Capturing Uncertainty in the Common Tactical-Environmental Picture

a.k.a. Better Applications of Uncertainty for the Battlegroup (BAUB)

Presented by

APL-UW
ARL-UT
NRL-SSC
Oregon State University
METRON
NRL-WDC

People

QuickTime™ and a GIF decompressor are needed to see this picture.

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Organization	POC	Area
APL-UW	Robert Miyamoto, 206 685 1303, rtm@apl.washington.edu Jim Pitton, 206 543 1366, pitton@apl.washington.edu Robert Odom, 206 685 3788, odom@apl.washington.edu Darrel Jackson, 206 543 1359, drj@apl.washington.edu	Acoustic modeling, bottom modeling, inversion, statistics, and sensitivity
NRL-SSC	Pat Gallacher, 228 688 4798, Gallacher@nrlssc.navy.mil Alex WanVarnas, Dan Fox, 228 688 5588, fox@vulcan.nrlssc.navy.mil Jim Fulford, fulford@nrlssc.navy.mil	Dynamic Ocean Modeling Assimilation Geoacoustics
Oregon State	Murray Levine, 541 737 3047, levine@oce.orst.edu	Internal Waves
ARL-UT	Brian La Cour, 512 835 3961, blacour@arlut.utexas.edu Karl Fisher, 512 835 3603, Kfisher@arlut.utexas.edu	Active signal and information processing
METRON	Larry Stone, 703 787 8700, stone@metsci.com	Data fusion/tracking
NAVOCEANO	Rob Lorens, 228 688 8070, LorensR@NAVONT3.NAVO.NAVY.MIL	Environmental Uncertainty
NRL-DC	Greg Schmidt, 202 767 0371, schmidt@ait.nrl.navy.mil Sue-Ling Chen	Visualization

Goals

- Use existing 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)

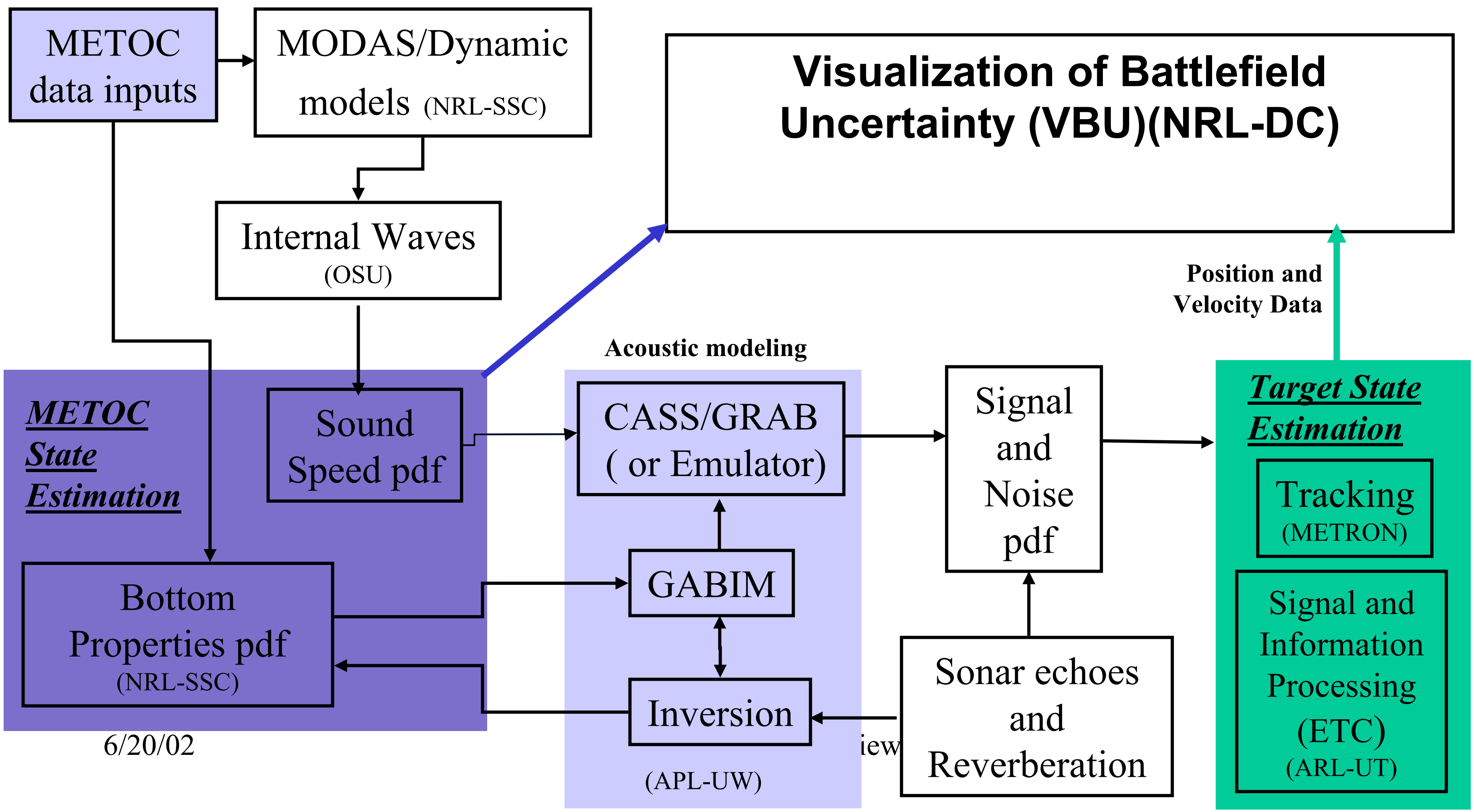
Overview

- 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.

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?

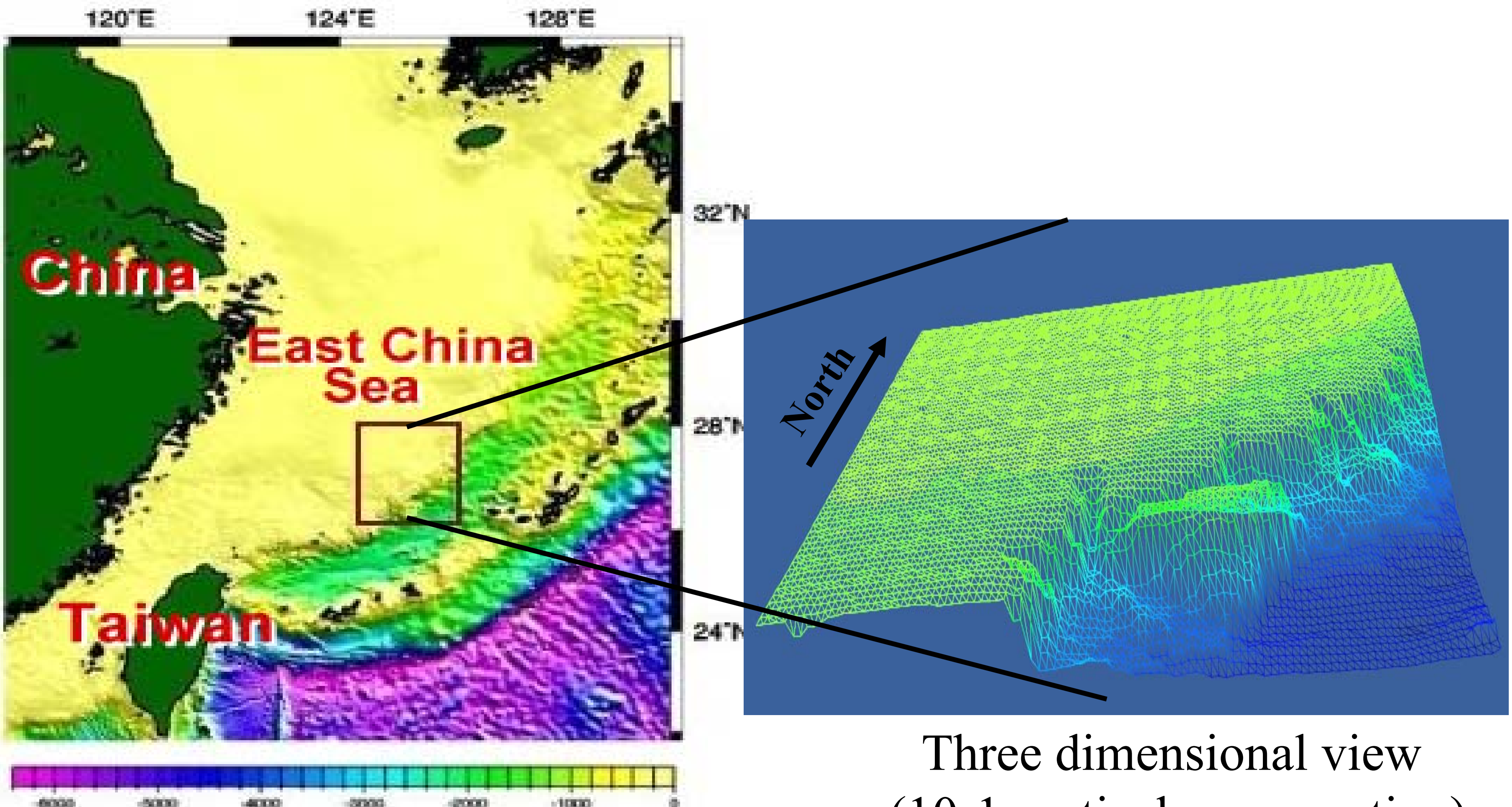
Notional Architecture



Significant Changes

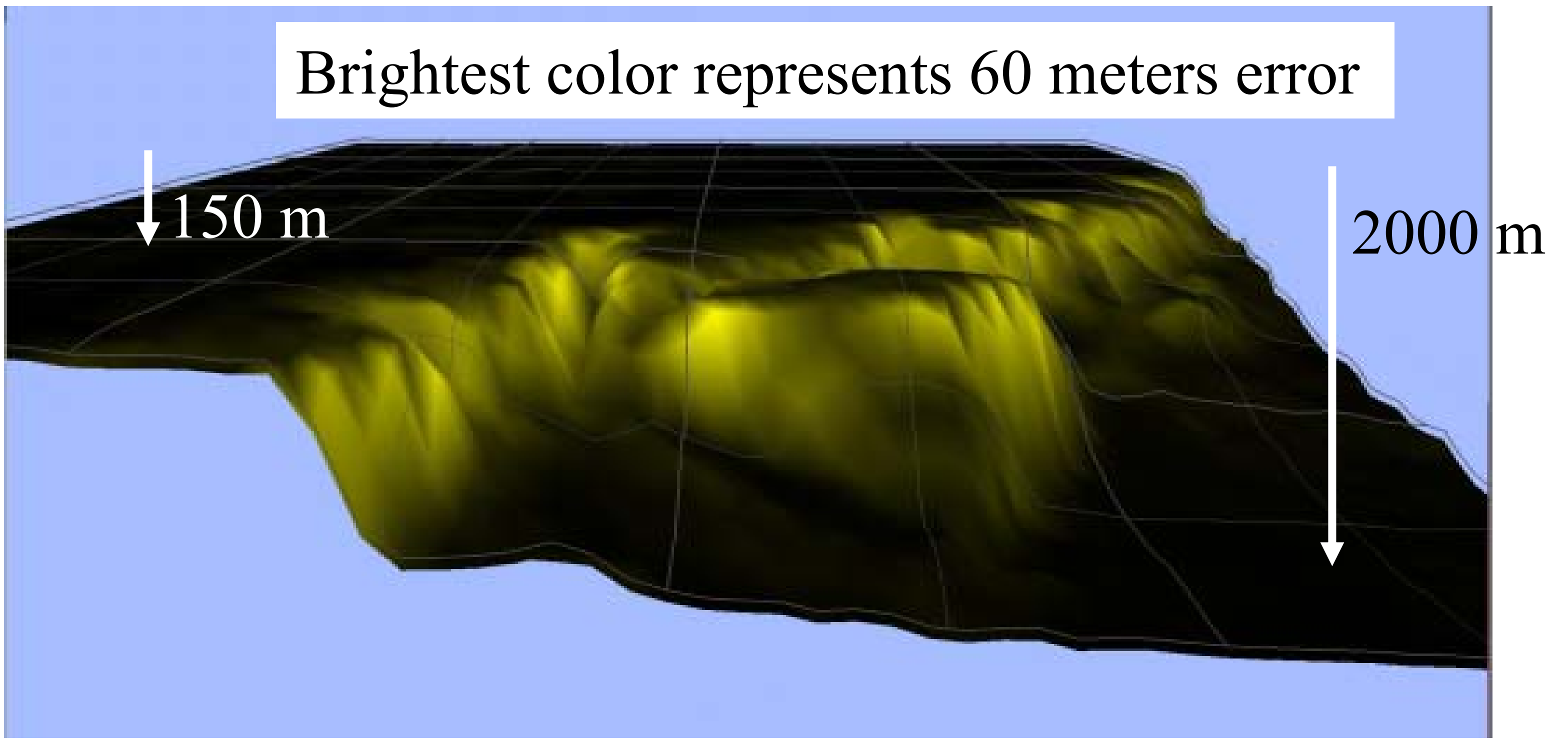
- Added NRL-DC (POC: Greg Schmidt) for visualization
- Focus on East China Sea
  - More relevant area
  - Environmental Characterization
    - Littoral Advanced Demonstrations
    - NAVOCEANO (sound speed, transmission loss, bottom composition)
    - Environmentally Adaptive Sonar Probe Pulses
    - Broadband impulsive (SUS) Sonobuoy data
    - ASIAEX
  - Tactical….
    - Several experiments

East China Sea Area



Three dimensional view
(10-1 vertical exaggeration)

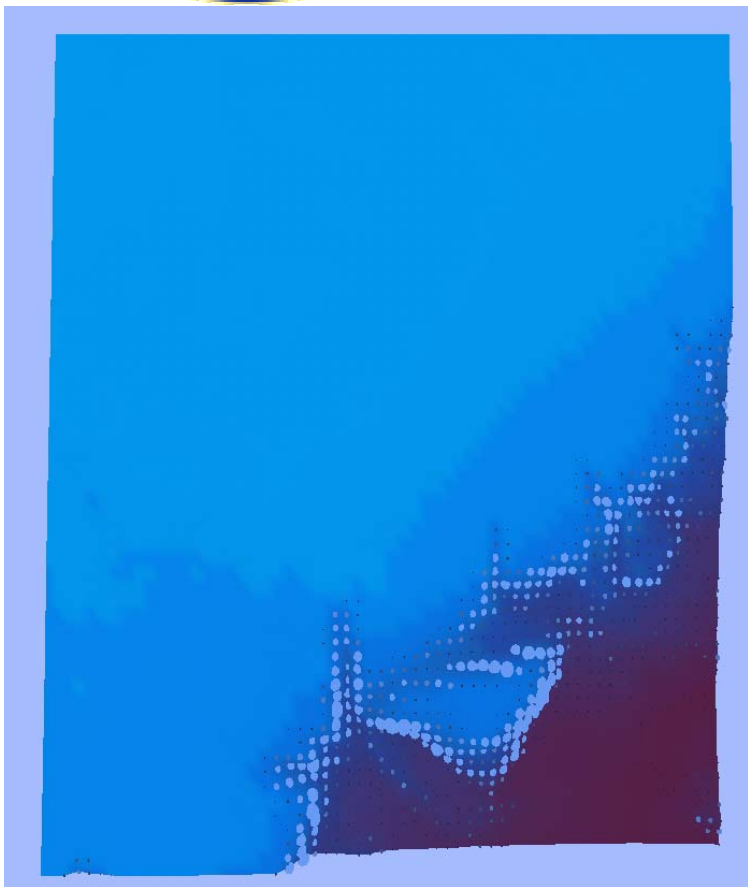
Visualization of bathymetry with color for uncertainty

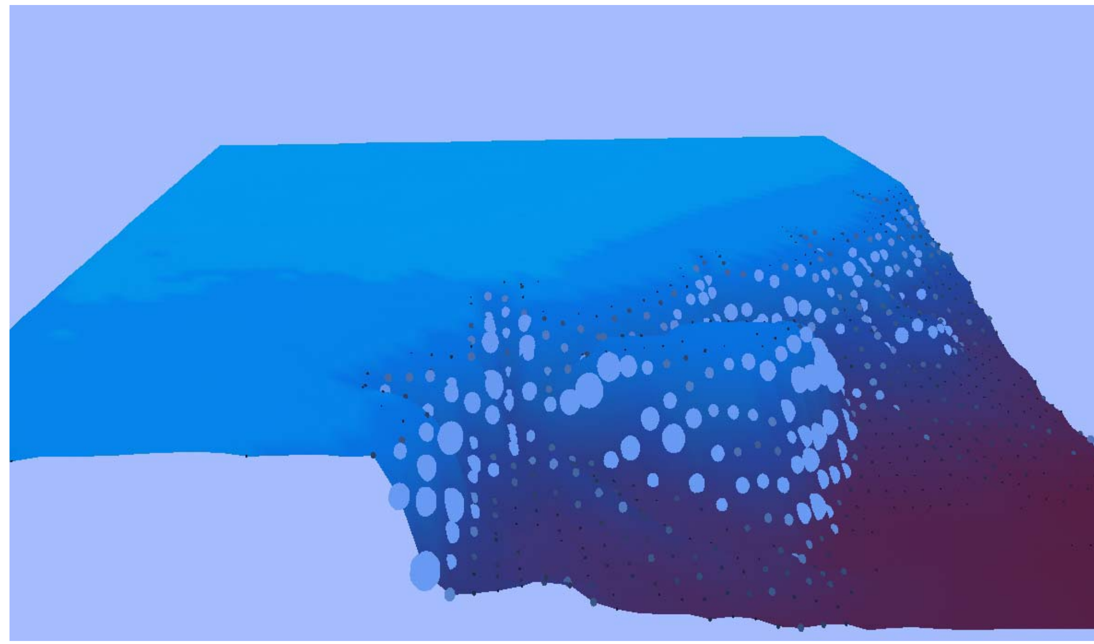


Error estimated from 2 nautical miles database versus high resolution data

ECS bathy + unc. Using spherical glyphs

⬢ = approximately 60 meters

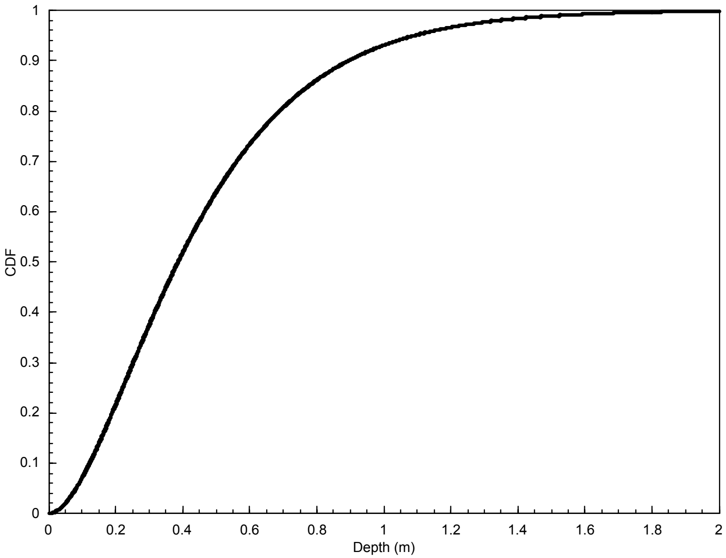


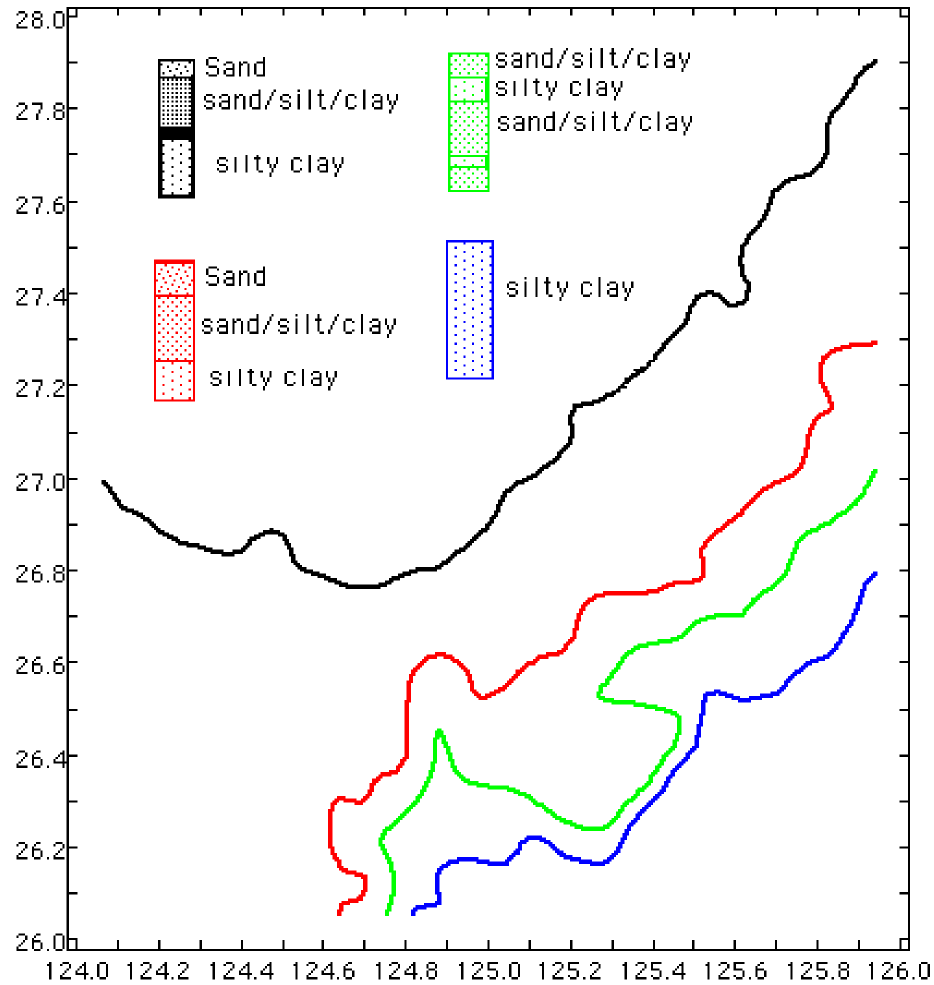


ECS bathymetry using spherical glyph method. Same data, different views. More uncertainty maps to larger spheres. This methods is based on Pang/Lodha/Wittenbrink’s work…

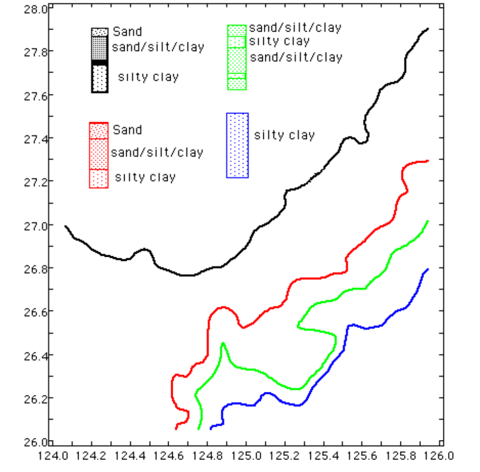
ESC bottom composition

CPDF of sand layer thickness in ECS in water depths greater than 90m and less than 120 m



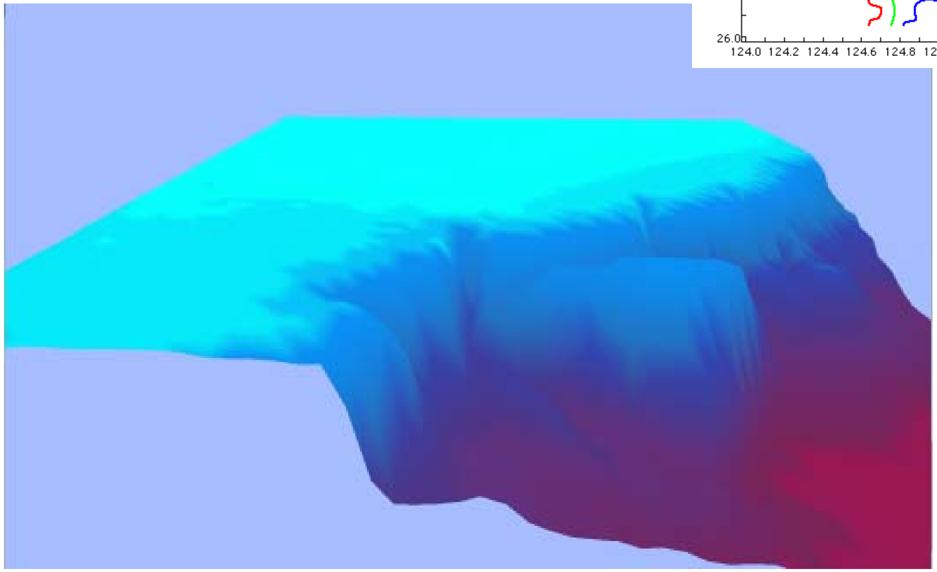


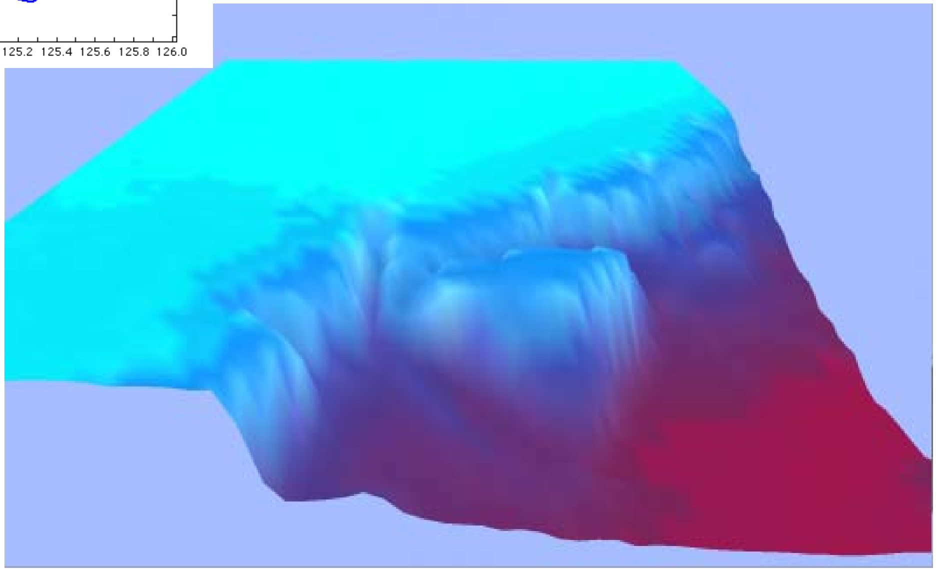
Bottom type visualization



Bottom type identified as color shades

Bottom type identified as color shades with depth uncertainty as intensity



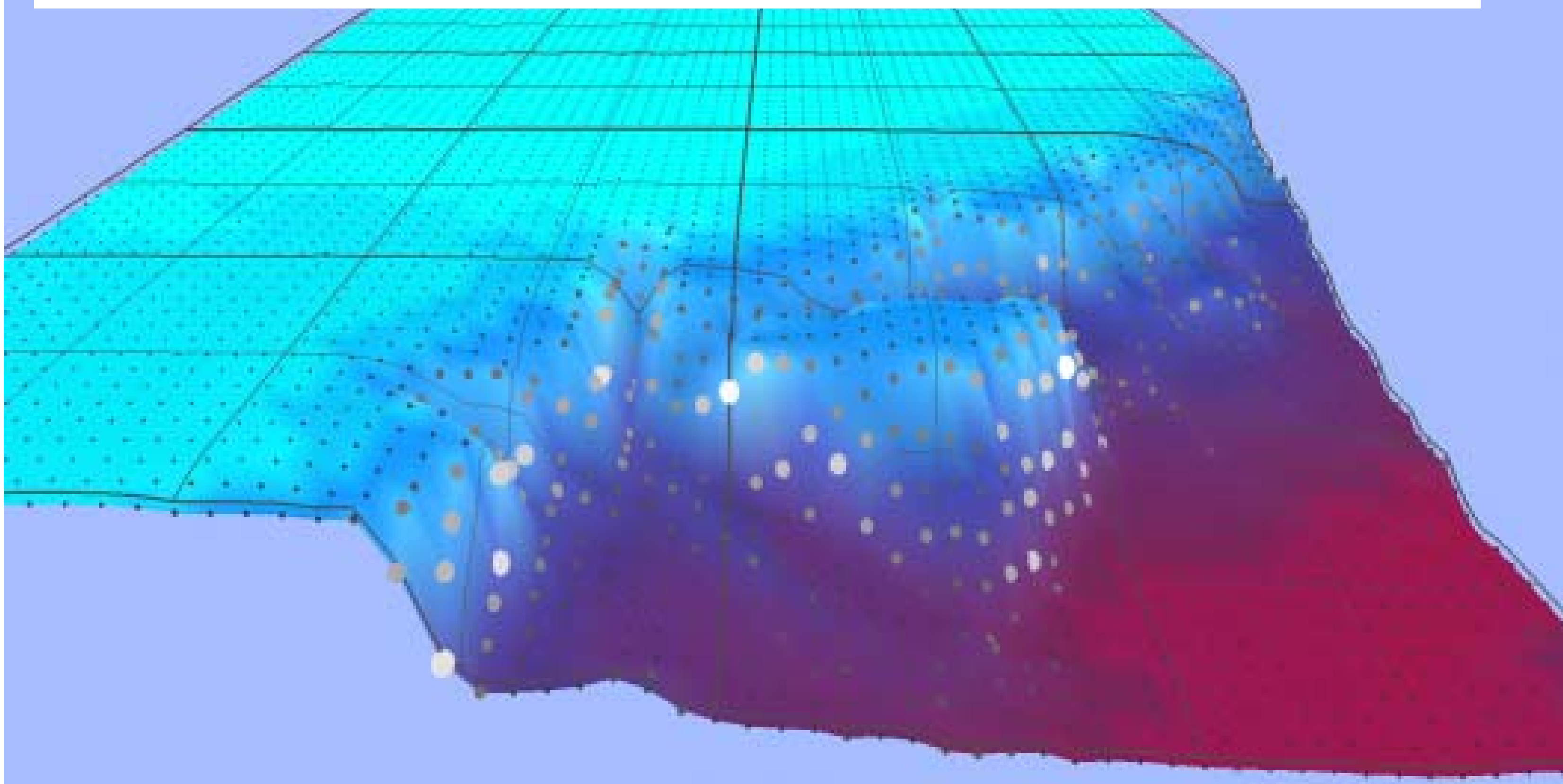


(a) Left shows geo-acoustic bottom types using color shades. (b) Right shows the same with depth uncertainty data.

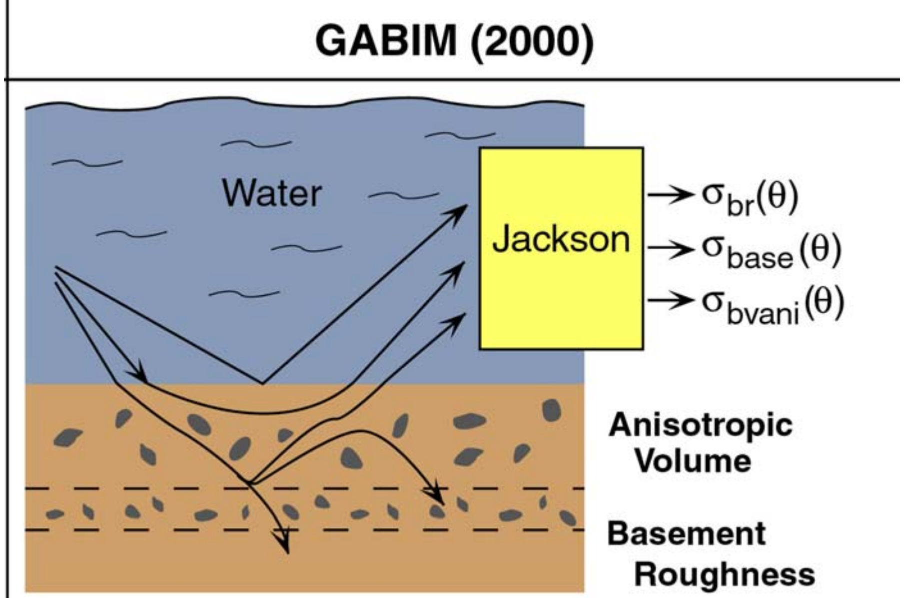
Bottom characterization

Bathymetry displayed with:

- color-shaded shallow geologic sediment characterization
- gray-shading and size of glyphs show depth uncertainty



Geophysical-Acoustic Bottom Interaction Model (GABIM)



- **SAFARI bottom propagation kernel (Schmidt, 1988)**
  - **arbitrary bottom structure**
  - **shear waves, transverse isotropy if necessary**
  - **fast, accurate numerical implementation**

Bottom Property Parameter Sensitivity

- Model-data sensitivities are required to construct an accurate picture of effect of variability on acoustic prediction uncertainty
  - Required quantities are the functional or Frechet derivatives

$$\left(\frac{\partial P}{\partial \kappa}, \frac{\partial P}{\partial \rho}\right)$$

  - Other quantities of interest are obtained from the derivative chain rule
- Linearize about a global model minimum
- The Frechet derivatives (using GABIM) are the sensitivity functions for the model and acoustic data.
  - Large derivatives $\Rightarrow$ acoustic data are sensitive to the model
  - Small derivatives $\Rightarrow$ acoustic data insensitive to the model

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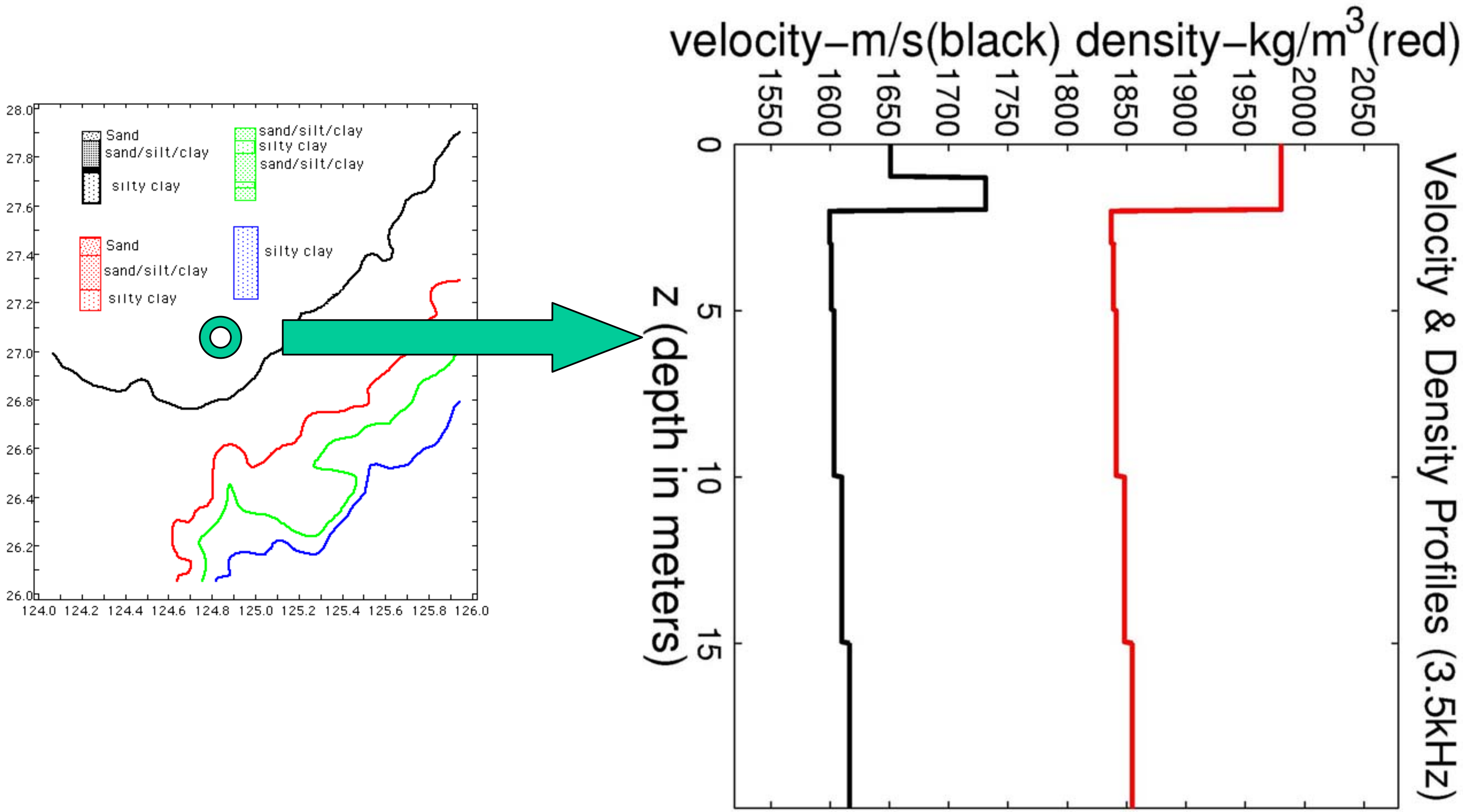
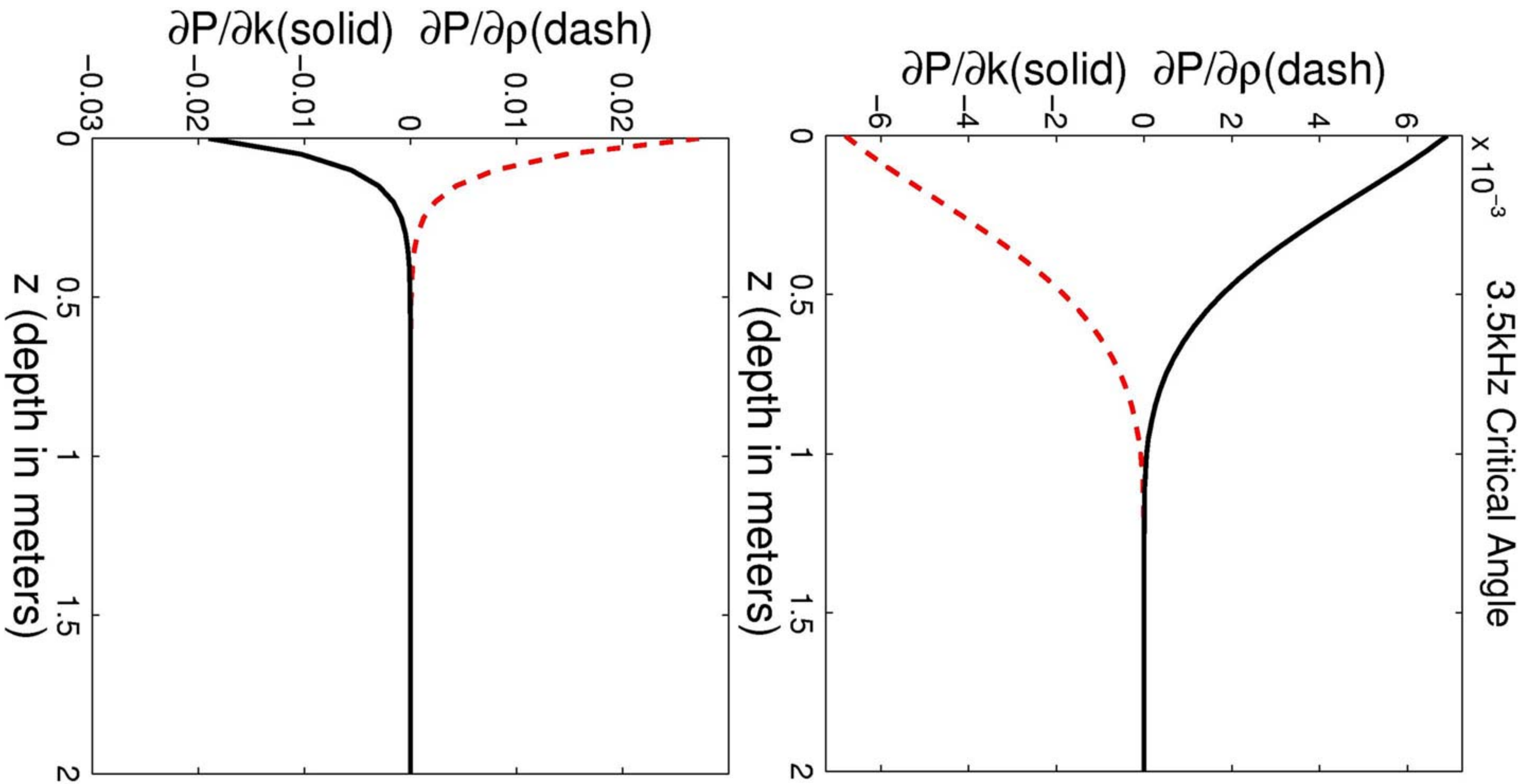
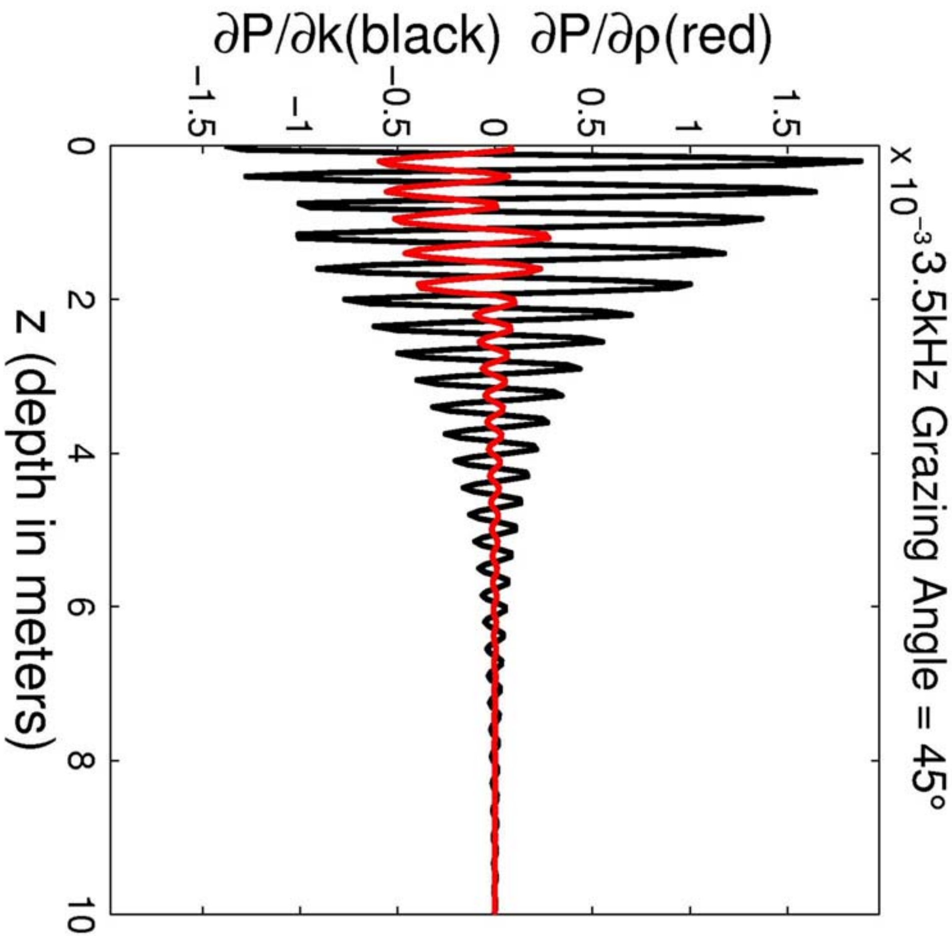
East China Sea
Velocity and Density Profiles



Frechet Derivative



Frechet Derivative 45°



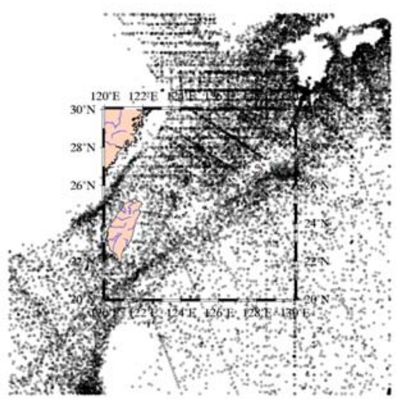
- At a grazing angle of 45 bulk modulus perturbations have a greater effect on the measured pressure than density, which will be poorly resolved below 2m.
- Effects of density are out of phase with the effects of bulk modulus.

Bottom characterization using inversion

- Several SUS data sets in the ESC area of interest
- Bottom loss and scatter vs frequency and grazing have been found via inversion
  - Also used to estimate surface sediment roughness spectrum and sediment volume scatter
- Comparisons to TL have been made and show improvements over using historical bottom loss
- Tactical sonar reverberation and TL data are available for inversion.

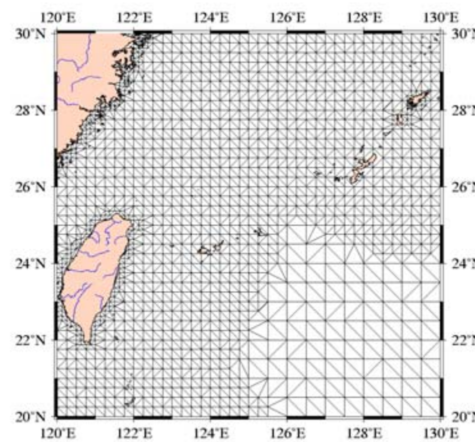
Modular Oceanographic Data Assimilation System (MODAS)

MOODS Profiles



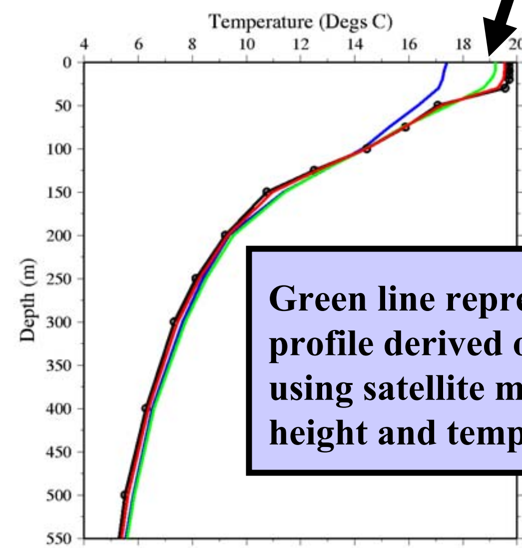
Decades of edited MOODS profiles are used to derive statistical relationships between surface height and temperature and subsurface temperature and salinity

MODAS Climatology



Relationships are stored on an irregular mesh, varying from 1 to 1/8 degree in resolution to permit high resolution analyses in shallow water regions

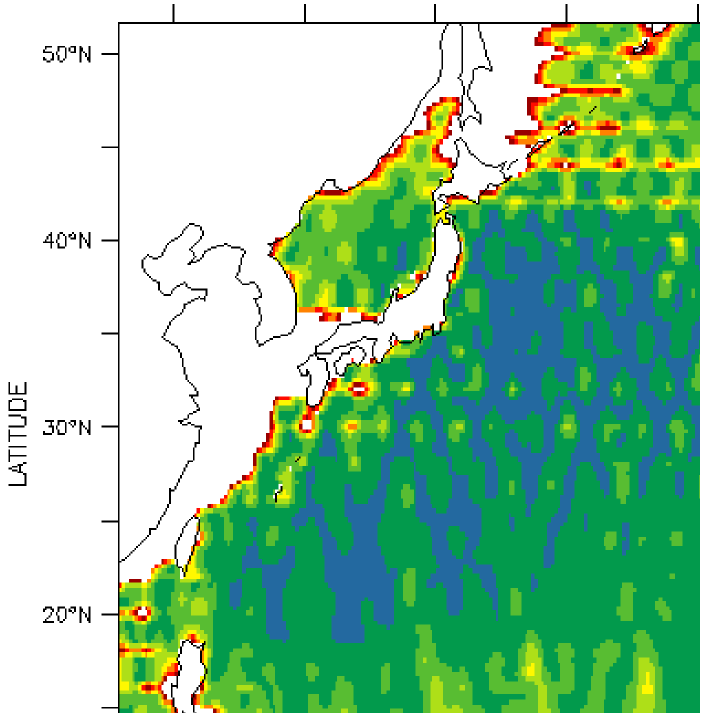
Satellite Measured SSH and SST

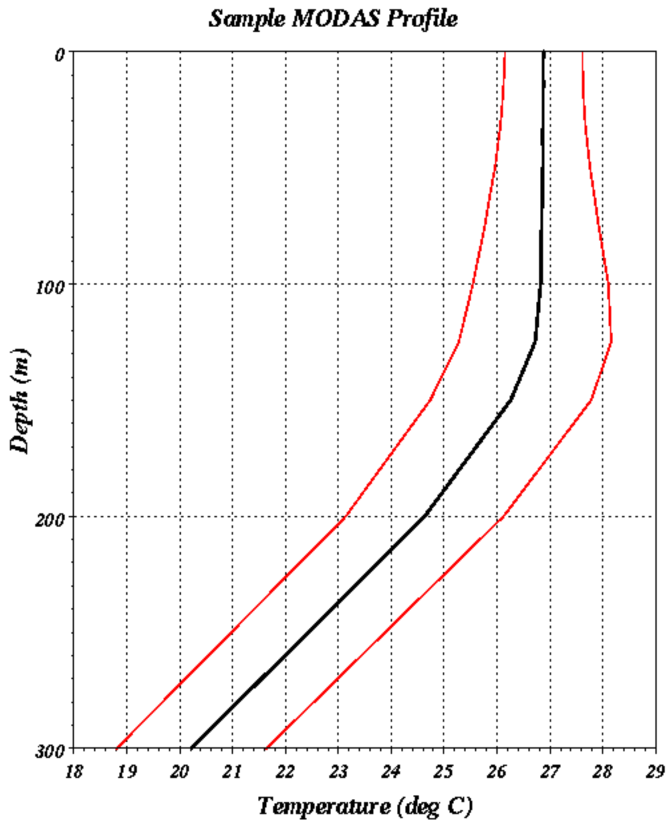


Green line represents profile derived only using satellite measured height and temperature

- **Climatology**
- **MODAS Synthetic**
- **Final Analysis**
- **In Situ BT**

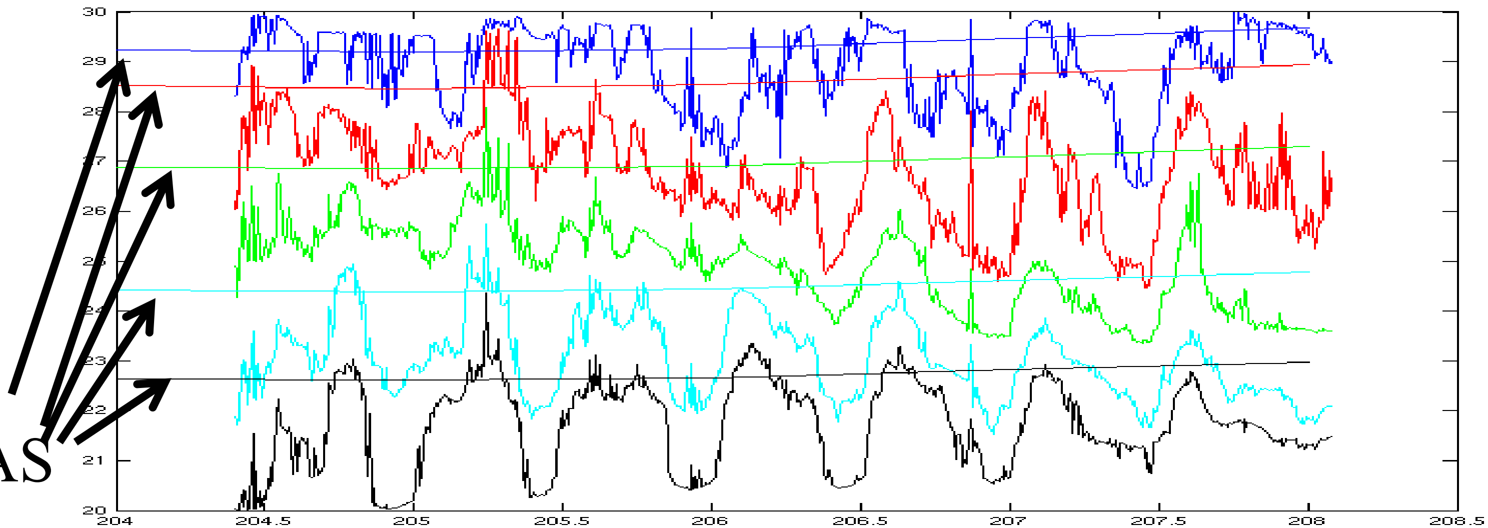
MODAS Uncertainty





Thermistor chain versus Synthetic (MODAS)

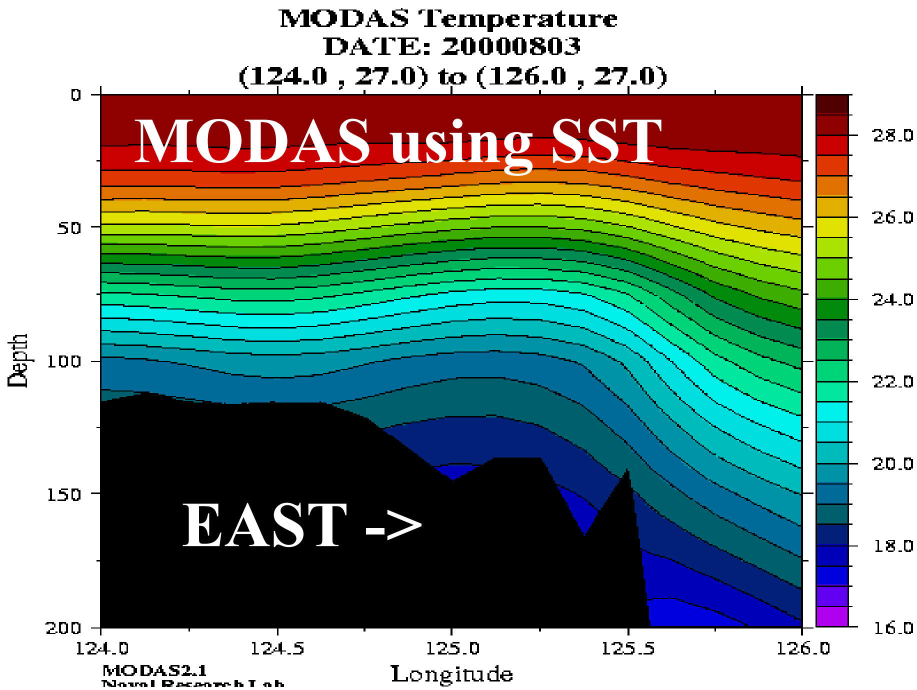
Goal: begin to evaluate uncertainty of MODAS

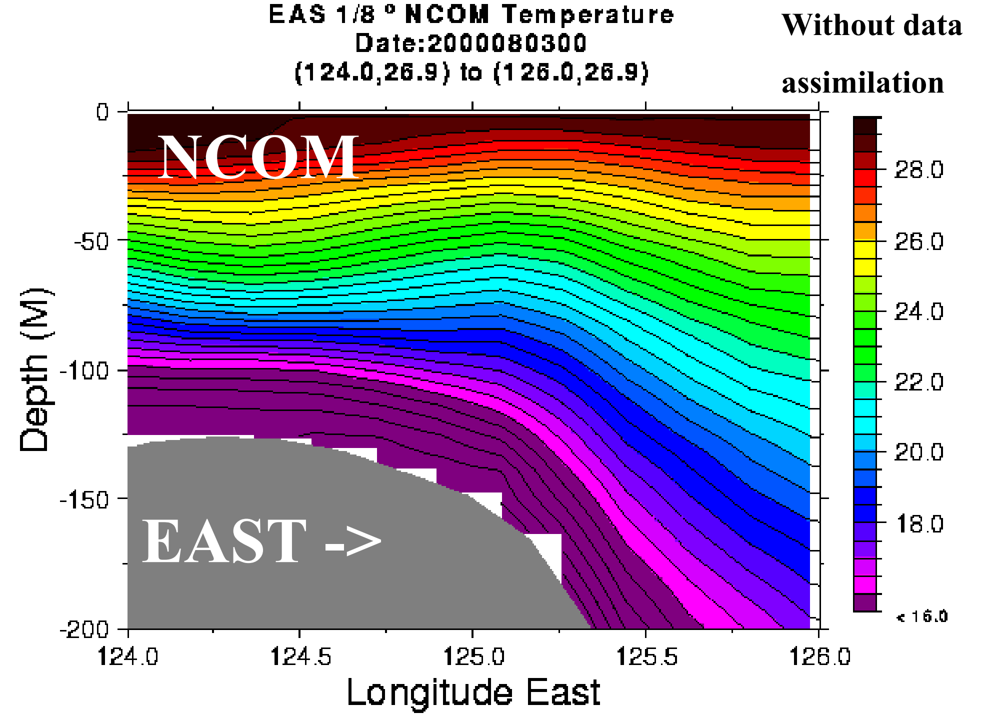


This is a poor comparison because the thermister chain was swinging in the current - we'll correct for the depth excursions and re-compare. Also evaluate for internal wave spectrum (if possible).

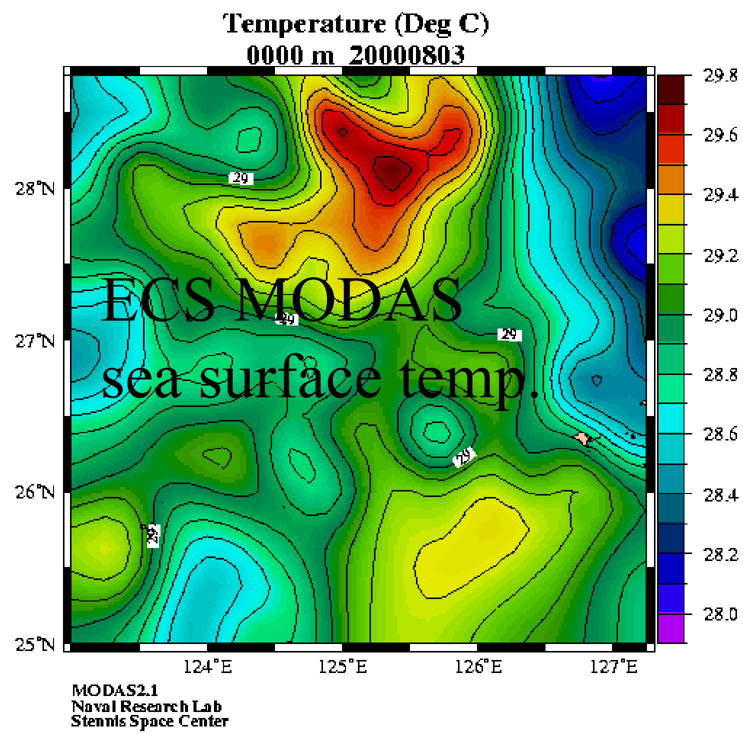
East Asian Seas Nowcast/Forecast System

- An automated real-time ocean prediction system
  - from 17°S to 53°N and from 99°E to 170°E
  - 1/8° horizontal resolution, 26 vertical levels
- Produces daily nowcast/forecast up to 72 hrs of
  - sea level variation
  - currents
  - temperature
  - salinity
- Restarted everyday from previous nowcast fields
  - continuously assimilates MODAS synthetic temp/salinity fields based on
    - sea surface height anomaly from satelite (GFO, TOPEX/Poseidon, ERS-2)
    - (AVHRR) sea surface temperature
- Forced by NOGAPS
  - wind stress
  - surface heat fluxes
  - surface air pressure

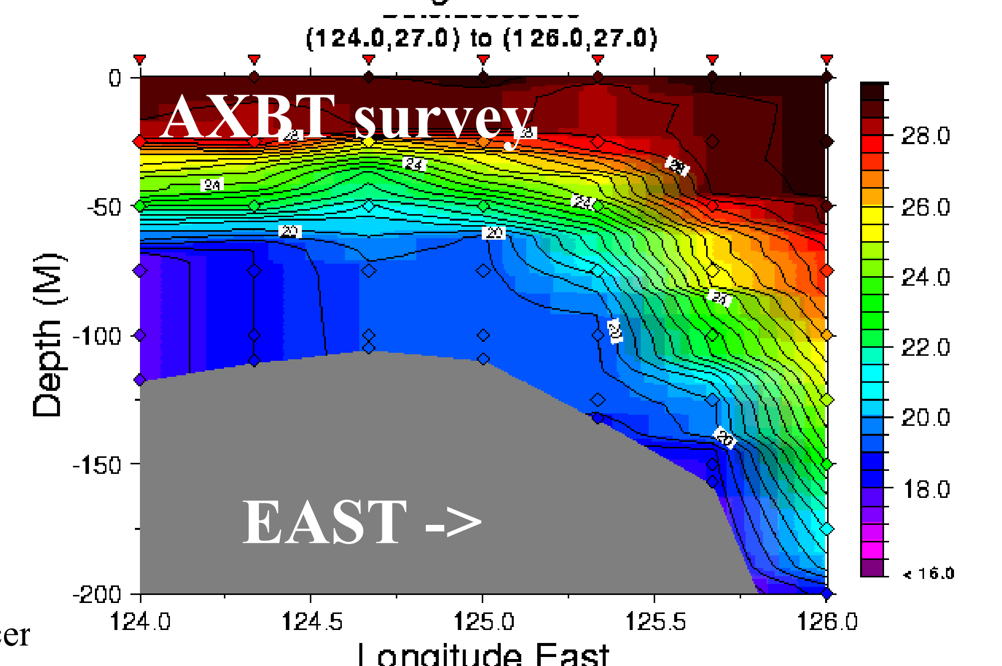


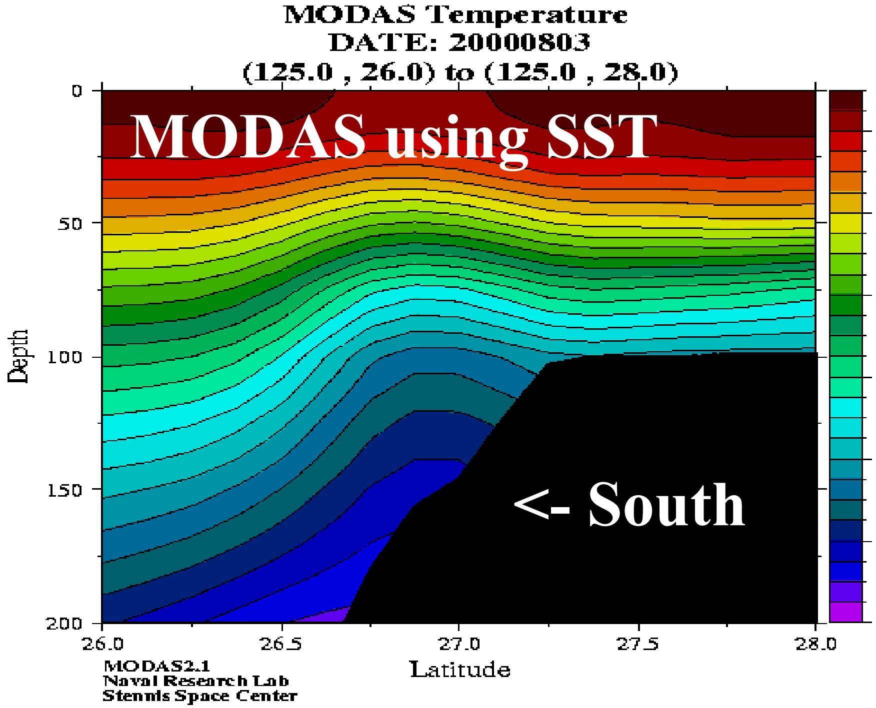


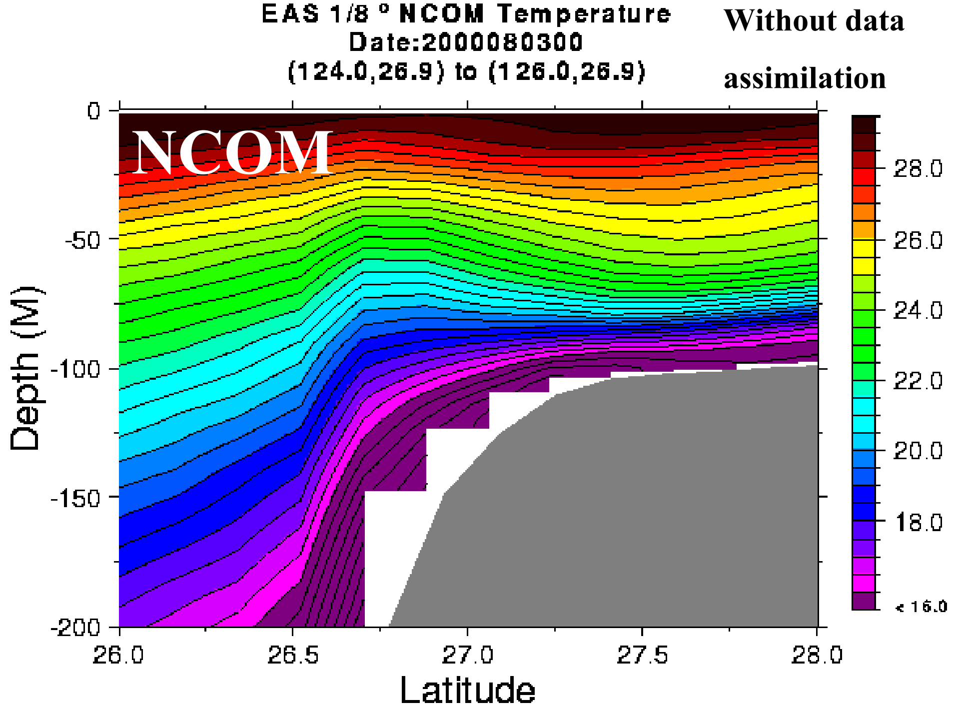
Without data assimilation

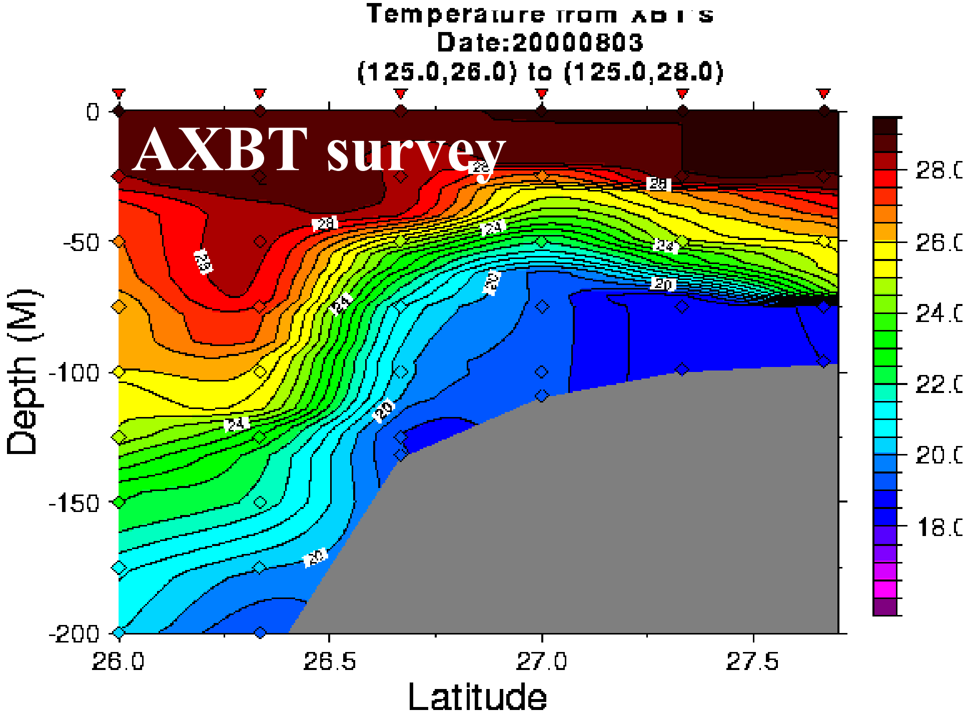


Uncer

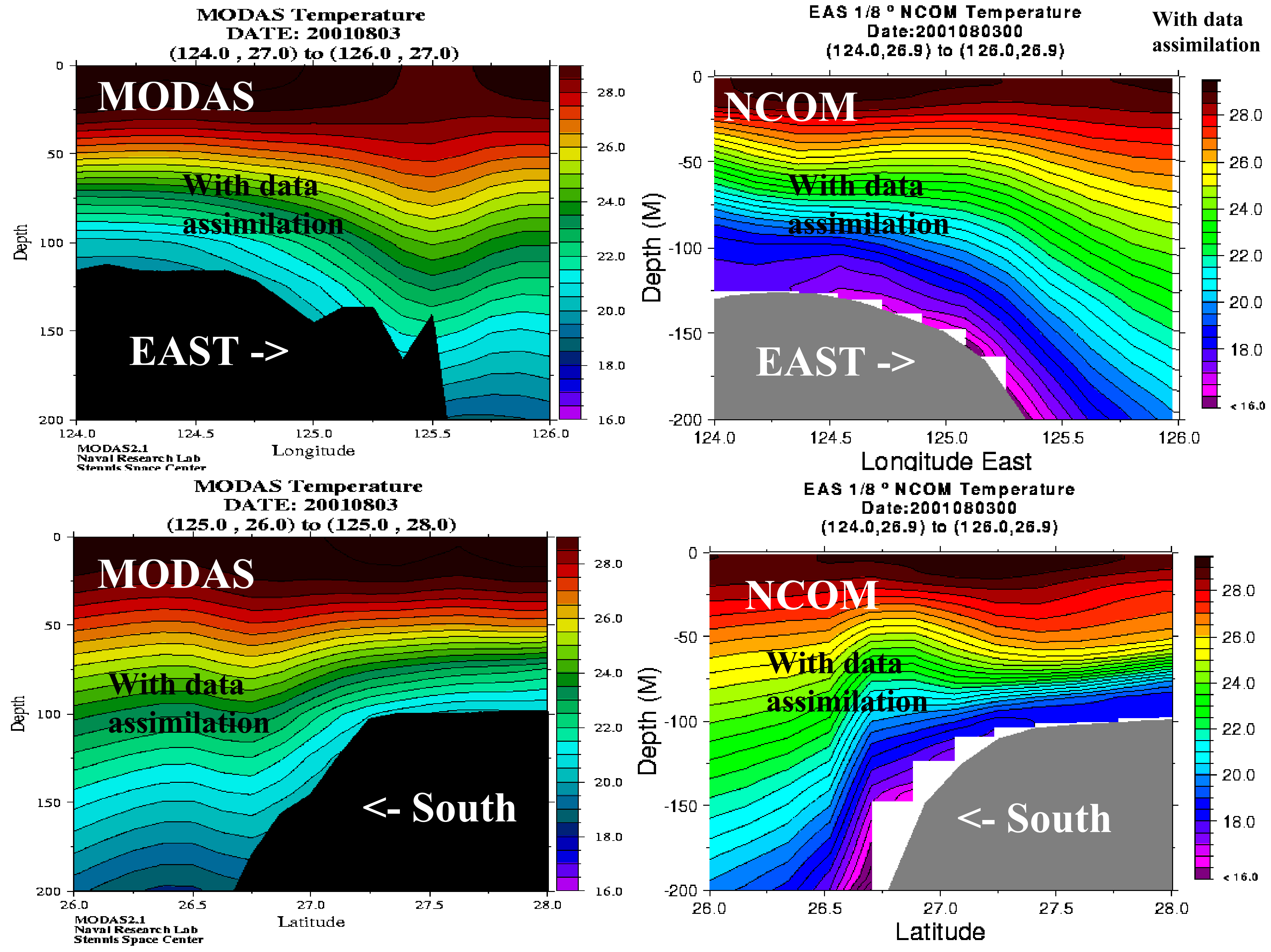



MODAS Temperature
DATE: 20000803
(125.0 , 26.0) to (125.0 , 28.0)
MODAS using SST
<- South
Depth
Latitude
MODAS2.1
Naval Research Lab
Stennis Space Center


EAS 1/8 ° NCOM Temperature
Date:2000080300
(124.0,26.9) to (126.0,26.9)
Without data assimilation
NCOM
Depth (M)
Latitude

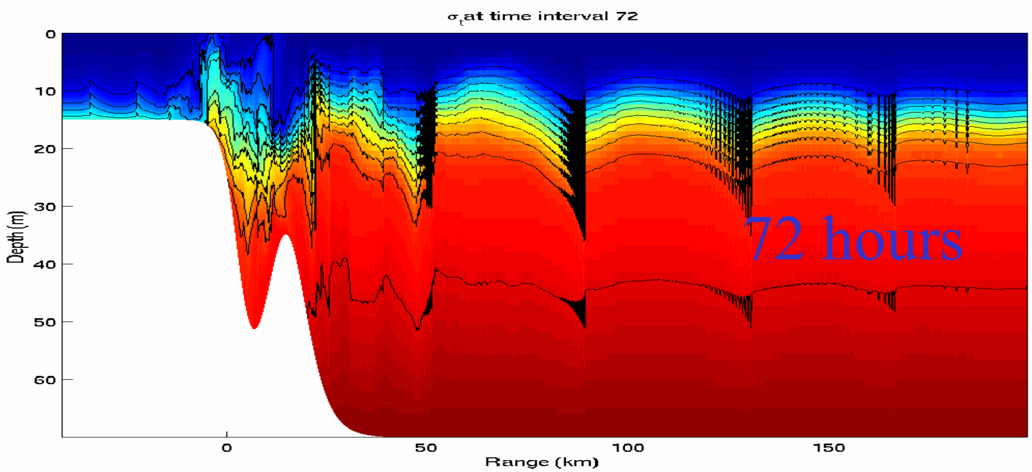

Date:20000803
(125.0,26.0) to (125.0,28.0)
AXBT survey
Depth (M)
Latitude

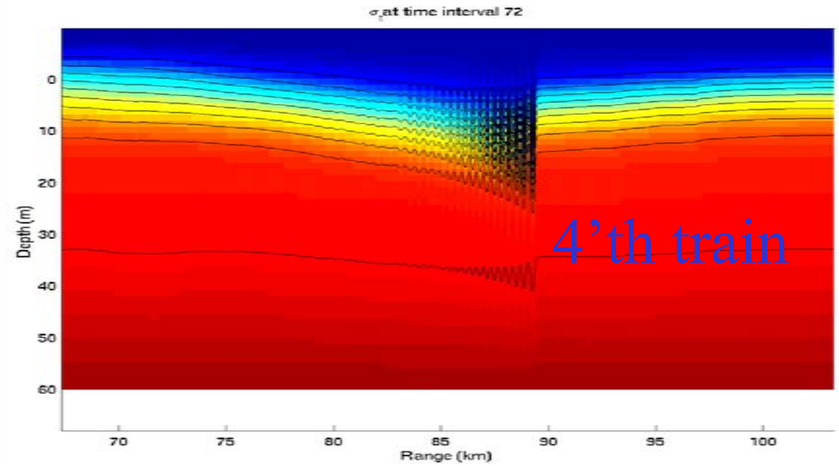
6/20/02

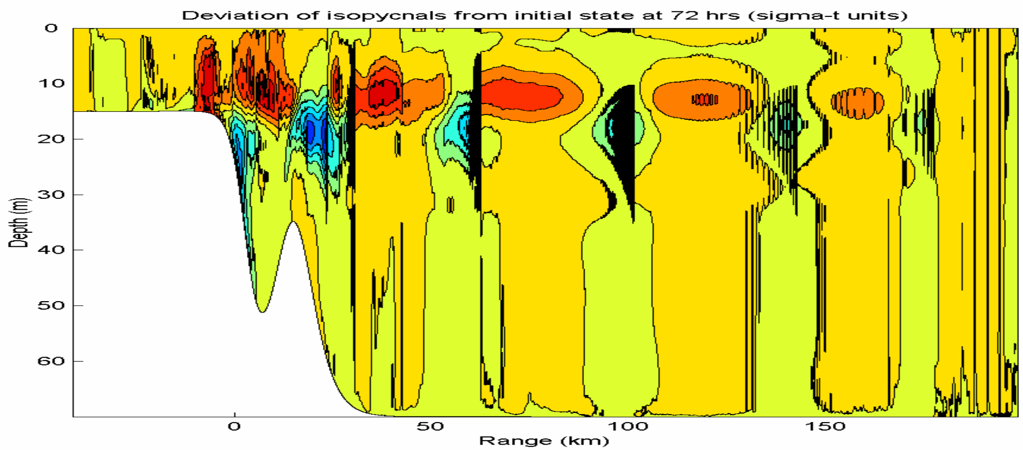


MODAS Temperature
DATE: 20010803
(124.0 , 27.0) to (126.0 , 27.0)
MODAS
With data assimilation
EAST ->
Depth
0
50
100
150
200
124.0
124.5
125.0
125.5
126.0
Longitude
28.0
26.0
24.0
22.0
20.0
18.0
16.0
MODAS2.1
Naval Research Lab
Stennis Space Center
EAS 1/8 ° NCOM Temperature
Date:2001080300
(124.0,26.9) to (126.0,26.9)
With data assimilation
NCOM
With data assimilation
EAST ->
Depth (M)
0
-50
-100
-150
-200
124.0
124.5
125.0
125.5
126.0
Longitude East
28.0
26.0
24.0
22.0
20.0
18.0
< 16.0
MODAS Temperature
DATE: 20010803
(125.0 , 26.0) to (125.0 , 28.0)
MODAS
With data assimilation
<- South
Depth
0
50
100
150
200
26.0
26.5
27.0
27.5
28.0
Latitude
28.0
26.0
24.0
22.0
20.0
18.0
16.0
MODAS2.1
Naval Research Lab
Stennis Space Center
EAS 1/8 ° NCOM Temperature
Date:2001080300
(124.0,26.9) to (126.0,26.9)
NCOM
With data assimilation
<- South
Depth (M)
0
-50
-100
-150
-200
26.0
26.5
27.0
27.5
28.0
Latitude
28.0
26.0
24.0
22.0
20.0
18.0
< 16.0

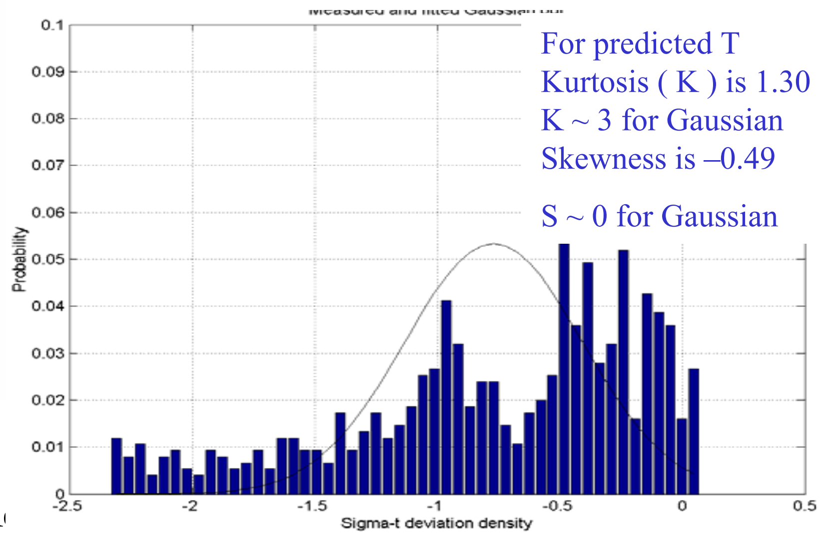
Propagation of Internal Solitary Wave In Yellow Sea







Predicted (T) and fitted Gaussian (G) Pdf's for 4'th train at 100 km



For predicted T
Kurtosis (K) is 1.30
K ~ 3 for Gaussian
Skewness is –0.49

S ~ 0 for Gaussian

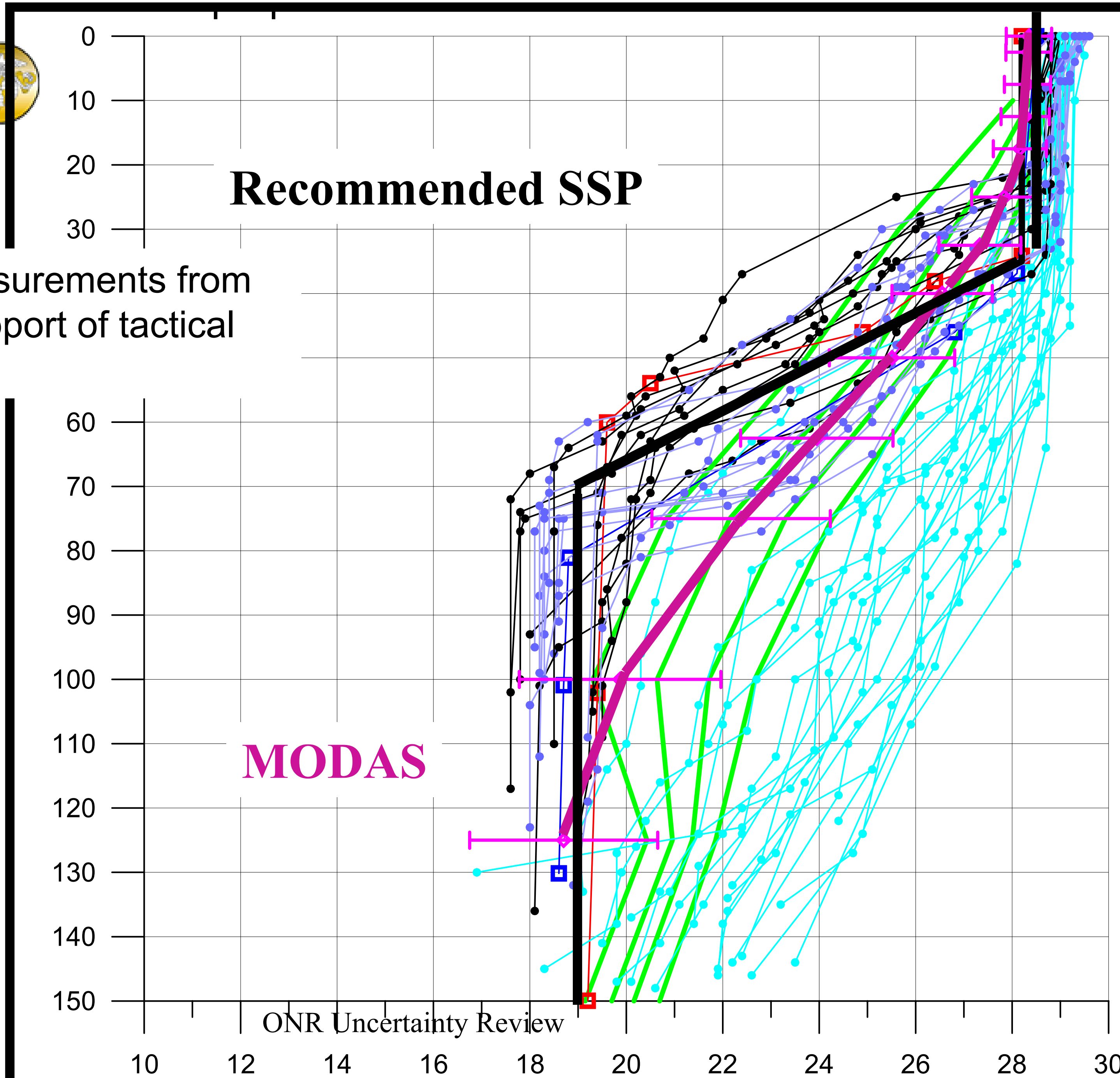
Sound speed mimics σ_t and is significantly affected by solitary waves packets.

Dynamic Oceanography Plans

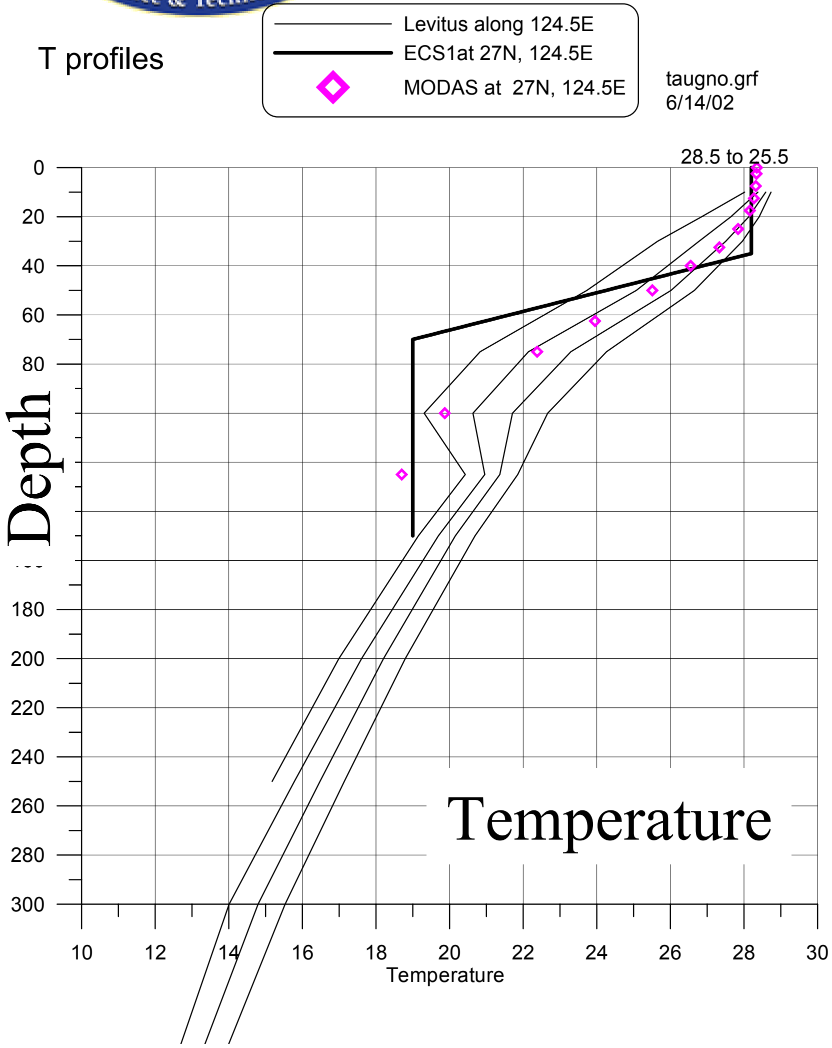
- Hydrostatic (NCOM) Model
  - Enhance 1/8° EASNFS to 1/16°
  - Add high resolution bathymetry (DBDB2)
  - Nest high resolution models inside EASNFS around SHAREM area at 1/24°, 1/72°, 1/216°, and possibly higher.
- Nonhydrostatic models
  - Uses simplified coastlines and bathymetries (at present)
    - AsiaEx
    - SHAREM
  - Extend to three dimensions
  - Extend to realistic bathymetry

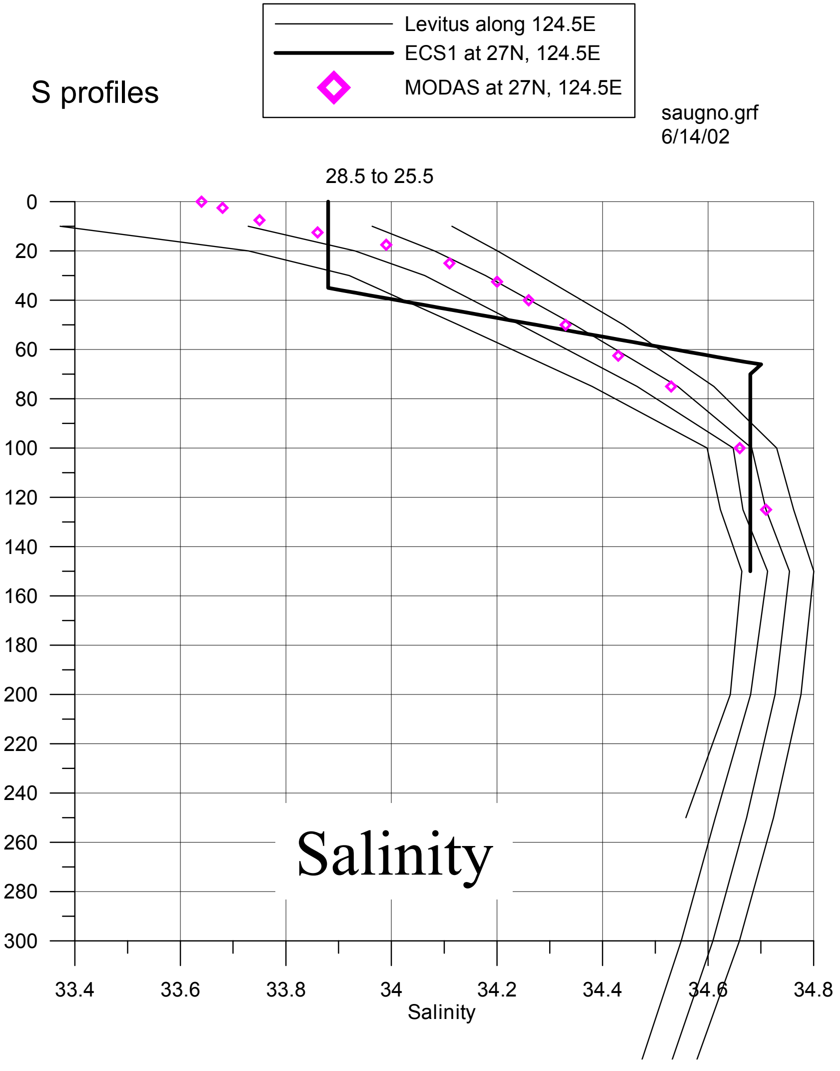
Uncertainty in sound speed

- Deviations about the mean profile need higher order statistics - vertical correlations.
- Not knowing where the bottom of the mixed layer is (given lack of measurements) impacts planning.
- Impact of having some measurements, but accounting for the effect of internal waves in execution.



ECS August measurements from AXBT flight in support of tactical exercise


T profiles
Levitus along 124.5E
ECS1at 27N, 124.5E
MODAS at 27N, 124.5E
taugno.grf
6/14/02
28.5 to 25.5
Depth
Temperature
Temperature

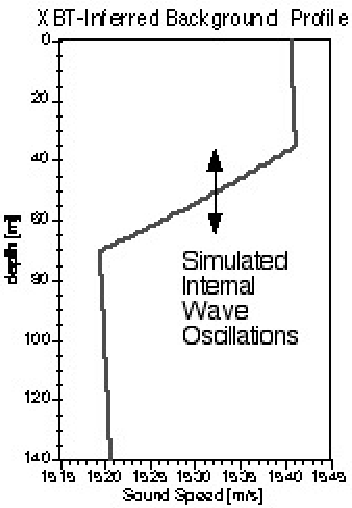

S profiles
Levitus along 124.5E
ECS1 at 27N, 124.5E
MODAS at 27N, 124.5E
saugno.grf
6/14/02
28.5 to 25.5
Salinity
Salinity

Adding internal waves into sound speed field

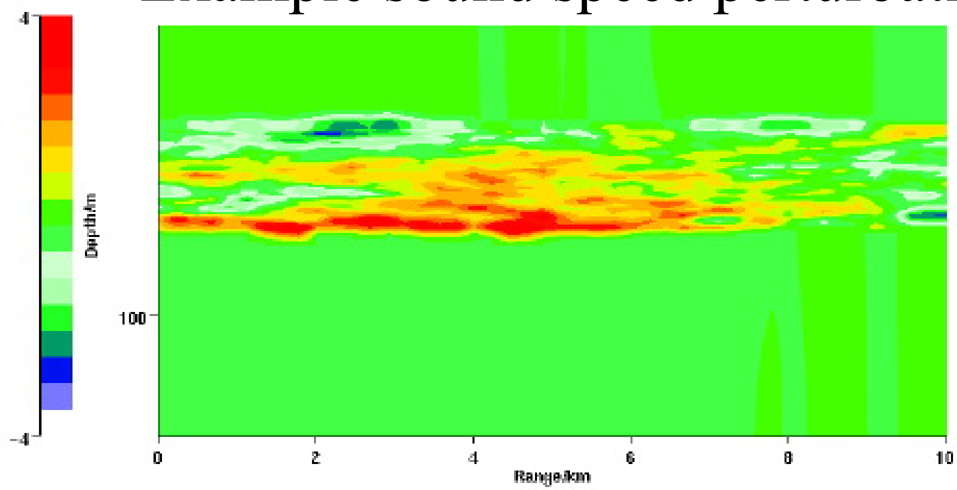
- Goal: determine how internal wave uncertainty correlates to environmental acoustic uncertainty
- Estimate average ***N*** (vertical density gradient) and its uncertainty from the MODAS and/or dynamic model T and S fields.
  - Note: depth dependence of ***N(z)*** determines the vertical structure (vertical mode shapes), and magnitude of N determines the energy level and frequency range
  - Average ***N(z)***
    - Initially assume horizontally uniform
    - Use MODAS and/or dynamic model mean T&S
  - Uncertainty in ***N(z)***
    - Estimate uncertainty in both magnitude and depth dependence
    - Use MODAS and/or dynamic model to estimate statistics of T&S and mixed layer depth
    - Estimate uncertainty by having assumed horizontal uniformity

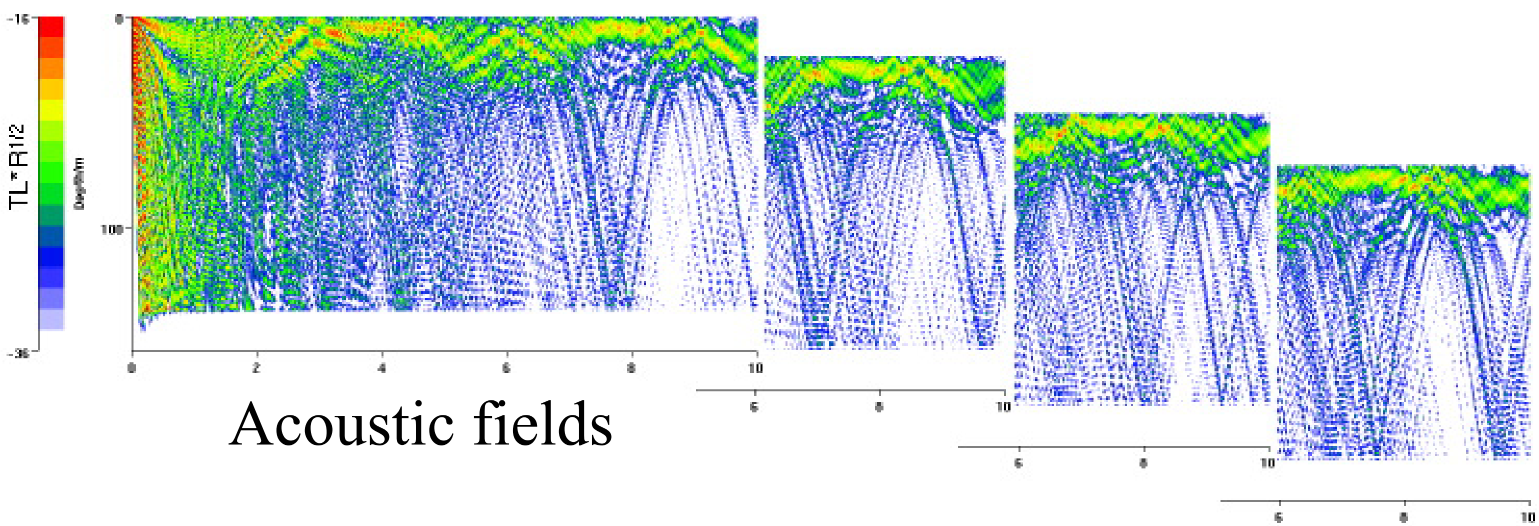
RAM Internal Wave field

East China Sea



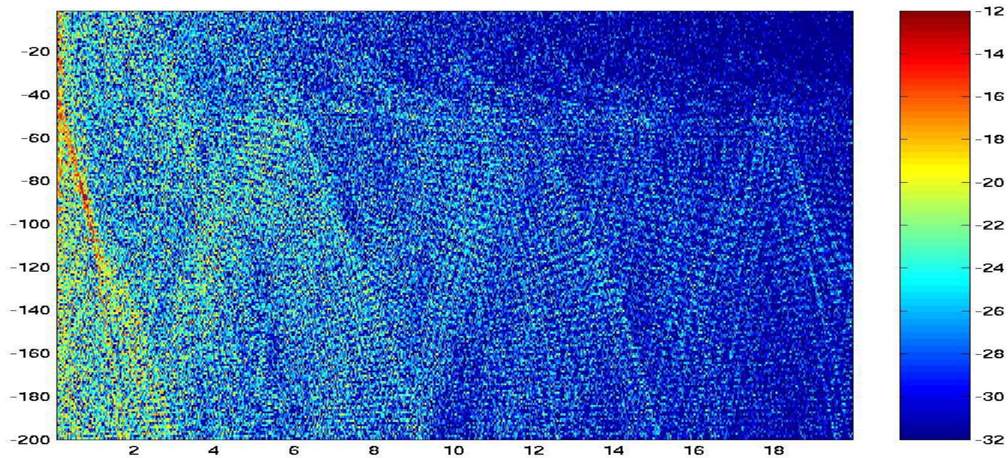
Example sound speed perturbations



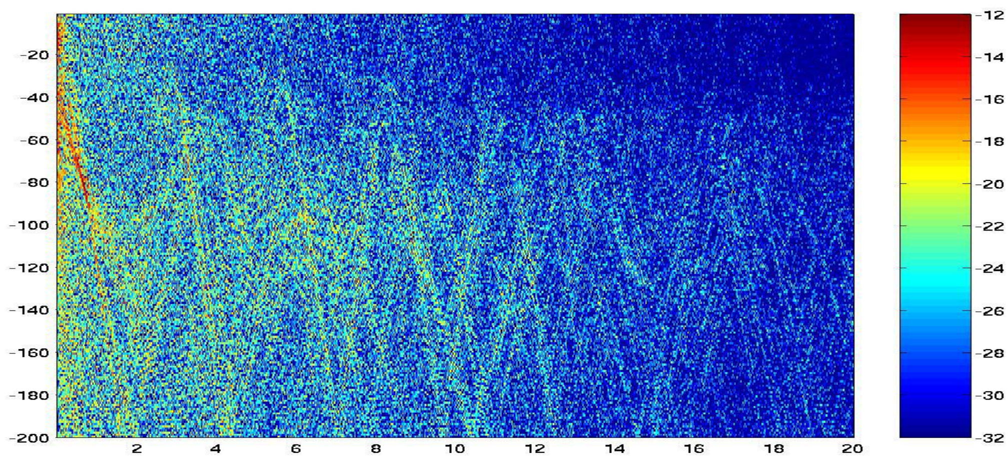


Acoustic fields

Acoustic Modeling



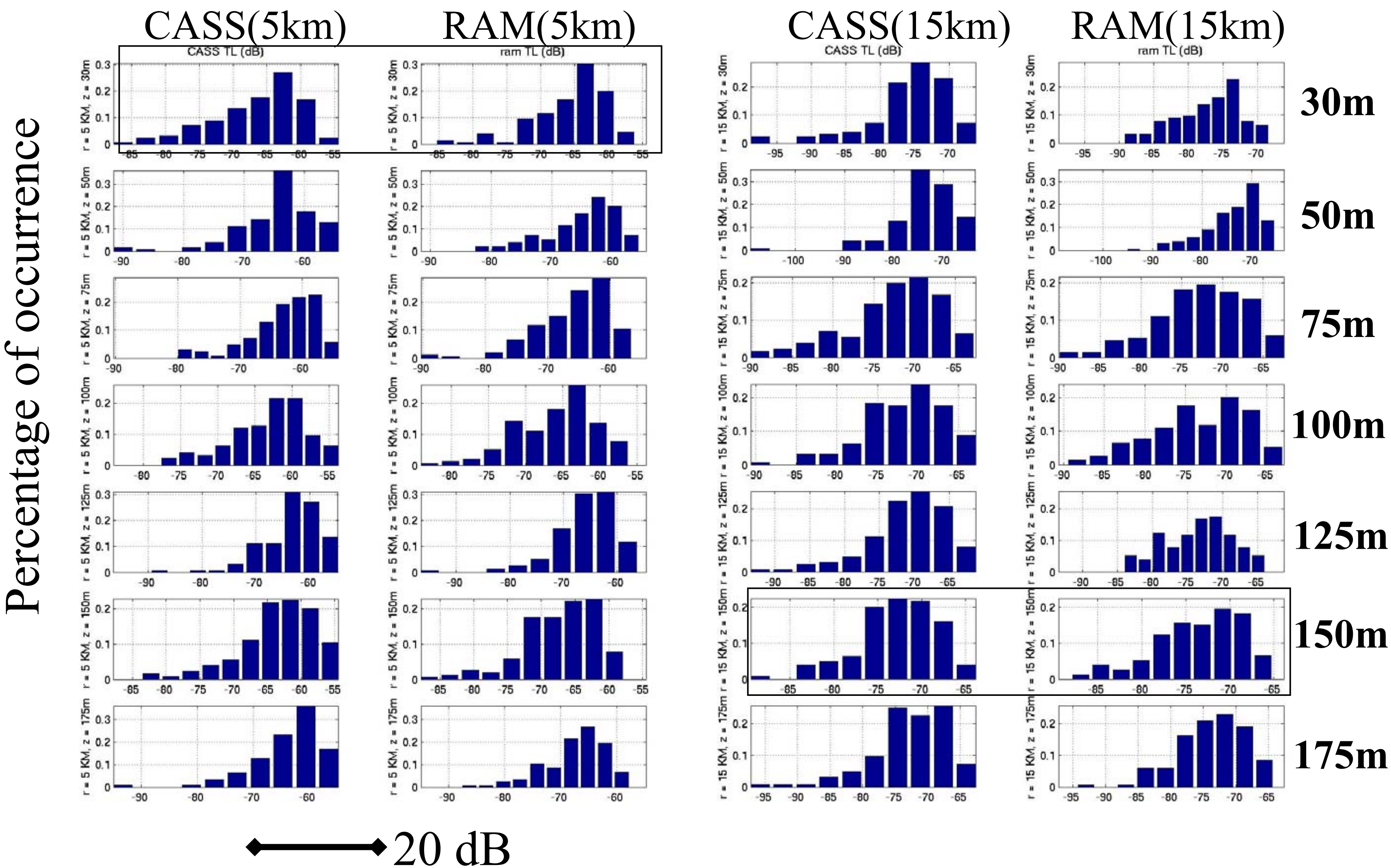
CASS without internal waves (matches to RAM)



CASS with one realization of internal waves

TL Statistics

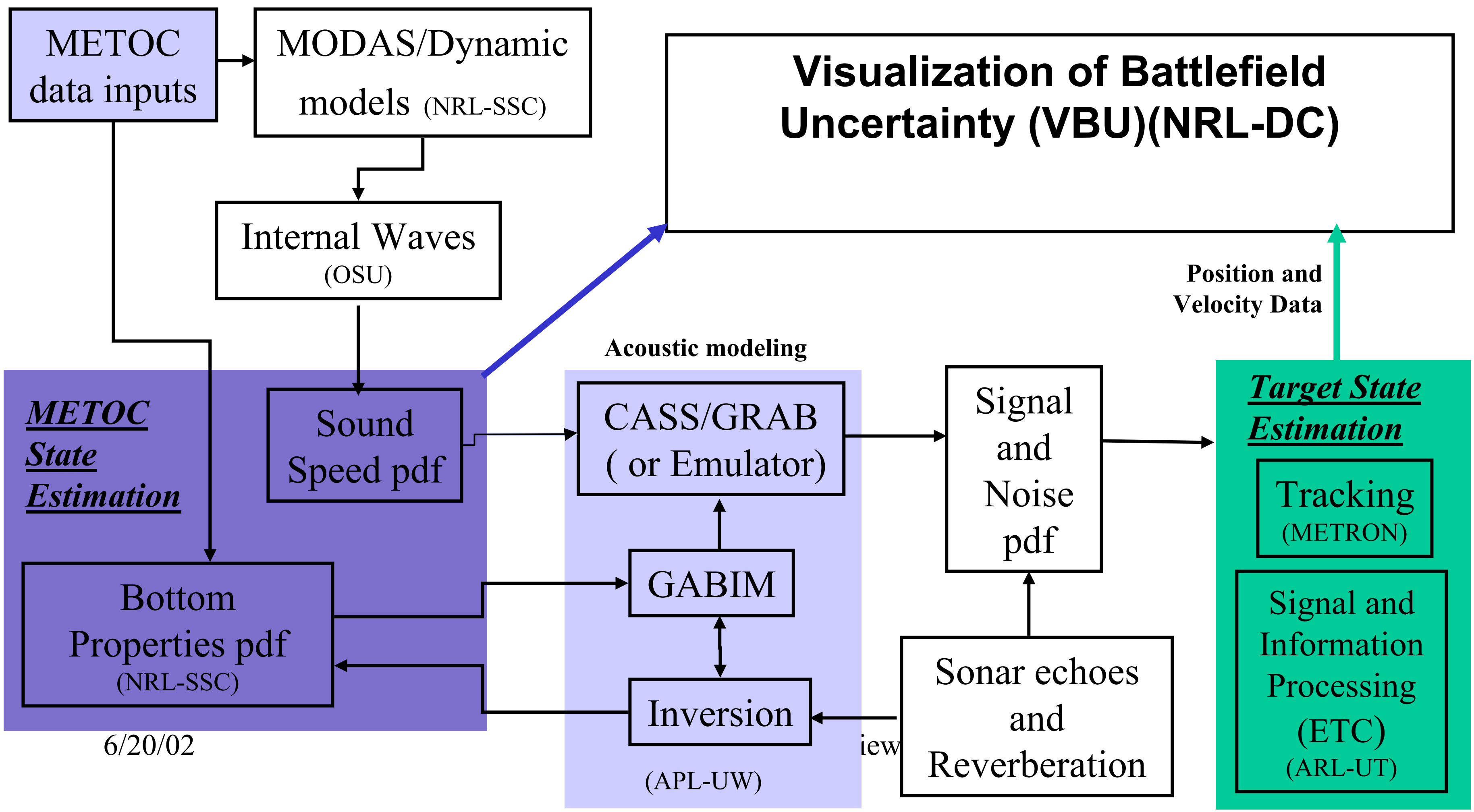
100 realizations of SSP with internal waves



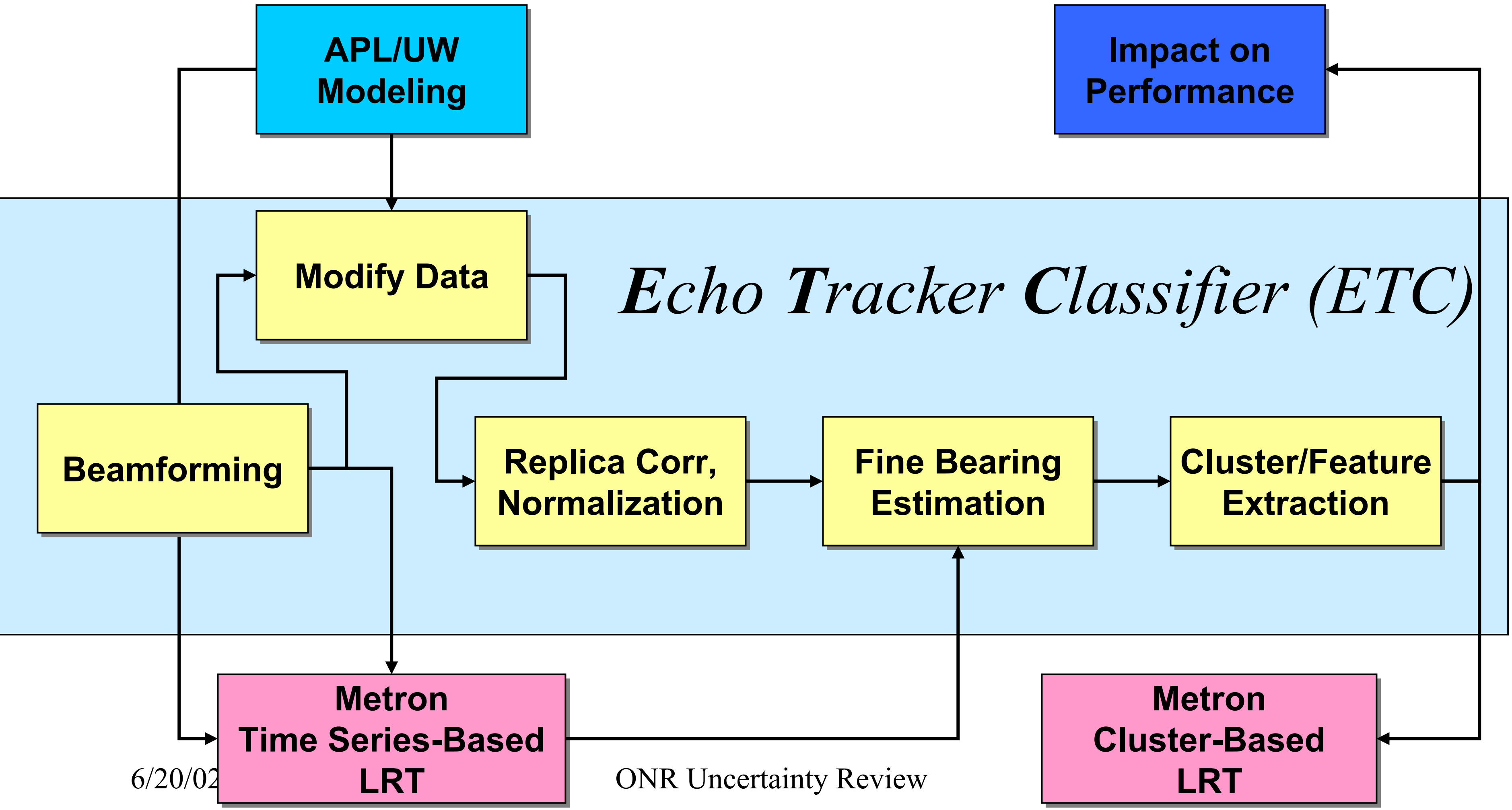
Combined IW simulation

- Next: determine how internal wave uncertainty correlates to environmental acoustic uncertainty
  - Parametric study of the impact of internal wave fluctuations on signal and information processing.
    - Use Garrett-Munk internal wave spectrum with modified parameters (i.e., energy, coherence).

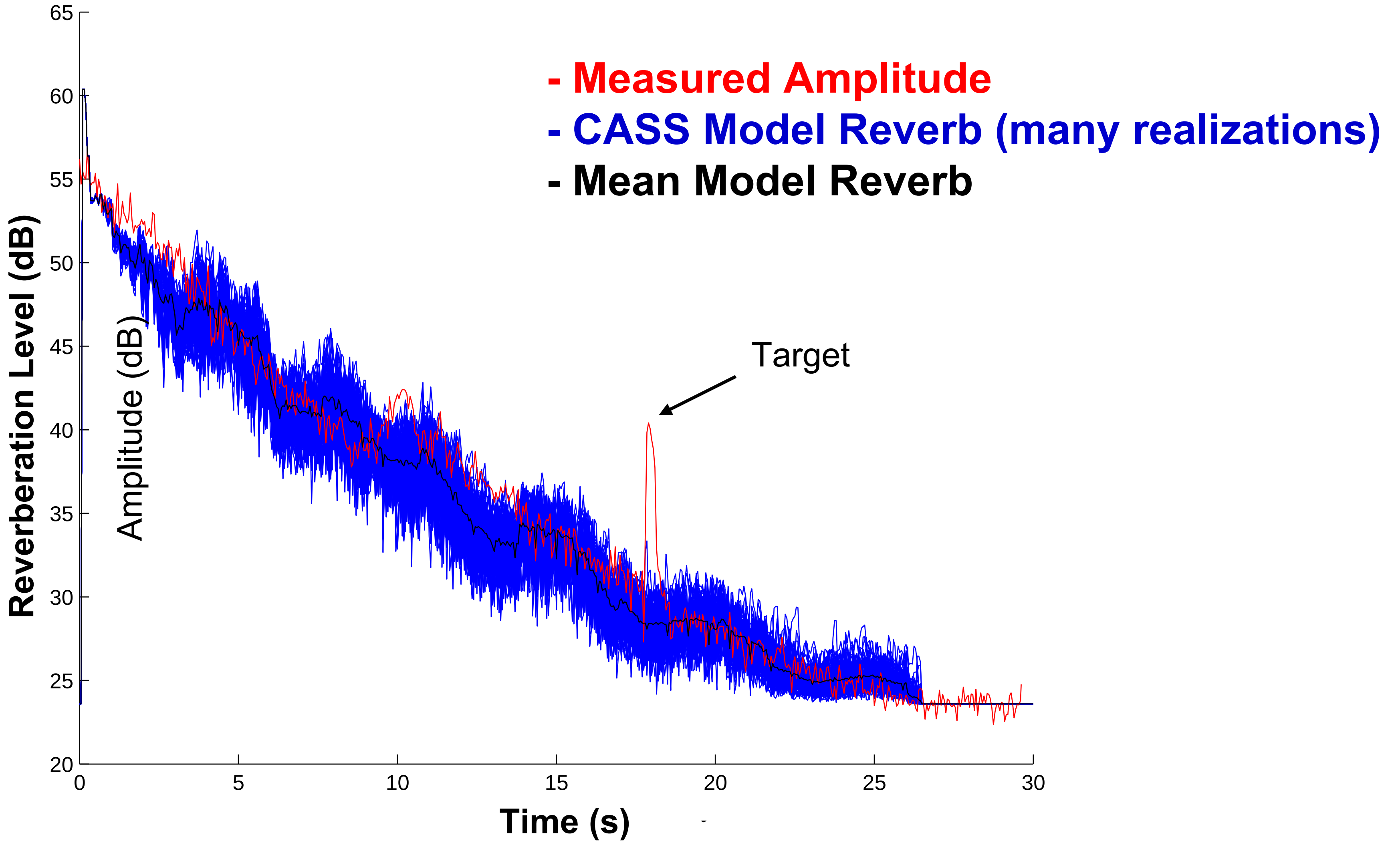
Target state estimation



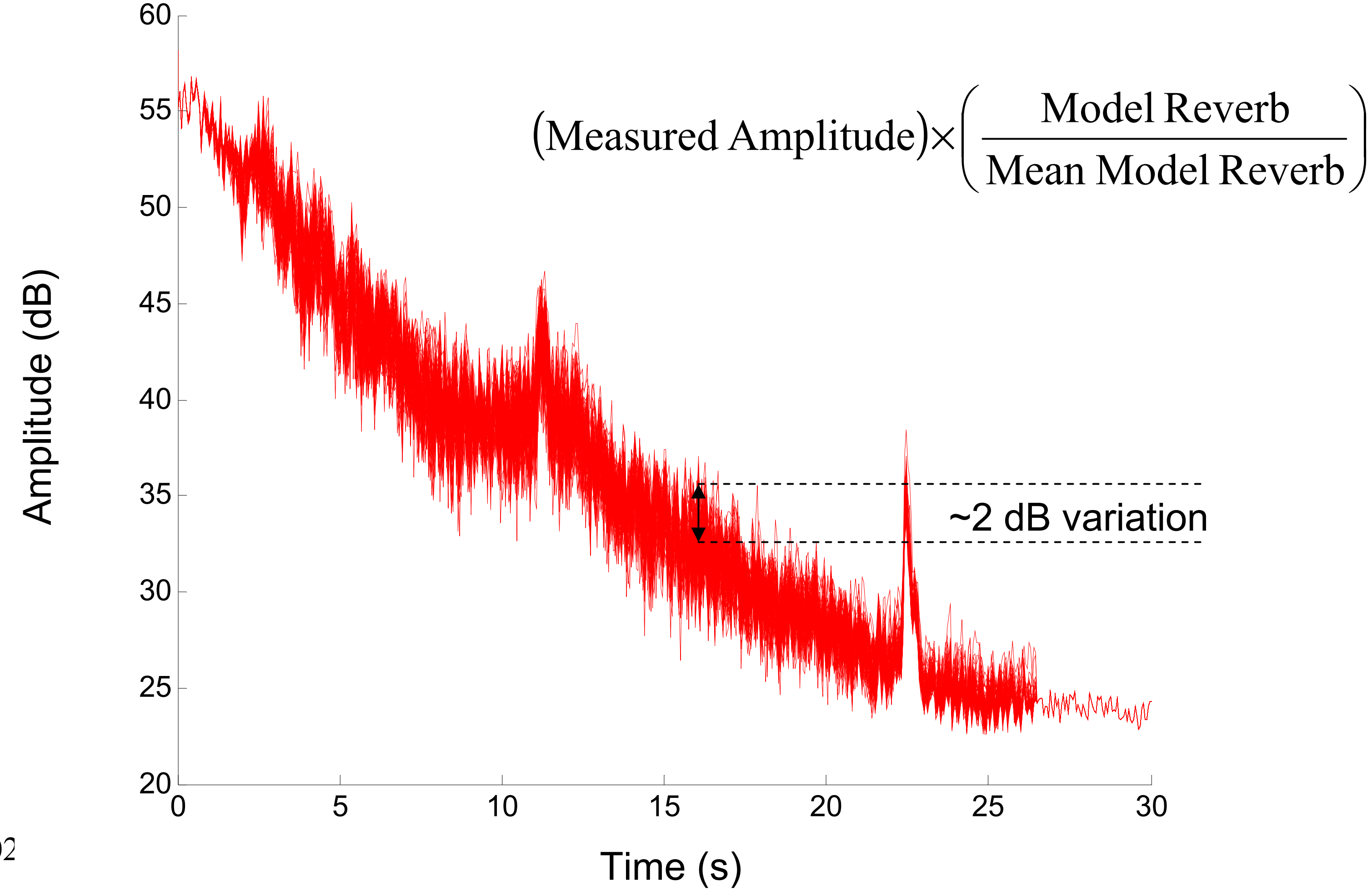
ARL:UT / Metron Flow Chart



ECS Model and Data Comparison

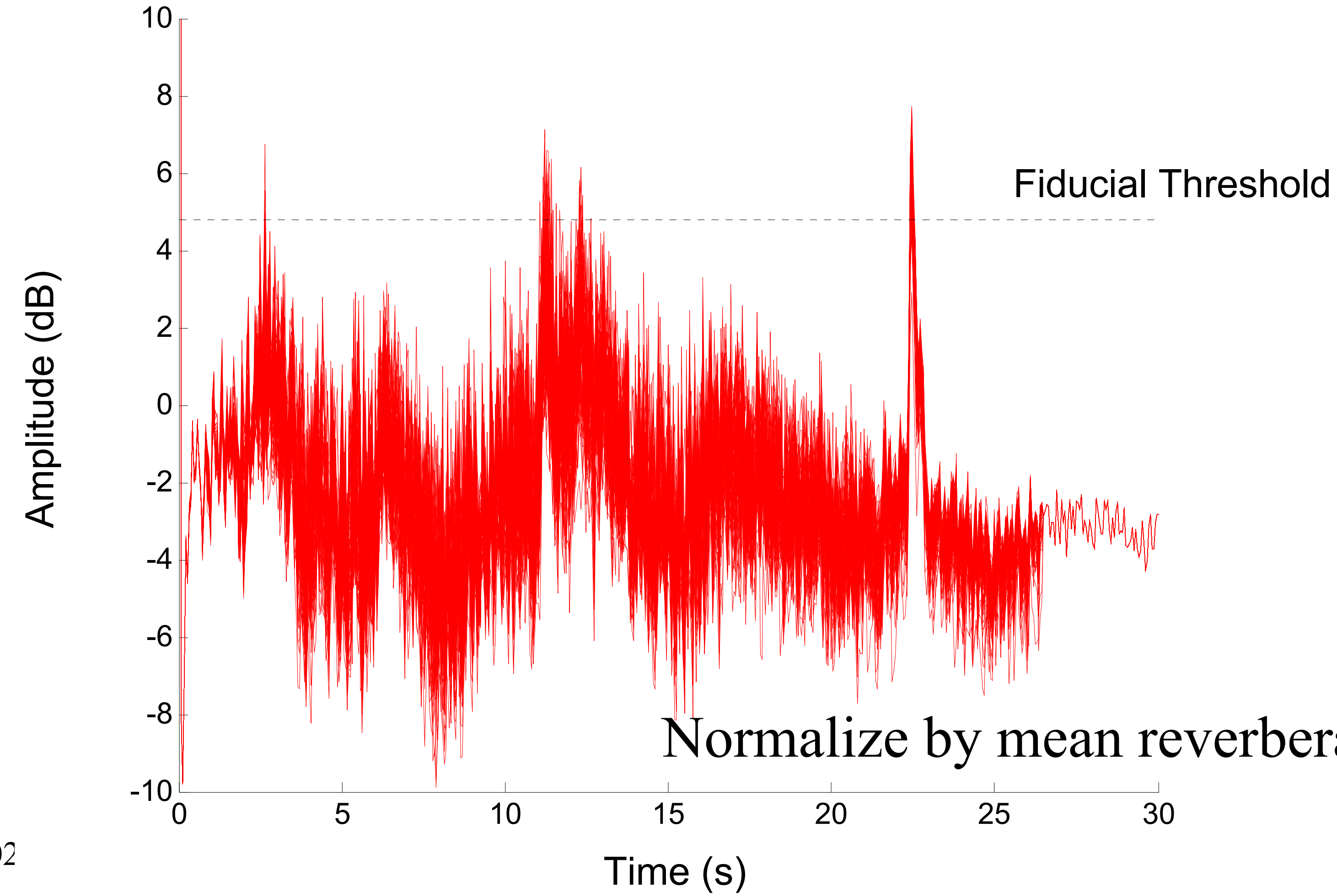


Variability of Data with SSP



Variability of Normalized Data

Even with 2 dB difference internal waves are important

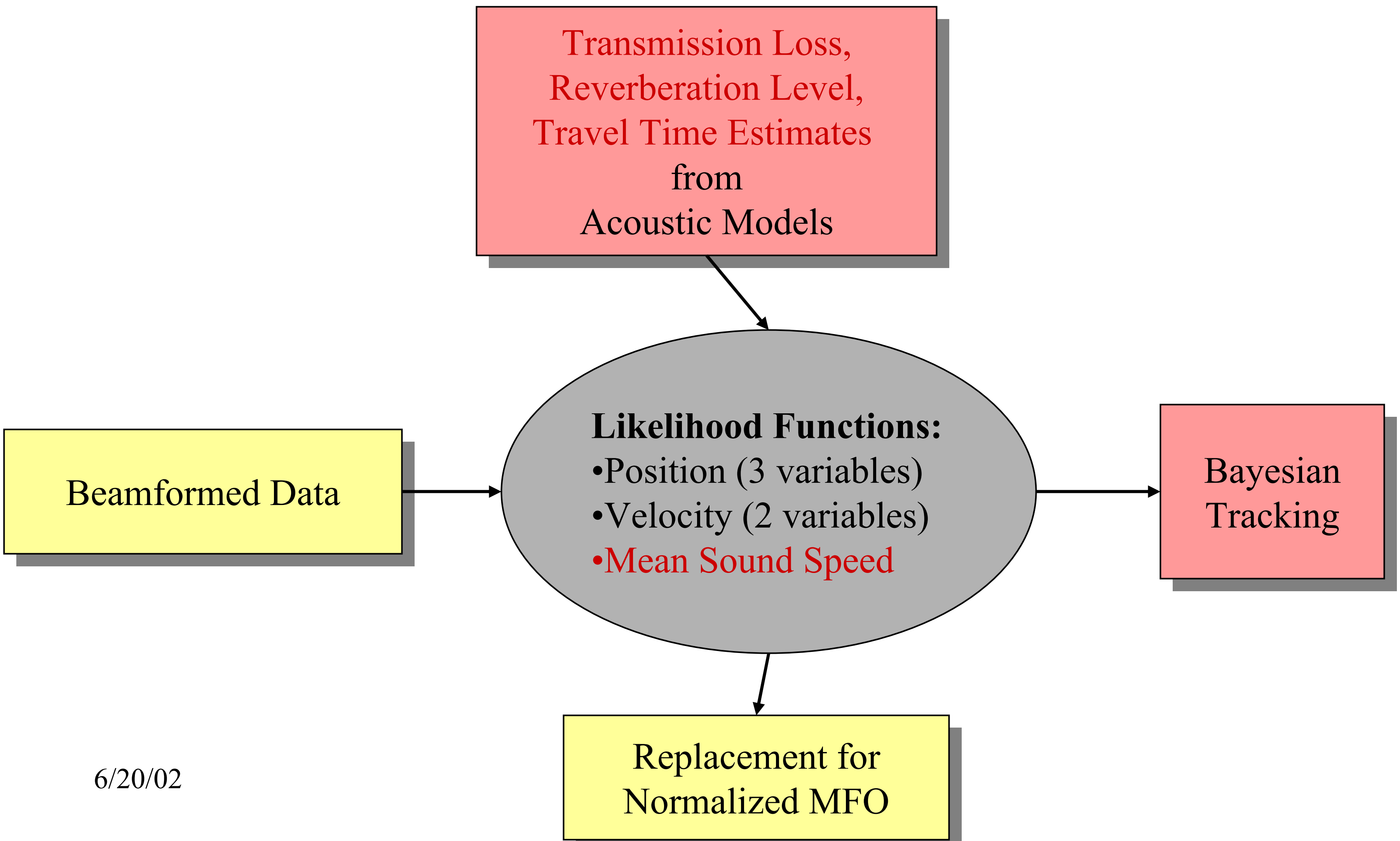


Normalize by mean reverberation

Likelihood Ratio Tracker

- LRT is a discrete non-linear Bayesian track-before-detect system for processing sensor responses to determine the presence and state of a target
- Using likelihood functions to represent sensor information LRT integrates these responses over time and space to increase detection probability without increasing false alarm rate
- LRT is capable of tracking multiple (non-overlapping) targets

Target State Estimation



6/20/02

Log-Likelihood Ratio

$$L(r \mid s) = \log\left(\frac{\text{prob. of } r(t) \text{ given a target in state } s}{\text{prob. of } r(t) \text{ given no target is present}} \right)$$

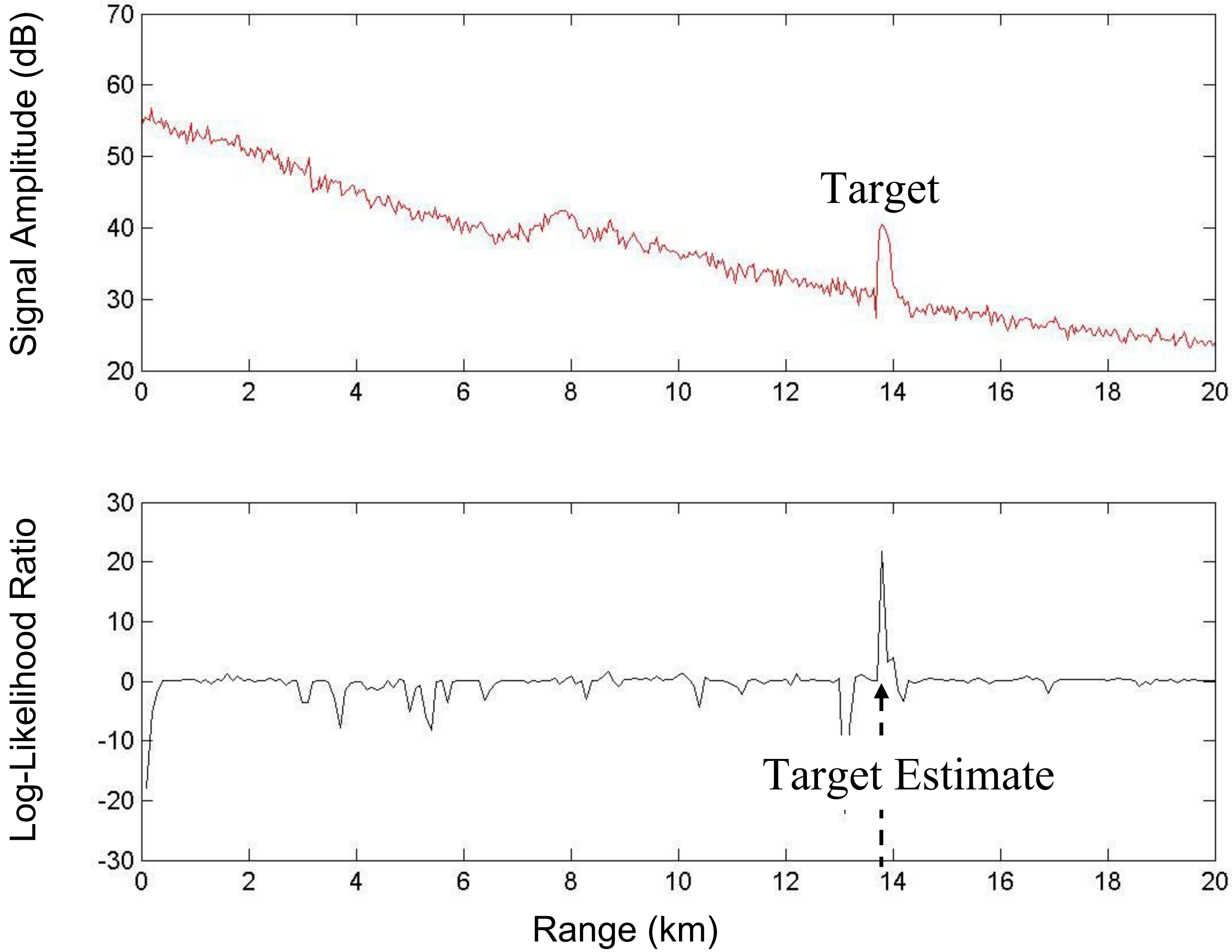
Target Model: $r(t) = \alpha(s)\,\xi(t - \tau(s)) + R(t)\,n(t)$

Non-Target Model: $r(t) = R(t)\,n(t)$

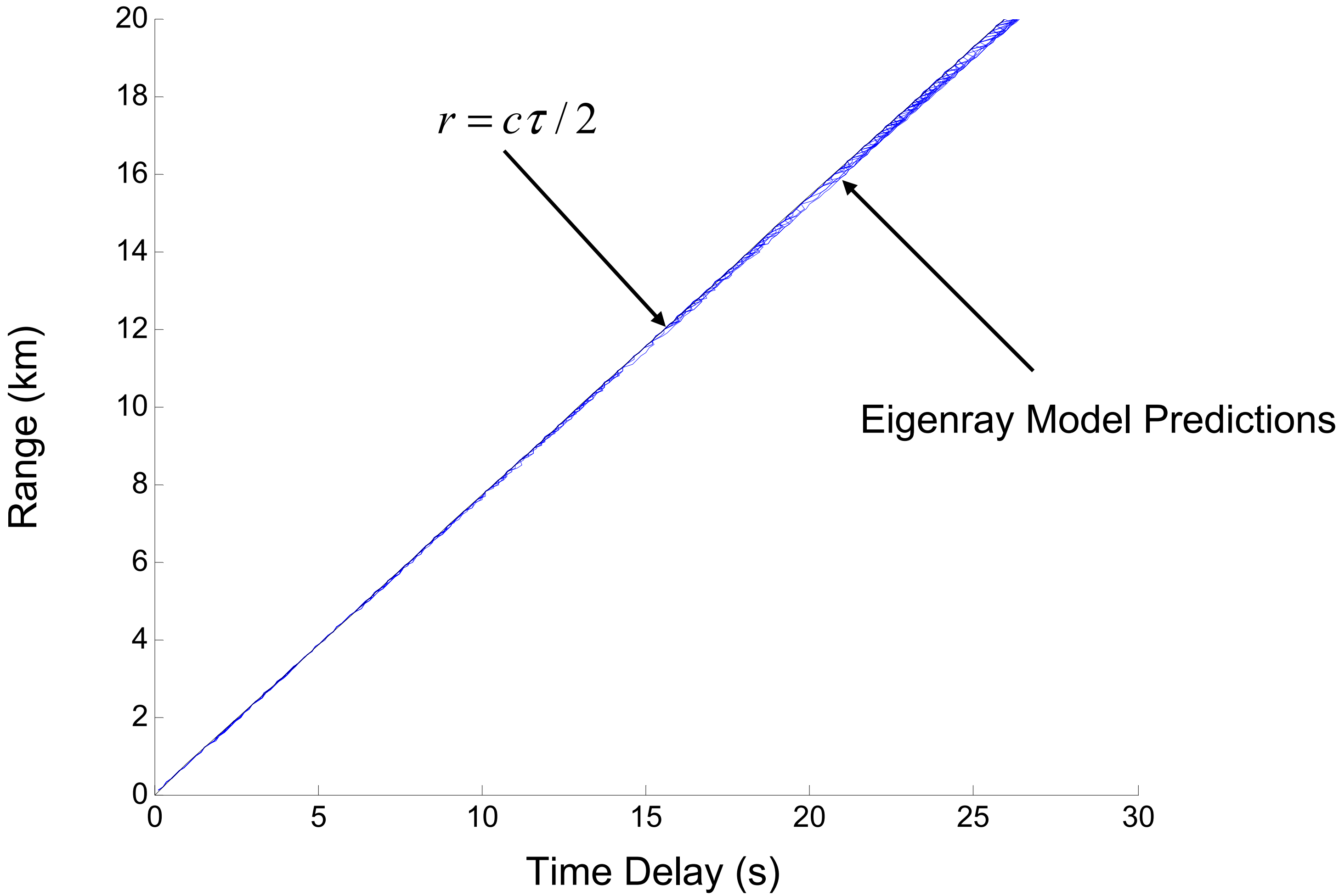
Gaussian

$$L(r \mid s) \;=\; \frac{\pi}{4}\int \left| r(t) \right|^2 / R(t)^2\,dt \;-\; \frac{\pi}{4}\int \left| r(t) - \alpha(s)\xi(t - \tau(s)) \right|^2 / R(t)^2\,dt$$

Sample Log-Likelihood Ratio



Uncertainty in Range Estimation

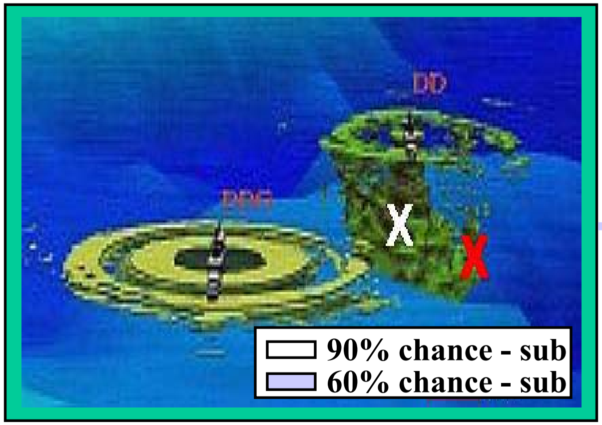


LRT Past/Future Work

- Worked with ARL/UT to develop models for calculating measurement Log Likelihood Ratios (LLRs) for Echo Tracker Classifier (ETC)
  - Noise limited case
  - Reverberation limited case
- Compare time series-based LLR to matched filter approximation using simulated data
- Design an LRT to use the likelihood functions
  - Add another state variable - error in mean sound speed
- Develop methods of calculating and displaying the effect of uncertainty in sound speed on the estimate of target state produced by the LRT

EXAMPLE OF DETECTION and a VISUALIZATION METHOD

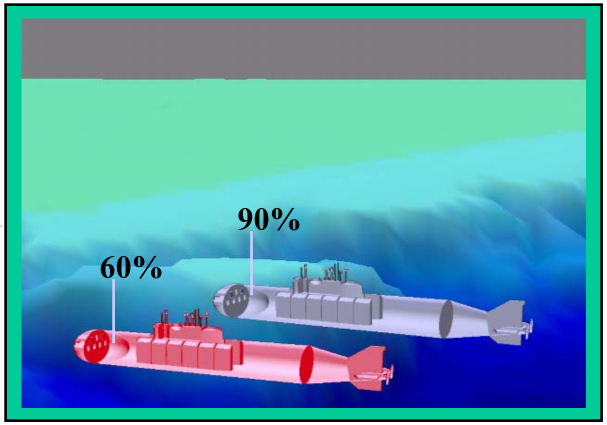
Color and Text – based method for target detection



Visualization Showing Regions Where There is Likely to be a Target

Might not want to use this since it was derived from the IMAT image.

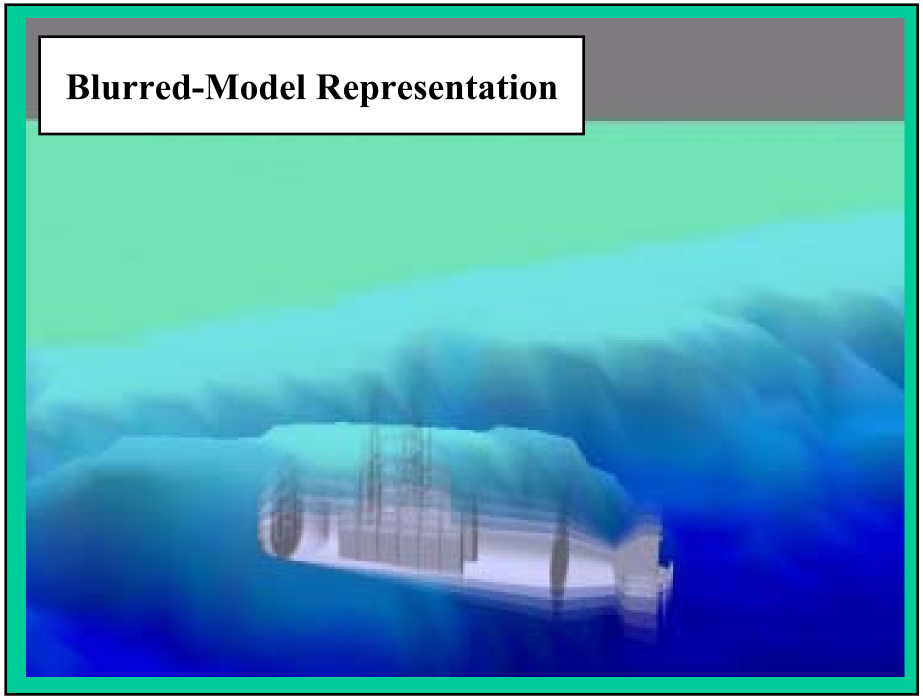
The image on the right is derived from the ECS bathymetry and images of subs.



Visualizations Taking into Account Uncertainty Representations –

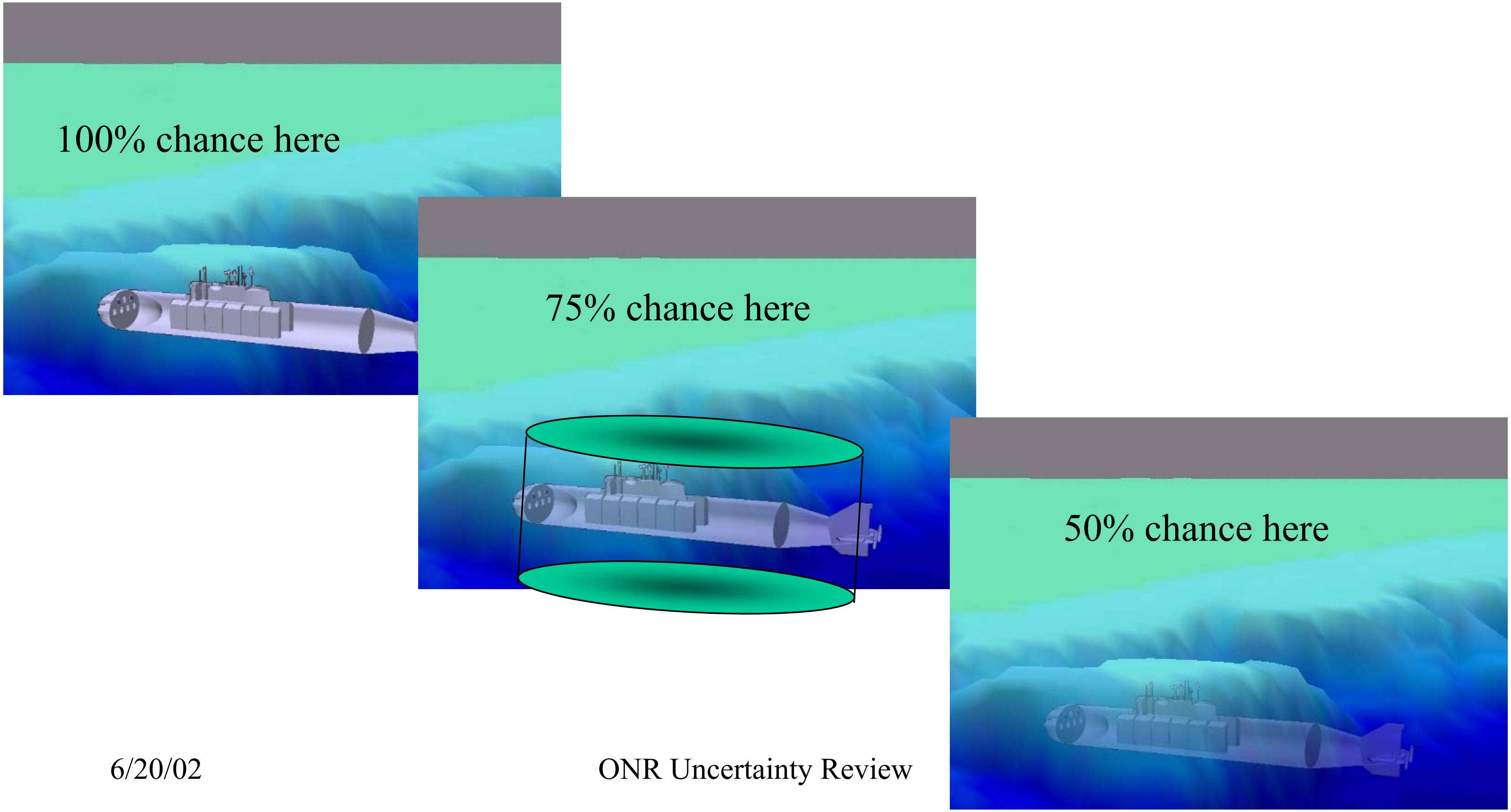
Text and color used to discriminate a target's detection with different degrees of uncertainty (one has a 60% chance it is there, the other, 90%).

Blurring for target detection



Could be used for detection with more blurring representing more uncertainty

Transparency for target detection



Accomplishments

- Focused on specific tactical exercises in the East China Sea
- Characterization of environmental uncertainty
  - Prototype characterization of water column including internal waves from MODAS fields
  - Preliminary simulations in East China Sea using NCOM nowcasting/forecasting system
  - Prototype characterization of the bottom
  - Sensitivity of bottom acoustics to bottom parameters
- Acoustic Propagation
  - Used sound speed fields from combined MODAS and internal waves to generate TL and reverberation
  - Compared statistics of RAM vs CASS TL from realizations of internal waves
- Signal and information processing
  - Initial results show impact of internal waves on acoustic processing
  - Initial formulation for LRT
- Visualization
  - Initial displays of uncertainty of the bottom
  - Combined displays of geologic characteristics and bottom uncertainty

Future Work

- Characterization of environmental uncertainty
  - MODAS vertical profile evaluation
  - Improve ocean model accuracy and resolution
    - Extend non-hydrostatic to 3-D and realistic bathymetry in ECS
  - Introduce bottom clutter and study its effect on uncertainty and performance.
  - Compare predictions based on Sharem 134 and 138 environmental measurements.
- Acoustic Propagation
  - Internal waves sensitivity of statistics and signal and information processing
    - Increase amplitude
    - Mixed layer depth
  - Nonlinear internal wave packets acoustic propagation uncertainty
  - Use bottom uncertainty in acoustic propagation to generate acoustic model output pdfs
- Signal and information processing
  - Process beam-level data modified by model predictions, evaluate effect on performance
  - ARL/UT and Metron to work jointly on a simulation to investigate
    - Matched Filter approximation to LLR for ETC
    - Effect of SSP errors on range estimation
  - Metron to demonstrate effect of SSP errors on LRT state estimation
- Visualization
  - Develop effective visual techniques that usable and useful
  - Incorporate the LRT outputs into a visualization

Summary

- 6.2 team is exploring characterization and application of uncertainty
  - Common geographical area
    - Area characterization leverages a number of programs and data sets
  - End-to-end process with tactical implications
    - Signal processing
    - Tracking
    - Visualization
- Strong integration among disciplines
- Work in progress……….