Uncertainty Visualization for Underwater Acoustics

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Outline

- Problem / Motivation
- Objectives
- Research Challenges
- System Design
- Information Visualization
- *User Evaluation/Formative Design
- Results/Conclusions
- Future Directions

Problem / Motivation

Current forecasting for underwater target detection is not precise enough.

- Current acoustic prediction methods do not incorporate enough (if any) environmental uncertainty.
- It is not clear how to statistically model the environmental uncertainties.

Objectives

Operational Objectives:

- Statistically characterize environmental uncertainty for acoustic detection techniques.
- Demonstrate techniques to Fleet.
- Transition statistical techniques to Fleet.
- Transition software systems to Fleet.

VR Lab Specific Objectives:

- Develop testbed software platform to demonstrate techniques.
- Develop visual information representations for statistical characterizations.
- Validate information representations with end-users.
- Transition final visual representations to Fleet software.

Research Challenges

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Research Challenges

- Visualizing multi-dimensional bathymetric uncertainty
- Visualizing multi-variate properties associated with bathymetry
- Determining how to manage displaying of large datasets in real time
- Visualizing high-degree (greater than 3D) multi-dimensional information spaces
- Developing visual representations that convey dataset attributes in positive discernable manner

System Design

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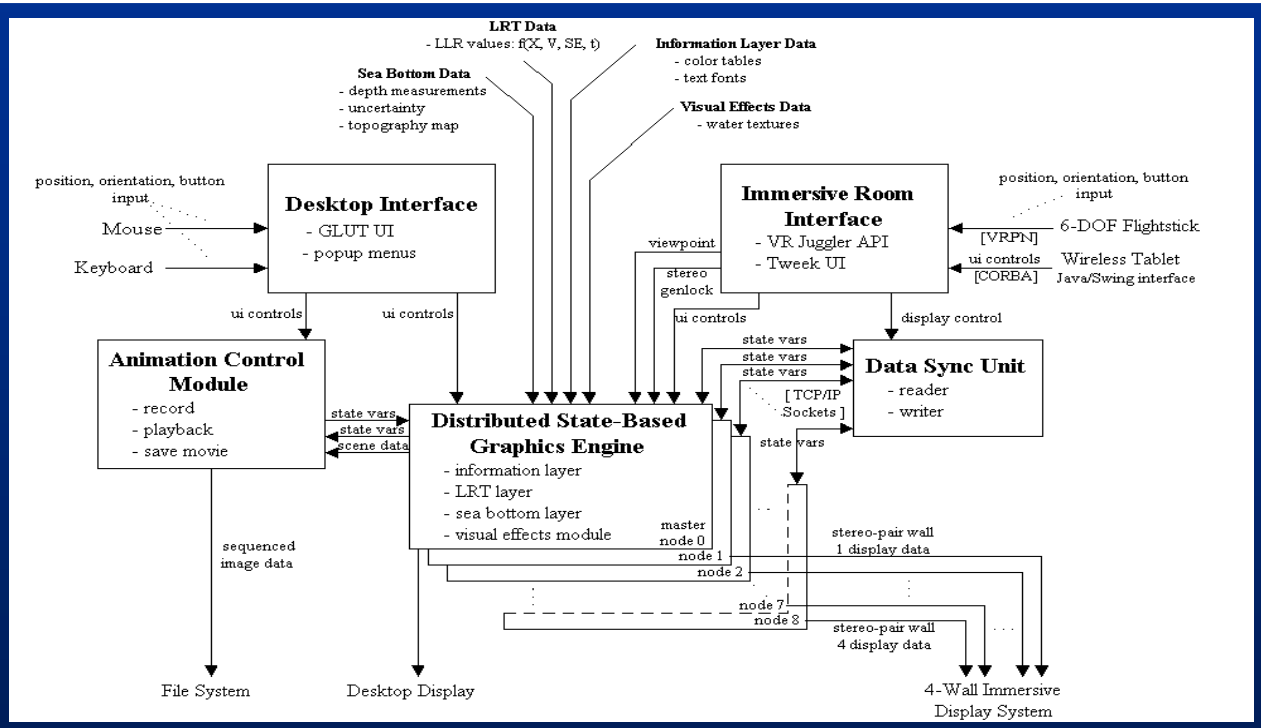
Testbed Display System Design

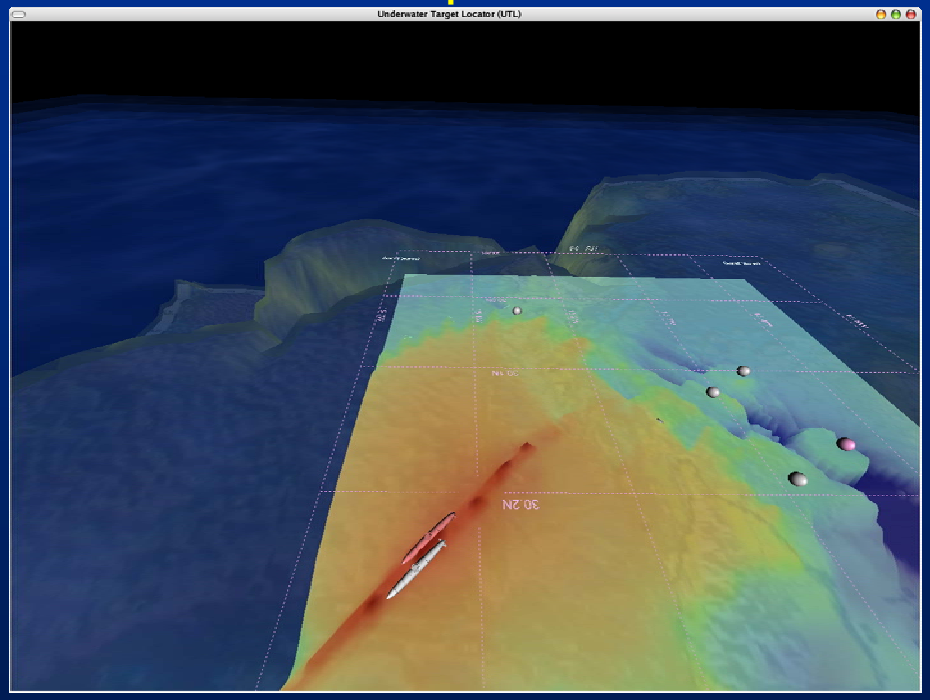
Design for Testbed Display Software System



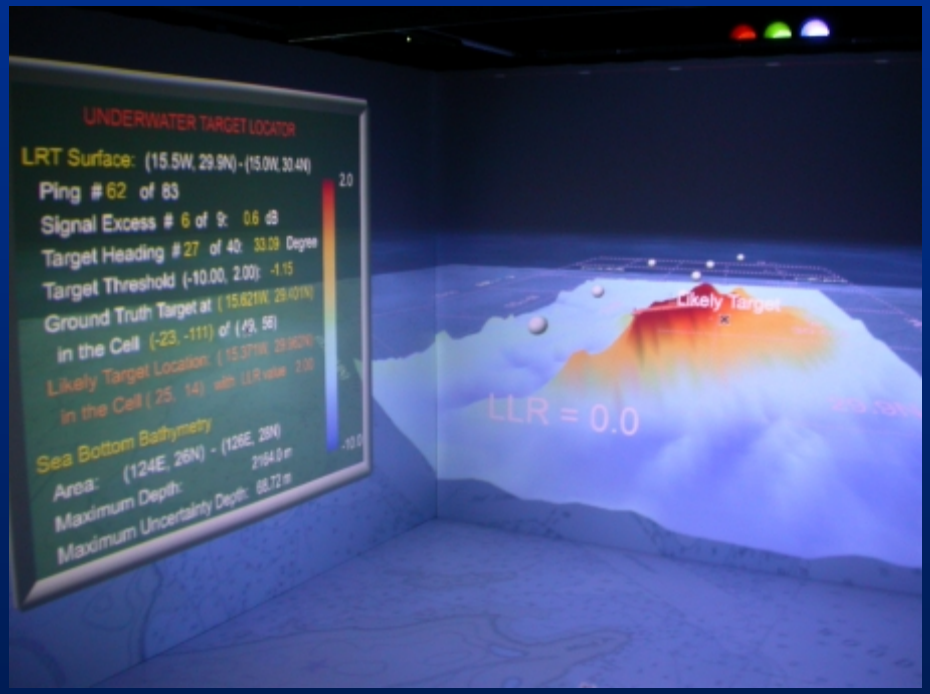
- Two display interfaces: desktop and immersive room
- Supports multiple interaction interfaces
- Central display engine
- Data synchronization between display nodes
- Animation control module

Testbed Display System in Operation

Desktop Interface



Immersive Room Interface



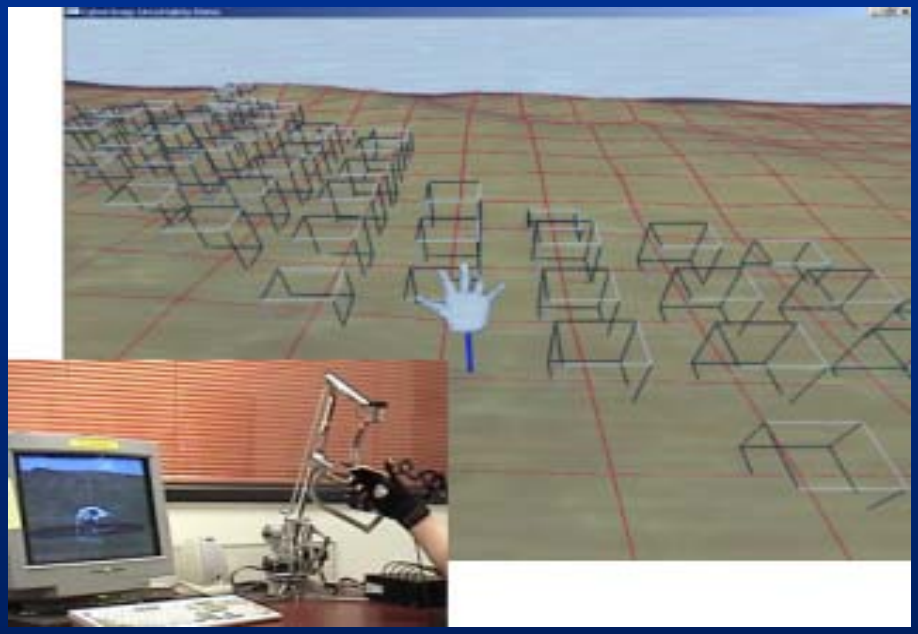
- **Shows views from the desktop and 4-Wall immersive room**

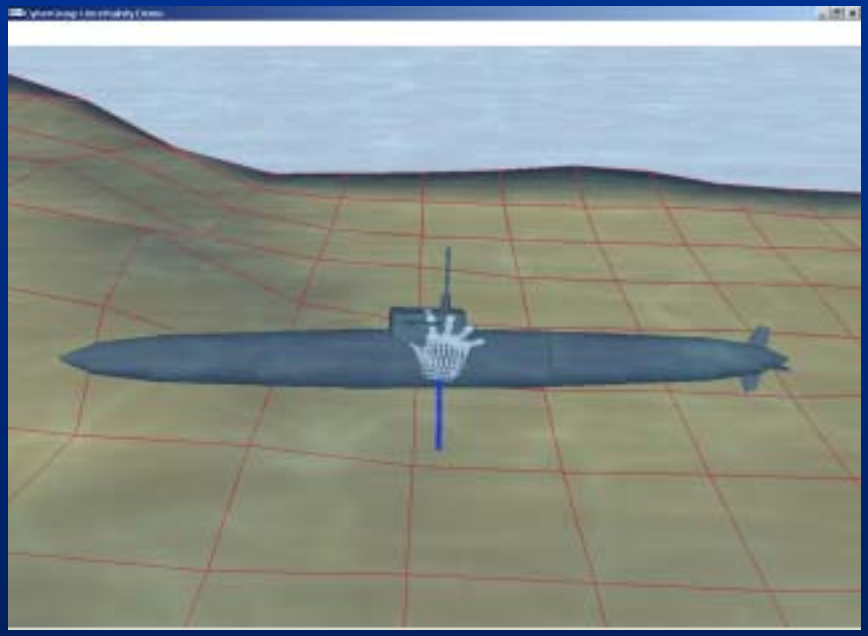
Testbed Haptic Display System Design

Testbed Haptic Display Hardware System

- Three machines (display, haptics and *tracker controllers)
- Haptics hardware: CyberForce, CyberGrasp, CyberGlove
- *Tracking Hardware: Polhemus, Wand
- Display: 50” Plasma TV, *Stereo emitter (*42.5 hz / eye)
- Miscellaneous: Speakers w/Subwoofer, touch screen, voice input headset

Testbed Haptic Display System in Operation





- Developed application using Virtual Hand Suite (VHS) 2.8
  - Utilized OpenGL graphics
  - Developed interaction methods for geometric shapes and models (submarine)
  - Can perceive grasp and weight

Information Visualization

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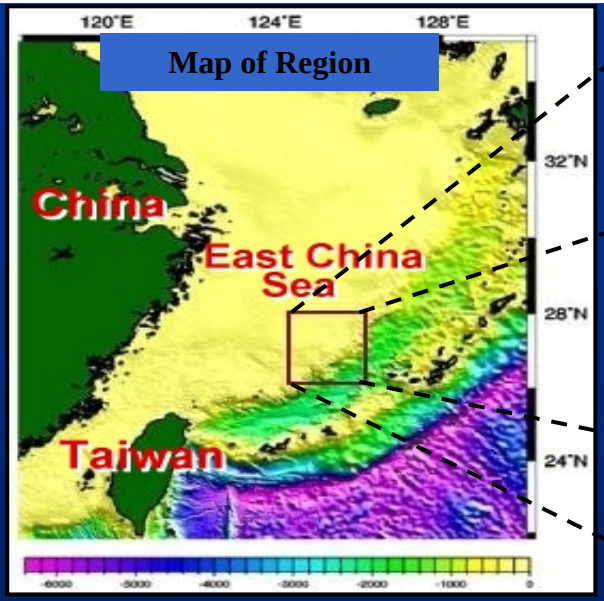
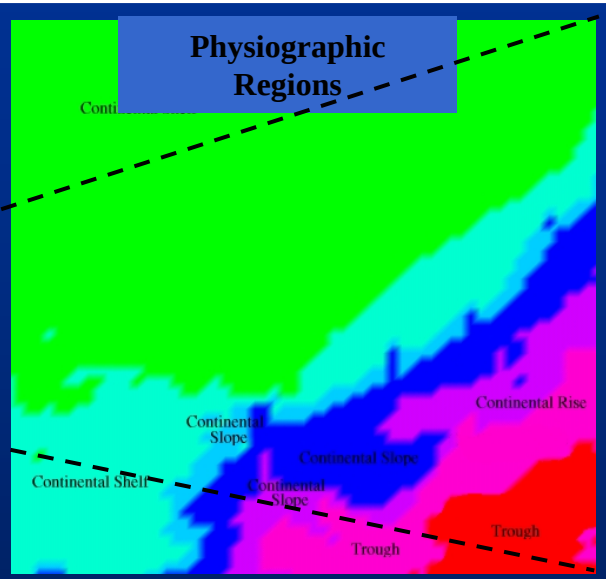
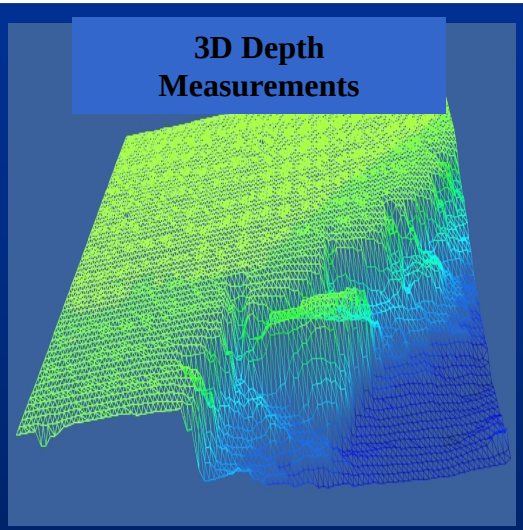
Information Visualization

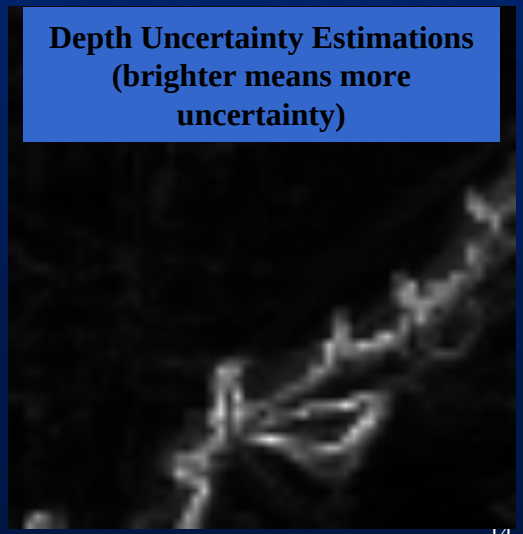
- Multi-dimensional Bathymetric Uncertainty
  - 1D depth
  - 3D spatial
  - 4D temporal
- Multi-variate bathymetric information
  - Physiographic regions associated with soil types
- Acoustic Datasets w/ Modeled Environmental Uncertainty
  - Obtaining datasets
  - Likelihood Ratio Tracker (LRT)
  - Visual representations for 5D state-space dataset
    - 3D, 4D and 5D subspace projections
    - Representing likelihood values and dimensional attributes
  - Target information highlighting

Information Visualization: Bathymetric Datasets







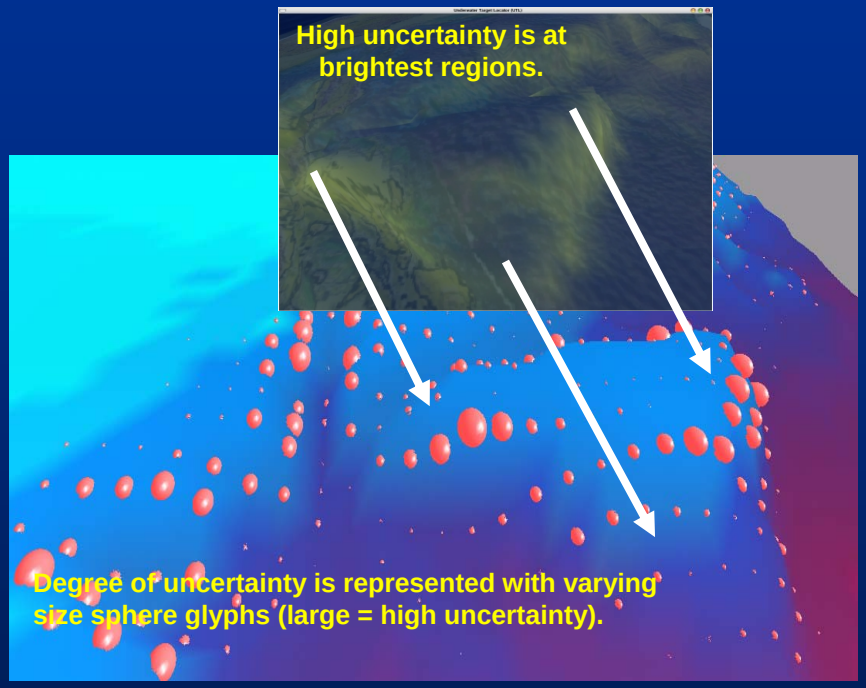


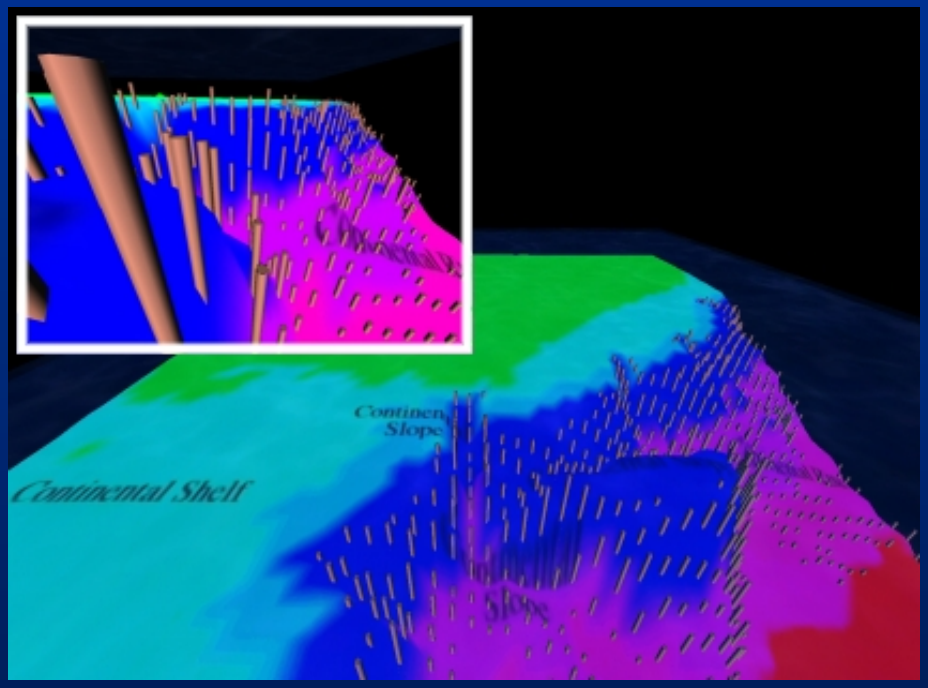
Dataset 1: East China Sea

- **Physiographic regional information**
  - Contains intercontinental shelf, slope/rise and a trough
  - Sea-bottom characteristics (soil types)
- **Depth measurements**
  - Down-sampled from actual measurements
  - Includes depth uncertainty estimations

Dataset 2: Panama City

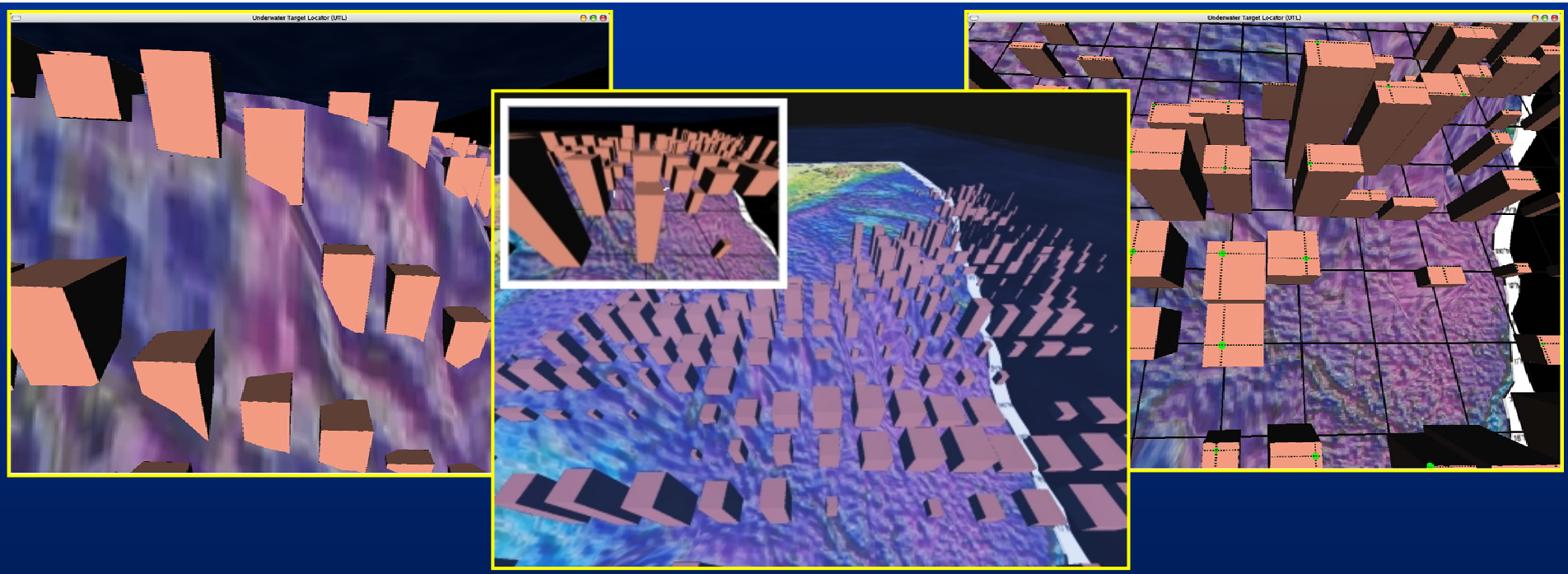
Information Visualization: 1D Bathymetric Depth Uncertainty





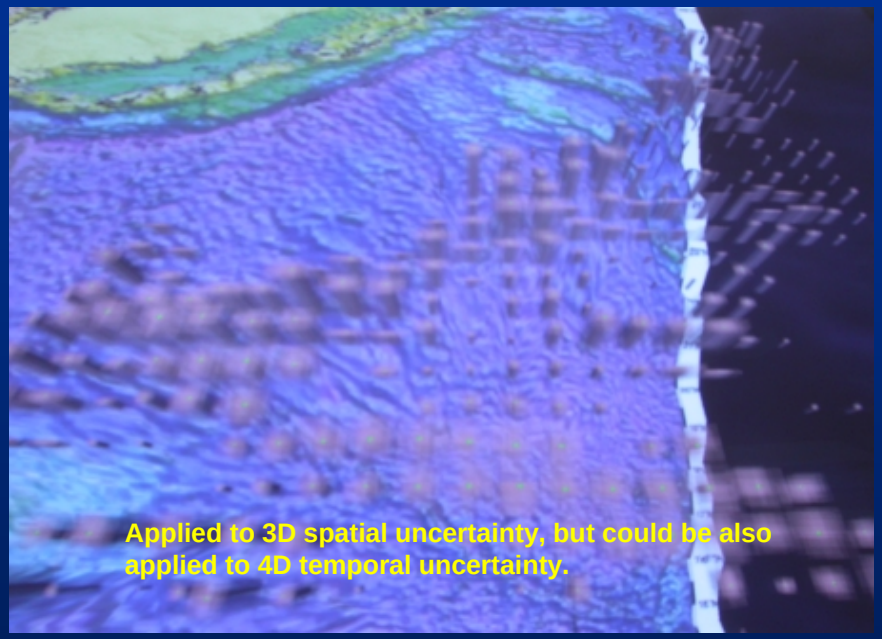
- Experimented with coloring, multi-shape glyphs & combinations
  - Glyph shapes: cylinders, cones, spheres
- Combined multi-variate bathymetric attributes w/ uncertainty
- Encountered visual design constraints (cross-correlation, viewpoint dependence in 3D, color selection)

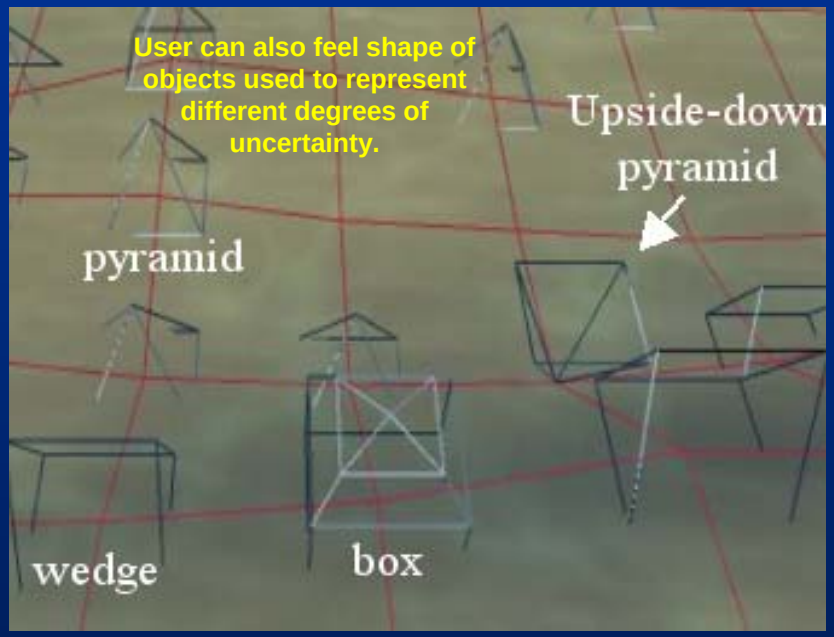
Information Visualization: 3D Bathymetric Spatial Uncertainty



- Experimented with regular and irregular uncertainty
- Experimented with boxes on surface, boxes on plane, animation
- Experimented with local and global display techniques
- Encountered visual design constraints (basis of reference, multi-viewpoint for different attributes, local vs. global)

Information Visualization: 4D Bathymetric Temporal Uncertainty

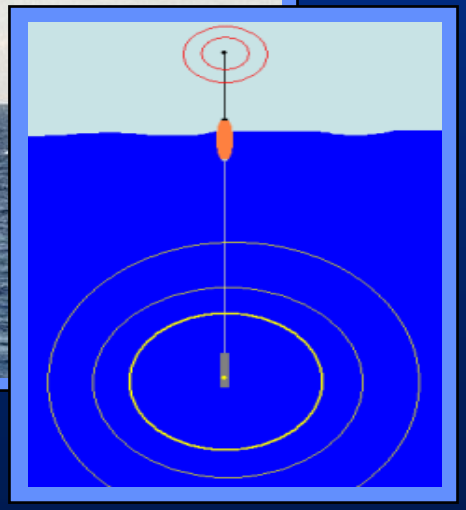




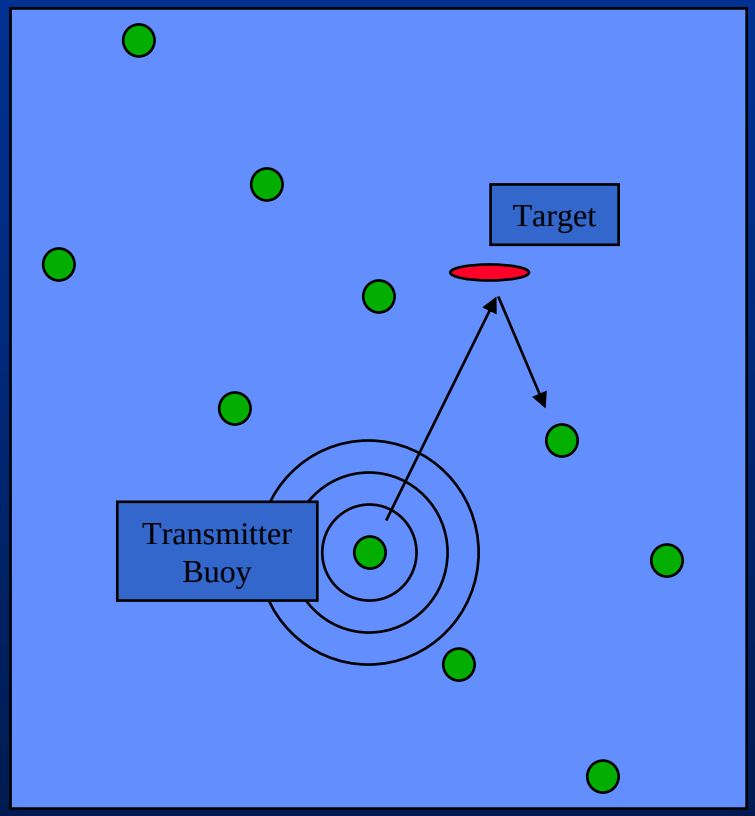
- Experimented with multiple box-like glyphs, haptics, *animation
- Experimented with connecting adjacent datasets together (each from different datasets), multiple measurements for same location (measured at different times)
- Encountered visual design constraints (global vs. local haptic interaction)

Information Visualization: Obtaining Acoustic Data

Patrol Planes Utilized to Drop Sonar Buoys in a Localized Region



A Typical Sonar Buoy Emits an Ultrasonic Pulse and Listens Using a Sensitive Microphone

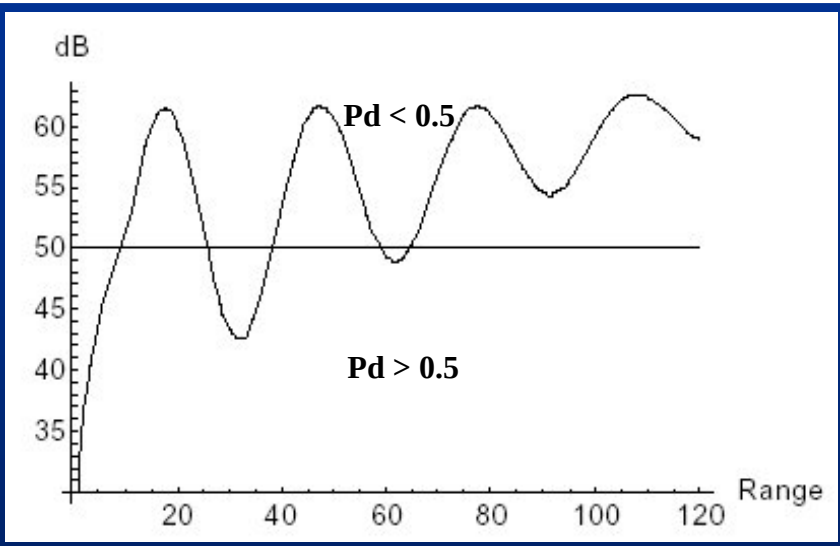


Depiction of Target Detection

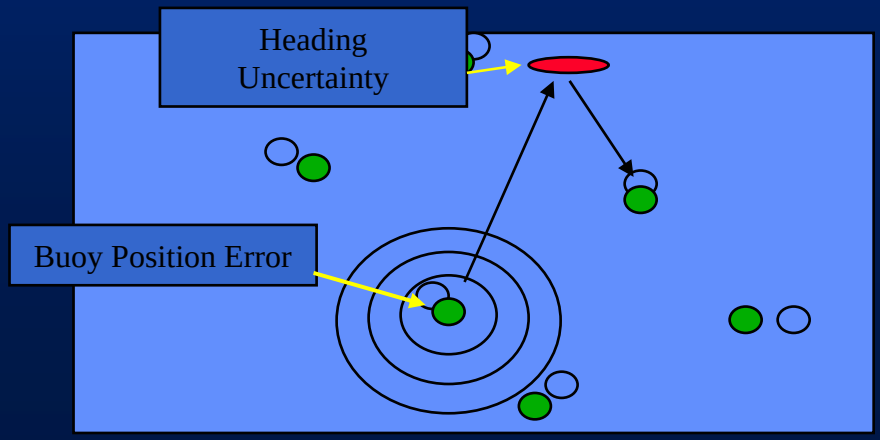
- Bi-static acoustic detection from sonobuoys
- Data is obtained using a processor aboard a P3 plane

Information Visualization: Sources of Uncertainty

- **Environmental Uncertainties**
  - Target strength (signal excess)
  - Transmission loss
  - Reverberation level
  - Ambient noise
  - Predicted travel path
- **Other Sources of Uncertainty**
  - Bearing errors
  - Target state uncertainties
  - Positions of buoys
  - Sensor detection model
  - Sea-bottom measurements



Sample Transmission Loss as a Function of Range



Sample Uncertainties Associated with Target Detection

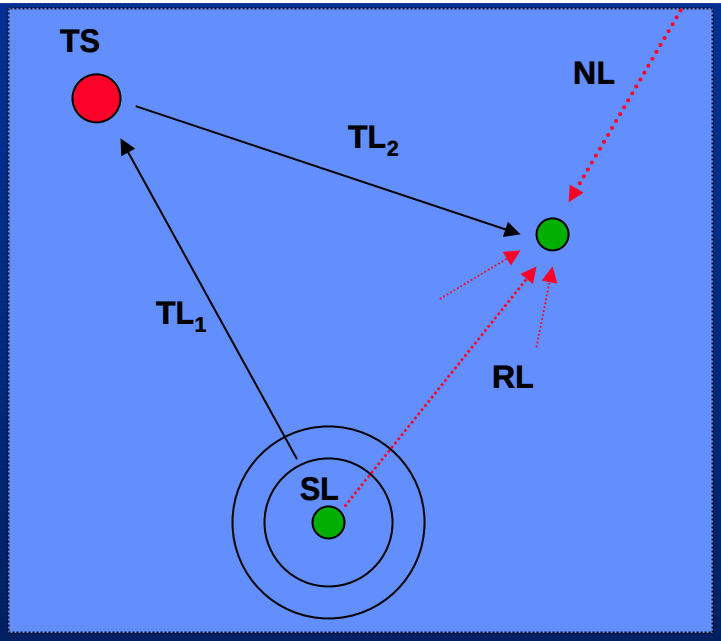
Information Visualization: Modeling Signal Excess/Heading

- **Signal Excess**

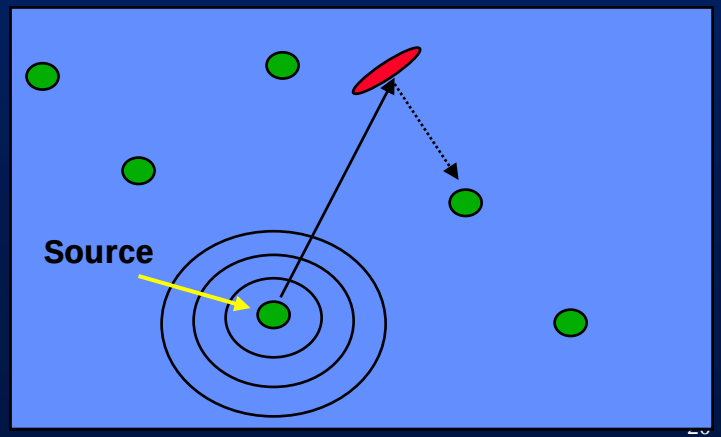
$$SE = SL - TL_1 - TL_2 + TS - (RL + NL) - DT$$

- **Definitions and Values Used:**

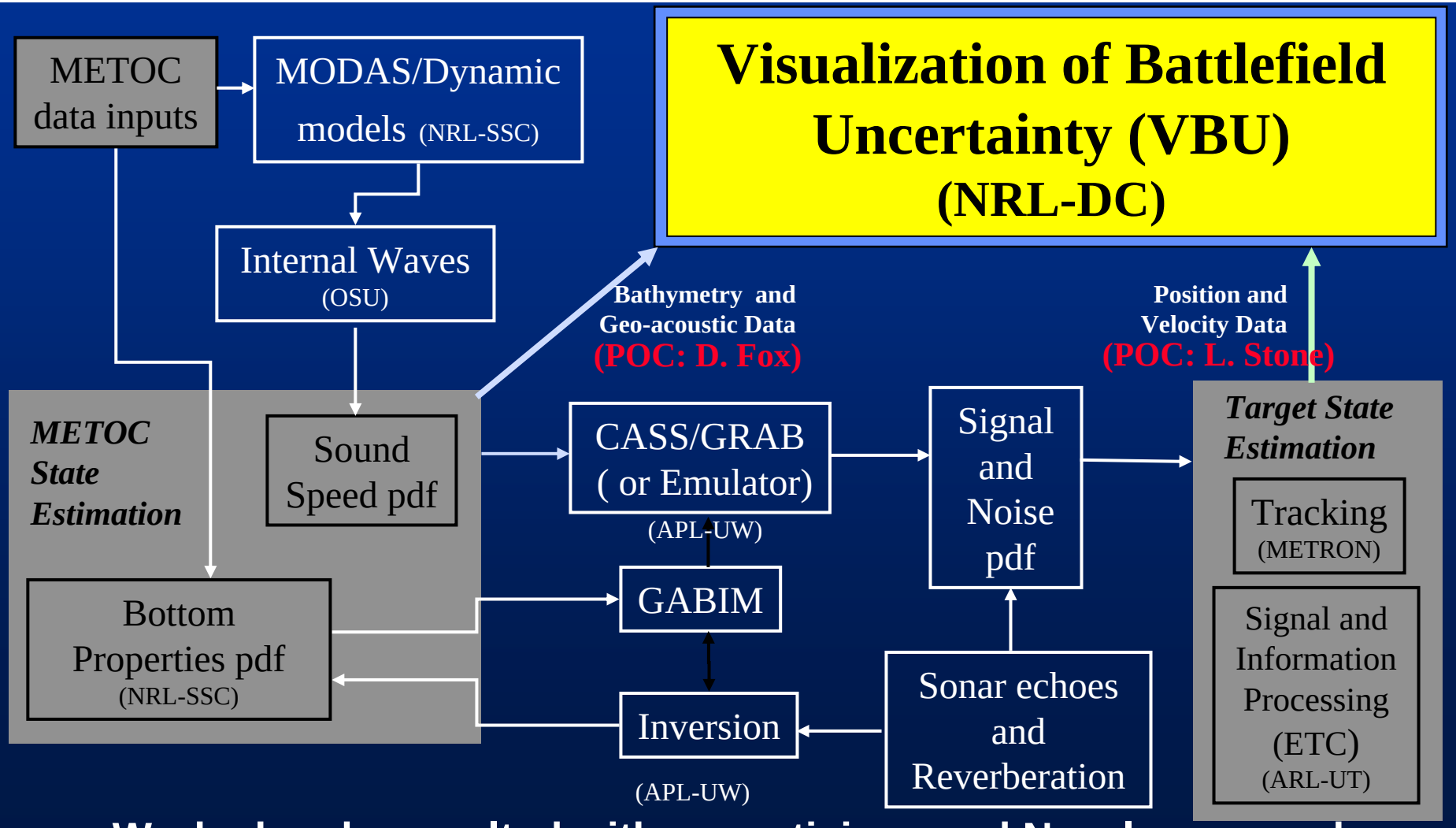
SL: Source Level (210 dB)
TL: Transmission Loss (spherical 20 log(R))
TS: Target Strength (BASIS Model, 50 Hz)
NL: Ambient Noise Level (60 dB)
DT: Detection Threshold (3 dB)
RL: Reverberation Level (assumed 0 for now)



- **Target Heading**
  - Range: 0-360 deg
  - Speed component ignored
  - Probability of detection computed by
    - Pd = 0.4 for broadside
    - Pd < 0.4 w/ Gaussian drop-off for non-broadside

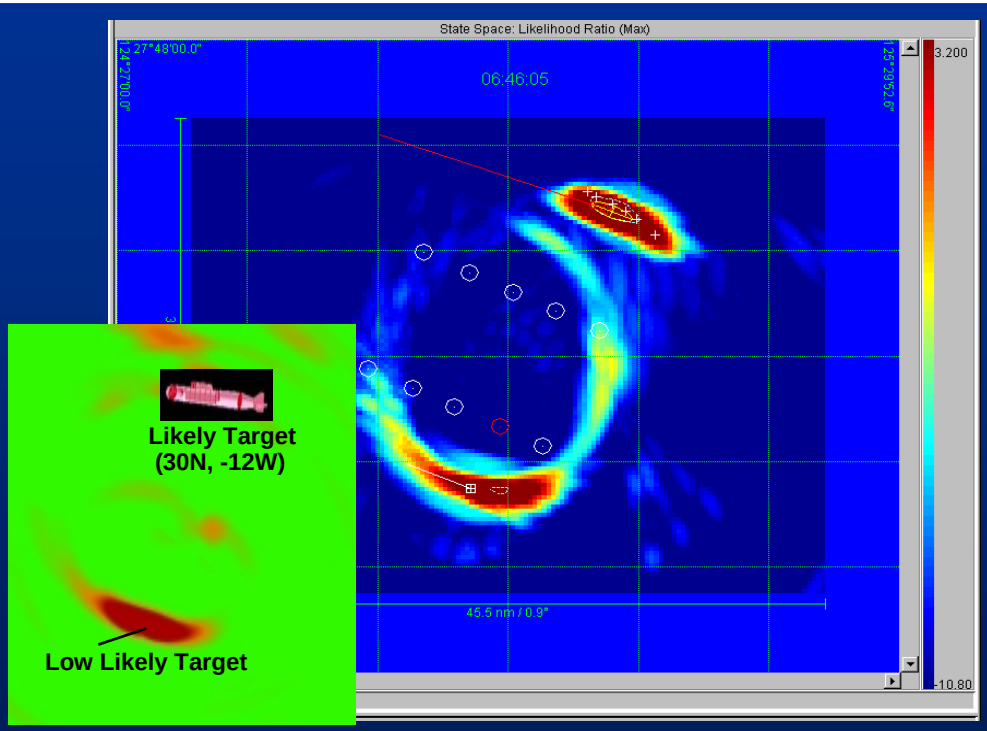


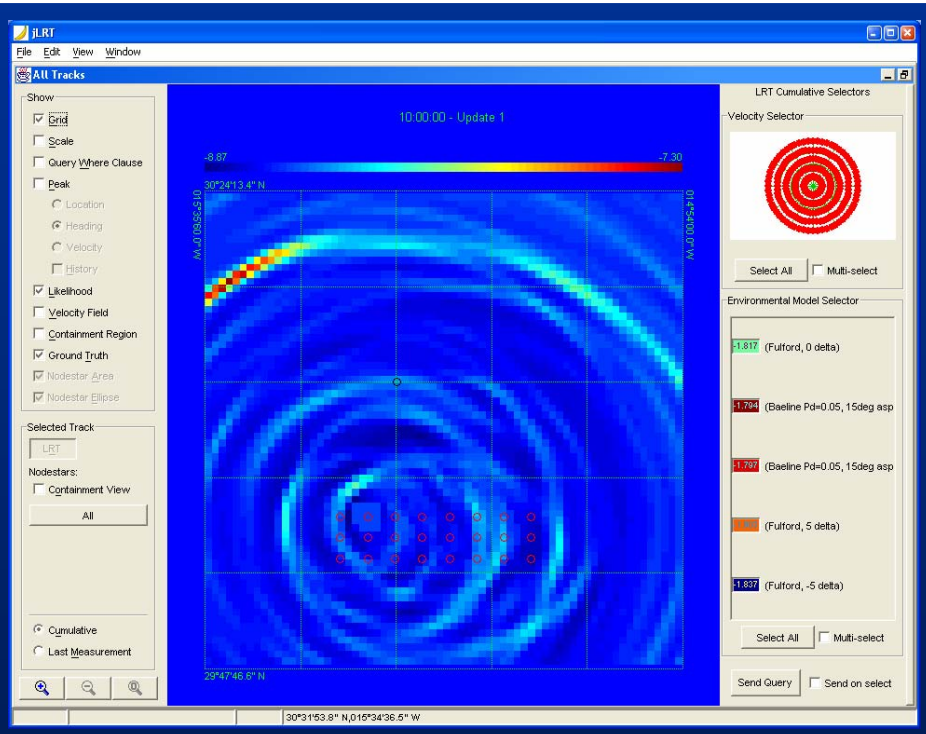
Information Visualization: Team of Domain Experts



- **Worked and consulted with acousticians and Naval commanders**

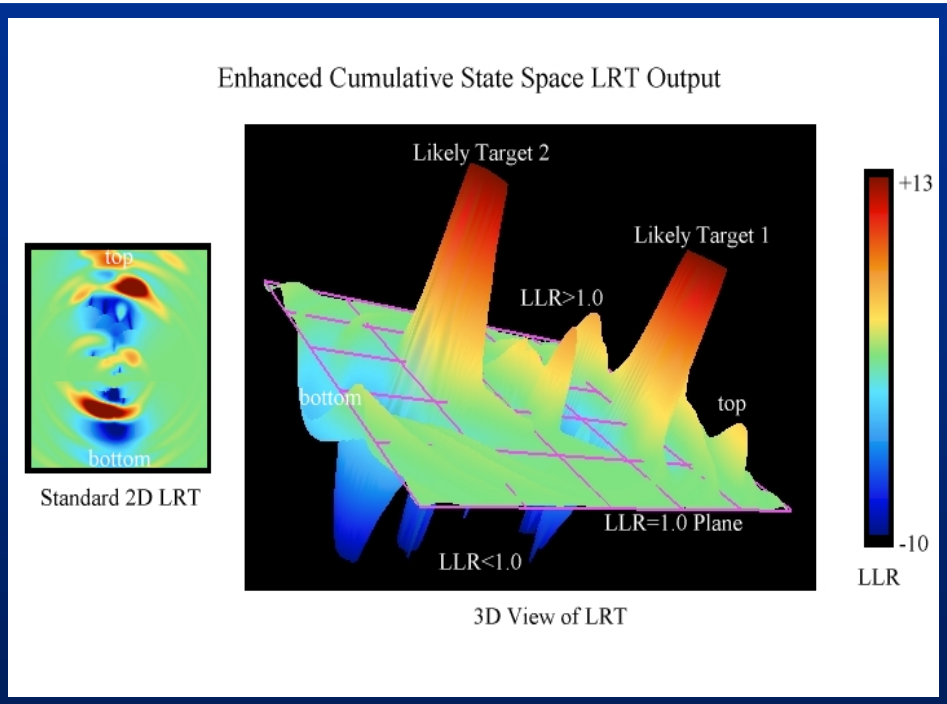
Information Visualization: 3D State-Space Data (2D LRT)

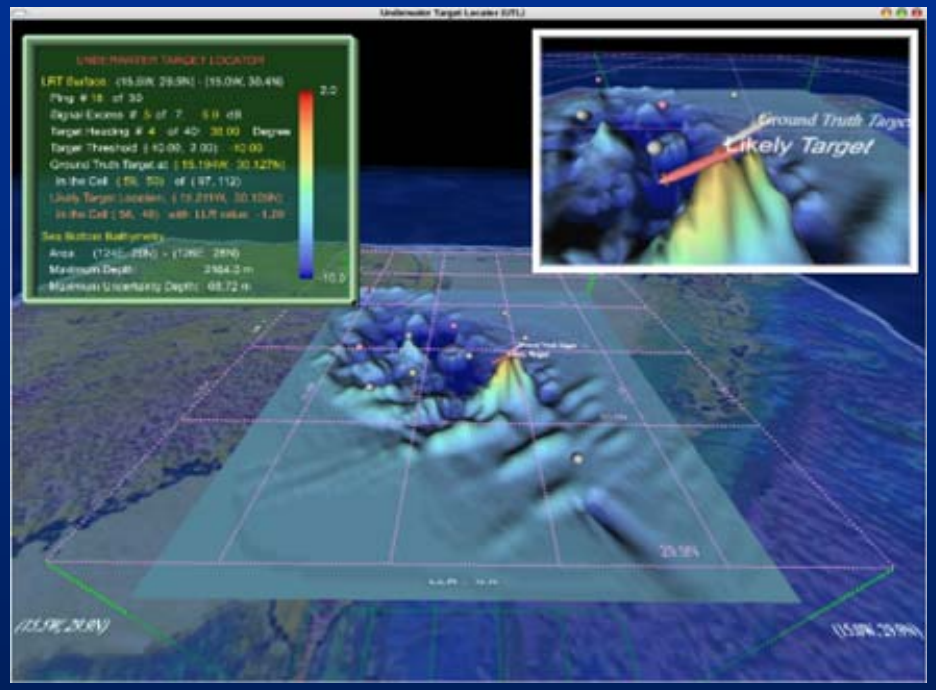




- Maps 3D state data to 2D image sequences (latitude, longitude and time)
- Uses color to display likelihood values
- Regions are cut out and tracked in separate window when a target is assumed detected

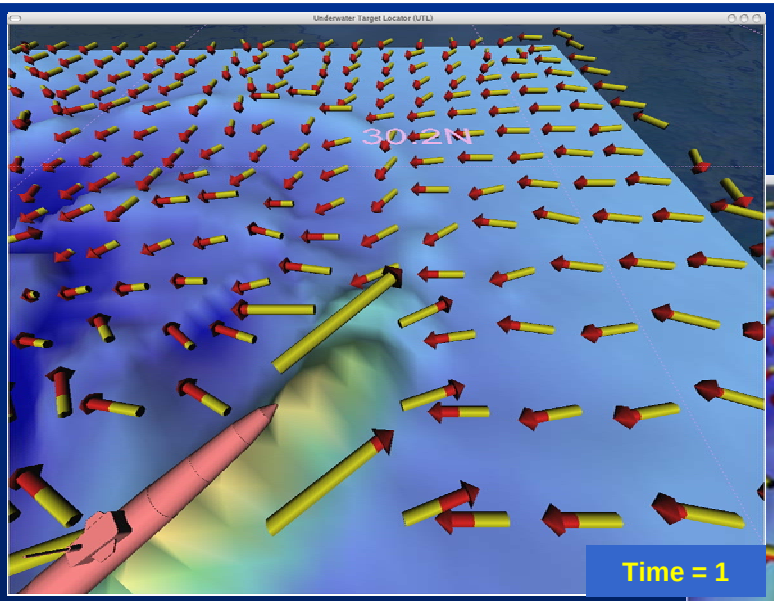
Information Visualization: 3D State-Space Data

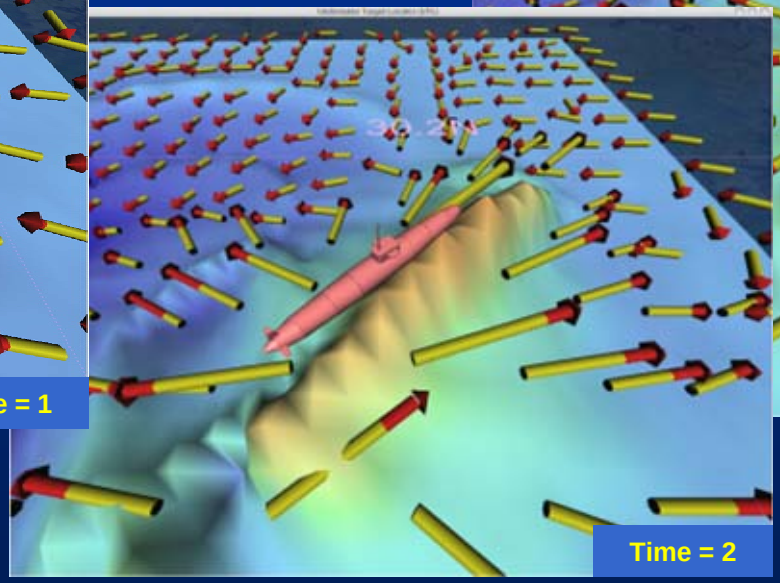


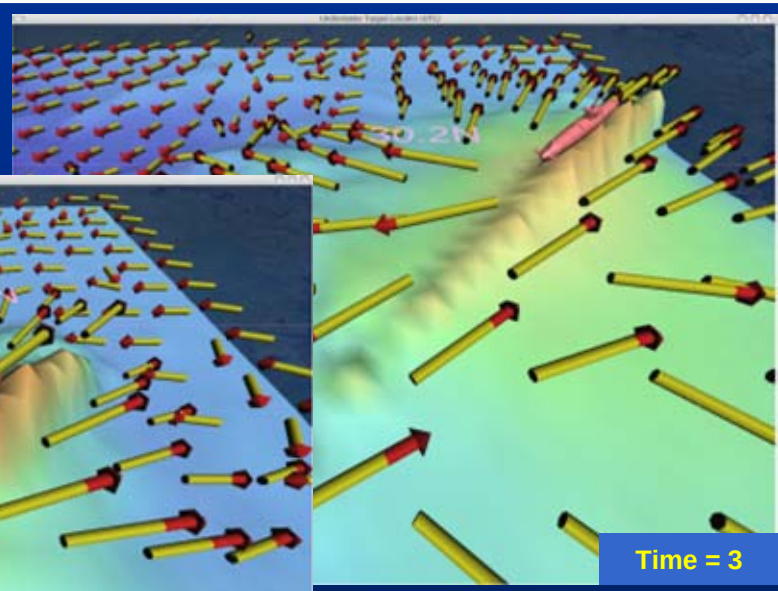


- Maps 3D (latitude, longitude and time) to color and geometry
  - Extends 2D LRT to 3D
  - Redundant mapping to height allows for better differentiation of likelihood values
- Experiments with models and text for likeliest position/heading of target submarine

Information Visualization: 4D State-Space Data

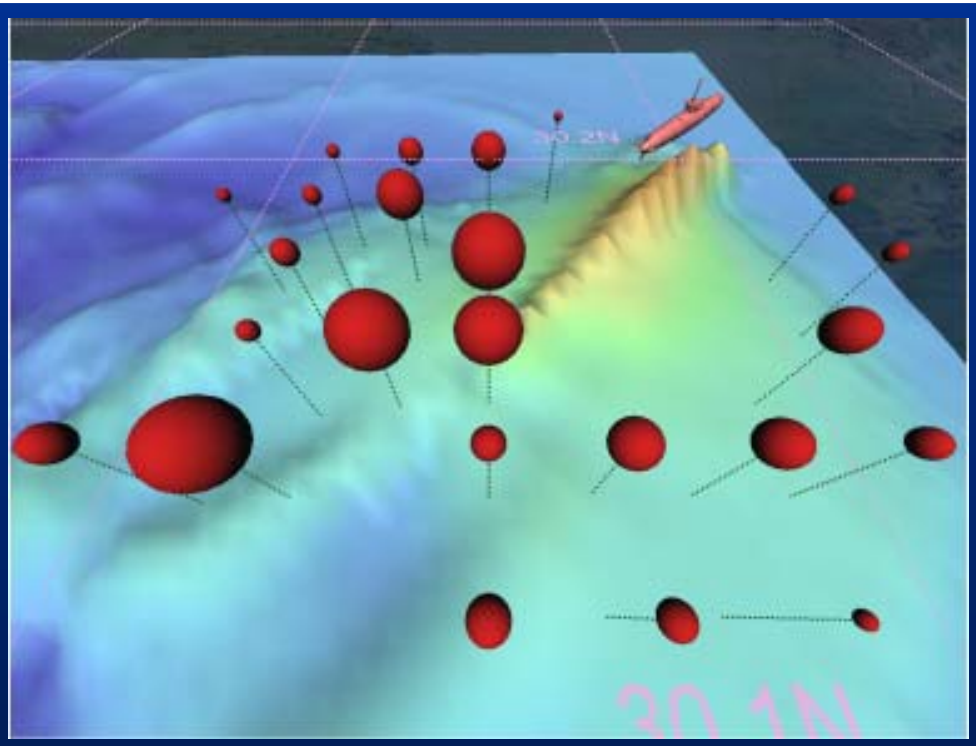


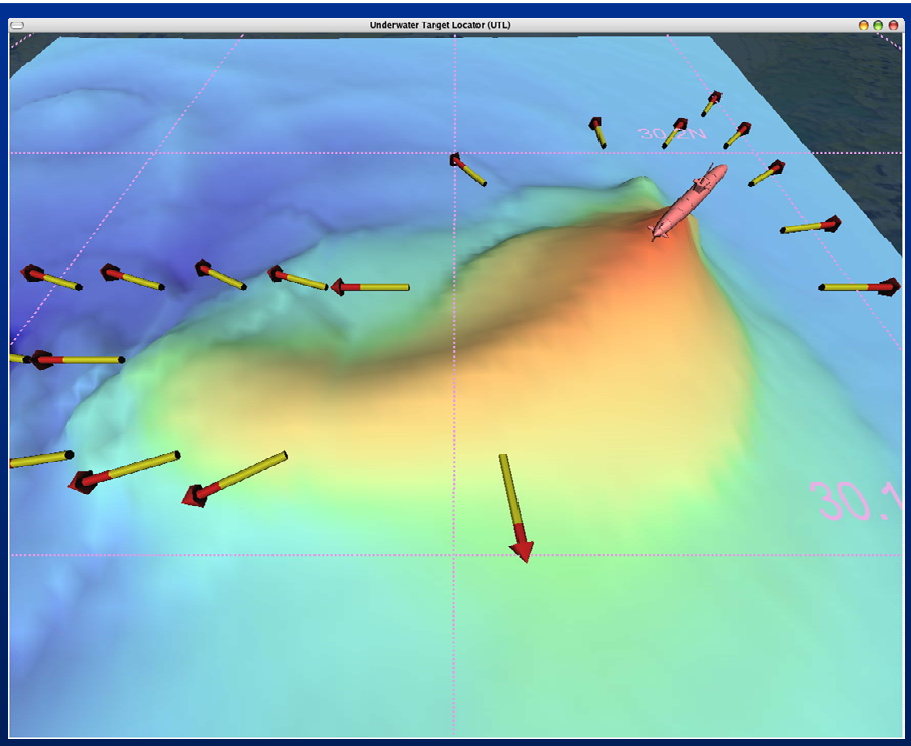




- Experimented with data aggregation in heading dimension
- Experimented with arrow glyph for heading, mean and maximum likelihood
- Mapped mean likelihood to surface color/height map

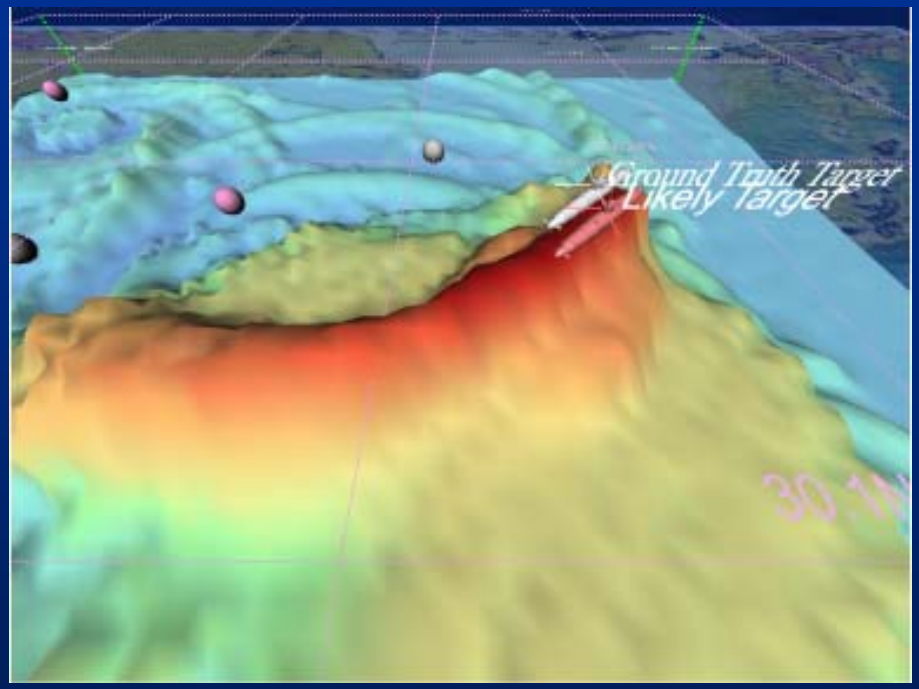
Information Visualization: 4D State-Space Data

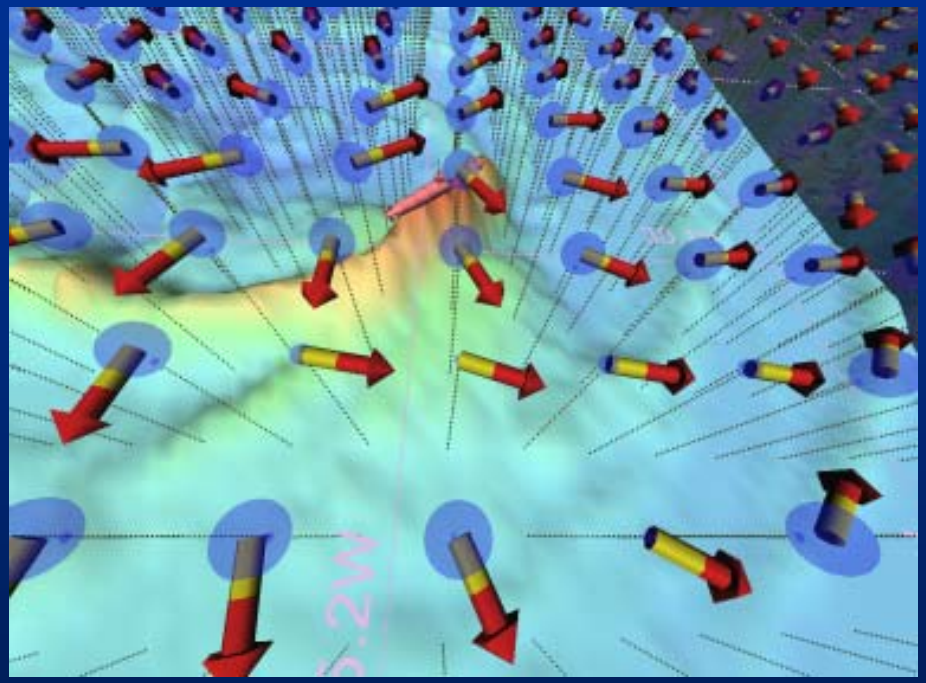




- Experimented with data aggregation in SE dimension (mean, maximum, variance)
- Experimented with de-cluttering algorithms based on surface maximums and maximal likelihoods at glyph locations
- Experimented with sphere glyphs

Information Visualization: 5D State-Space Data





- Experimented with mean and maximum data aggregation
- Experimented with multi-faceted glyph (sphere-arrow)
  - Maps heading, maximum and mean LLR, difference, SE range

User Evaluation / Formative Design

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User Evaluation / Formative Design

1. ***User Task Analysis:*** **analysis of user tasks by user interface design experts, in consultation with users**
2. ***Domain Expert Evaluation:*** **assessment by user interface design experts, to determine violated usability design guidelines**
3. ***User Scenario Evaluation:*** **assessment with users, to iteratively determine and improve usability**
   - Follow formal task scenario
   - Collect both *quantitative* and *qualitative* data
4. ***Comparative Evaluation:*** **assessment with users, to determine which among several design alternatives is "best"**
   - Classical *n* x *m* experimental design

[Ed Swan, NRL and Dr. Deborah Hix, VA Tech]

- **Intended to utilize a usability engineering evaluation methodology**
  - **Formative design of visual information representations**
  - **Integrate representations into testbed systems**

Results / Conclusions

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Results: Guidelines for Developing Visual Representations

- *Determine a basis for reference when distinguishing values of information*
- *Cross-correlation of visual representation of error with data is important*
- *Plan visual approach according to primary and secondary features*
- *Plan visual approach for wide-area and local-scale observations where appropriate*
- *For 3D representations, the effectiveness of the visual approach should consider the changing viewpoint*
- *In most cases, having consistent proportions for the dimensions of the data is desirable*
- *Minimize interference between visual representations for uncertainty, multi-variate properties of the data, and the data*
- *Presenting the data with multiple approaches or display systems may be better at conveying the information*

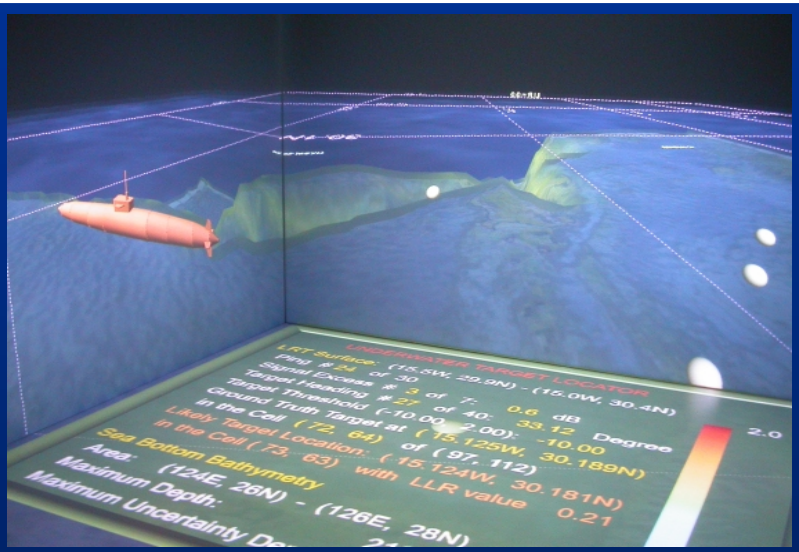
- **Coupled with Previous Work, Compiled Guidelines for Developing Visual Representations for Multi-Dimensional Uncertainty and Multi-Variate Information**

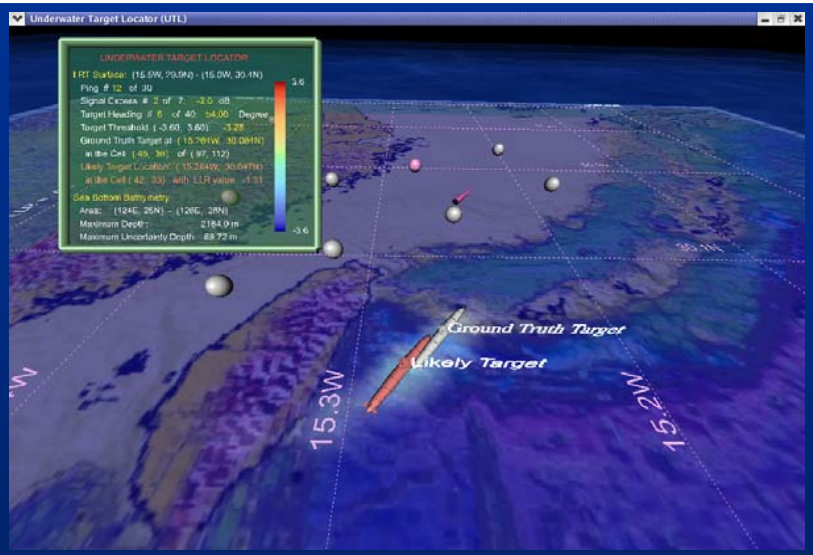
Results / Conclusions

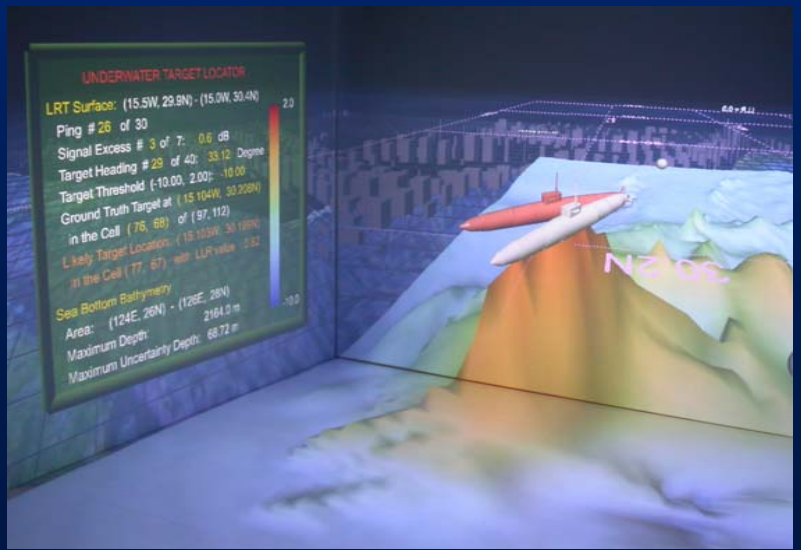
- **Developed Visual Approaches for Environmental Uncertainty**
  - Introduced information visualization approaches (candidate techniques) to the sonar community that can be applied to operational software
  - Received positive feedback from Naval commanders and acousticians

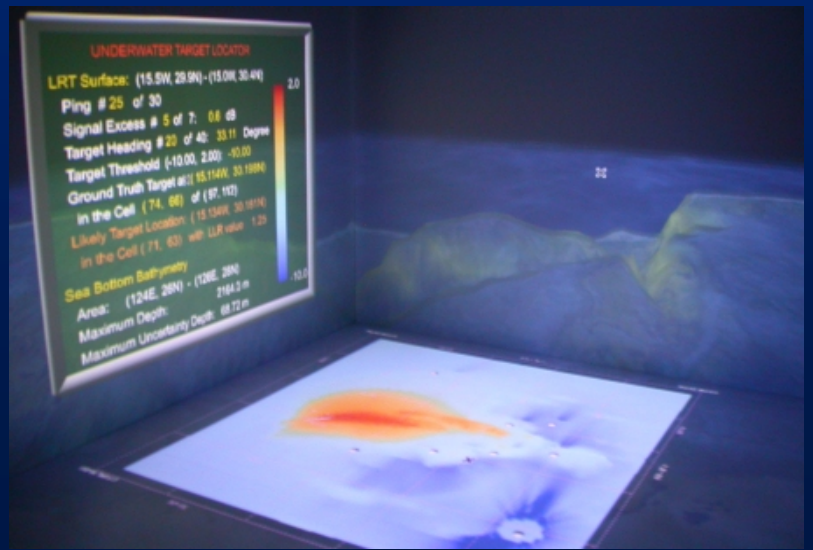
- **Developed Two Systems for Testing Visual Representations**
  - Allows acoustic scientists to perform analysis on environmental uncertainty data
  - Applying dual-display system for ESME project

Results: Image Gallery









Future Directions

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Future Directions

- Statistical teams still developing statistical characterizations
- LRT system techniques being transitioned to NUWC
- Improve testbed software to be used as platform for ESME project (Effects of Sonar on Marine Environment)

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