Capturing Uncertainty in the Common Tactical-Environmental Picture

Uncertainty DRI – Program Review
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Newport, Rhode Island

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Outline

- Summarize past results to June 2002
- Recent fleet contributions
- Architecture
- Individual components
  - Focus on information flow between “blocks”
- Summary

Overall Goal

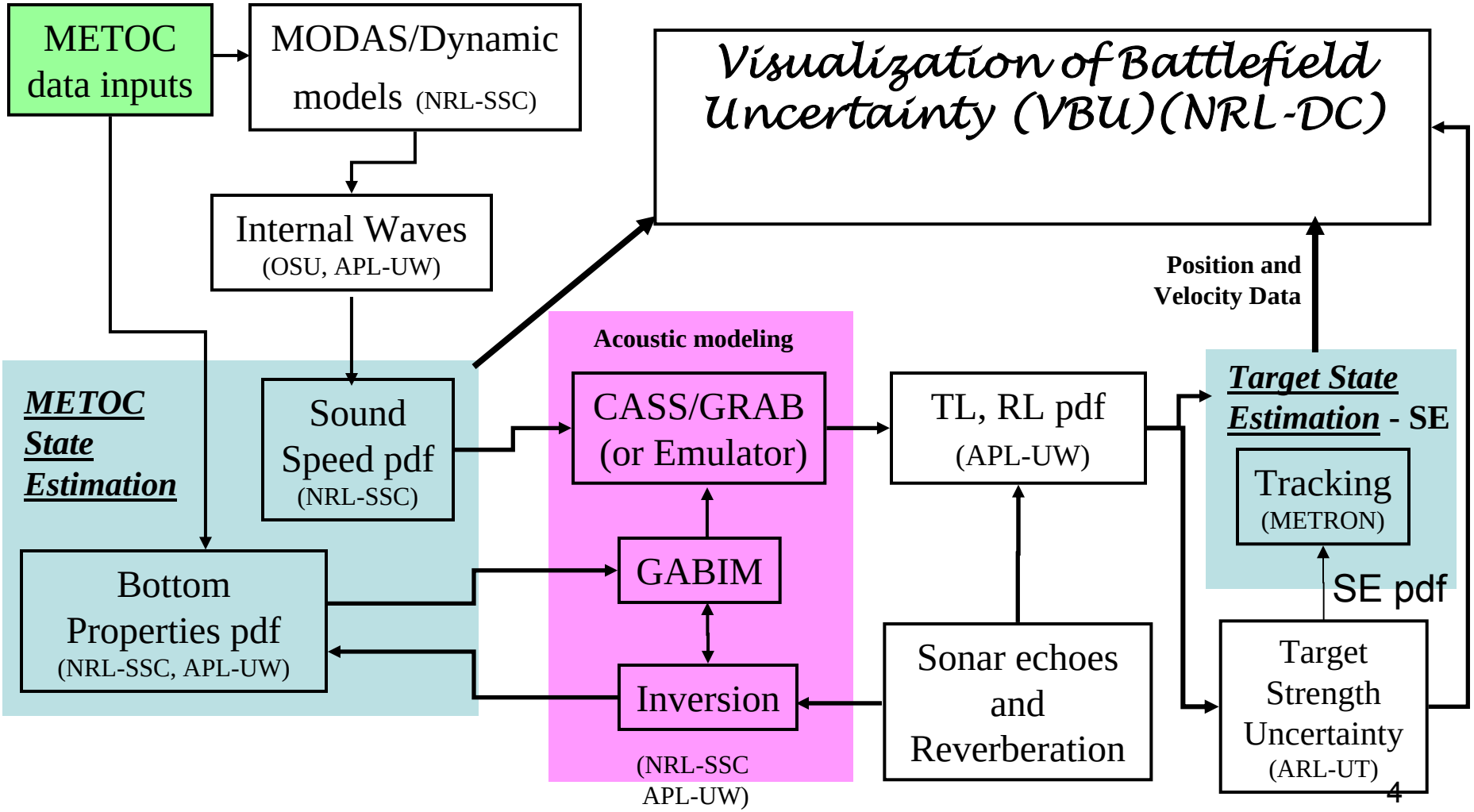
- Use <u>existing</u> science to characterize and represent the uncertainty in the tactical and environmental picture due to uncertainty about environmental features that affect acoustic detection and classification of threats.
- Improve prosecution of threats!

Focus on active acoustic sensors

Uncertainty = PDF(Estimate - Truth)

Architecture – Big Picture

(Minor modifications)



2002 Overview

- Provide:
  - measures or estimates of the uncertainty in environmental parameters relating to the ocean and bottom;
  - methods of efficiently propagating this uncertainty through acoustic models;
  - methods for estimating and representing the effect of environmental uncertainty on estimates of tactical quantities such as target state.
  - tools for computing, visualizing, and mitigating the resultant uncertainty at all levels of the process.

2002 Key Questions

- How to merge regional ocean predictions with internal wave estimates to generate sound speed distributions?
- How to characterize environmental uncertainty?
- How to propagate uncertainty through an active acoustic model?
- Can we provide and represent *a more realistic* target state estimate by accounting for environmental uncertainty?

2002 Review summary

- Definition of end-to-end process for active sonar characterizing uncertainty in environmental state through acoustic models to signal and information processing.
  - MODAS -> internal waves -> CASS -> Echo Tracker Classifer
  - Showed that CASS propagation gave reasonable coherent results for propagation as compared to standard parabolic equation model
  - Identified issues with using CASS for prediction of “coherent” reverberation
  - Sensitivity of bottom loss defined and calculated
  - Initial use of reverberation pdf in ECS for improved signal and information processing.
  - Initial prototype visualizations

Current Work

- Expand sound speed PDFs
  - Cluster historical data within MODAS to provide structure
  - Evaluate use of dynamic model (including solibores) to generate PDFs
  - Continue implementation of background internal wave model
- Creation of bottom property PDFs
- Acoustic model propagation of uncertainty
  - Monte Carlo approach
    - Use conventional acoustic model
    - Neural Nets to speed process
  - Produce PDFs of reverberation and propagation loss
- Target strength (TS) uncertainty
- Incorporate TS and acoustic model PDFs into Likelihood Ratio Tracker (LRT)
- Visualization to support decisions

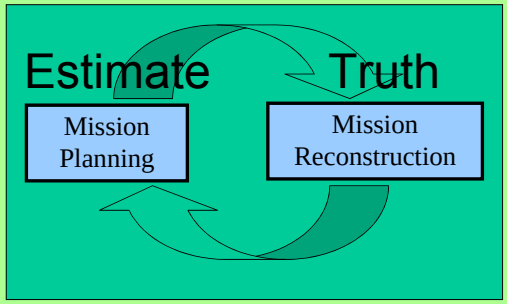
Programmatic changes

- Move to support transition to Air ASW community
  - Loss of 6.3 FNC transition to Advanced Estimation of Sensor Prediction
  - Difficult transition to surface ship because of loss of acquisition program funding
  - Likelihood Ratio Tracker already on path to transition to Air ASW (DT)
  - Leverage fleet Air ASW program to collect uncertainty data and the need to explain why performance predictions do not seem to predict operational performance

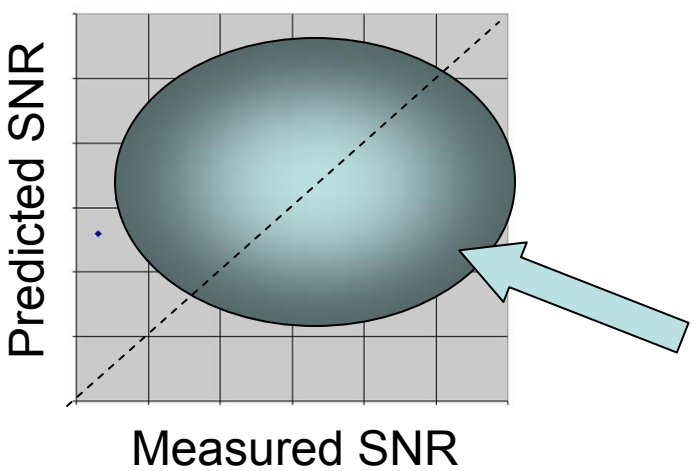
Working with the Operational Air ASW to measure and begin to use uncertainty

Uncertainty = PDF (Truth - Estimate)

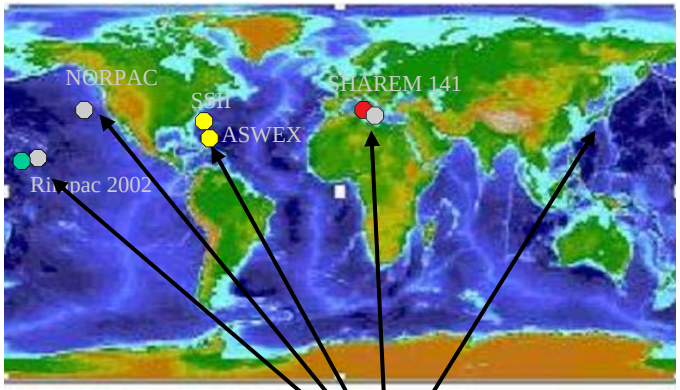
What is the difference between predicted performance and actual?



Notional comparison of predicted versus measured target SNR

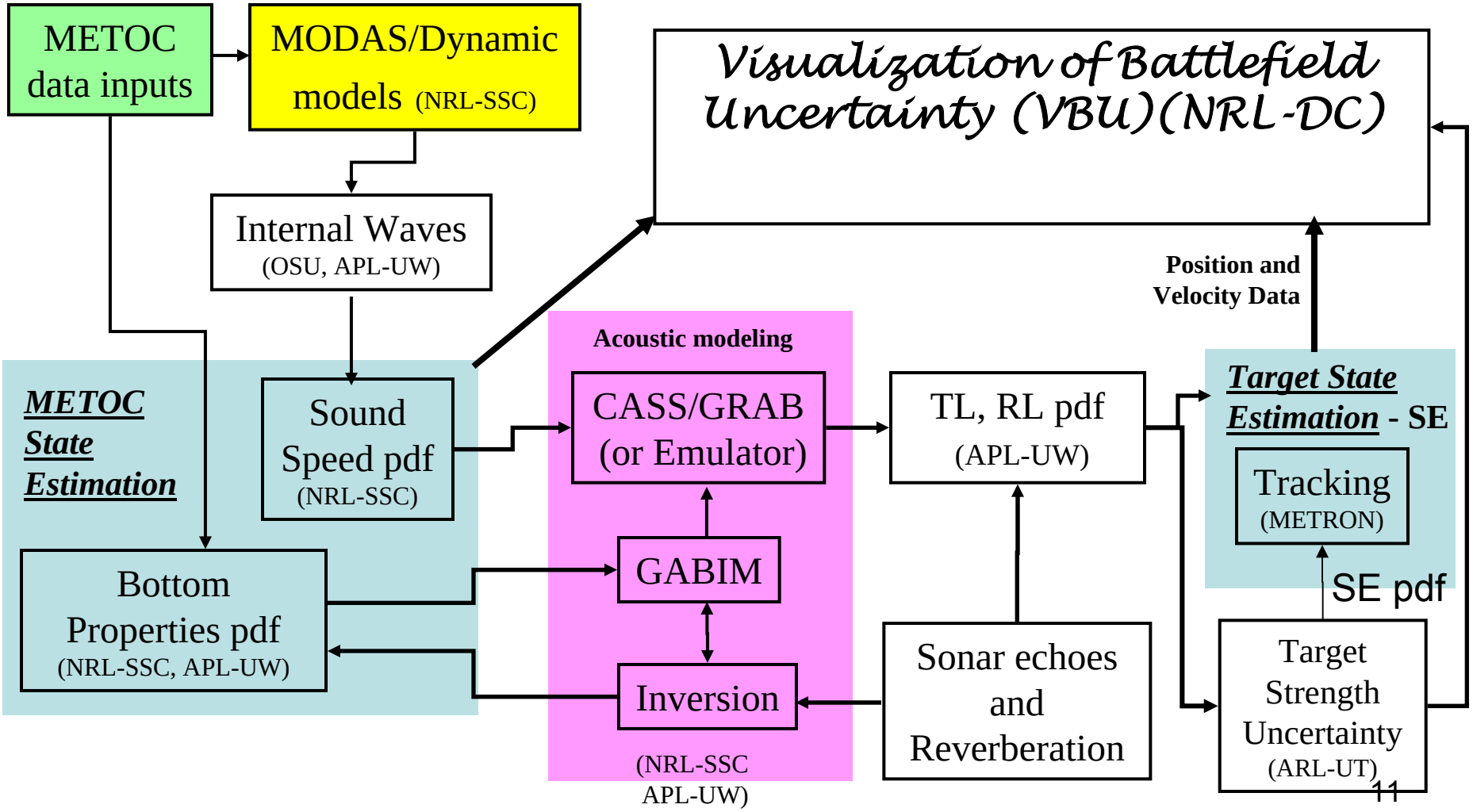


Can we predict the uncertainty?

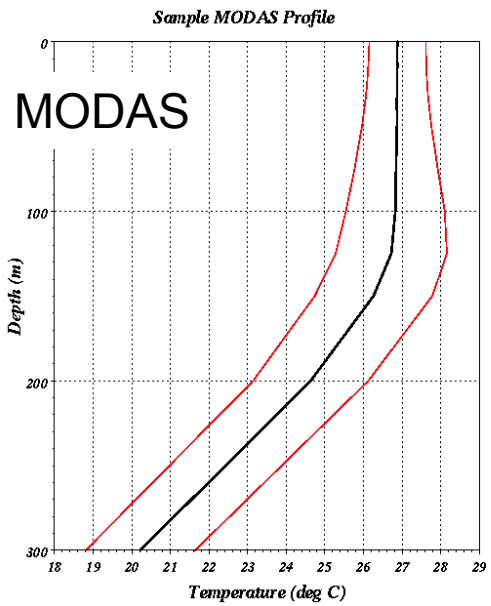


Better Pd estimates

Architecture – Big Picture

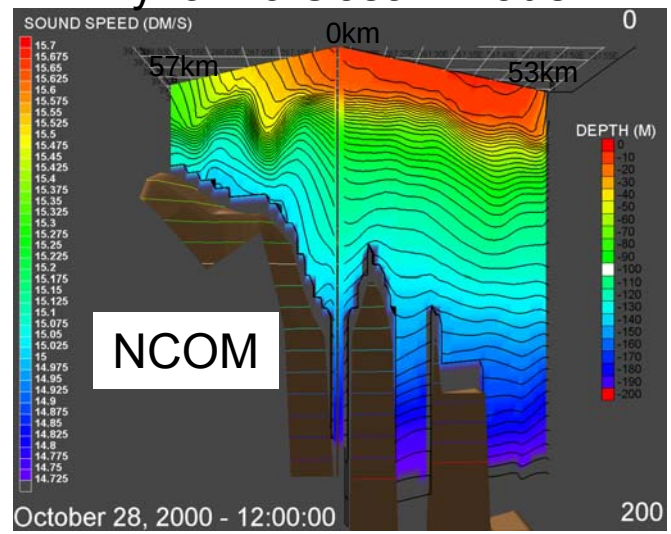


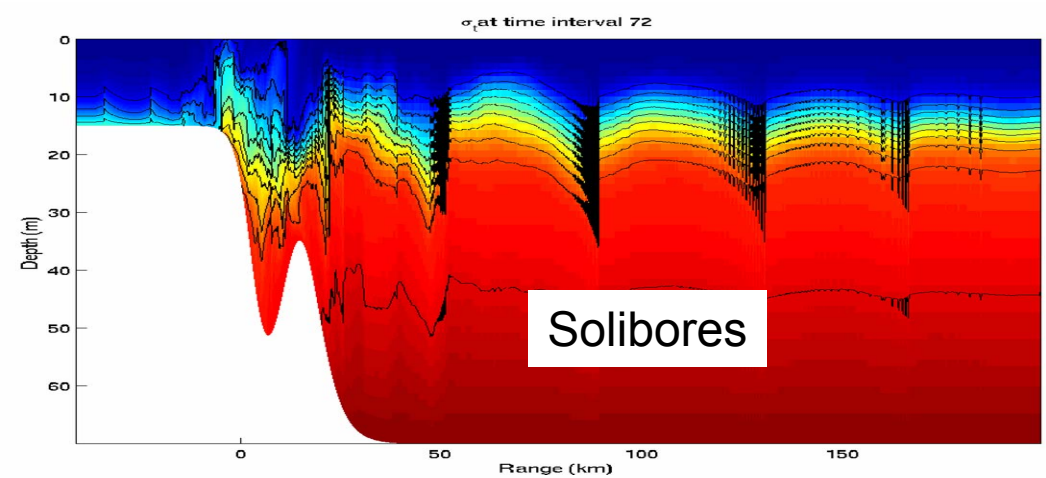
Sound Speed

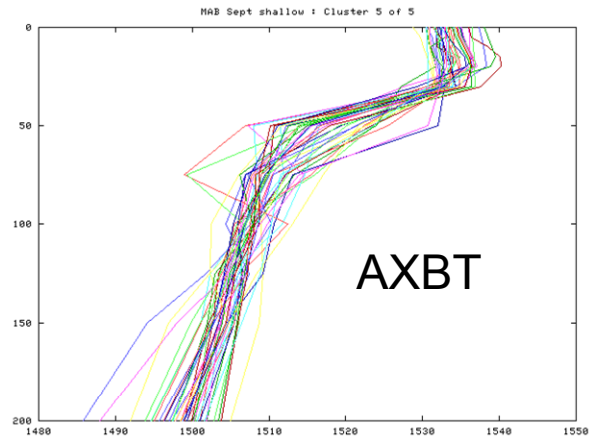


How to bring these into a common framework for use in uncertainty?

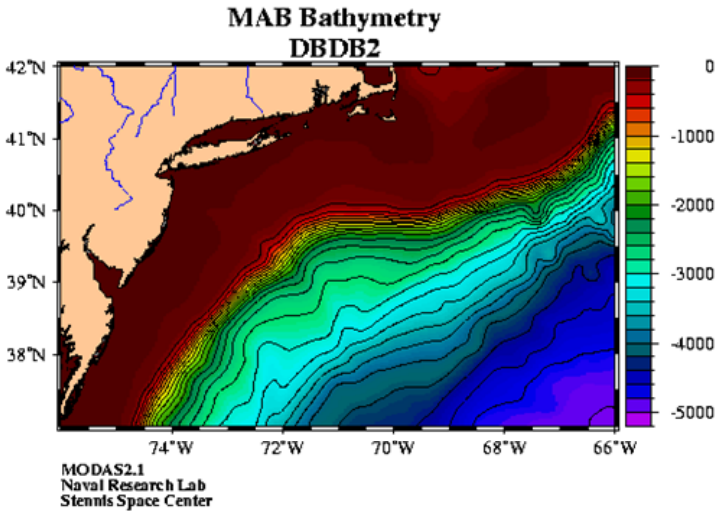
Dynamic Ocean Model

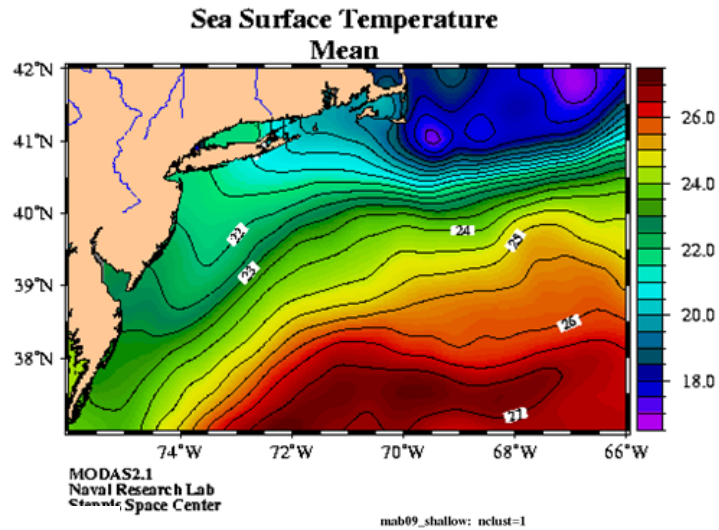






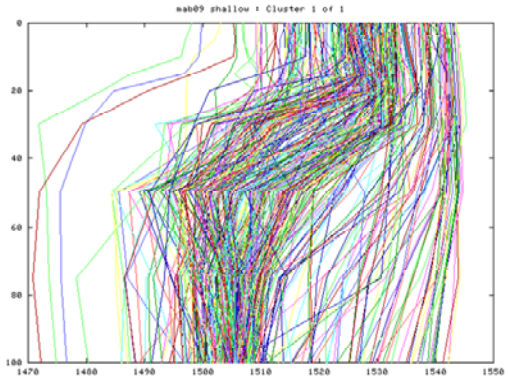
Mid-Atlantic Bight Profiles – Sept 1993 - 2002

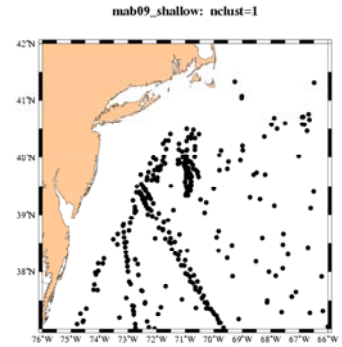




Upper 100 meters

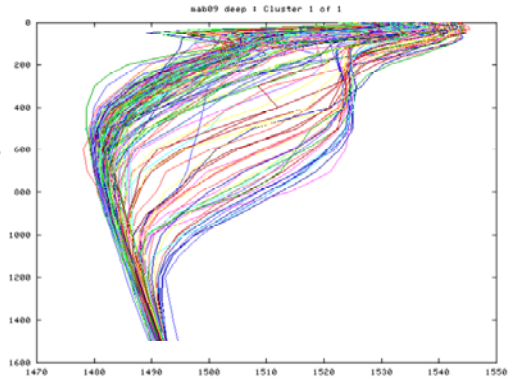
324 profiles

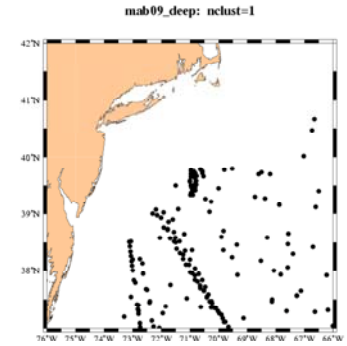




Upper 1500 meters

175 profiles

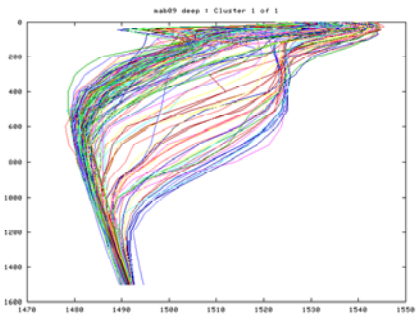


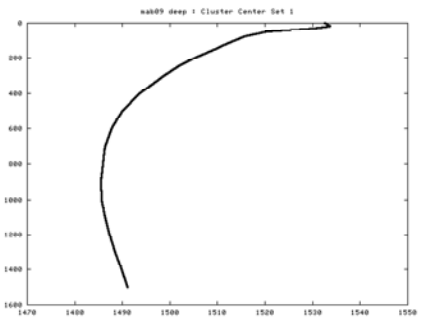


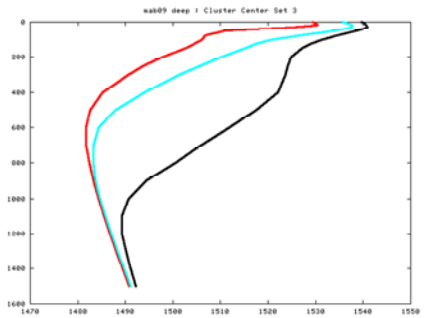
Mid-Atlantic Bight Profiles – Sept 1993 – 2002

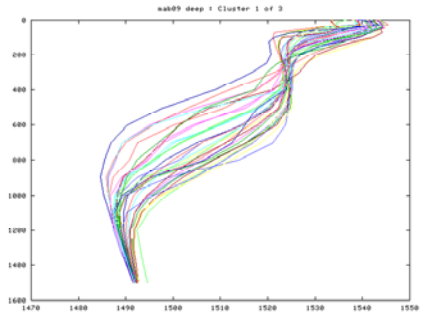
Upper 1500 meters: Case of 3 presumed clusters

1 – 18% - mostly south of GS (black)
2 – 63% - mostly north of GS (red)
3 – 19% - mixed (cyan)









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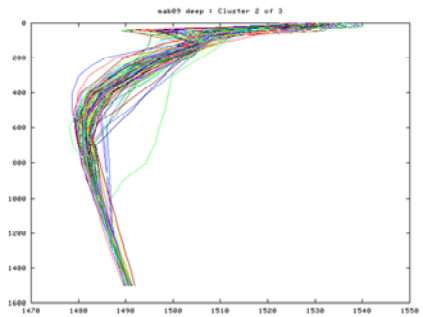

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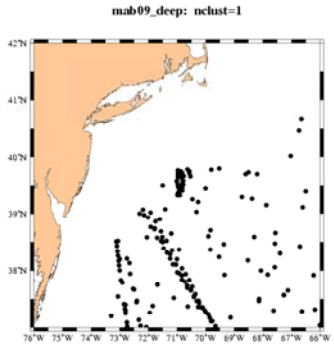
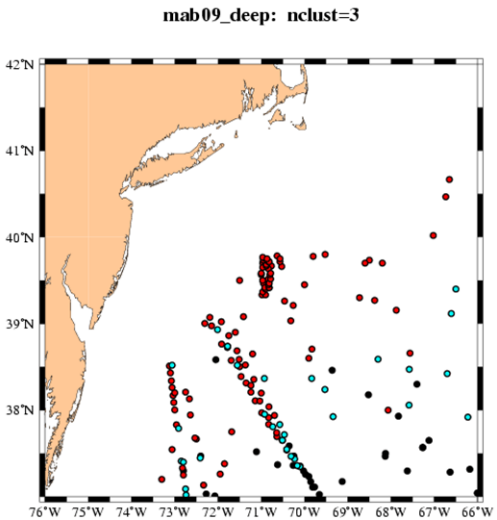
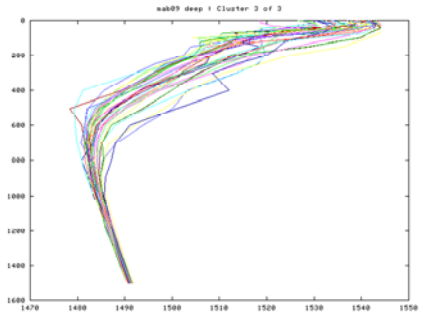




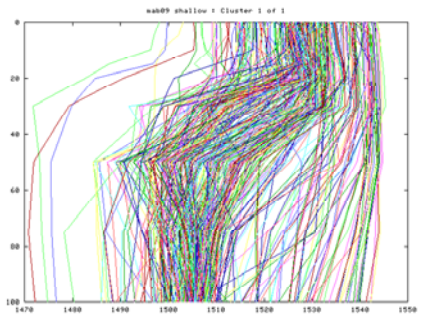


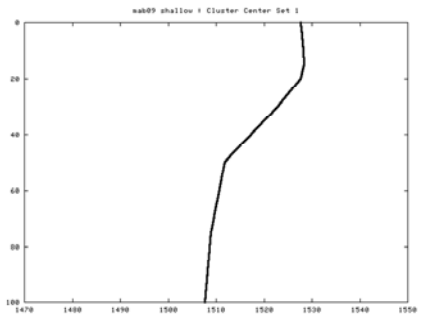
3

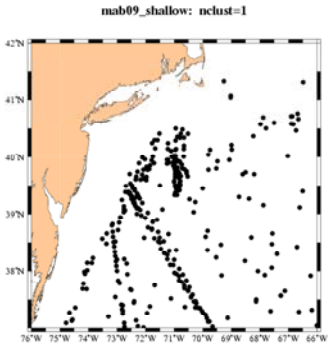
Mid-Atlantic Bight Profiles – Sept 1993 – 2002

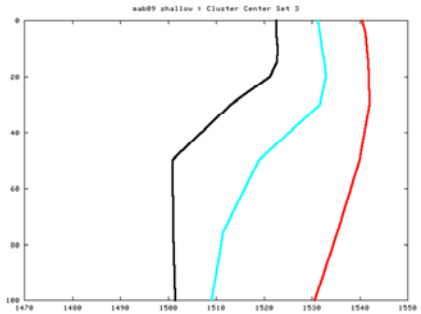
Upper 100 meters: Case of 3 presumed clusters

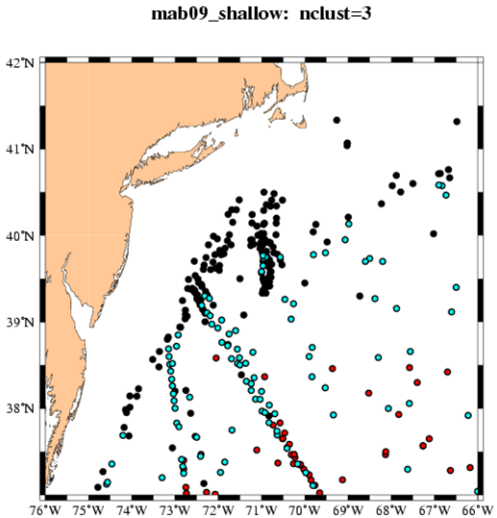
1 – 55% - mostly north of GS (black)
2 – 13% - mostly south of GS (red)
3 – 32% - mixed (cyan)

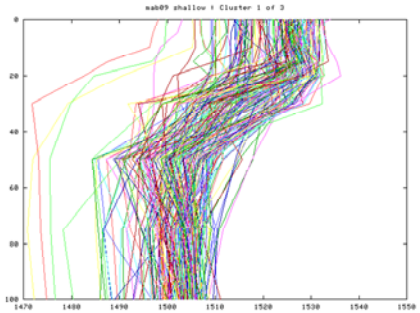


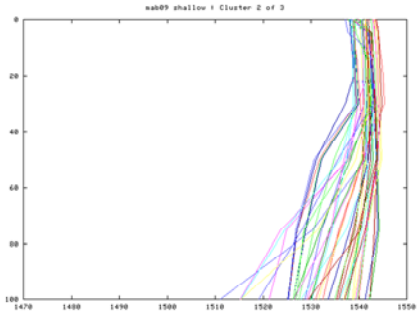


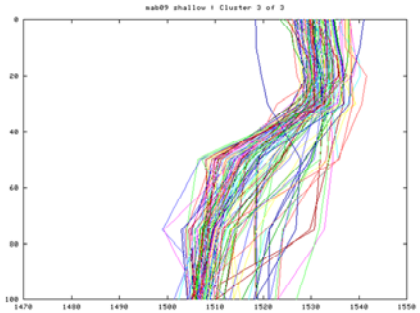








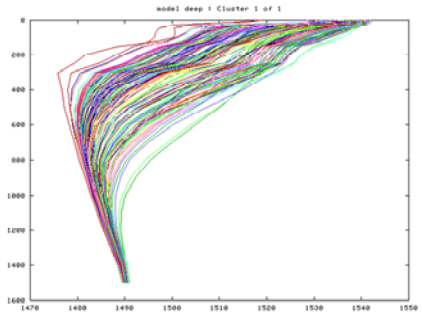


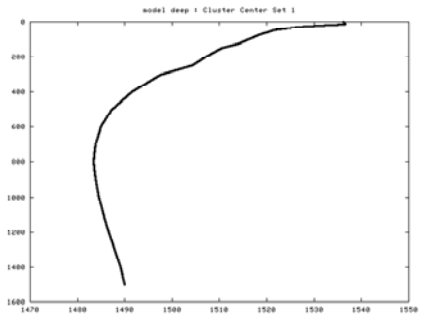


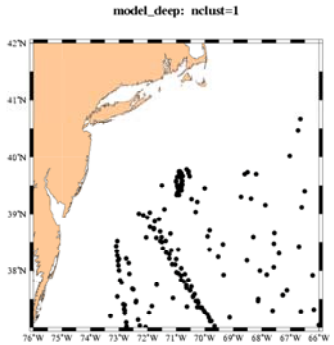
Mid-Atlantic Bight NCOM Model – Sept 2000

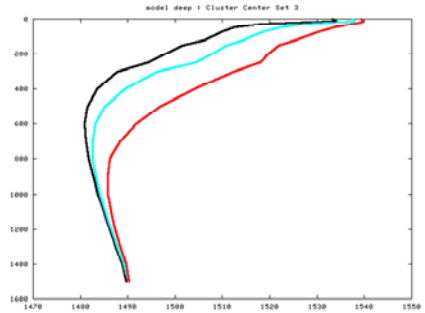
Upper 1500 meters: Case of 3 presumed clusters

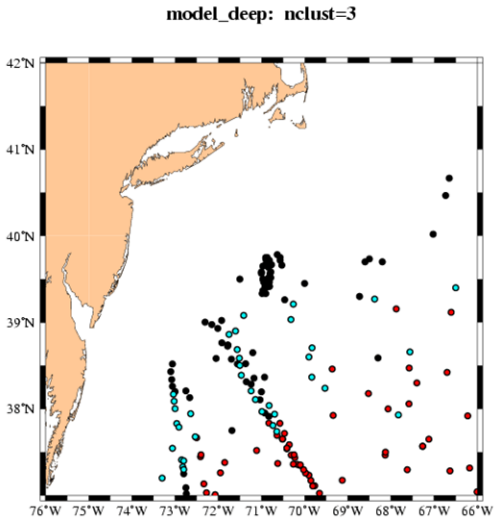
1 – 46% - mostly north of GS (black)
2 – 32% - mostly south of GS (red)
3 – 22% - mixed (cyan)

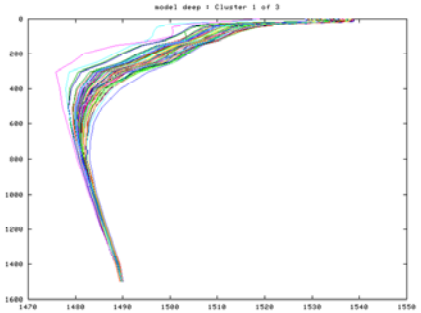












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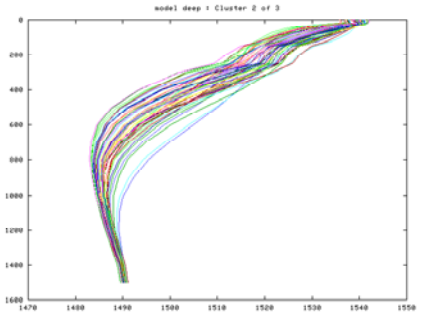

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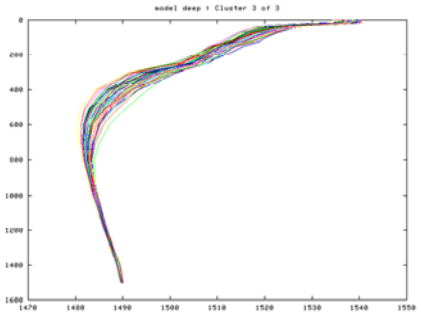
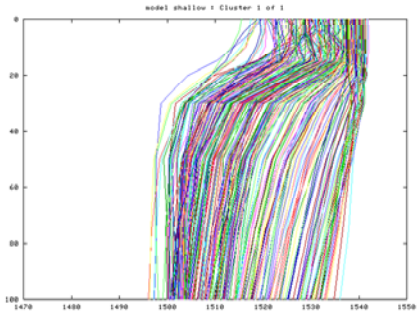


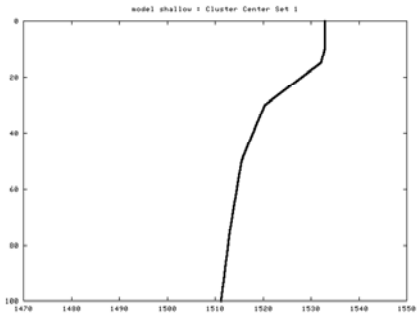
3

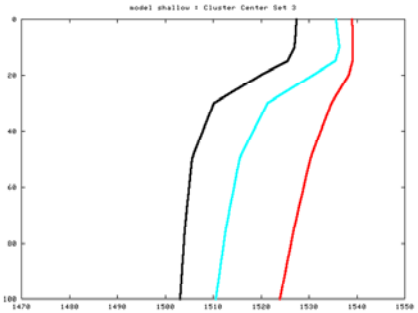
Mid-Atlantic Bight NCOM Model – Sept 2000

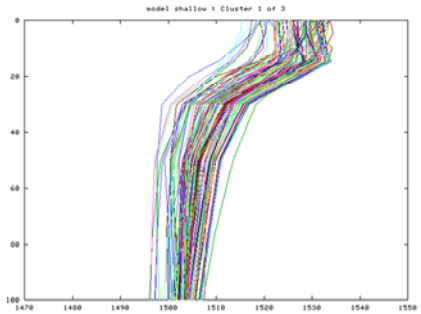
Upper 100 meters: Case of 3 presumed clusters

1 – 46% - mostly north of GS (black)
2 – 31% - mostly south of GS (red)
3 – 24% - mixed (cyan)









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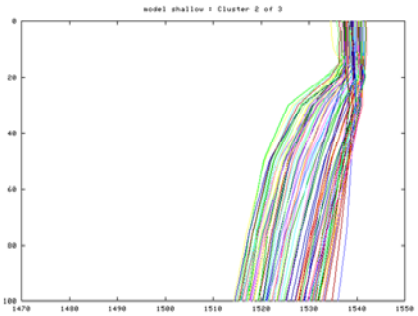

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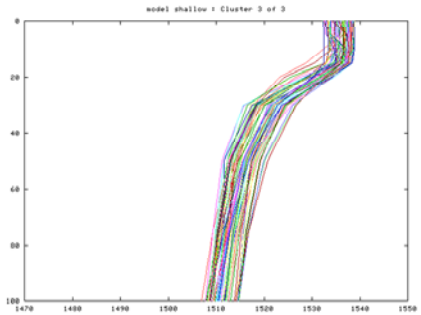

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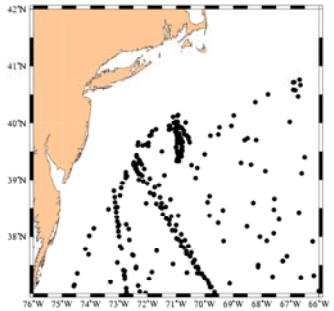
model_shallow: nclust=1



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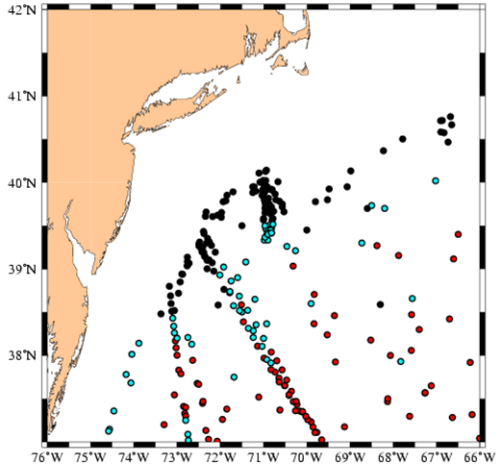
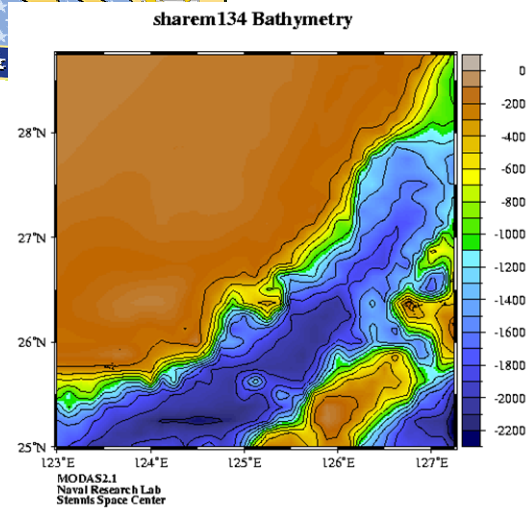
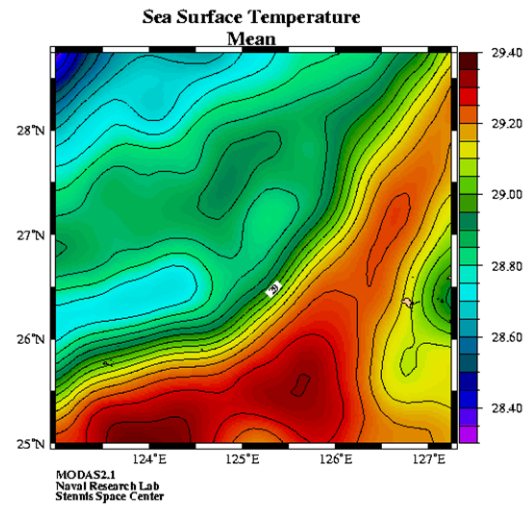


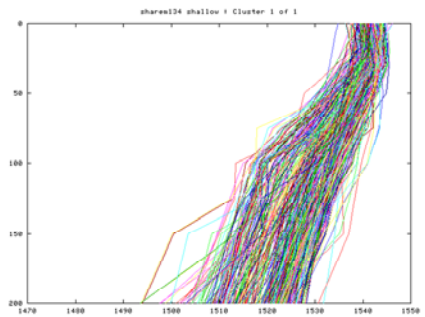
SHAREM-134 Profiles – Jul/Aug 1990 - 2002

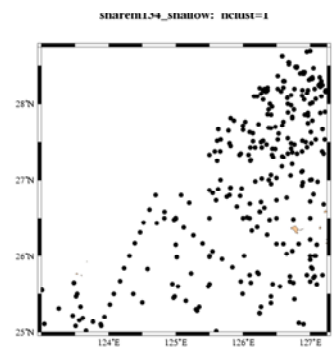




Upper 200 meters

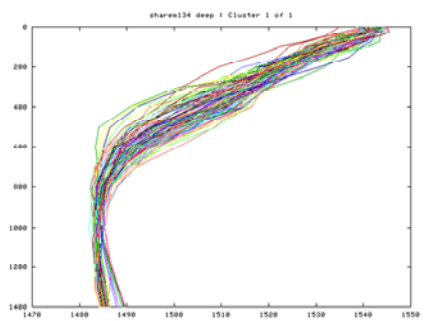
362 profiles

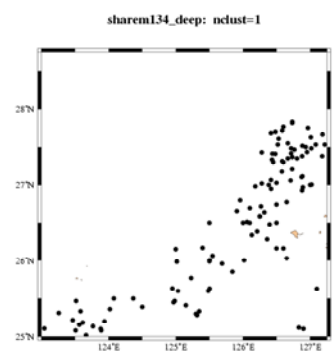




Upper 1400 meters

110 profiles



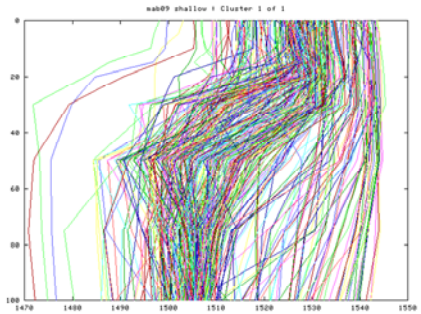


Mid-Atlantic Bight Profiles – Sept 1993 – 2002

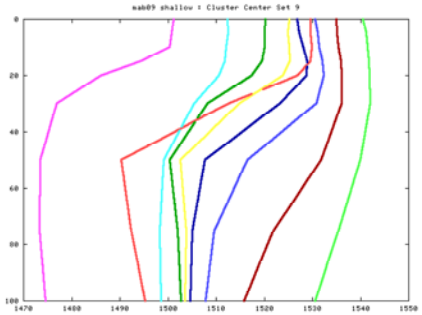
Upper 100 meters: How many clusters to use?

Example of 9 clusters

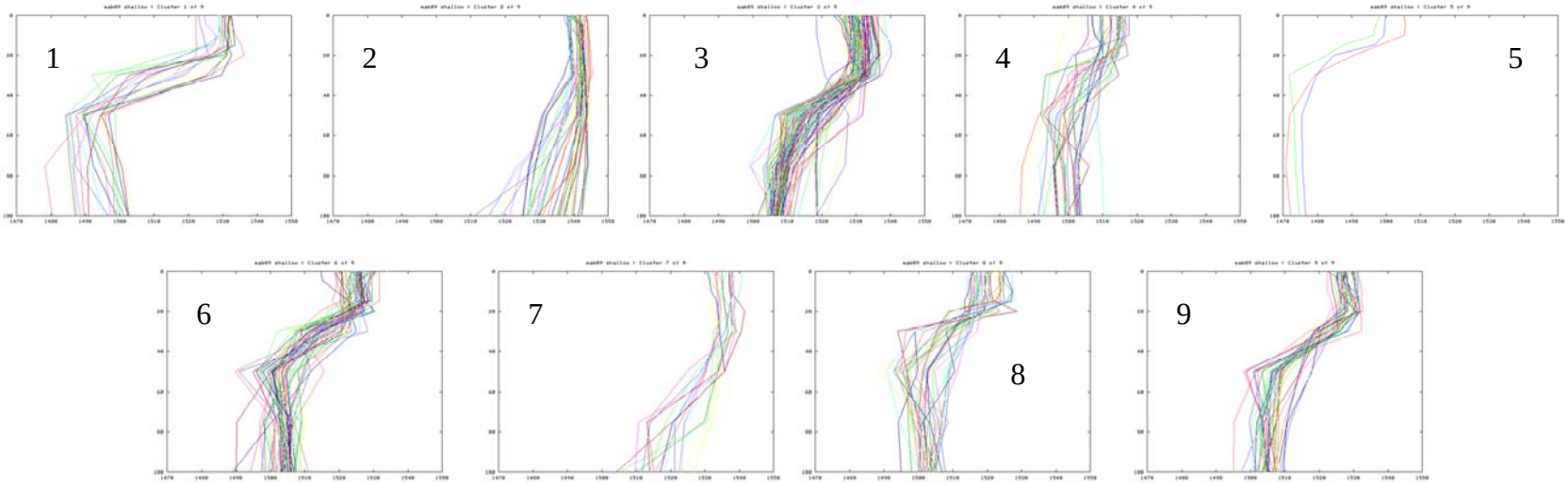
#clust	Relative Distribution								
1	100.0								
2	54.9	45.1							
3	54.9	13.3	31.8						
4	35.2	13.3	31.8	19.8					
5	35.2	13.3	31.8	18.8	0.9				
6	5.9	13.3	31.8	18.8	0.9	29.3			
7	5.9	13.3	26.9	18.8	0.9	29.3	4.9		
8	5.9	13.3	26.9	9.3	0.9	29.3	4.9	9.6	
9	5.9	13.3	26.9	9.3	0.9	17.3	4.9	9.6	12.0



All Profiles



9 Cluster Centers

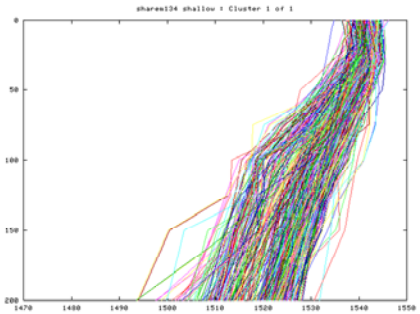


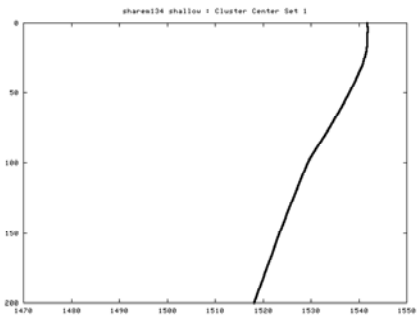
Profiles belonging to each cluster – 1 through 9

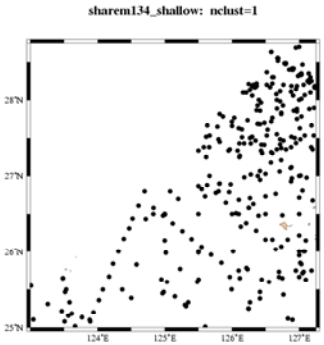
SHAREM-134 Profiles – Jul/Aug 1990 – 2002

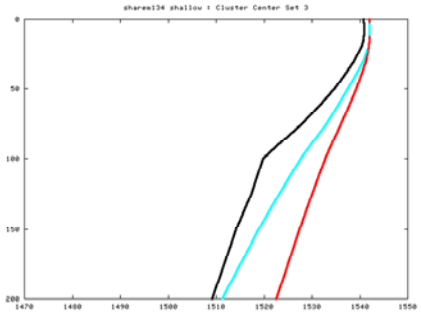
Upper 200 meters: Case of 3 presumed clusters

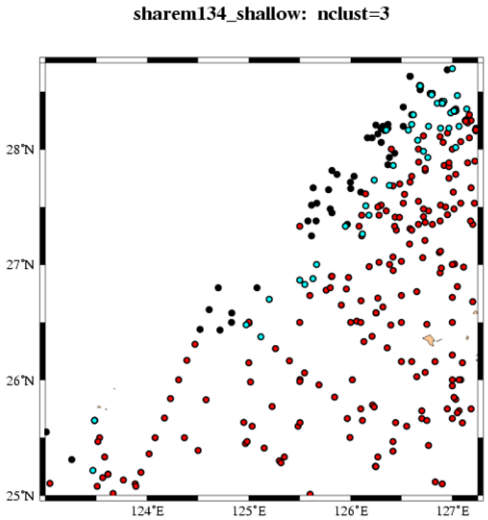
1 – 20% - mostly shelf (black)
2 – 64% - mostly deep (red)
3 – 16% - mostly slope break (cyan)

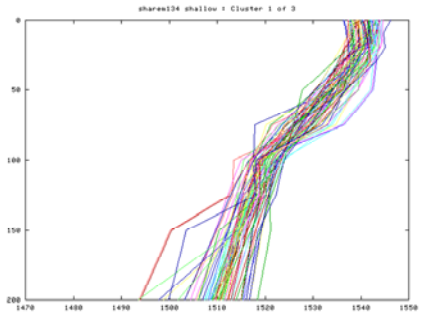




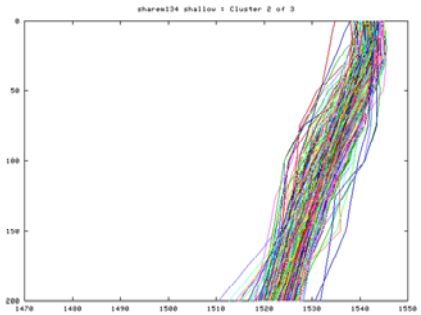








1



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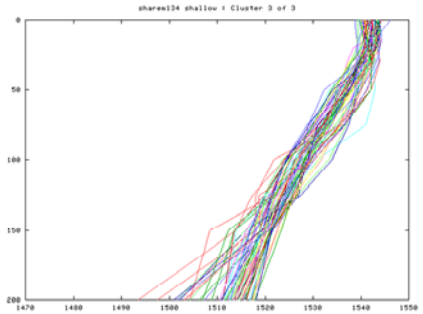
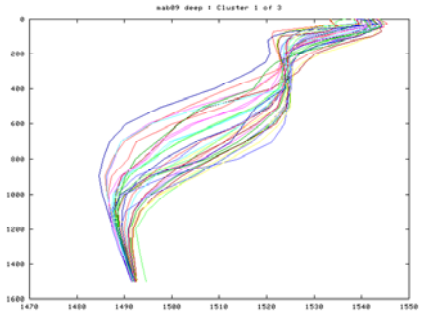


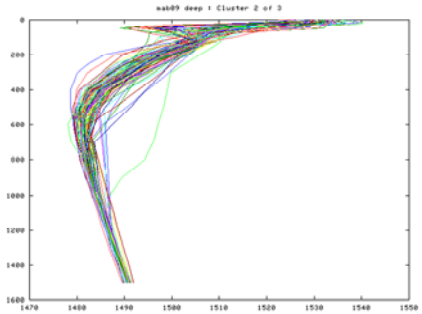
3

Mid-Atlantic Bight Profiles
Upper 1500 meters: Case of 3 presumed clusters

Observations
Sept 1993 – 2002



1



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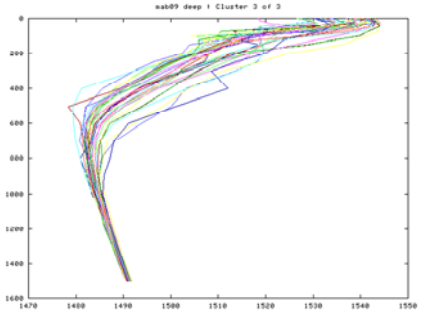

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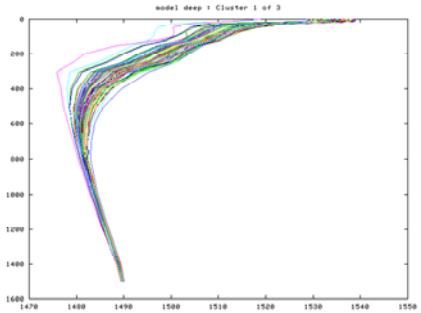
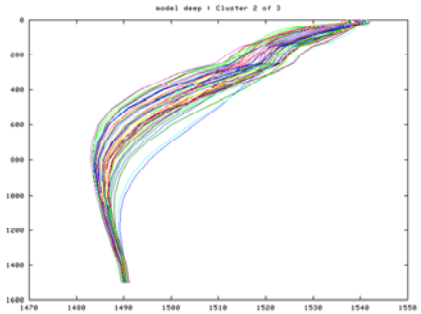


1



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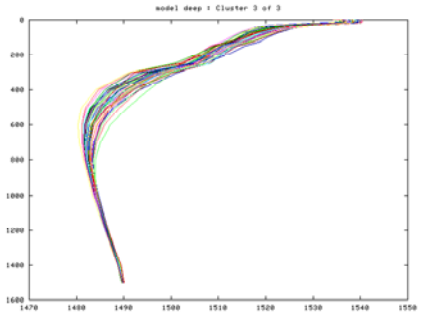
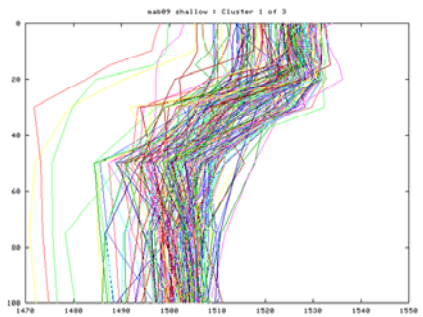


3

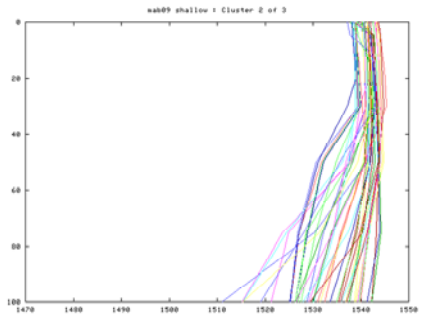
Model
Sept 2000

Mid-Atlantic Bight Profiles
Upper 100 meters: Case of 3 presumed clusters

Observations
Sept 1993 – 2002



1



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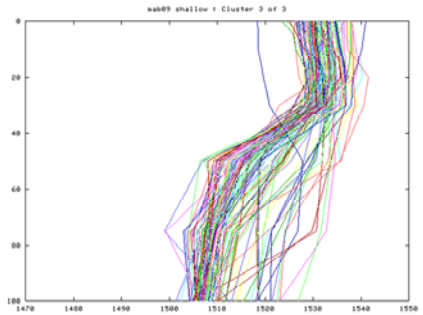

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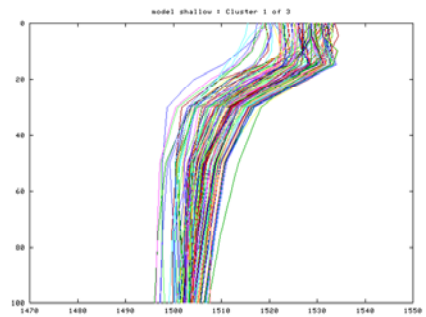

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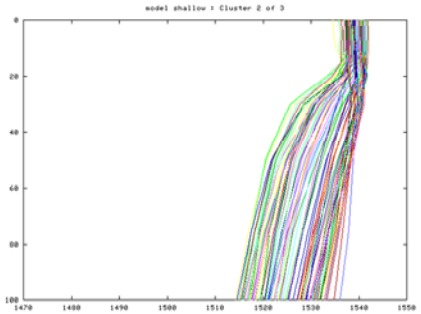

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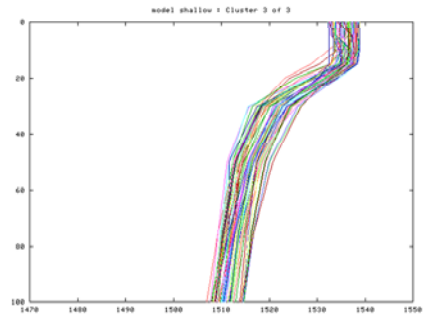
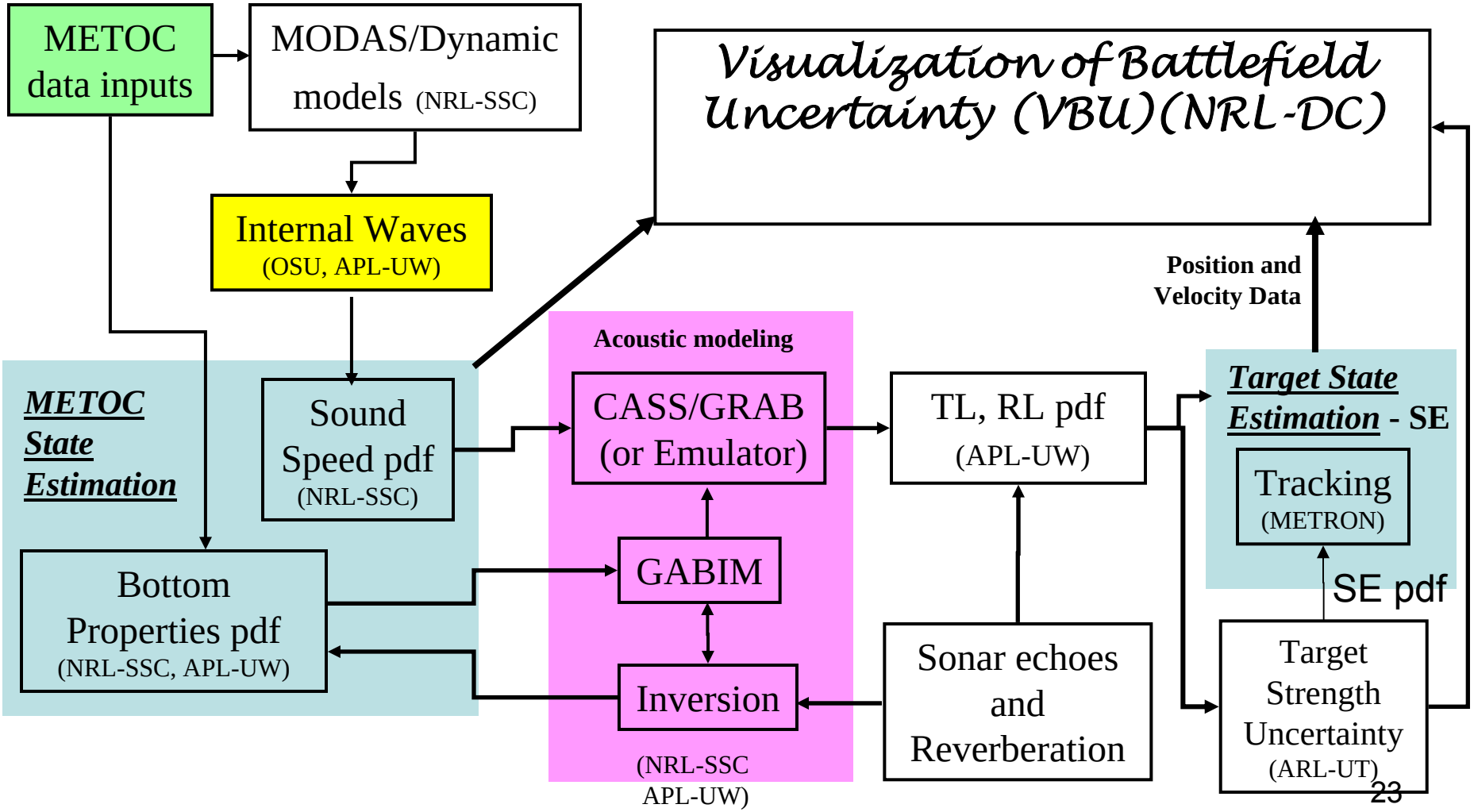


3

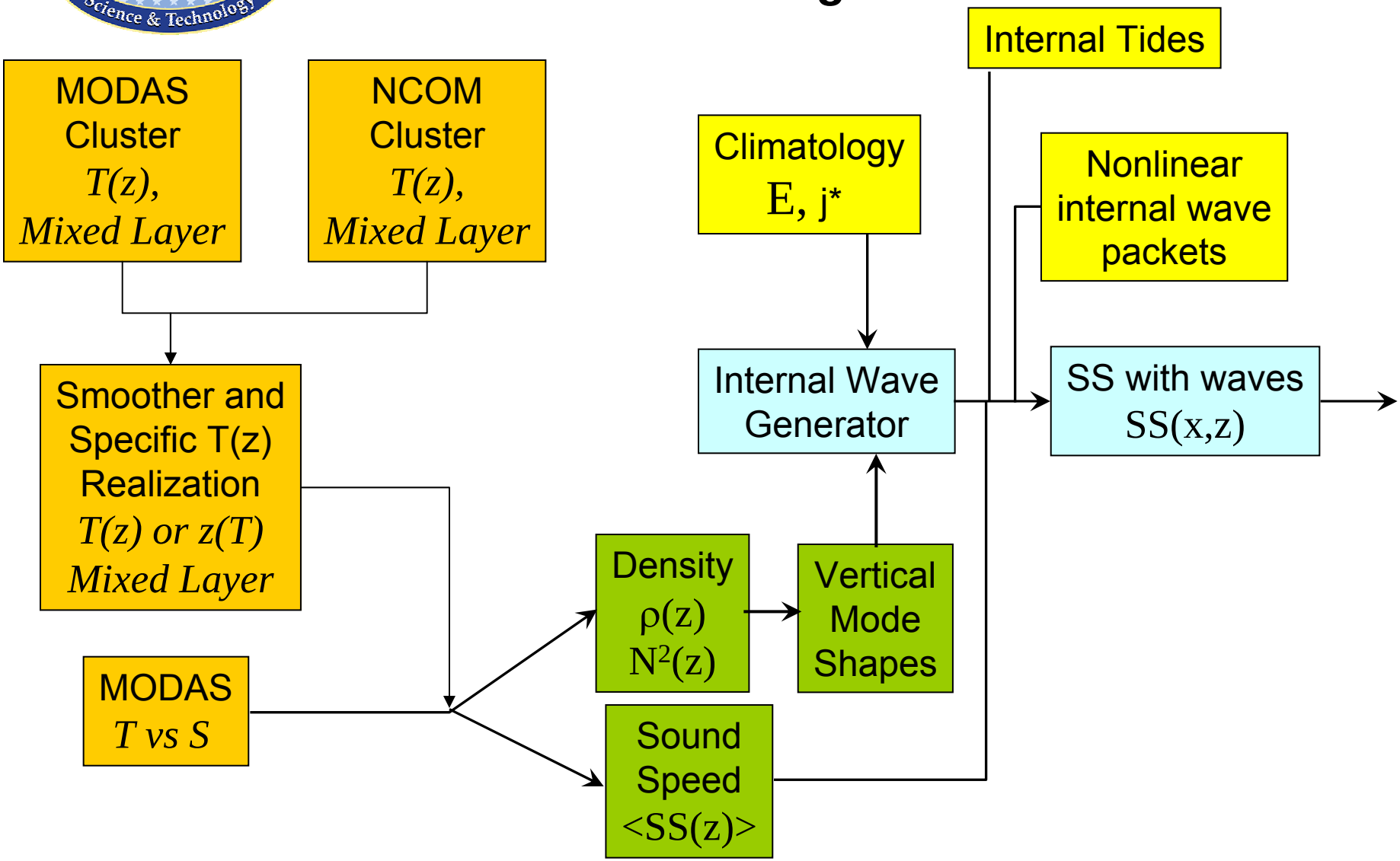
Model
Sept 2000

Architecture – Big Picture

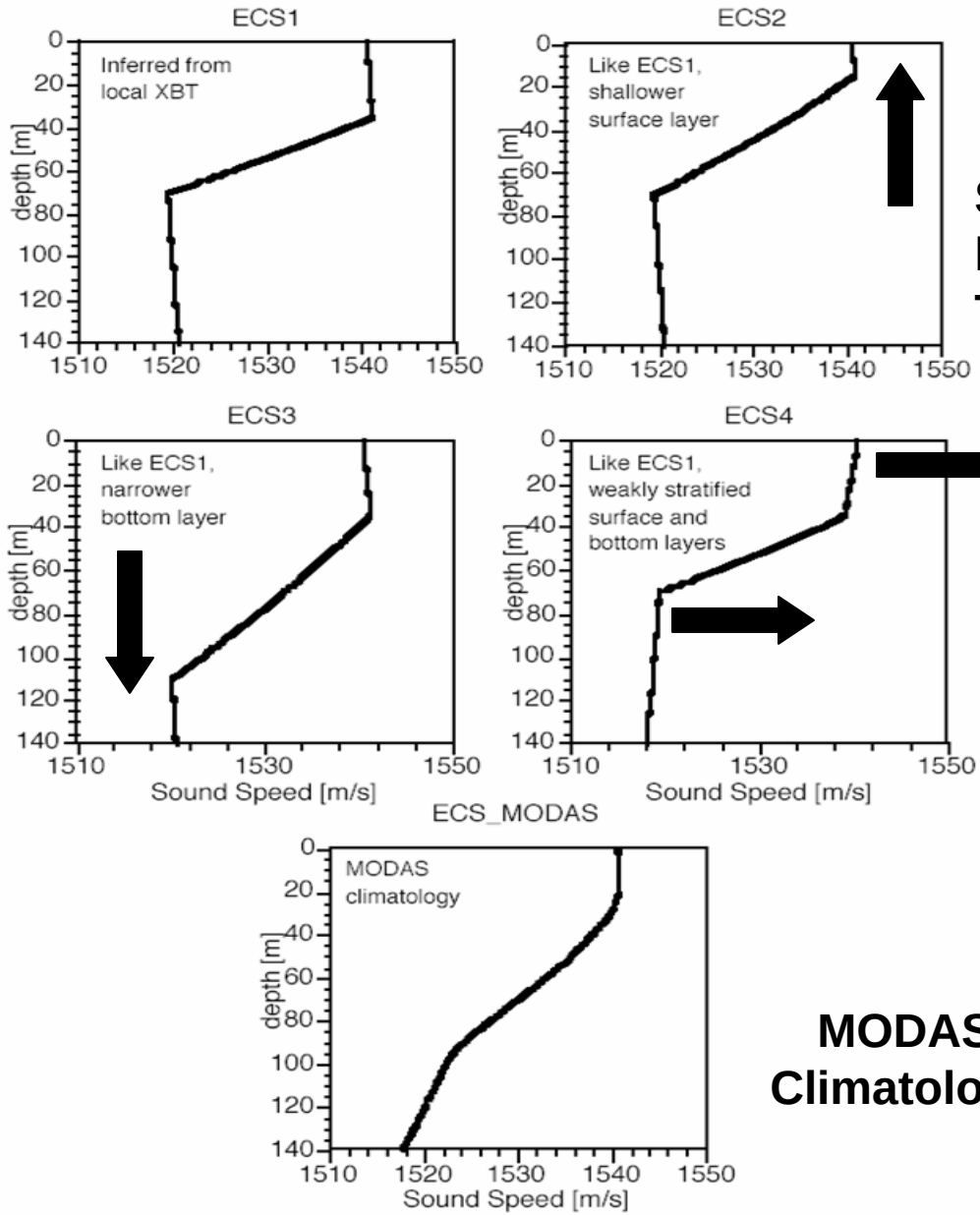
(Minor modifications)



Levine Block Diagram - details



Local XBT



Shallower mixed layer, steeper T-Cline

Shallower deep mixed layer, steeper T-Cline

Positive slope to mixed and deep layers

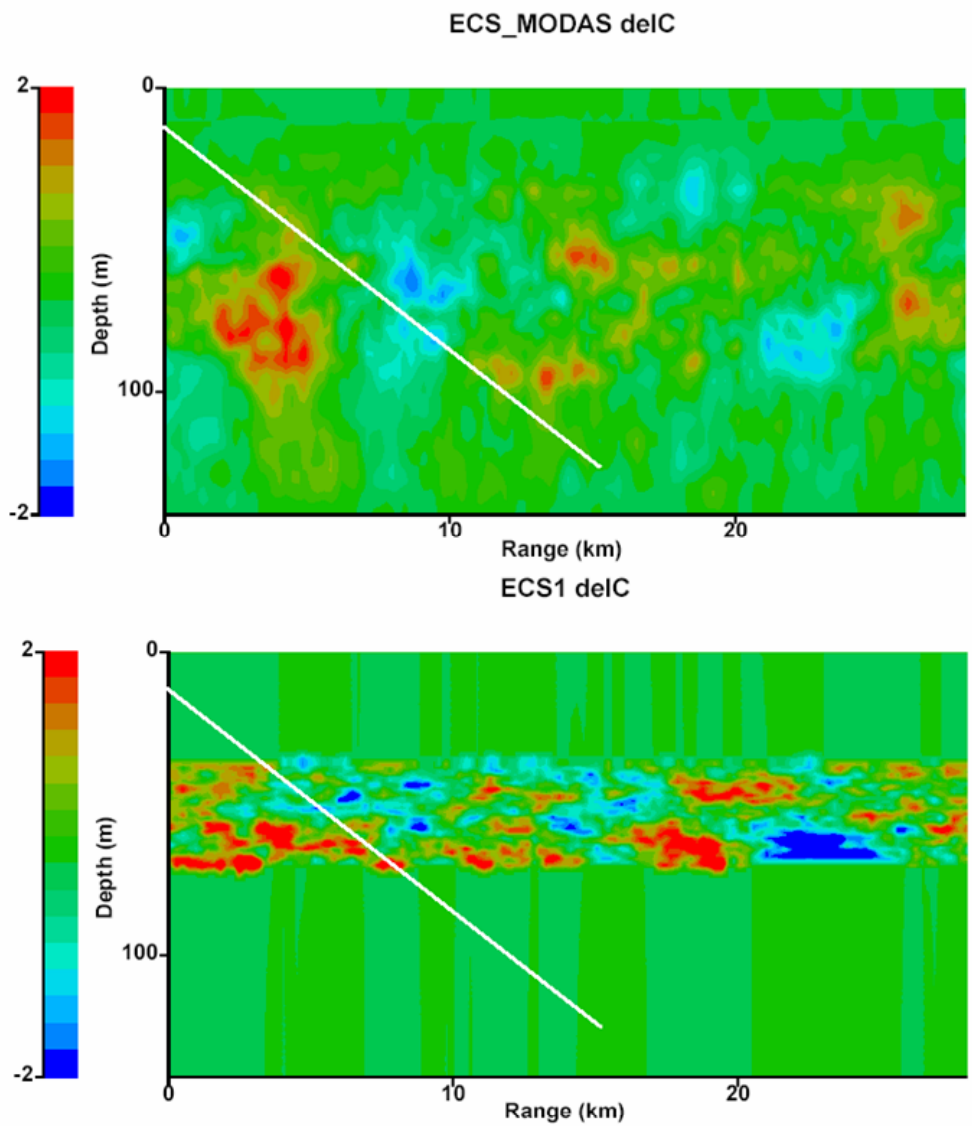
MODAS Climatology

Figure 1. Five deterministic SSP scenarios for the East China Sea in August

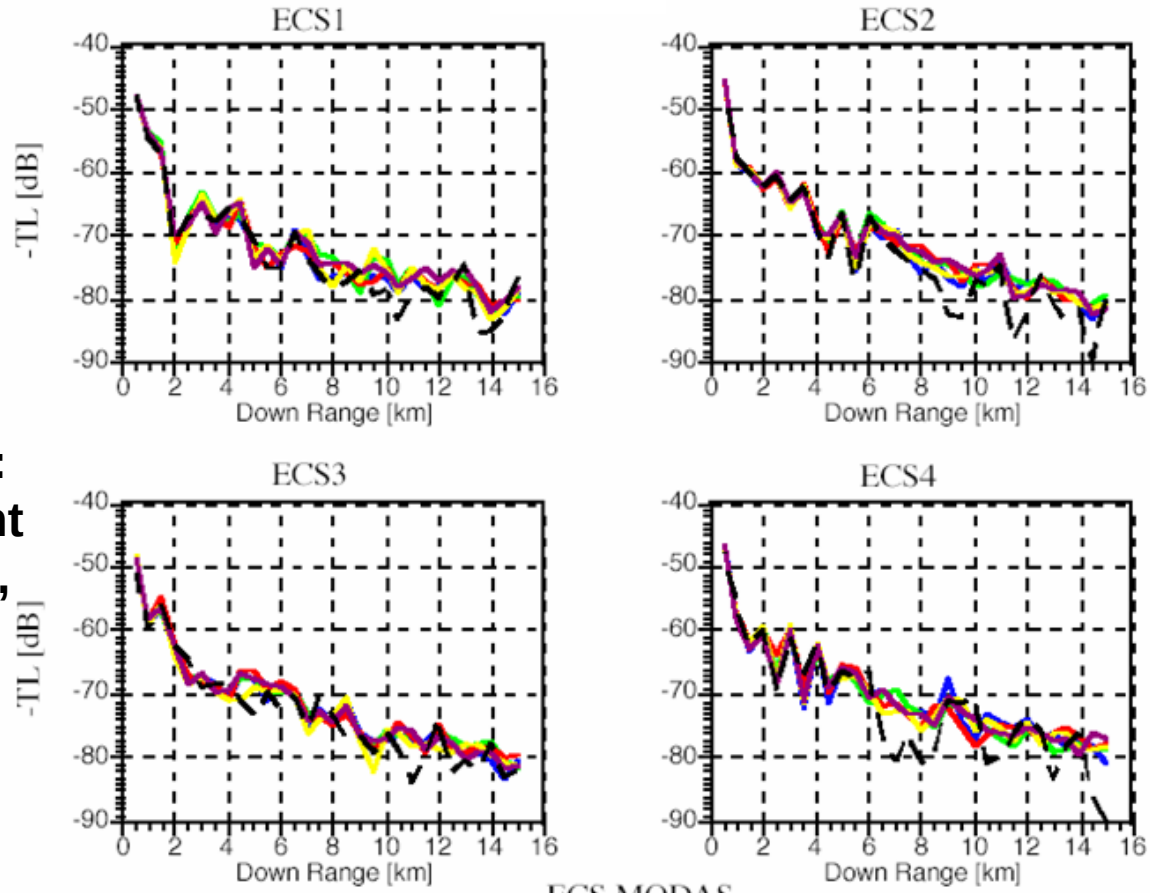
Input information

- 140m flat bottom: 1585m/s; 0.5dB/m; s.g.1.85
- 7.6m source, 3Khz
- Winters and D'Asaro (1997) internal wave simulator
- TL to point 128m deep, at 15km
- RAM PE propagation model

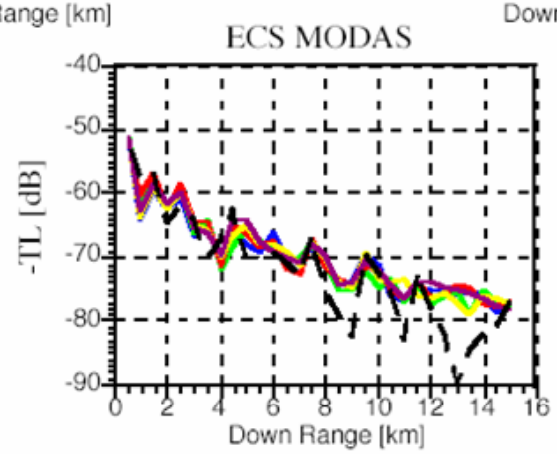
Graphical depiction of 4-D SSP



White line depicts depth of source (7.6m) and TL measurement end-point at 128m depth, 15km distant from source overlaying internal wave field

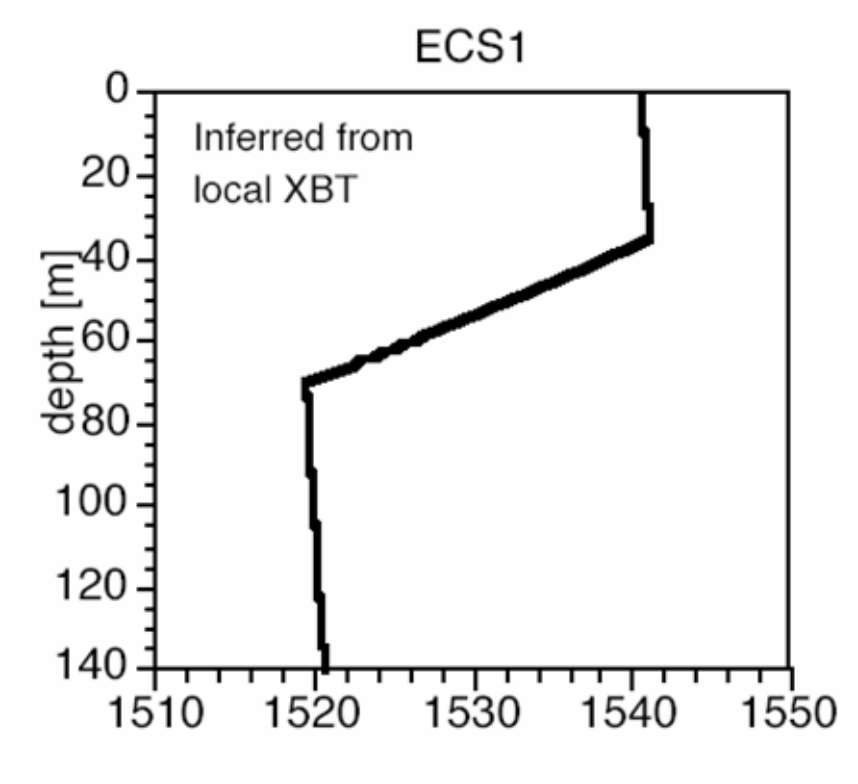


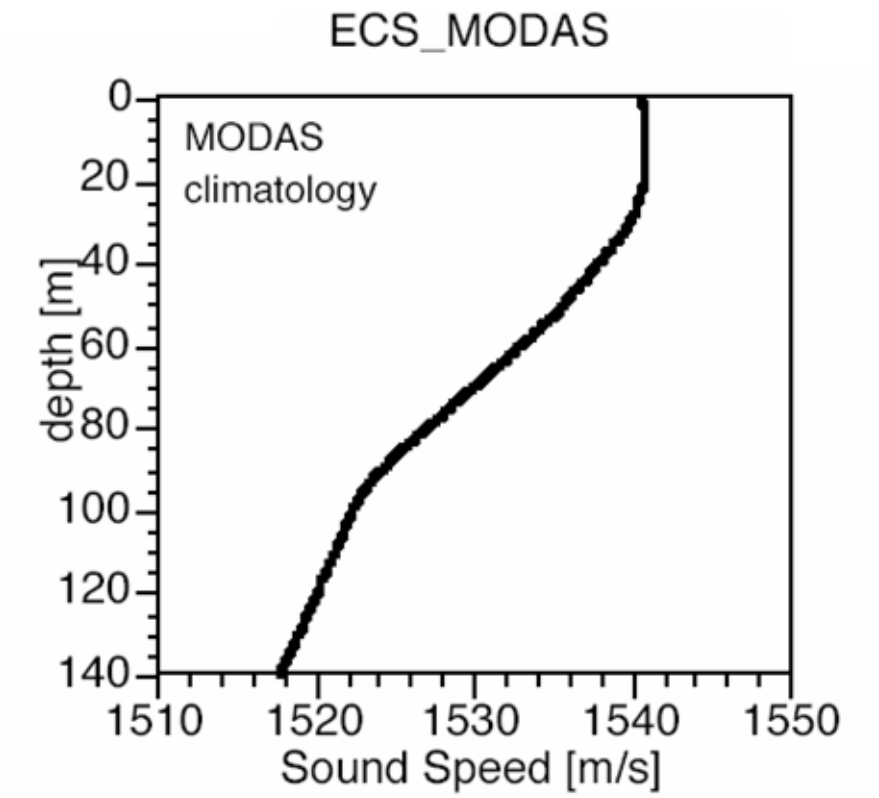
Six curves per plot:
- **Range independent**
- **Each of five seeds, 14 time steps/seed**



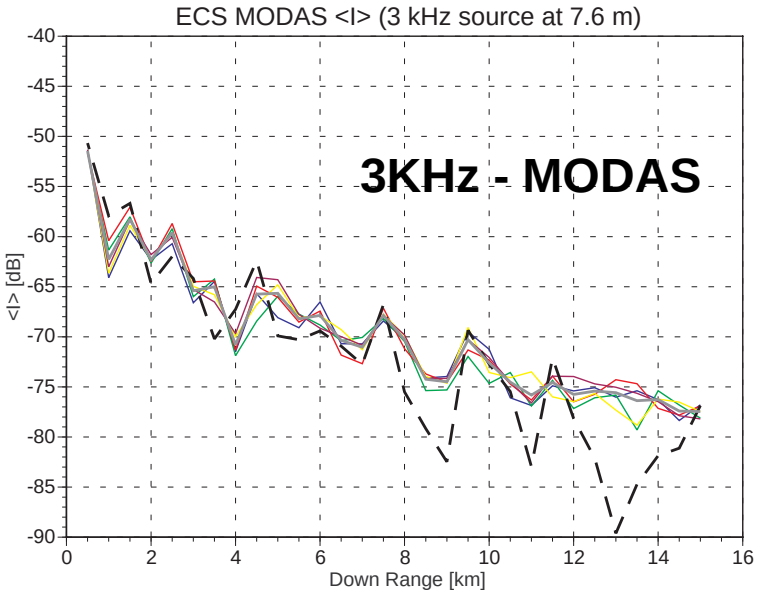
Similar to about 6km, then smoothing effect of Internal wave instances

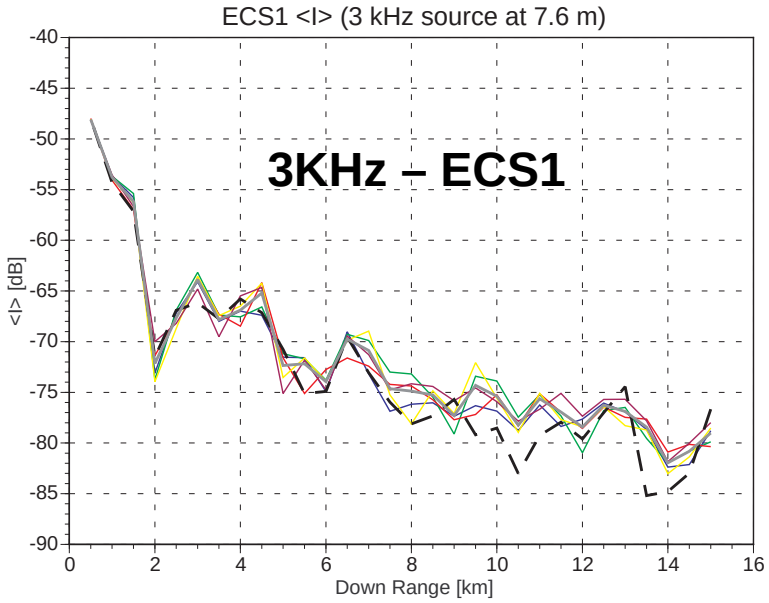
Deeper source depth, lower frequency comparisons

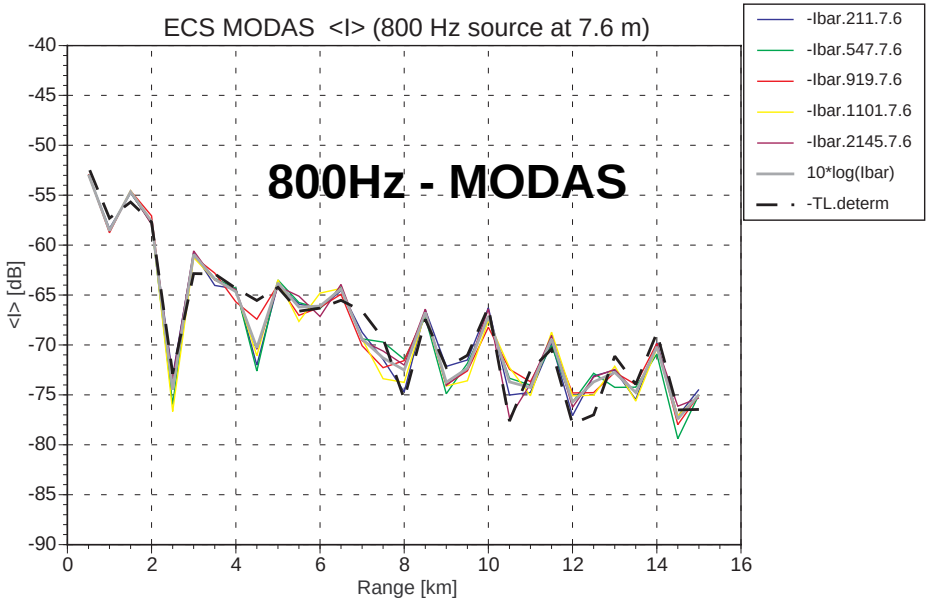


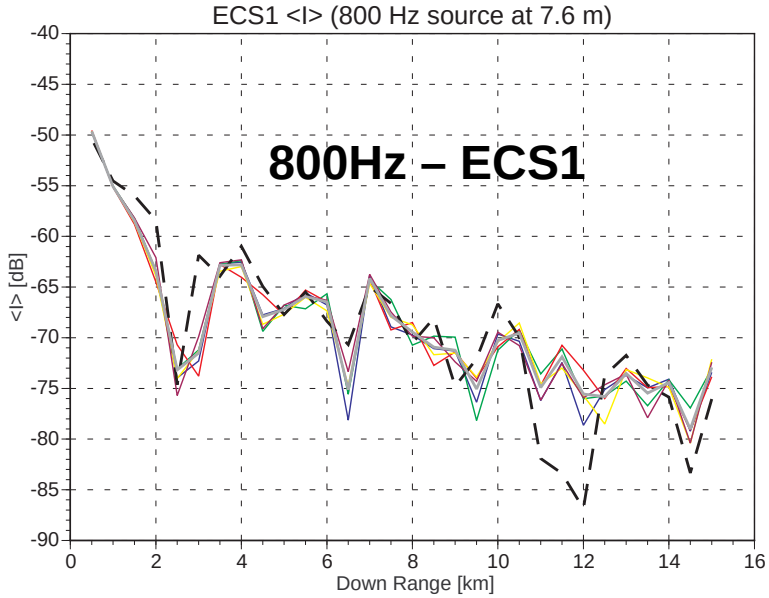


Results - 7.6m source, two frequencies



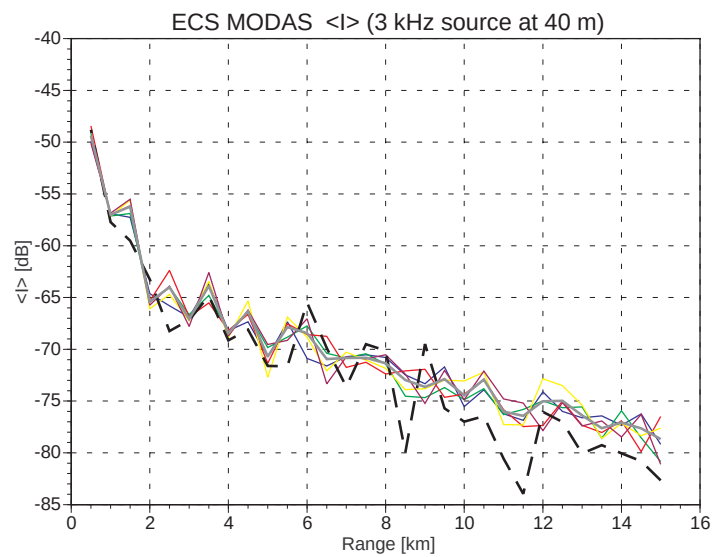


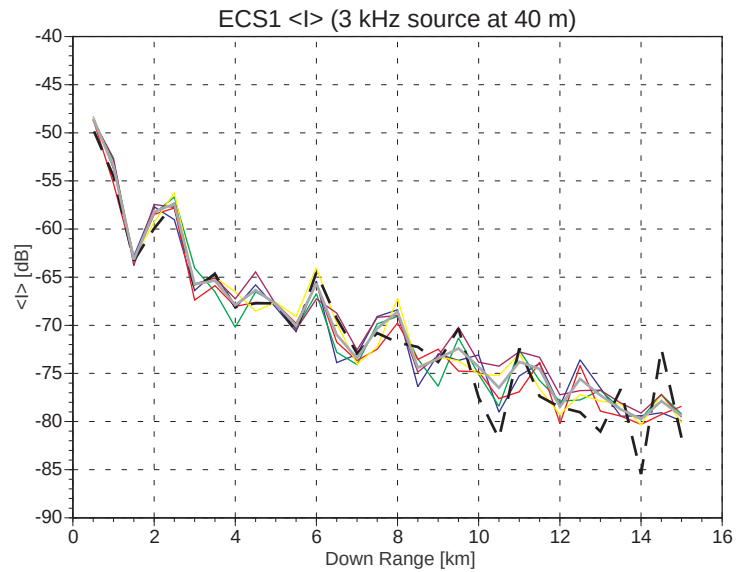


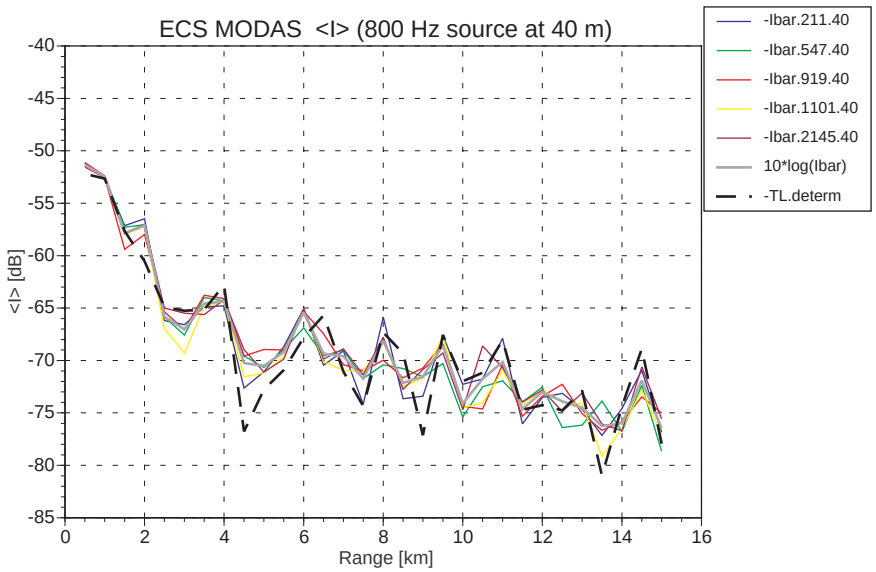


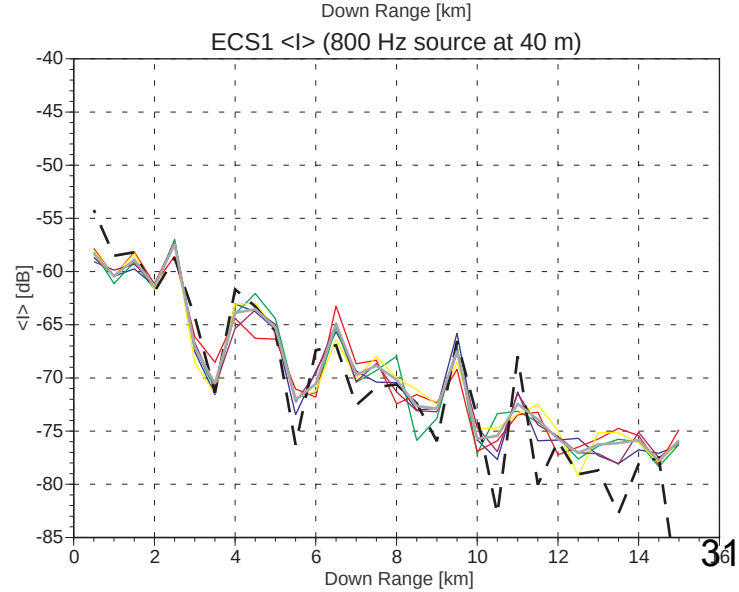
Results - 40m source, two frequencies

(NOTE: Scale differences)





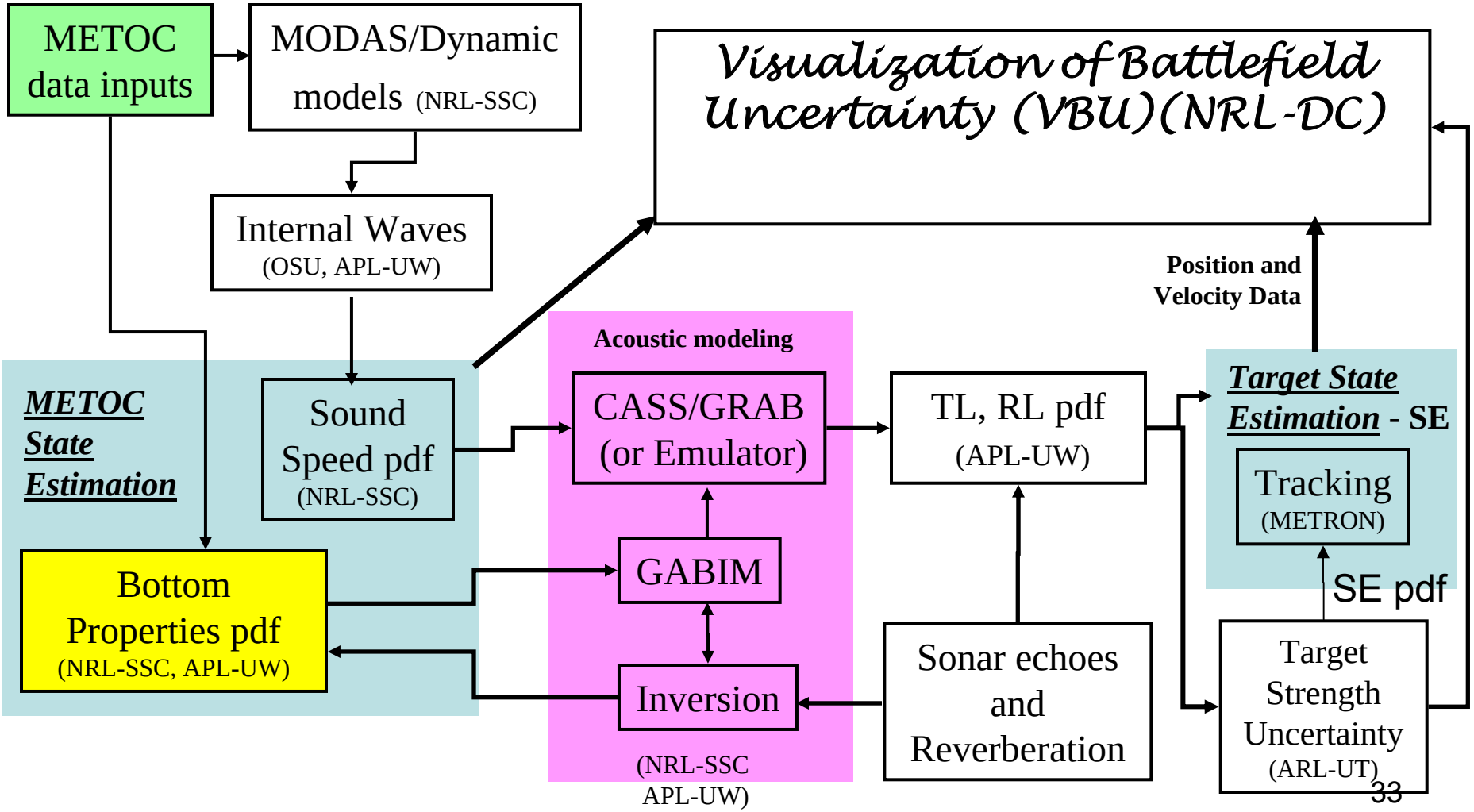




Observations

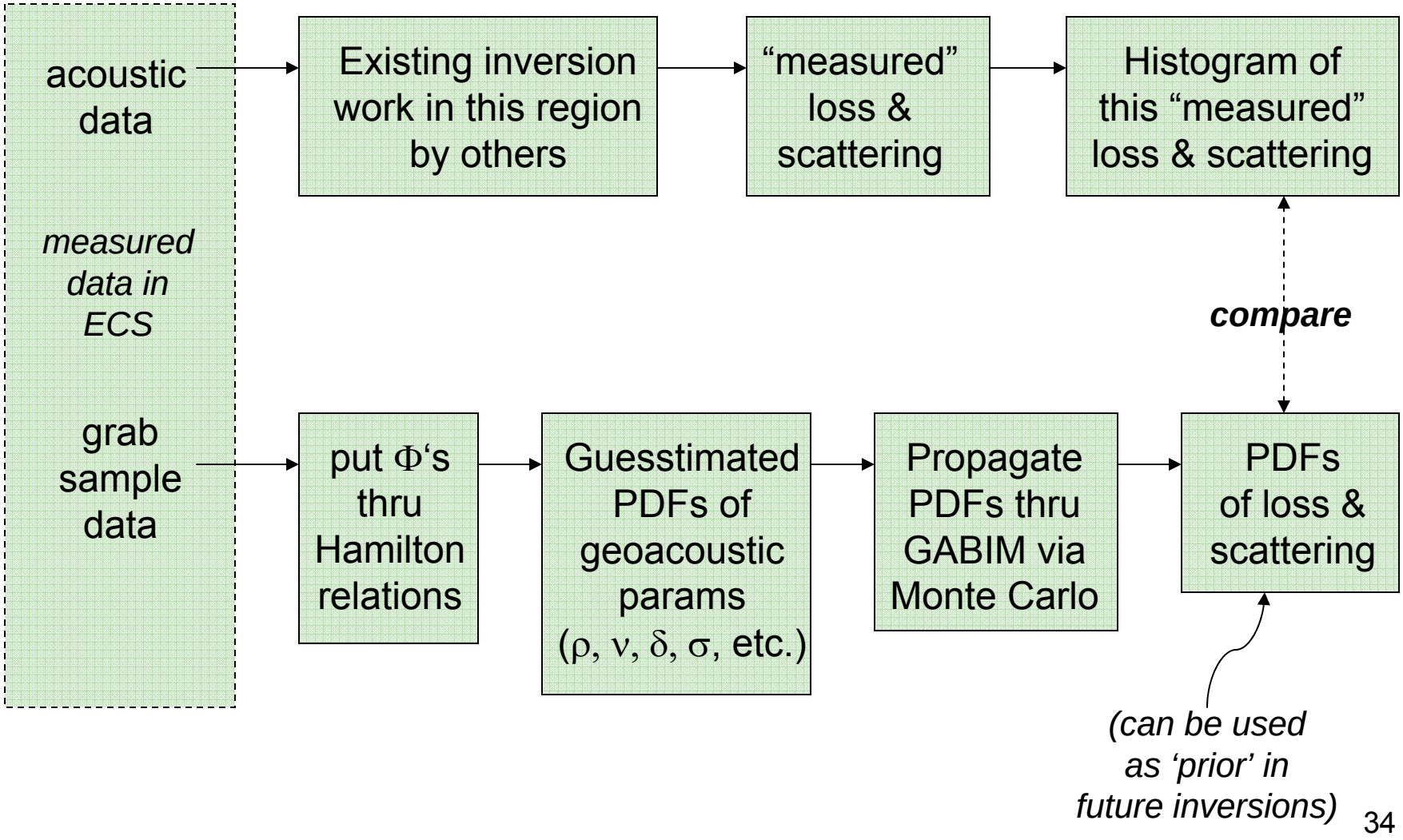
- 40m vs 7.6m source depth: internal waves have a little less influence
- 800hz vs 3Khz: internal waves have a little less influence
- MODAS results still statistically different from other profiles – as with early case.

Architecture – Big Picture



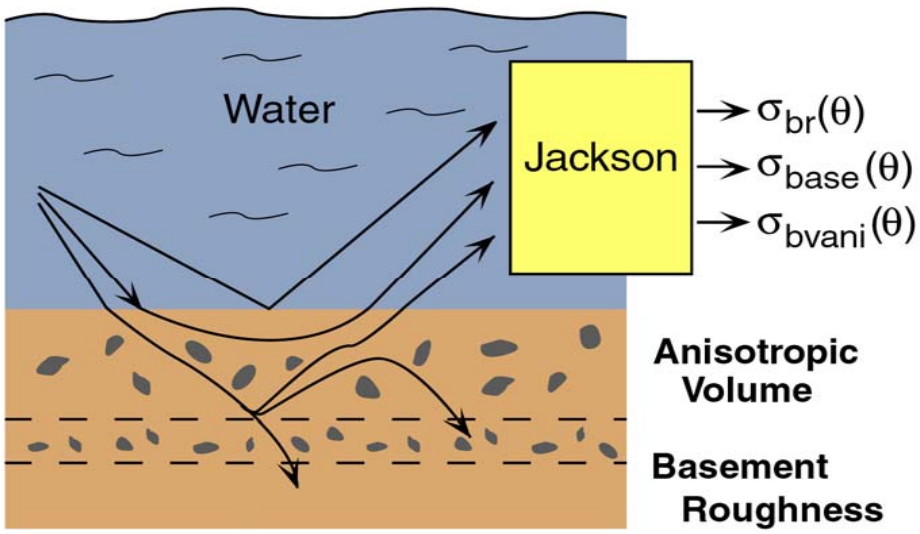
Initial "PDF of the bottom"

(for East China Sea region, for a given frequency)



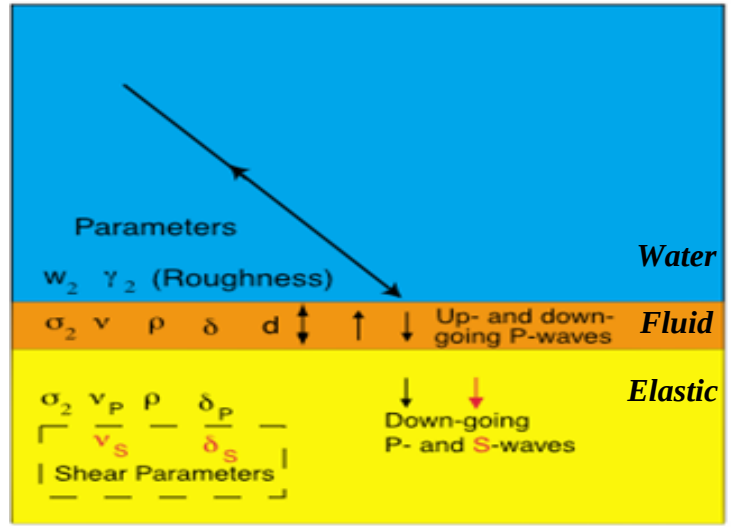
Differences Between "Full" GABIM & 2-Layer Analytic Version of GABIM

"Full" GABIM



- SAFARI (Schmidt) bottom propagation kernel, numerical implemention
- No derivatives yet but Bob Odom is working on this
- N layers, shear waves in all layers
- Much more complete & flexible solution, for all gr. angles

Simple, 2-layer analytic version



- Simpler, fully analytic propagation kernel:
  - very fast
  - in both Matlab and Fortran
  - has analytic derivatives worked out for optimization and sensitivity analysis
- 2 layers only – fluid sed. over elastic basemt
- No Kirchoff → bad results at high gr. angles

Passing Geoacoustic Parameter PDFs Through GABIM via “Monte Carlo”*

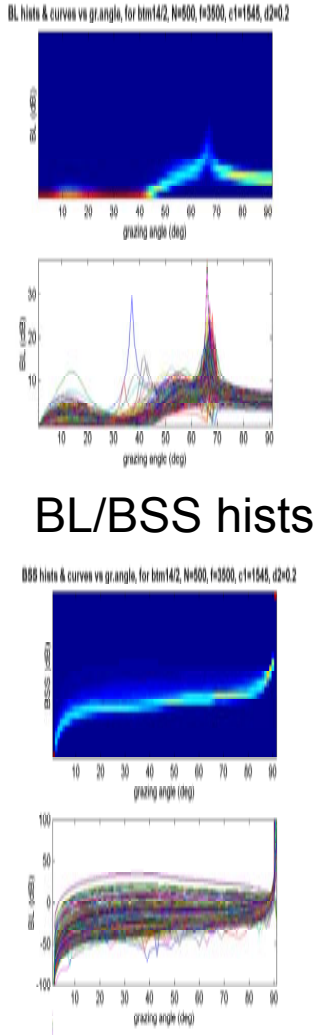
Gaussian distributions of geoacoustic parameters guesstimated from empirical data (Jackson). Density & soundspeed correlated from beginning.

ρ_2 }
ν_2
δ_2
σ_2
γ_2
ω_2
ρ_3 }
ν_3
ν_{3t}
δ_3
δ_{3t}
σ_3

500 runs

validate for model domain and realistic combo of parameters

gabim_analytic

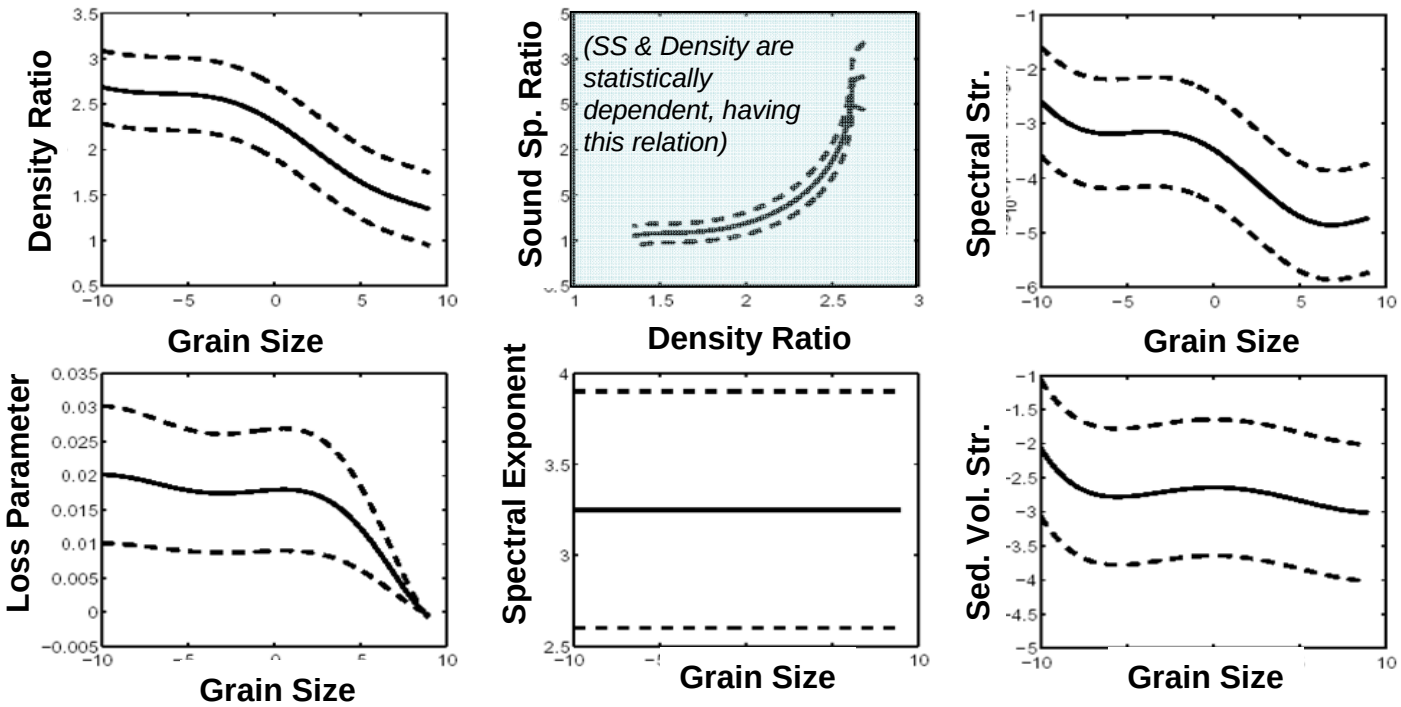


BL/BSS hists

*(Monte Carlo is in quotation marks because the validation filtering truncates the statistical distributions and messes up the statistics of the MC simulation. This is currently being studied.)

Estimated Distributions of Geoacoustic Parameters Based on Measured Data

D. Jackson, APL-UW



Important note: grain size is being used here to parameterize the system under one value to describe the sediment. So with phi=-10 here we're not really talking about kilometer-sized boulders!

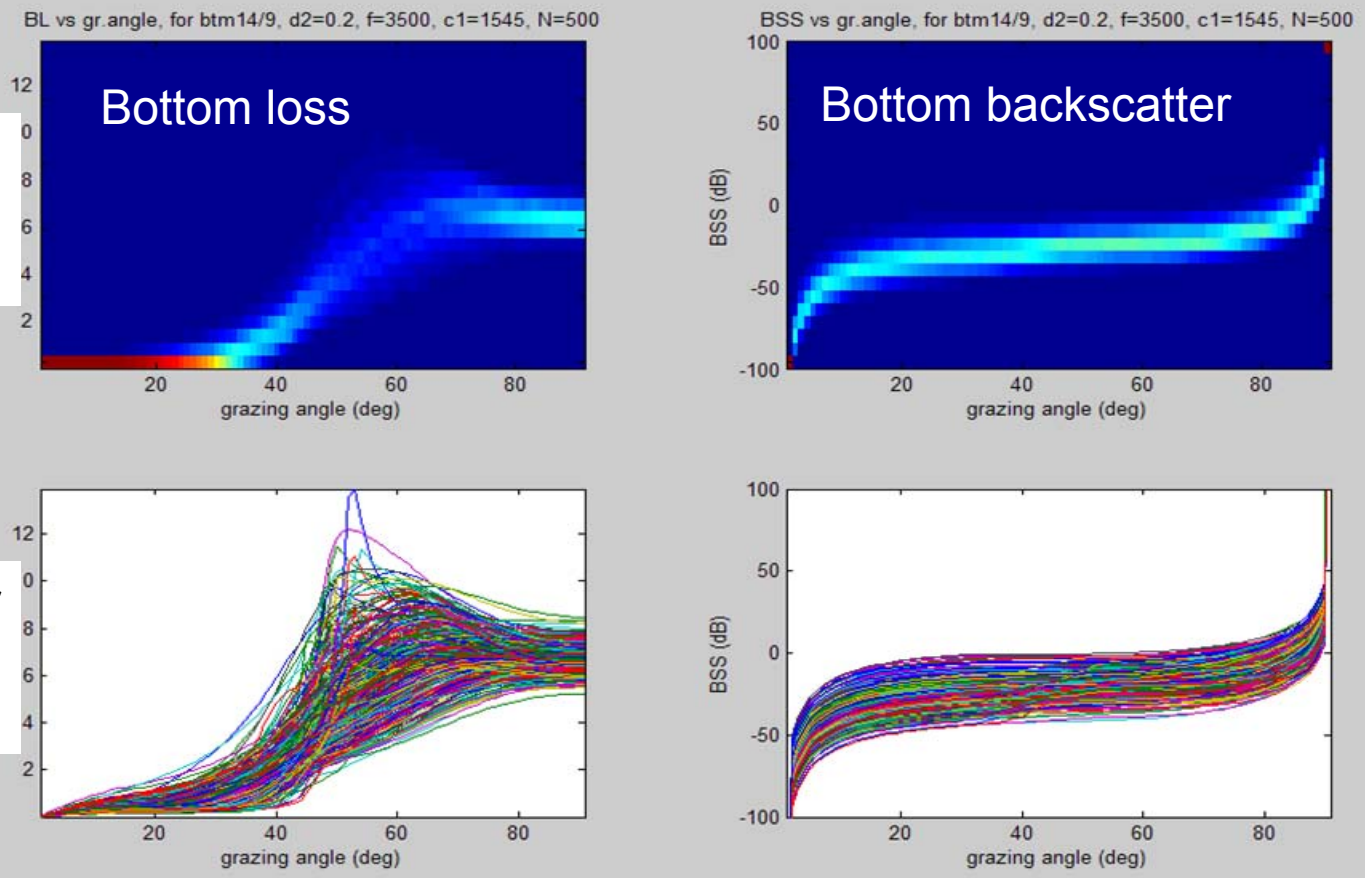
- Sample creation and validation uses these polynomial fits of the means and standard deviations of geoacoustic parameters. This is global but can specialize this to a localized region.
- Density and soundspeed statistically coupled (note polynomial fit for their empirical relation).

Histograms of Loss & Scattering

for 20cm of sediment of “coarse-sand” hardness over basement of “pebble” hardness

Histograms of BL or BSS realizations

All BL or BSS realizations



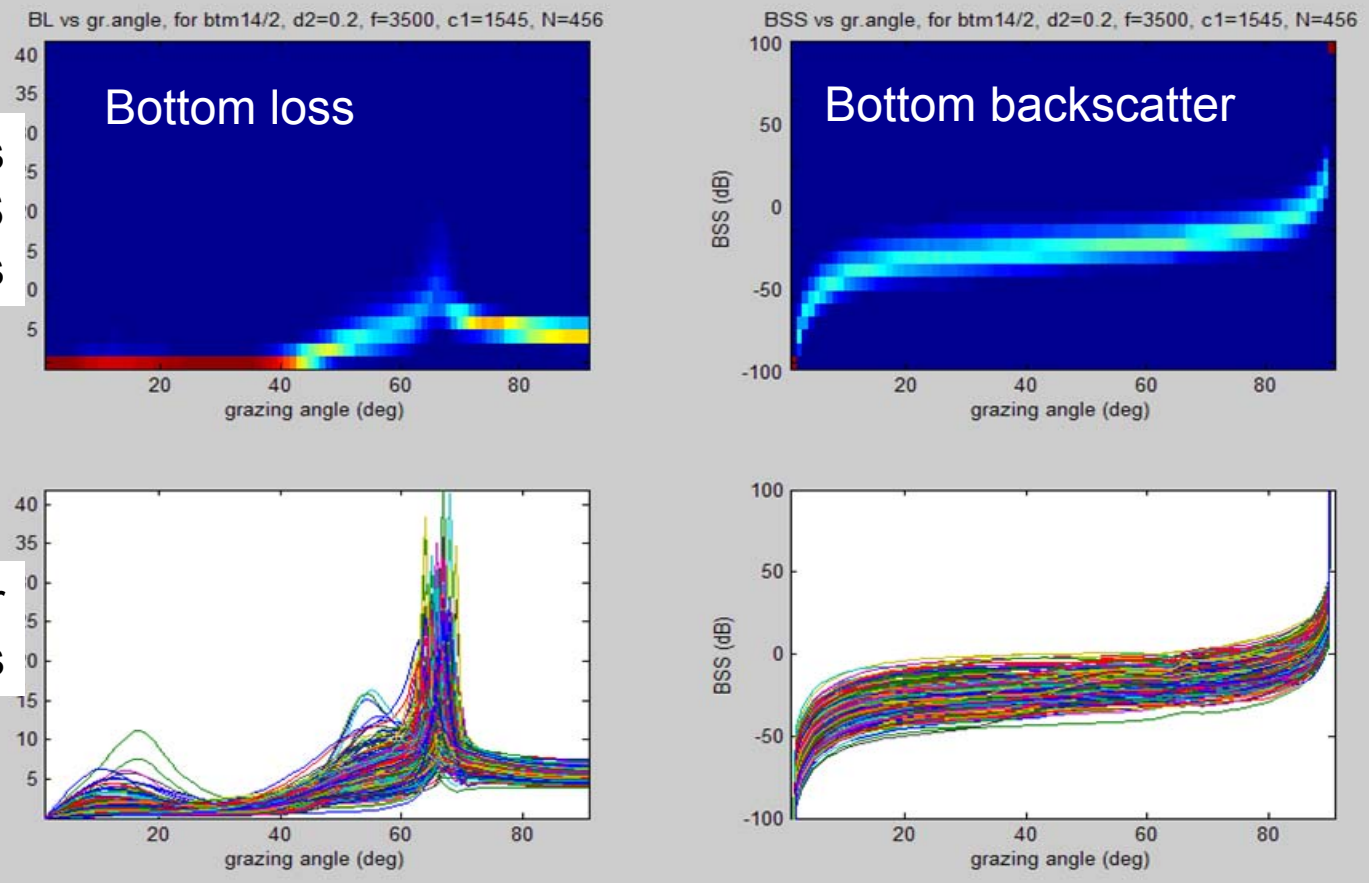
(recall this analytic model is bad at high grazing angles because no Kirchoff)

Histograms of Loss & Scattering

for 20cm of sediment of “coarse-sand” hardness over basement of “rock” hardness

Histograms of BL or BSS curves

All BL or BSS curves

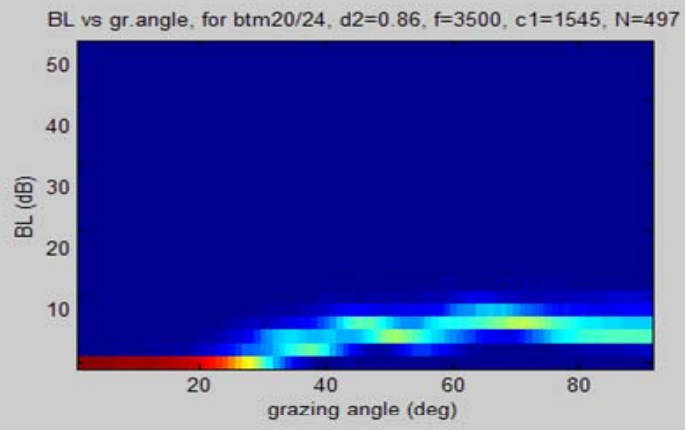


(recall this analytic model is bad at high grazing angles because no Kirchoff)

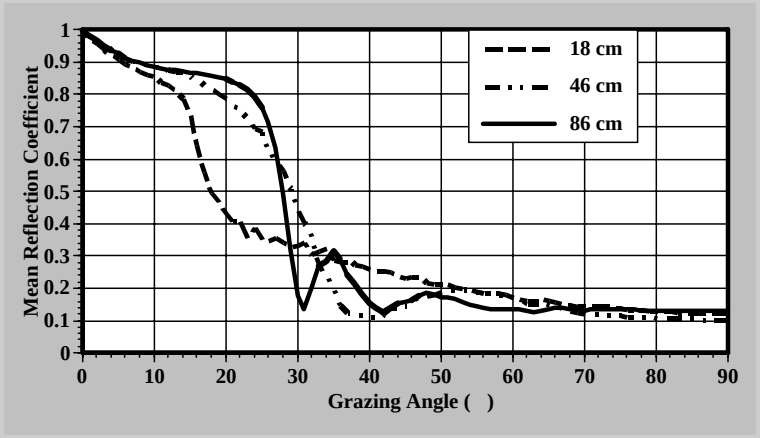
Comparing Some Results to Fulford's

Comparing to one of Fulford's runs (from "Some Effects of Thin Relic Surficial Sand…") : 86cm of sediment of "very-fine-sand hardness" over a basement of "medium-silt hardness". His basement is not included here because we only have 2 layers in our model, but at 3500Hz theoretically the acoustic energy won't penetrate that far anyway...

Ganse

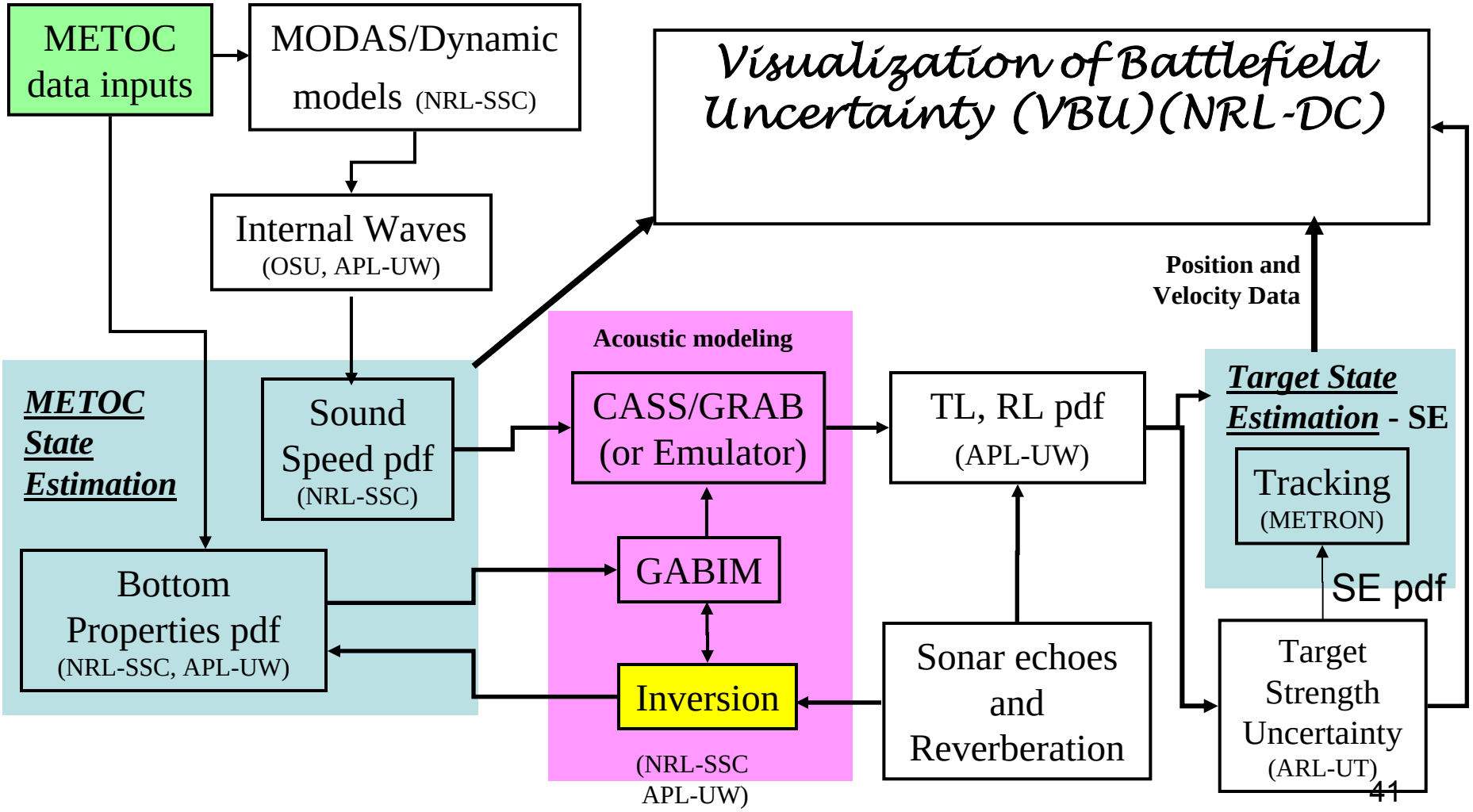


Fulford



These do show similar results, just in different units. BL in dB is $-10\log_{10}(|R|)$, where $|R|$ is the magnitude of the reflection coefficient. Even the "wiggles" roughly match up.

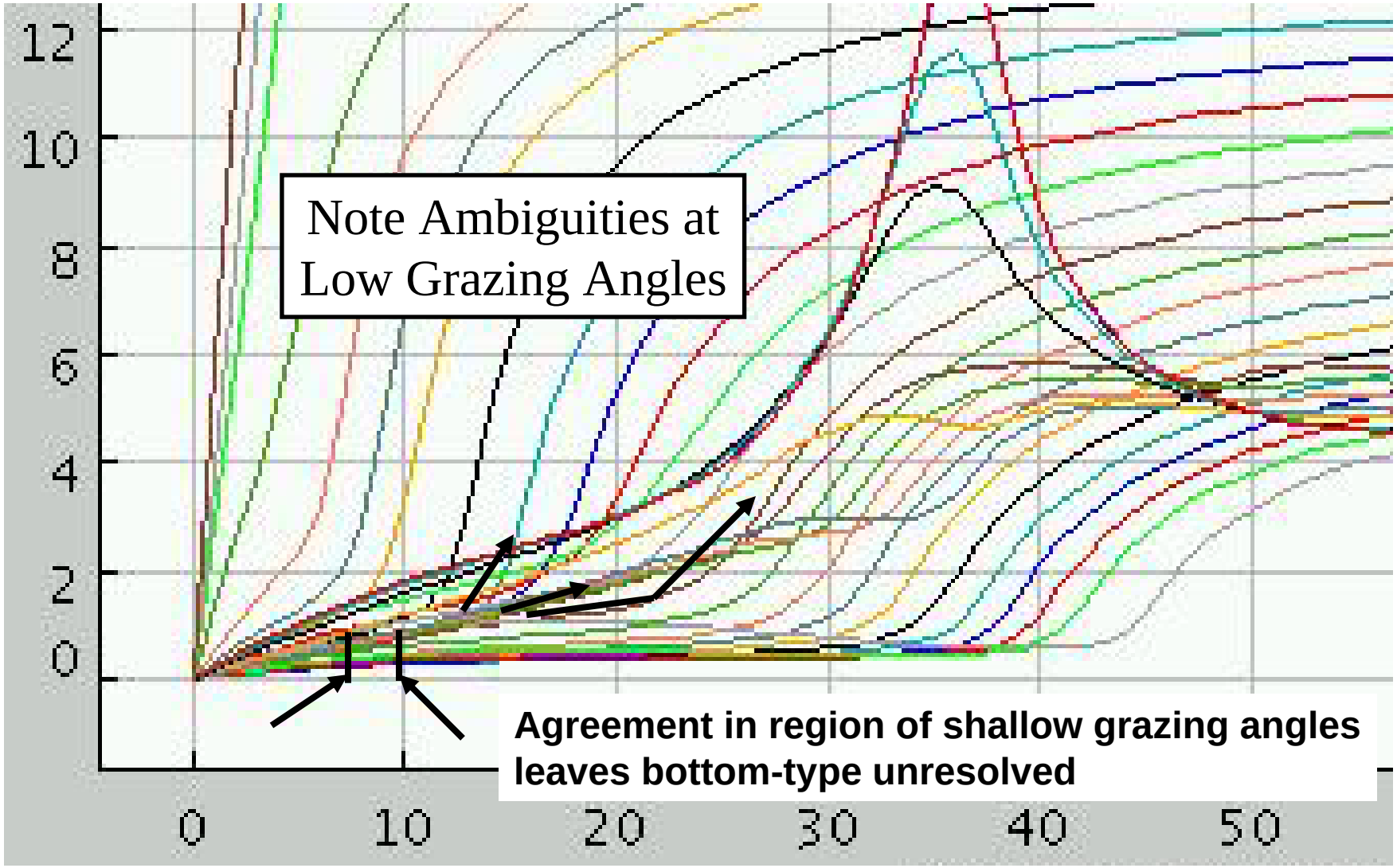
Architecture – Big Picture



Inversion

- Detailed inversion by Fulford in ECS
  - Geoacoustic characterization consistent with independent grain size measurements of bottom
  - Relatively insensitive to sound speed in ECS
  - JUA Article
- Resolution matrix
  - Discussed by Odom on Thursday
  - Applied to ECS Sonar Environmental Parameters Estimation System (SEPES)
    - Analytic derivatives (sensitivity) written for two layer bottom
    - Resolution matrix computed

SEPES-Lite Canonical Bottom Loss

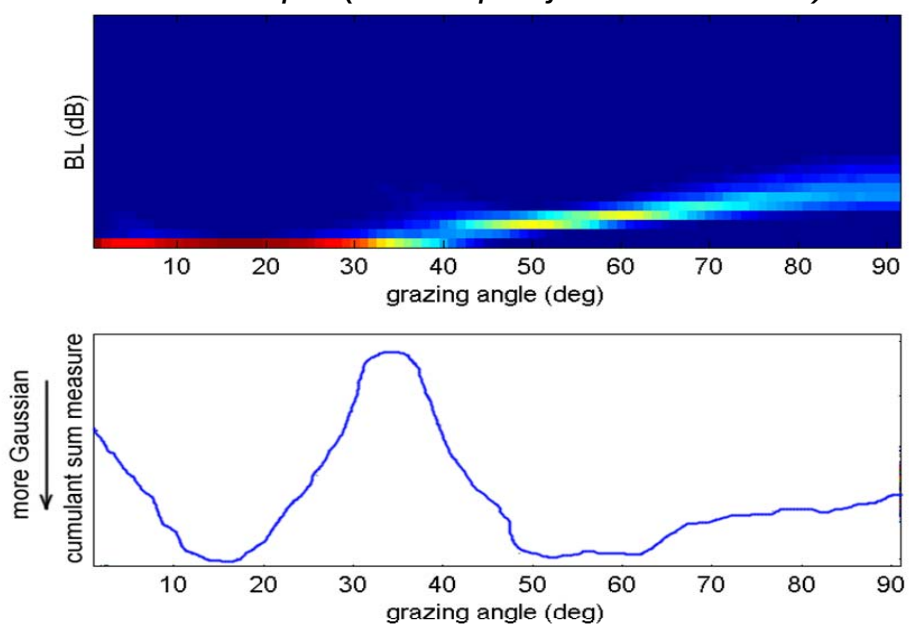


Currently Working On…

- figuring out a good way to handle the truncation of the statistical distributions by the validation/filtering of the geoacoustic parameters

- exploring ways to show “how Gaussian” a histogram slice is at a given angle is by the use of cumulants and quantile-quantile plots:

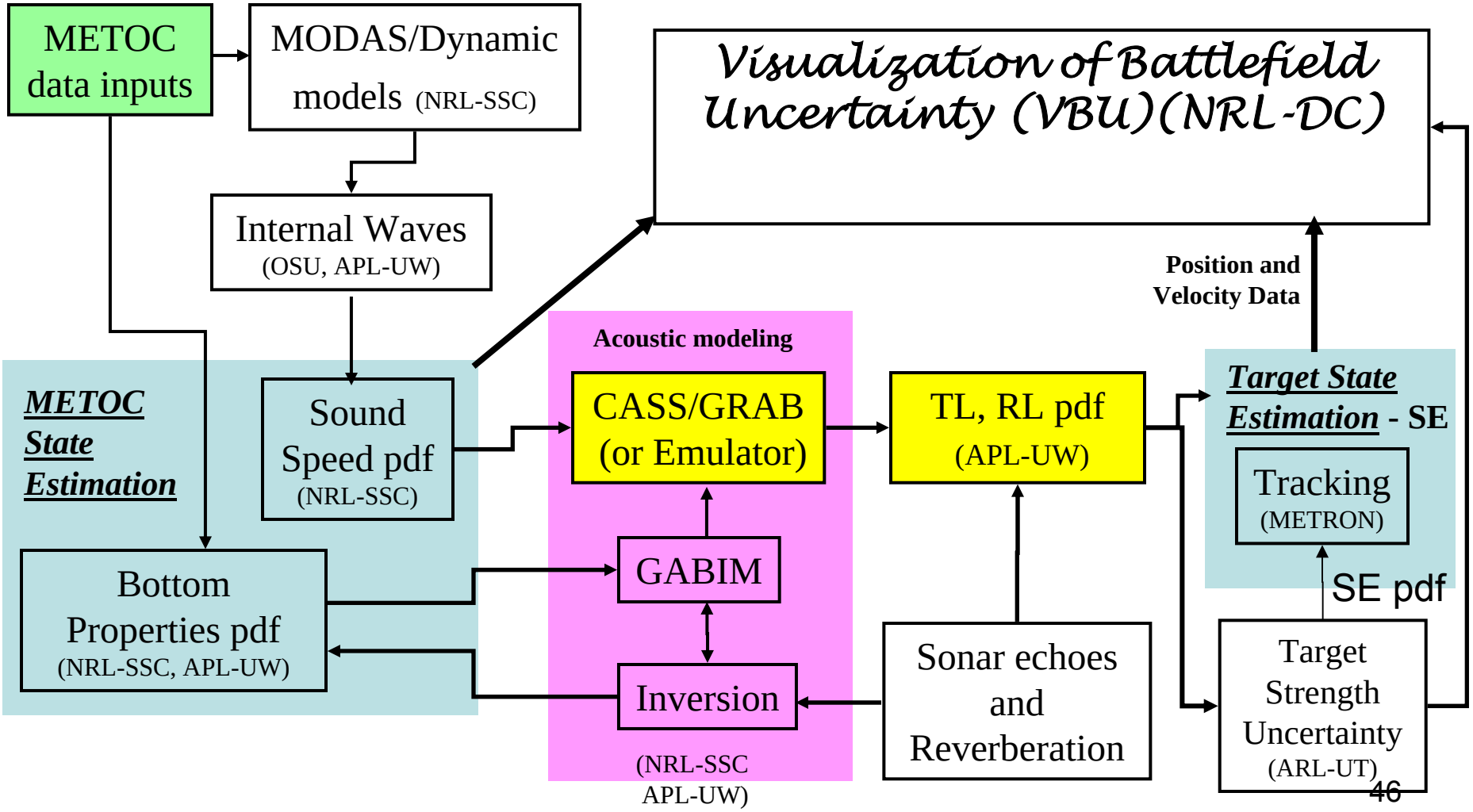
for example (bottom plot just hand-drawn) :



Issues for Future Work

- How results differ in other regions of globe
- Temporal changes in bottom (via storms, currents, seasonal sed temp changes…)
- Multi-modal bottoms (eg sand with rocks) – no model for this
- Accounting for sources of error at each step (measurements, inversions…)
- How to estimate PDFs of geoacoustic parameters from existing bottom data
- How to handle sparse geographic sampling of bottom data

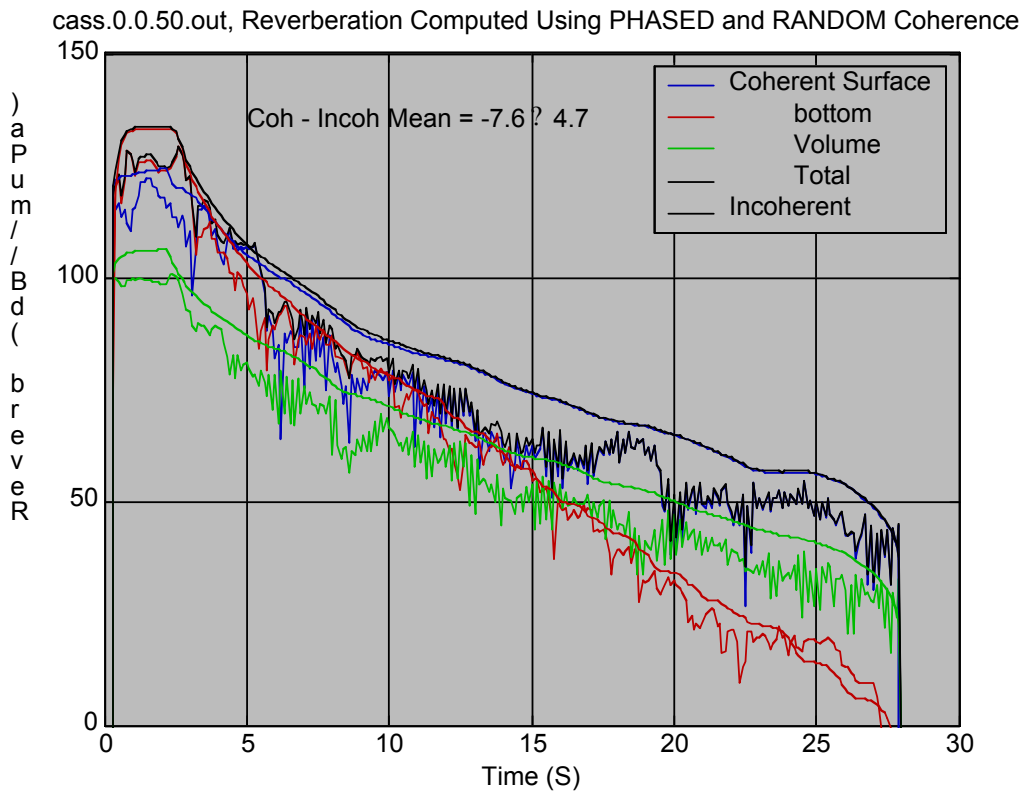
Architecture – Big Picture



CASS coherent reverberation computation issues

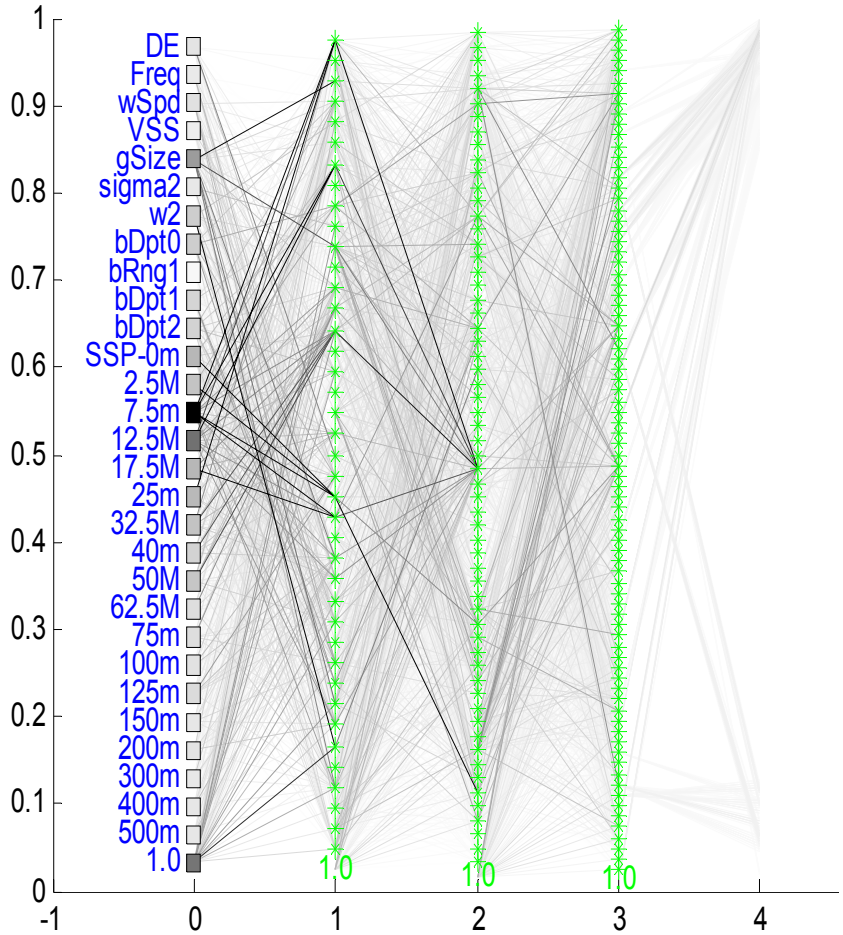
• Smoothed amplitude of CASS-computed coherent reverberation depends on the arrangement of reverberation grid points. (Smoothed amplitude inaccurate, at least where transmitter / receiver are nearly co-located vs. field of reverberation scatterers.)

•Computation results in time fluctuations different than observed in measurement.



More efficient Monte Carlo

- Faster
  - Use of neural nets to emulate acoustic model
    - ONR 6.3 program in sonar control
- Sensitivity
  - Identify critical parameters that impact RL, TL pdfs



Acoustic model data generation

- First attempt to provide data to LRT
- Look at very simplistic set of “realizations” for a geographical area

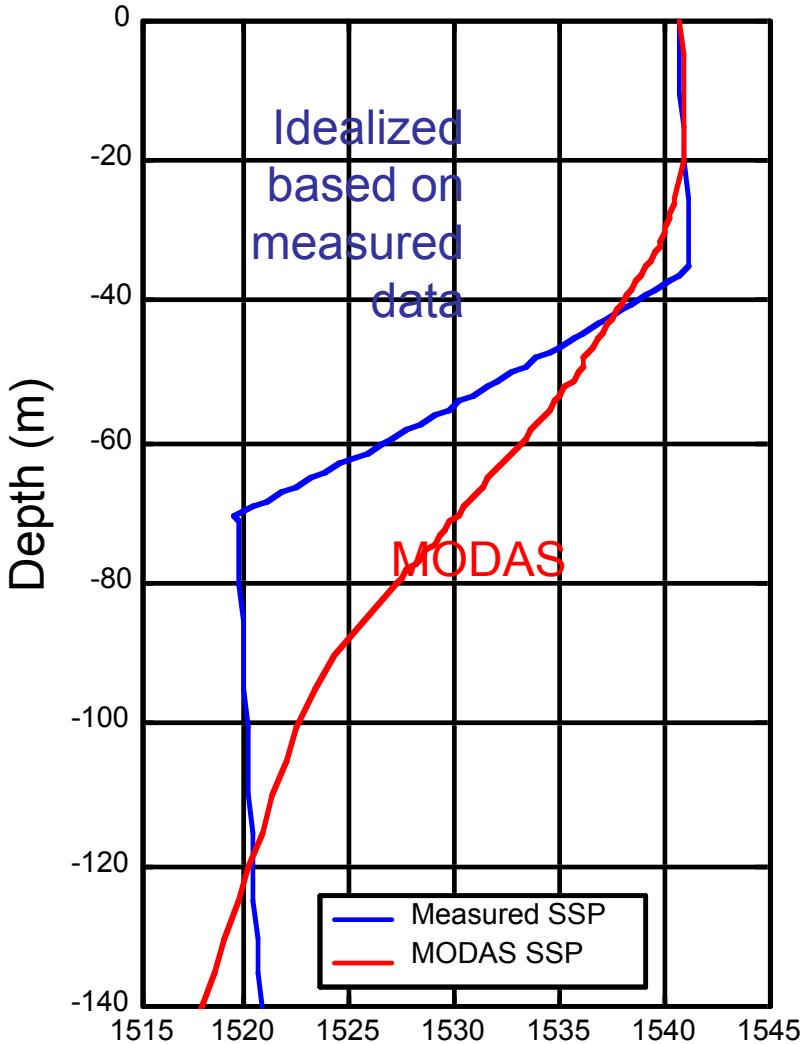
Fixed environmental and system parameters for preliminary CASS runs

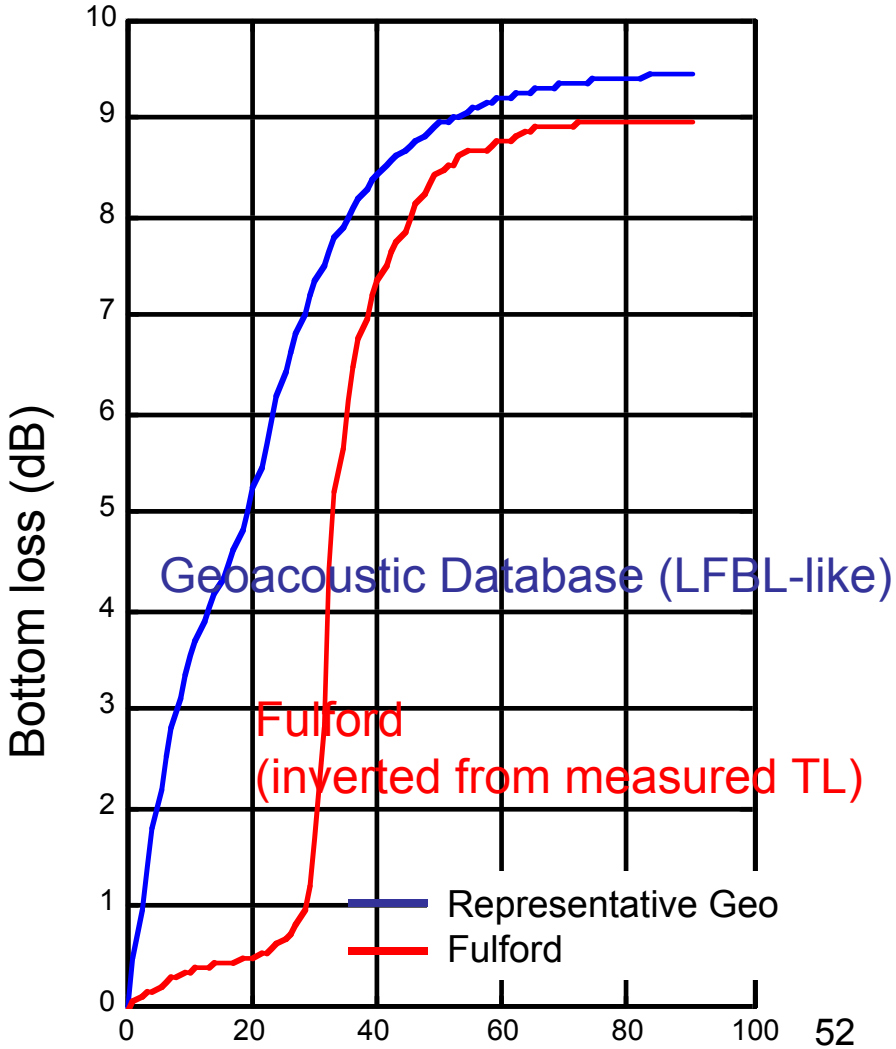
- Transmitter Depth = 30 m
- Receiver Depth = 10 m (Same Lat and Lon as Transmitter)
- Bottom Bathymetry: Gentle Downslope from 95 to 105 m
- Bottom Scattering Strength: Mackenzie
- Surface Reflection Loss: Coherent computed using Small Slope Approximation (Similar to modified Eckhart)

Fixed Environmental Parameters for CASS Runs

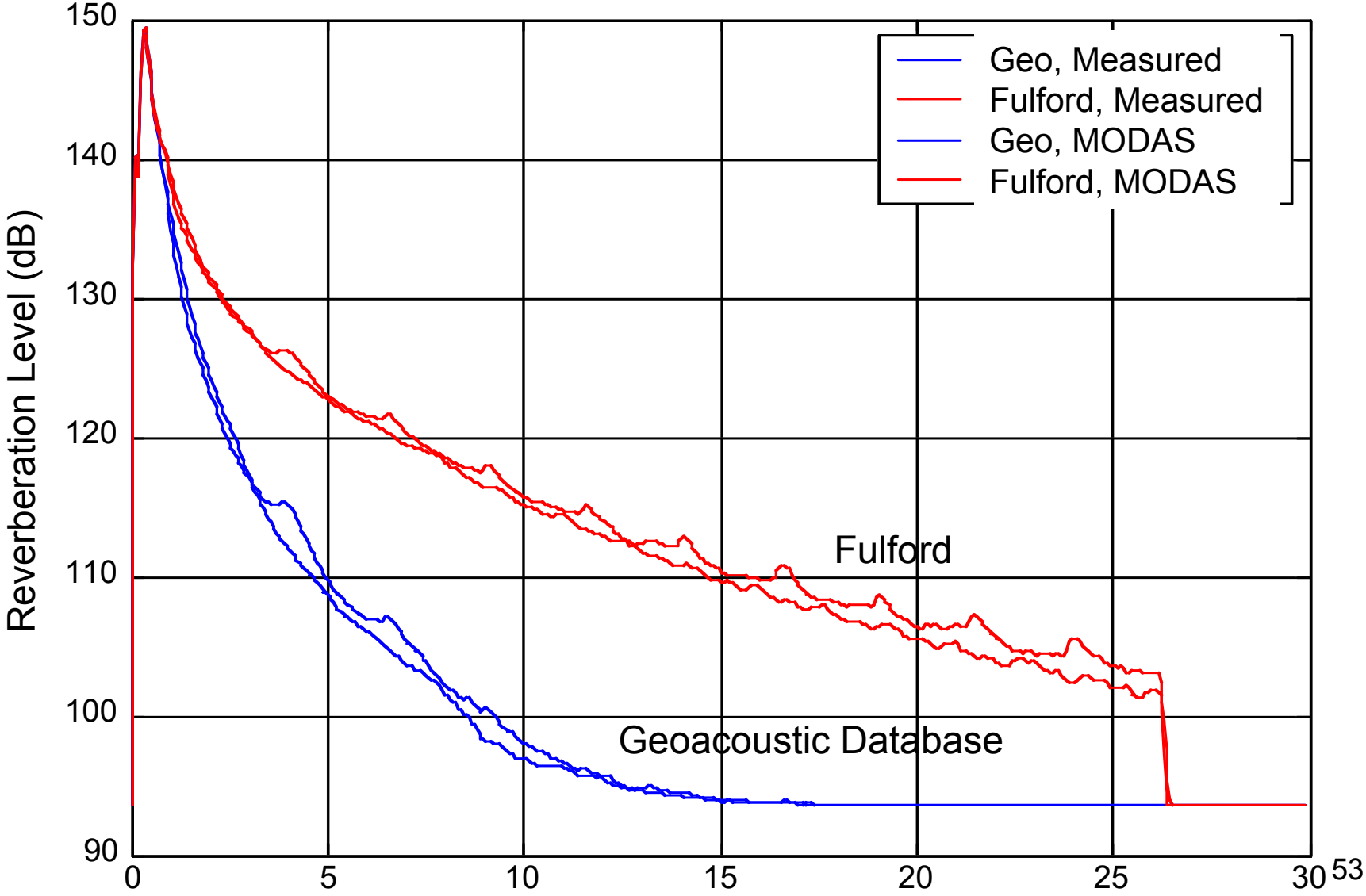
- Surface Scattering Strength: NRL (Gauss) Model for Surface Roughness and Bubble Clouds for wind speed = 8.8 m/s (17 kn)
- Volume Attenuation: Thorp
- Volume Scattering Strength: -84 dB//m
- Eigenray Model: Two Dimensional

Varying Environmental Parameters for CASS Runs

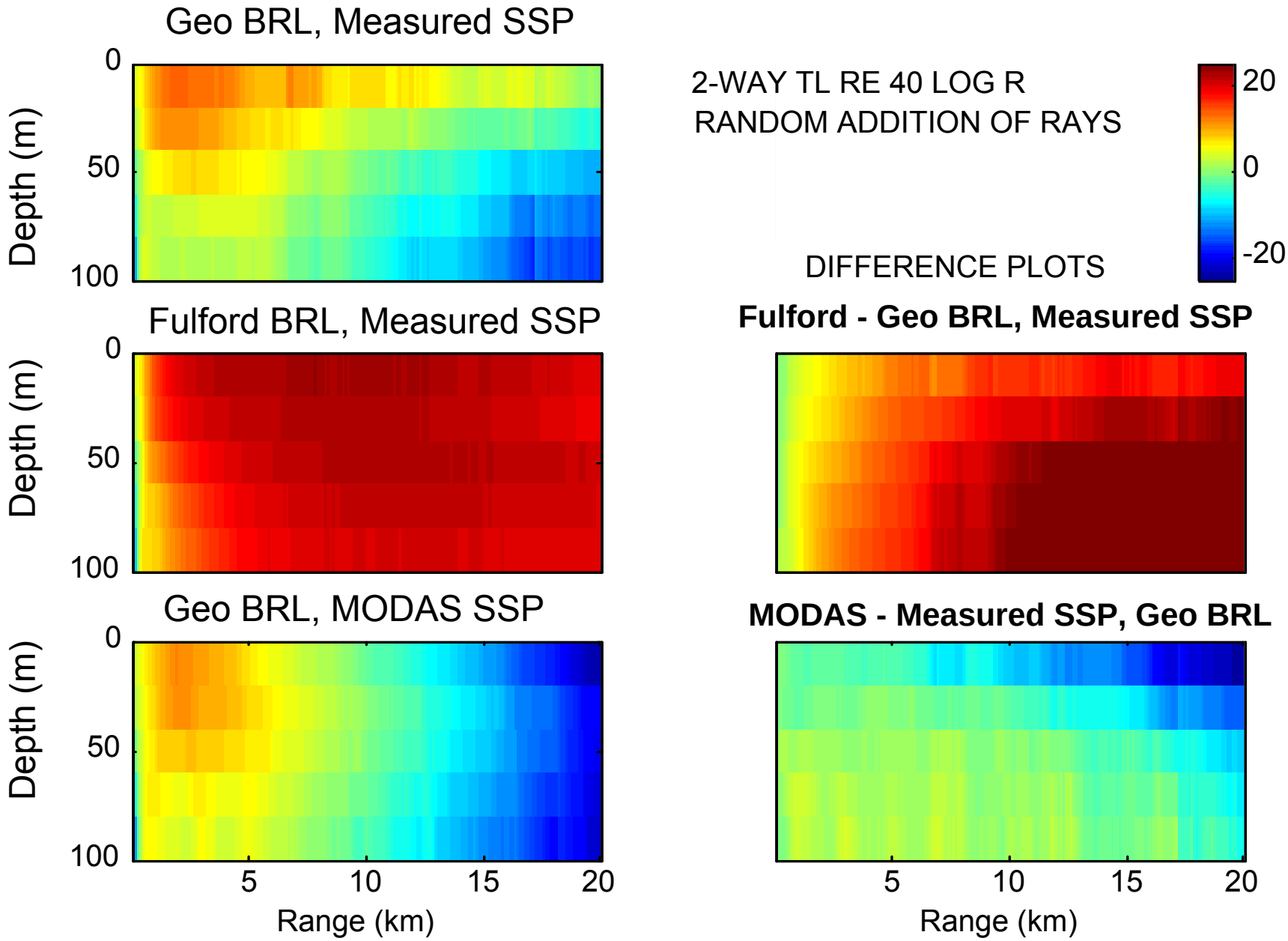




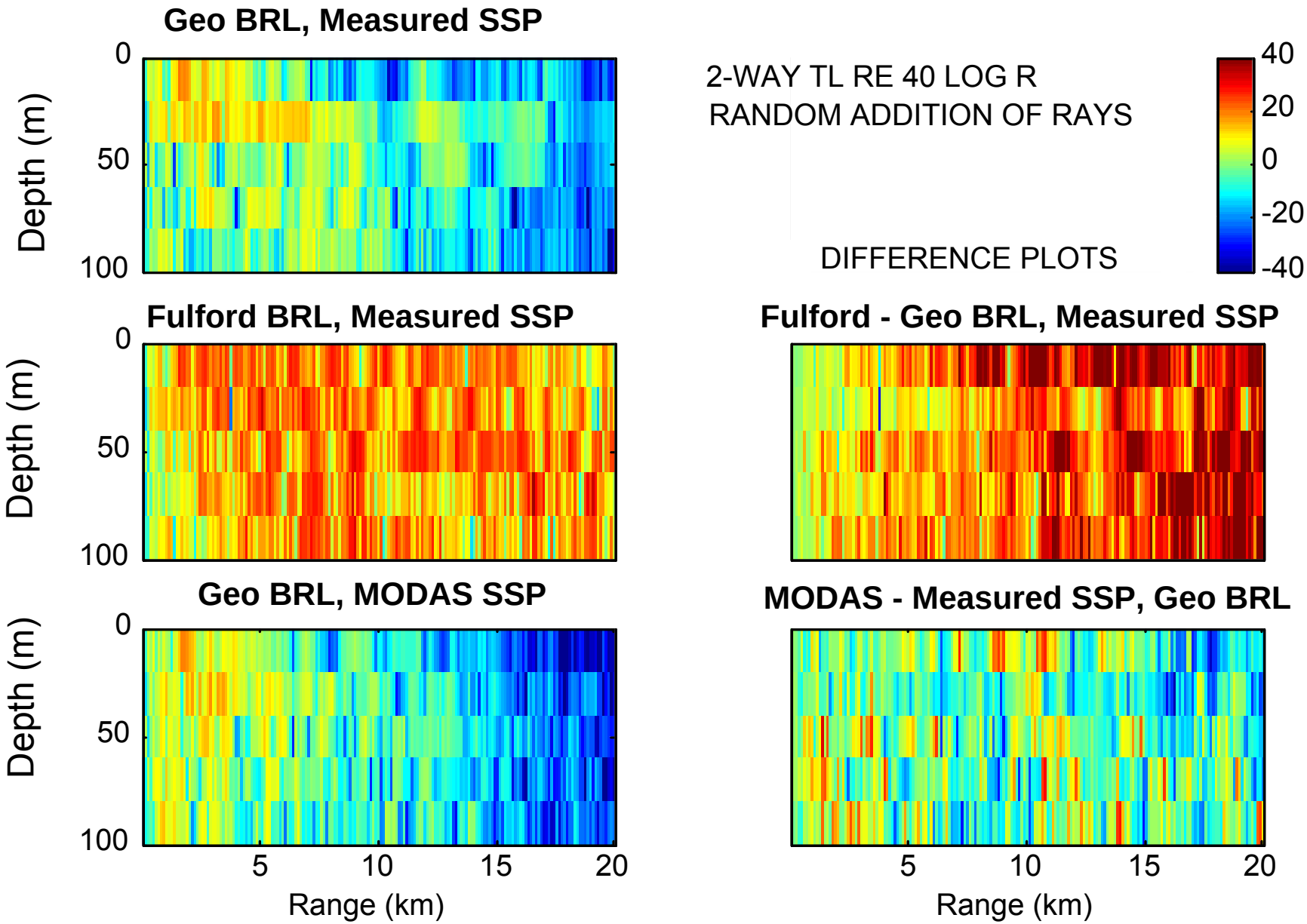
Reverberation for All SSPs and BRLs



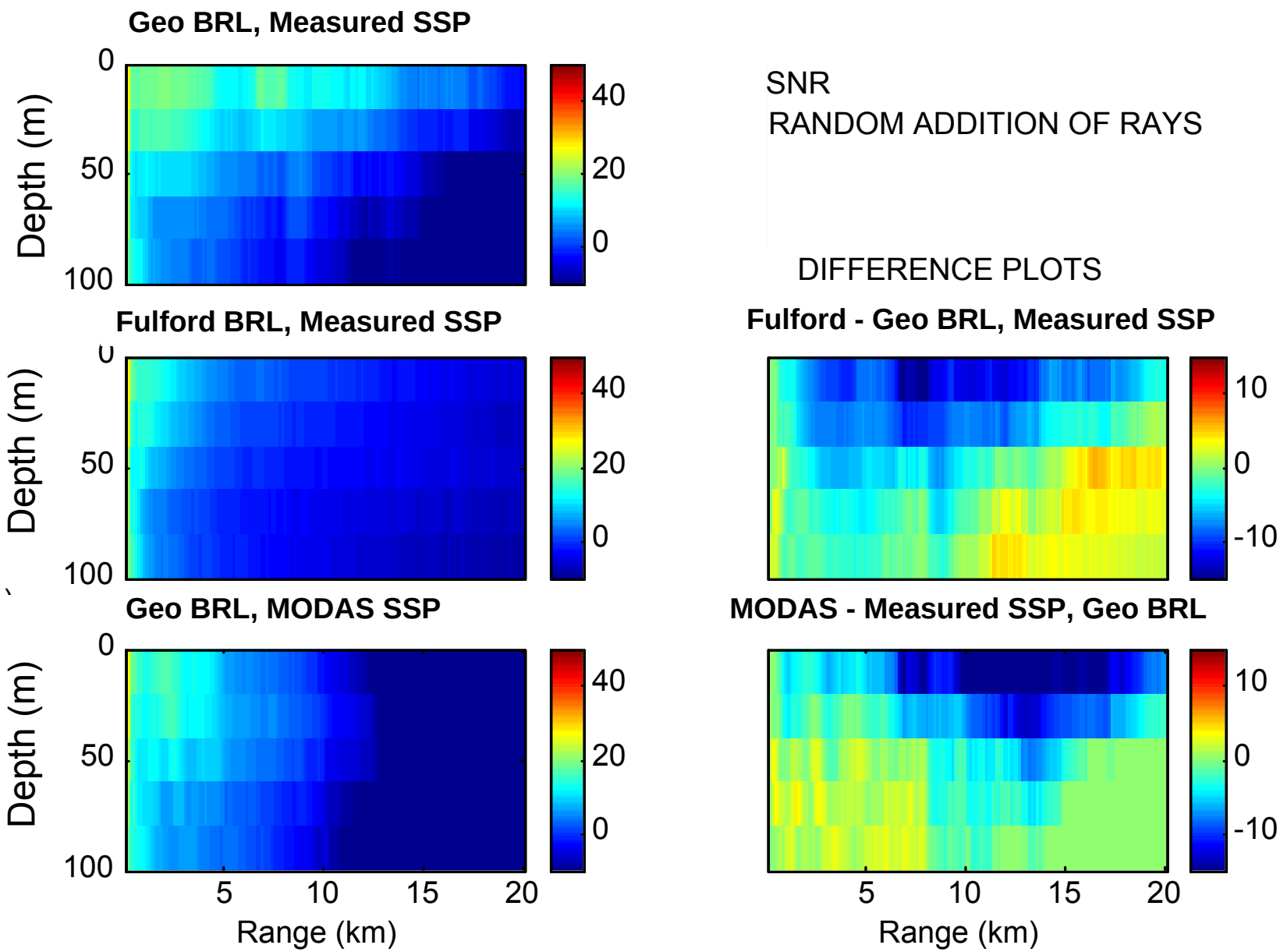
Two-Way TL for Three Sets of SSP and BRL



Two-Way Coherent TL for Three Sets of SSP and BRL

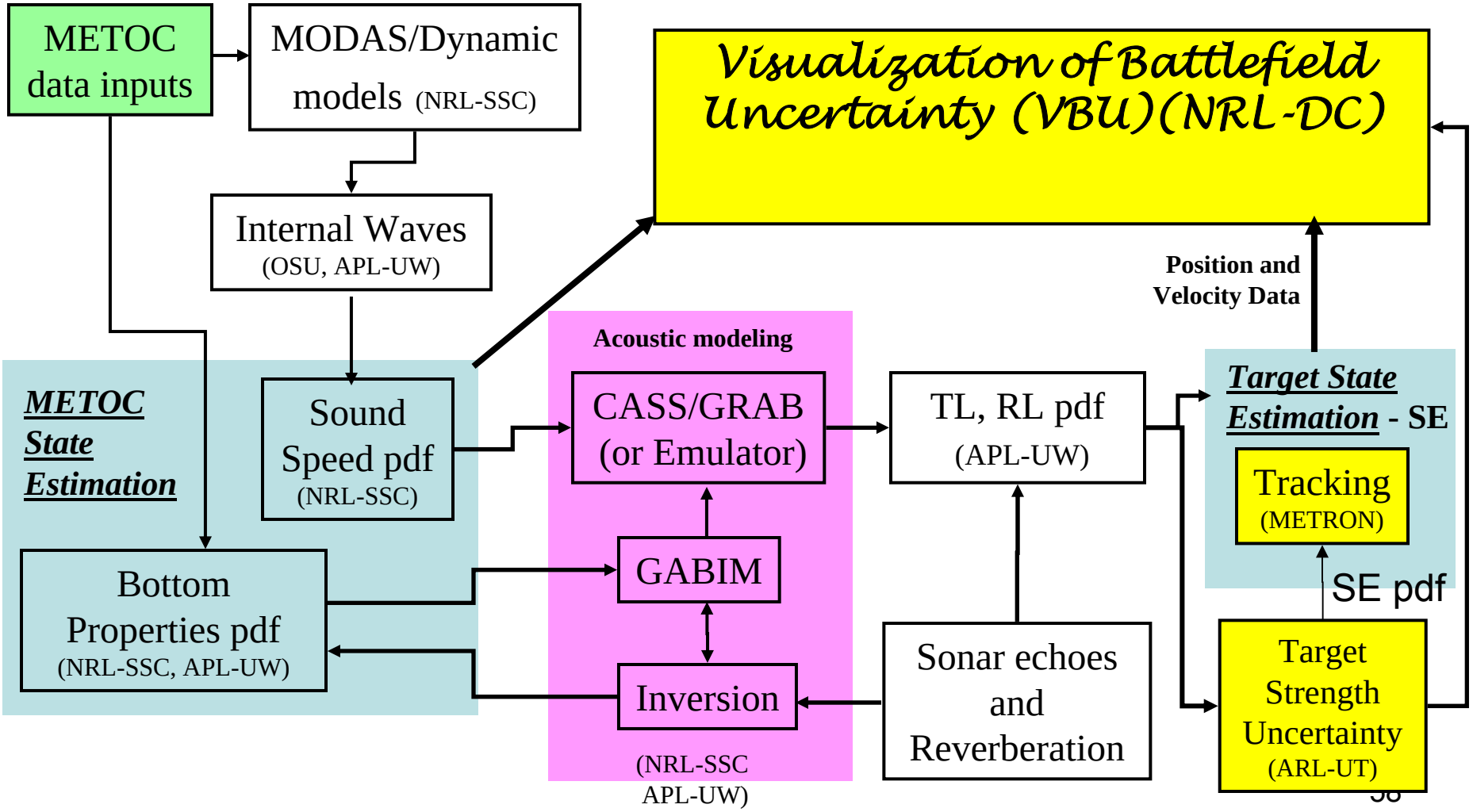


SIR for Three Sets of SSP and BRL



- And, the data go to……

Architecture – Big Picture



Looking Ahead

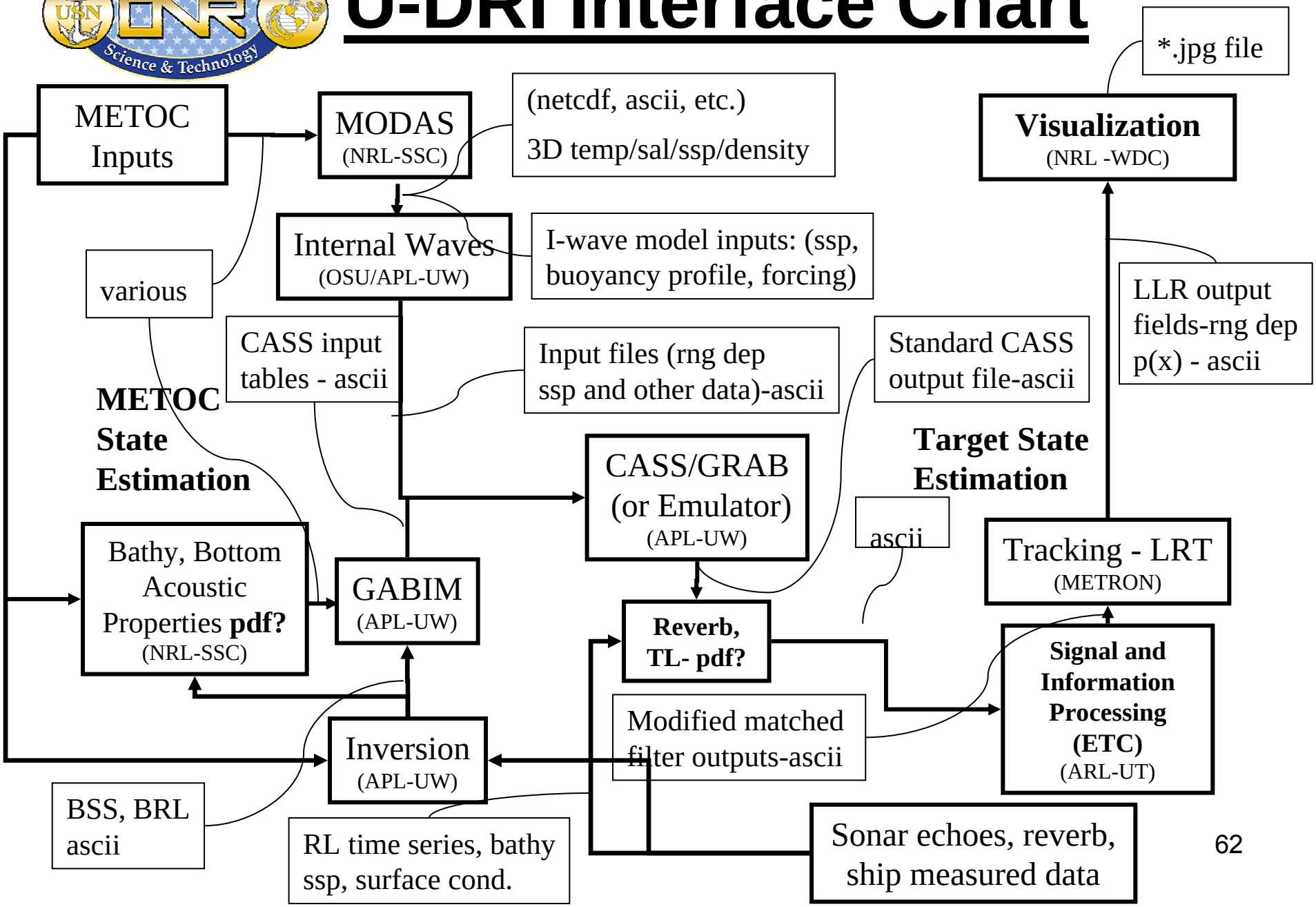
- Develop a working prototype…
  - Look at impacts of the different components on final tracking
  - Look at predictability of distribution of measured versus predicted SNR
- Transition path to…TAMDA, SPPFS/STDA, others

Summary

- We have data collection by the fleet and a desire for the information
- We keep working the issue of interfaces
- We keep working the end-to-end system
  - Relocatable
  - May not be very fast
- Information exchange continues to improve
- Results still to come……

Backups

U-DRI Interface Chart



Navy Coastal Ocean Model (NCOM)

- Combined sigma-z vertical coordinate
  - improves simulations over steep topography
- Nesting
  - allows submesoscale regions, Δx=O(10-100m)
  - inside mesoscale regions, Δx = O(1-10km)
- Based on Princeton Ocean Model (POM) physics
- And Coupled Ocean Atmosphere Prediction System(COAMPS) numerics

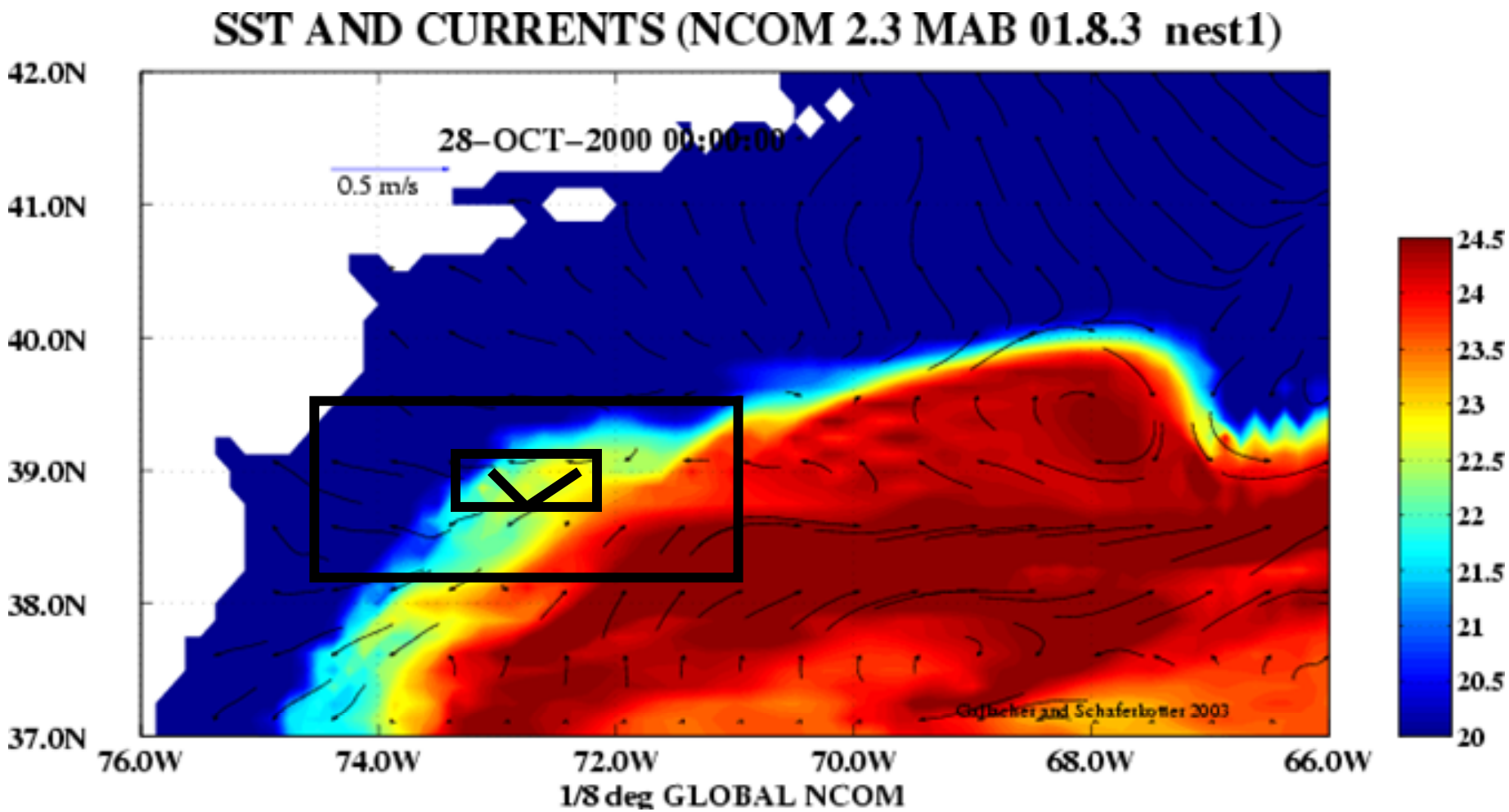
Numerical Grids

- Horizontal
  - C grid, dx = dy = 1/8º = 12km, dt = 360s
  - C grid, dx = dy = 1/24º = 4km, dt = 120s
  - C grid, dx = dy = 1/72º = 1.33m, dt = 40s
- Vertical
  - 41 levels, 21 sigma, 20 z
  - dz varies between approx. 1m and 100m
- Bathymetry
  - DBDB5 enhanced with DBDB2 and Sandwell and CIA coastline (Ko and McKinney)

Initial and Open Boundary Conditions and Atmospheric Forcing

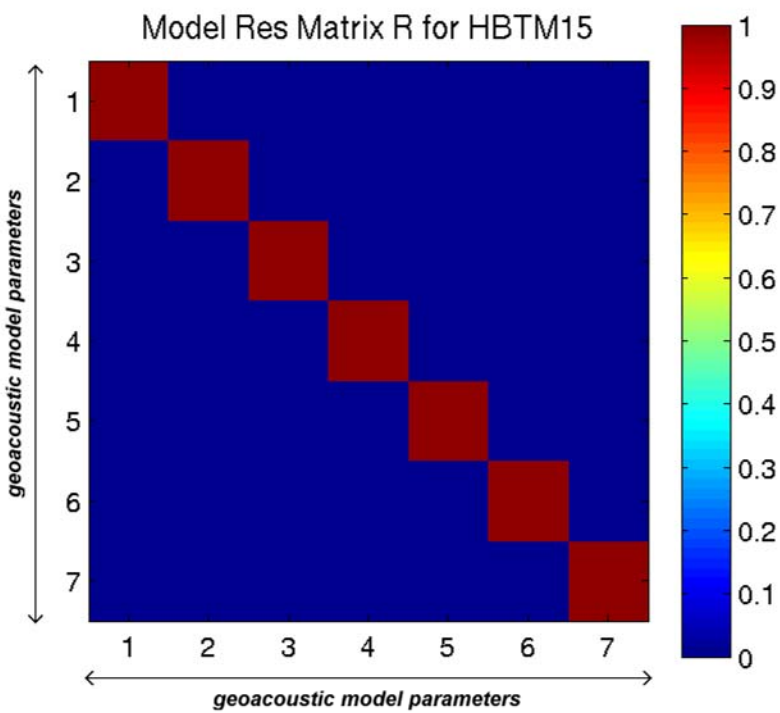
- NCOM Global 1/8° Model
  - Currents (U, V)
  - Temperature
  - Salinity
  - Sea surface elevation
- ADCIRC
  - 8 Tidal components
- COAMPS West Atlantic Domain
  - Wind Stresses

Model Domains

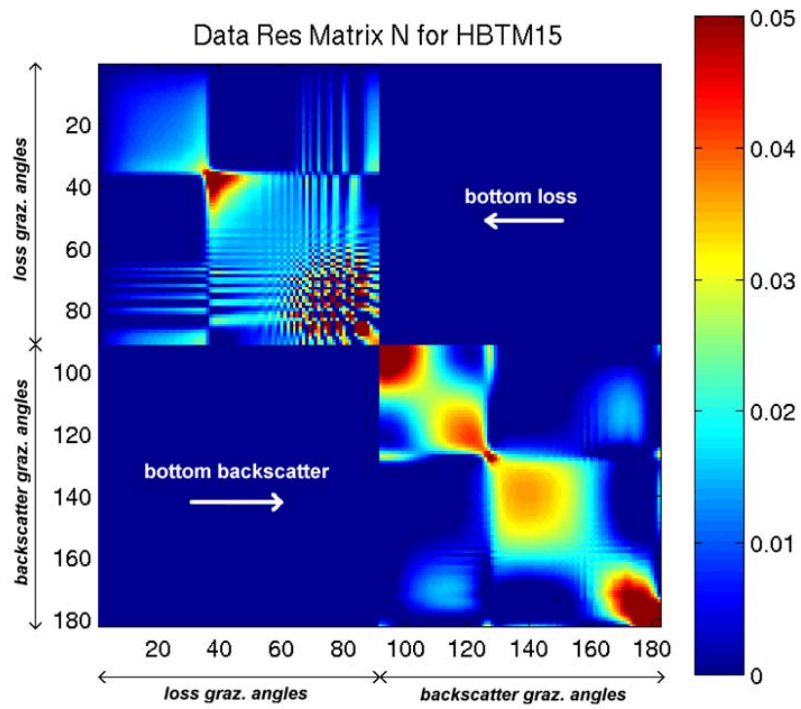


Resolution Matrices to Quantify Uniqueness Issues in the Inversion

These are created entirely as functions of just the model derivatives (or finite diffs), as seen in Menke's *Geophysical Data Analysis*. Distance from being an identity matrix is a measure of uniqueness inherent in the model and its inverse.



going *from* model params *to* model results.
identity matrix → perfectly unique

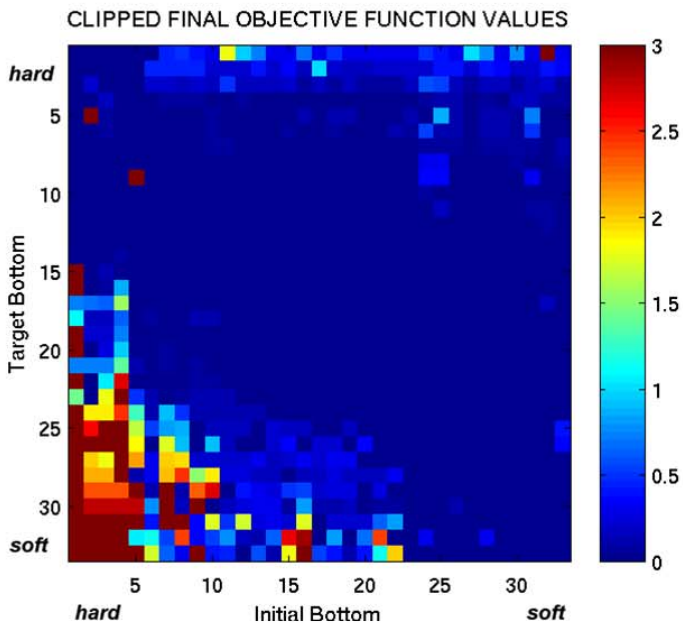


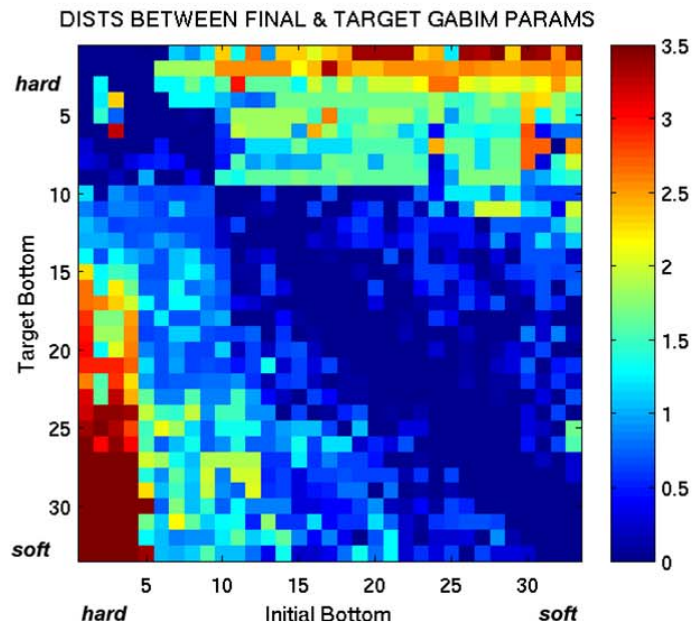
going *from* model results *to* model params.
not identity matrix → not unique at many angles,
but close to unique at critical angle

Inversion Results on Synthesized Data

Using 2-Layer Analytic Version of APL-UW's GABIM Bottom Model

33 canonical/theoretical bottoms used to represent both the target bottom (ie synthesized measured data) and initial guess for bottom used in inversion. These two matrices show two different inversion-success measures for all 33x33 combos of these target & initial bottoms.





- **Left side matrix :** objective function values (smaller = better), dists between final & target loss/scattering.
- **Right side matrix :** mean-square dist between final & target geoacoustic parameters (normalized to 0-1).
- **Overall does pretty well.** Good convergence for most combos, but uniqueness issues since right ≠ left.