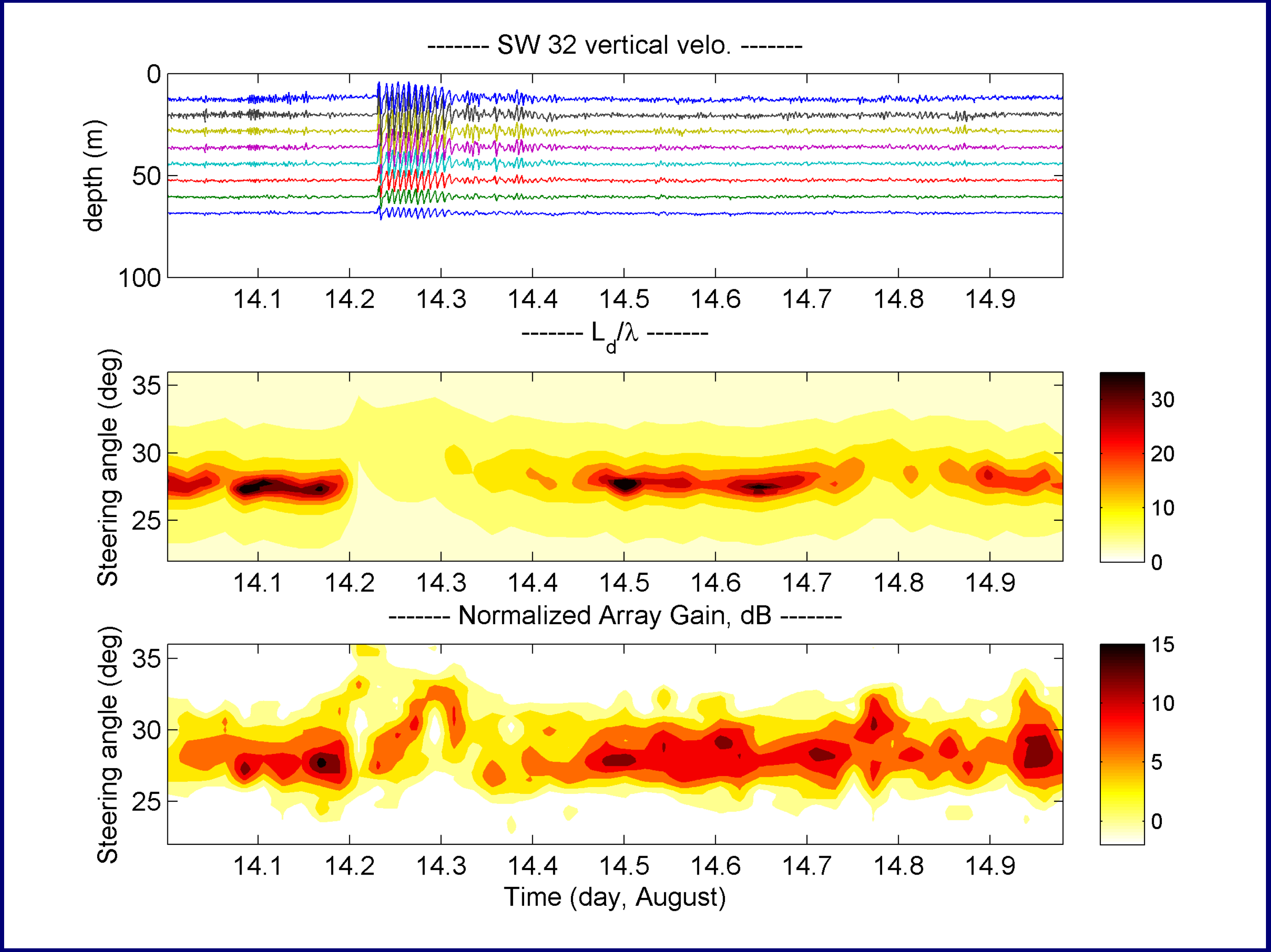
3. Coherence Lengths, Steered-beam analysis
100 Hz, 19.2 km NE path (along wave crests)

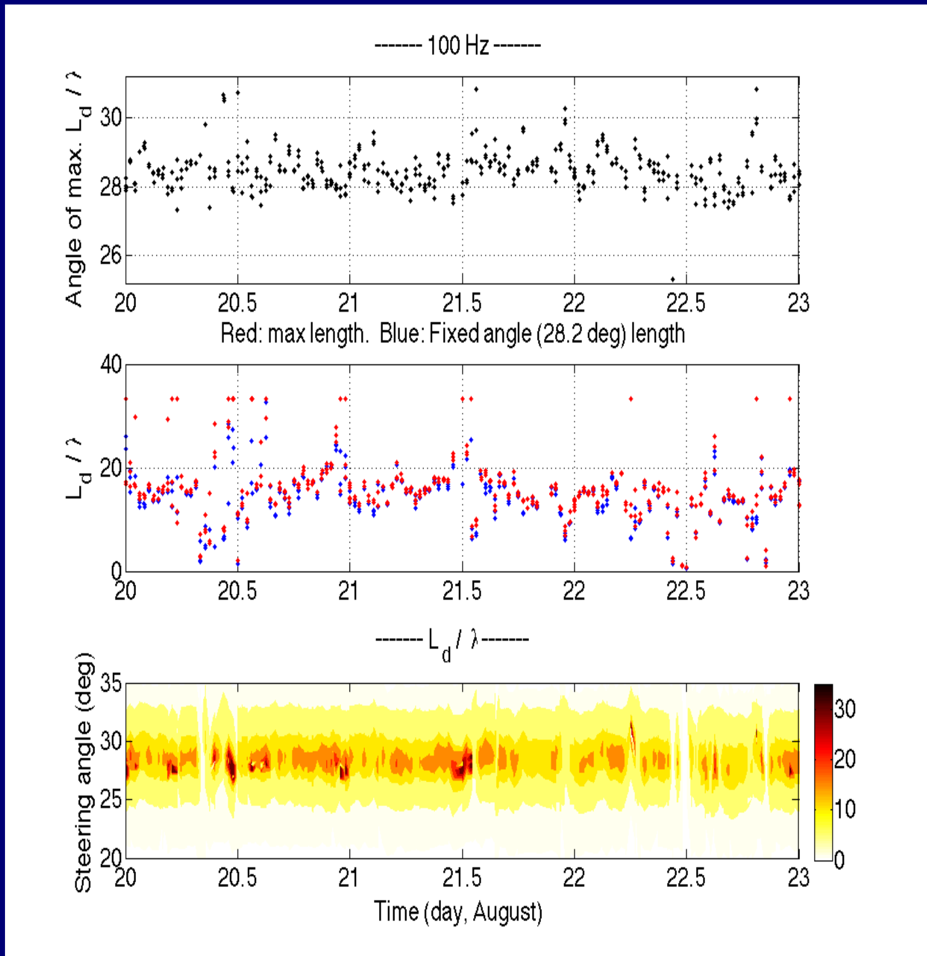


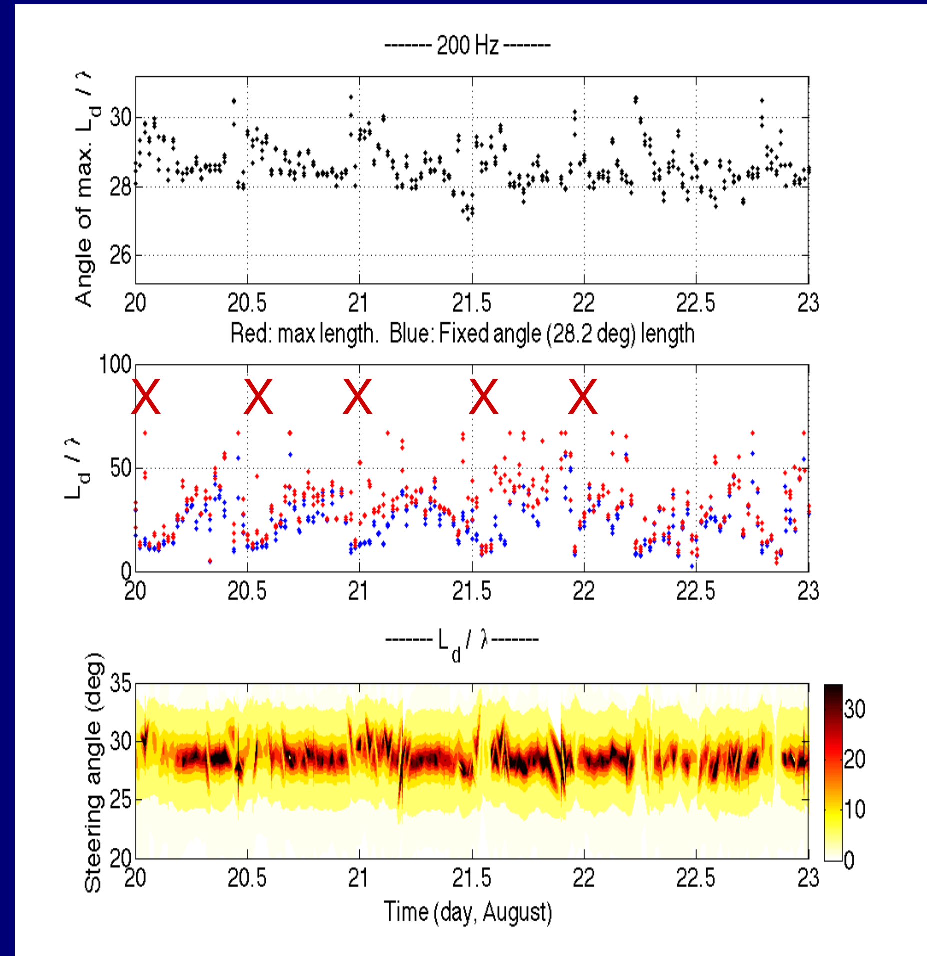


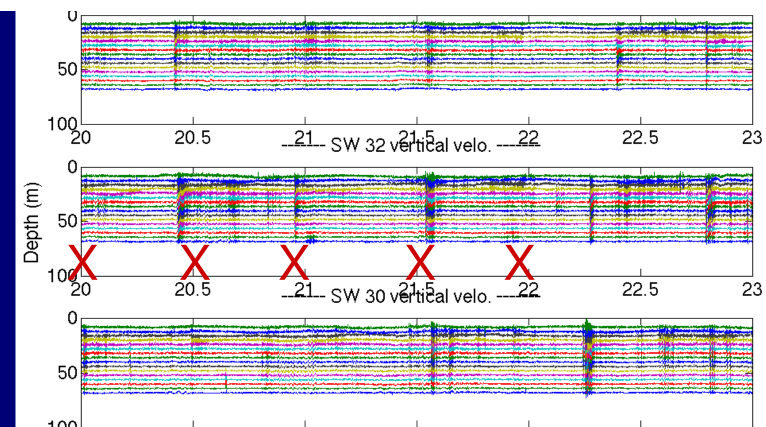
Multiple steering angle analysis. 200 Hz, NE 19.2 km path.

As waves pass, signal direction wobbles and coherence length decreases.



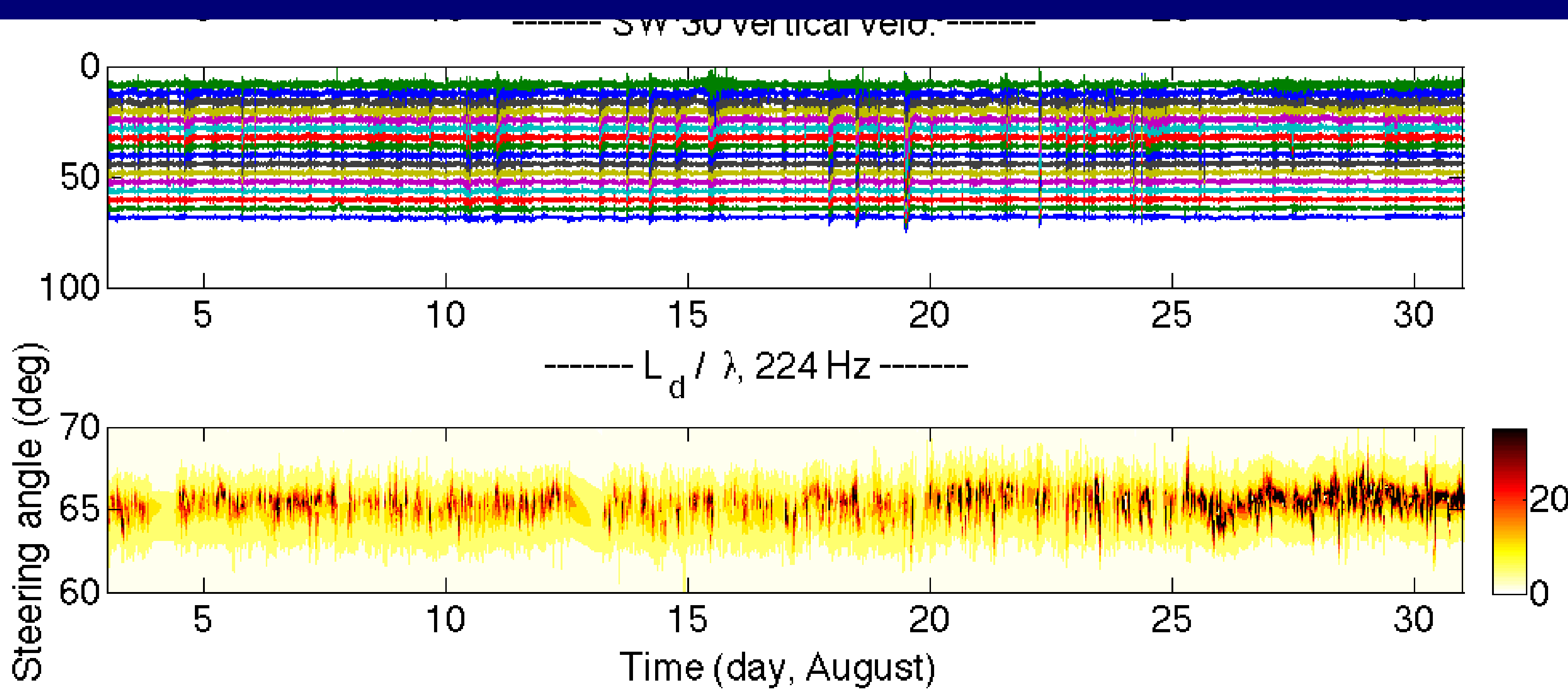






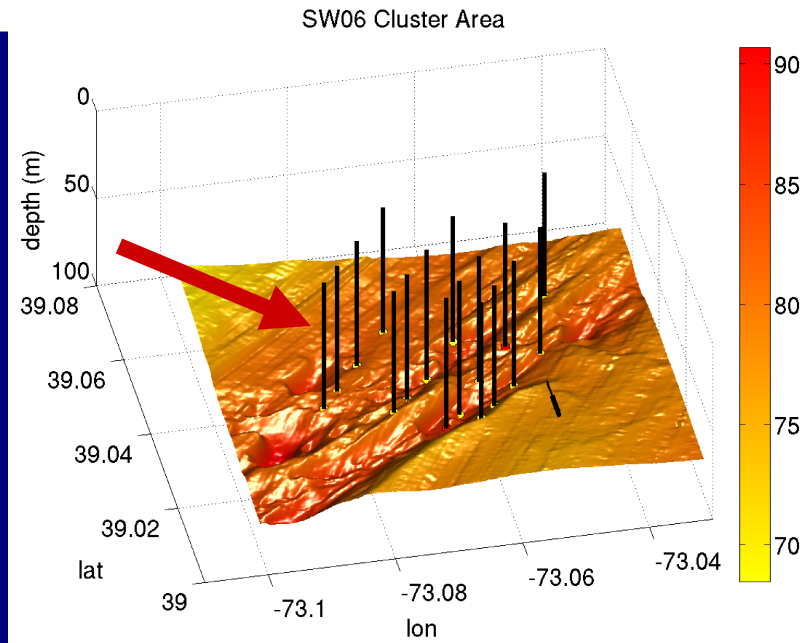
Top: angle wander
Center: Fixed angle vs peak estimate
Bottom: full result contoured

Similar results using beam power



Cross-shelf NW path: Coupled-mode propagation situation.

Short and variable coherence length estimates. Cause (?): Short-scale variations of the internal-wave crests, micro-bathymetry, short-scale static finestructure or slope water intrusions, …



Summary

- **Along-shelf (along wave crest) propagation**
  - *Correlation and array-gain analyses quantify differences in signal character with/without nonlinear internal waves*
  - *Down-range mode interference and azimuthal variations of field can be separated. A simple description of correlation length vs. steering angle is possible.*
  - *Coherence length reductions coupled (more or less) with wave passage and quantified for our array geometry. (Ducting and refraction of modes)*
- **Across-Shelf propagation**
  - *Temporal variations occur at periods of many hours, internal-tide linked. There is a slightly sloped spectrum,* $f^{-1/2}$
  - *Temporal variations at periods less than one hour consistent with coupling variations caused by internal wave motion.*
  - *Horizontal coherence scales are shorter than anticipated. Strong refraction is unlikely, implicating effect of small-scale medium*

- **1pAO1. Observed intensity and horizontal field coherence variability of low-frequency pulse transmissions on the continental shelf.**
- **Session: Monday Afternoon, Nov 10**
- **Time: 1:30**
- **Author: Timothy F. Duda**
  Location: Woods Hole Oceanograph. Inst., AOPE Dept., MS 11, Woods Hole, MA 02543
  Author: Jon M. Collis
  Author: Ying-Tsong Lin
  Author: James F. Lynch

  Abstract:
- Rapid coastal environmental evolution leads to highly variable acoustic fields. To quantify such variability, one component of the Shallow-Water 2006 (SW06) program on the shelf east of New Jersey was time series measurement of sound transmitted from fixed sources to joined horizontal and vertical line arrays. Transmission paths were both cross-shelf and along-shelf (across and along dominant internal-wave crests). Data were collected for over one month. Intensity time series of 100–400-Hz pulses was found to have strong variability at periods from hours to over a day, consistent with long-wavelength internal-tide effects. Such effects can arise from adiabatic mode and/or coupled mode propagation. Separation of fluctuations into slow and rapid contributions allows calculation of a time-varying horizontal coherence-length statistic. For along-wave crest transmission, this was highly variable, typified by values ranging from a few acoustic wavelengths to over 40 wavelengths, typically 10–25. The slow coherence-length fluctuations had signatures of periodic (tidal) mode-refraction episodes (with short scale) during active intervals, caused by internal-wave ducting. Conditions were more steady at other times. Across-crest transmissions showed shorter than expected scale lengths of tens of wavelengths with more subtle tidal dependence. [Work supported by the Office of Naval Research.]