Presentation at the Second Plenary Meeting of the Advisory Committee on Acoustic Impacts on Marine Mammals

28-30 April 2004

Arlington, Virginia

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ESME

Effects of Sound on the Marine Environment

A review of the ONR ESME acoustic risk modeling program presented to:

The Marine Mammal Commission Advisory Committee on Acoustic Impacts on Marine Mammals

28-30 April 2004

Arlington, Virginia

Dr. Robert Gisiner

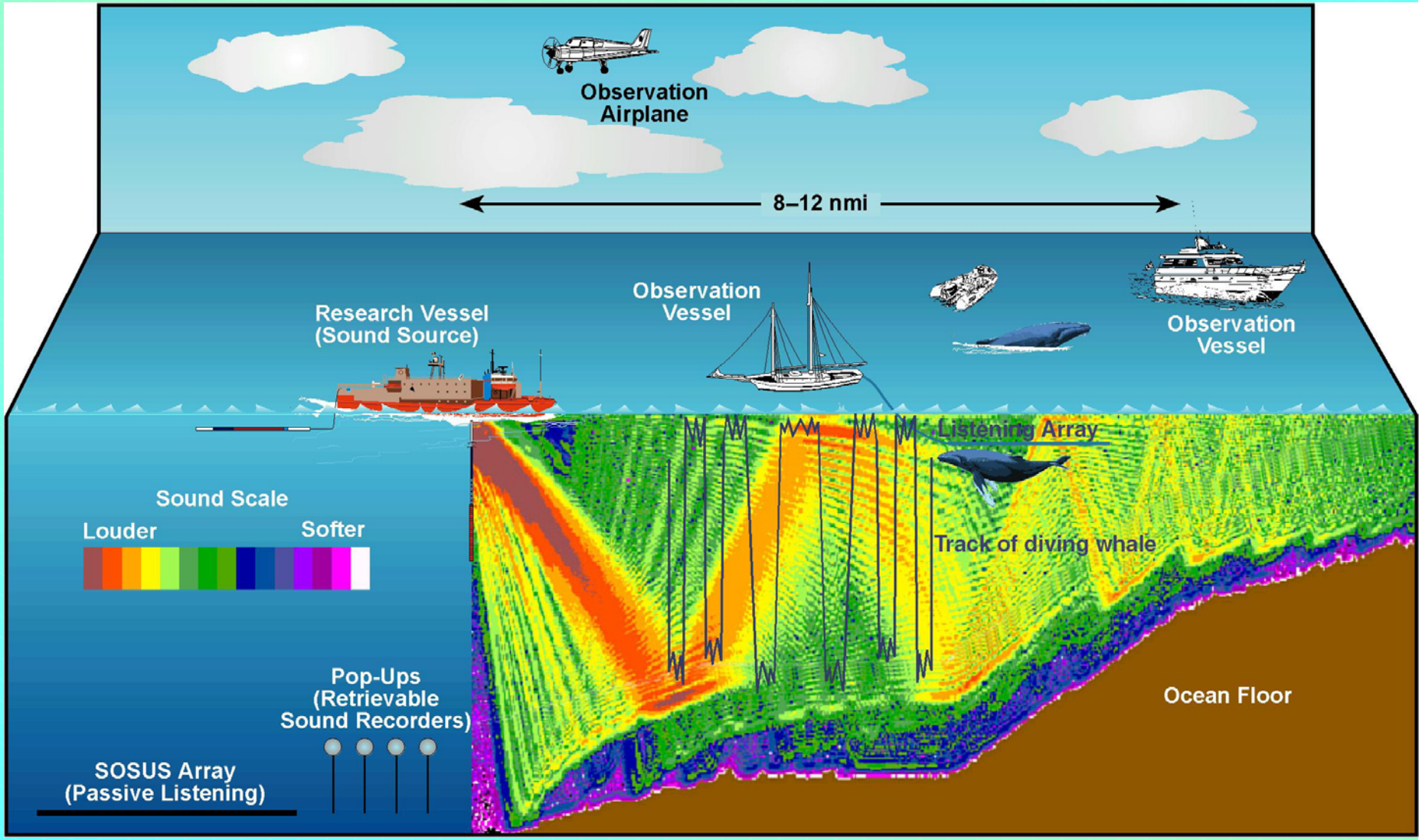
Marine Mammal S&T Program Manager

Office of Naval Research

What is ESME?

- An attempt to capture the state of the art in all relevant scientific fields,
- for the purpose of modeling the risk to protected marine life,
- from any specified human sound exposure regime.

Visualizing the problem space



Defining the Problem Space

Source → Transmission → Receiver → Response → Risk

Source
- amplitude
- frequency
- duration
- duty cycle
- directionality
- others

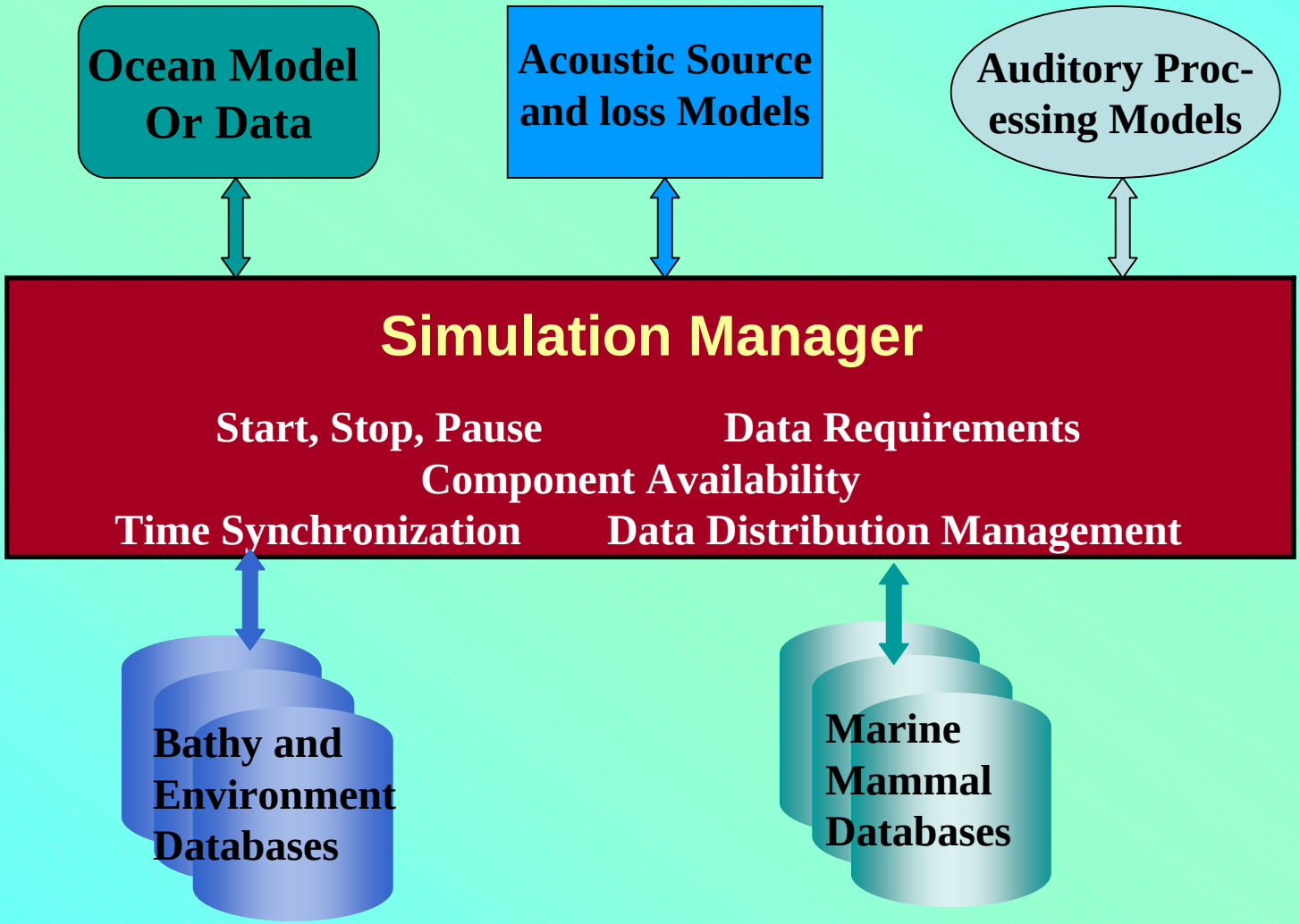
Transmission
- bottom type
- sound speed profile
- internal waves
- scatterers
- bathymetry
- others

Receiver
- position
- species
- auditory characteristics
- behavior
- others

Response
- behavioral
- TTS
- auditory damage
- injury
- mortality
- others

features to be accounted for in the model

Notional Diagram



The history of ESME

- Program initiated by ONR in June, 2000
- The team meets every six months
  - to discuss technical issues
  - to select and work test problems
- First working model and test problem: August 2001
- Alpha test on a draft EIS (Navy VAST): February 2003 (ongoing)
- Publish the ESME model in a peer-reviewed journal (Journal of Ocean Engineering): fall 2004
- ESME software and documentation publicly available: winter 2004-2005
- Further interactive development with the user and regulatory communities: 2005

ESME Goals

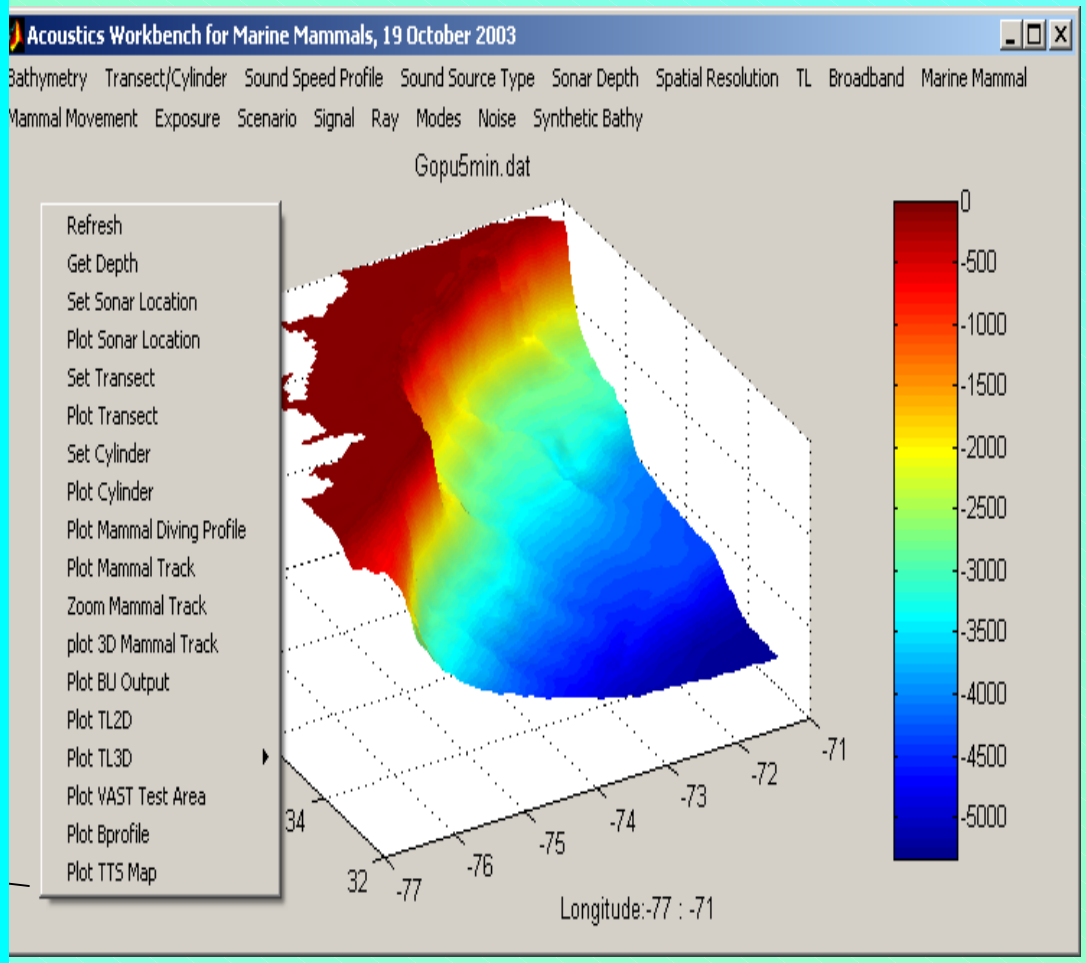
- Use the **best available science**
  - To quantify the best available science, as required by ESA, MMPA
- **capture uncertainty**
  - to enable estimation of high risk and low risk options as well as average outcomes by estimating variance in the data and model outputs
  - to enable sensitivity analysis of model components to guide research investments to reduce uncertainty
- **An integrated model**
  - All databases and model algorithms need to communicate successfully
- Provide **meaningful measures of risk**
  - express model output in a form consistent with current regulatory guidance and accepted best practices in risk assessment documents such as EA, EIS and MMPA Letters of Authorization.
- An **Update-able** model (modular organization)
  - ESME should be able to undergo modifications of the component databases, model algorithms, or output products without the need to rebuild the entire model

The ESME Team

- ONR managing program staff
  - **Marine Mammals**: Bob Gisiner
  - **Ocean Acoustics**: Ellen Livingston
  - **Ocean Dynamic Modelling**: Scott Harper
- Content Experts
  - **Sound sources**: Bill Carey; U Rhode Island
  - **Geophysics**: Jim Miller, Gopu Potty; U Rhode Island
  - **Ocean dynamic processes**: Jim Lynch, Glen Gawarkiewicz, John Colosi; Woods Hole O.I.
  - **Propagation Models**: Mike Porter, Martin Siderius; SAIC Corp.
  - **Animal Distribution and Abundance**: Jay Barlow, NOAA SWFSC; Tom Norris, SAIC Corp.; Angela D'Amico, SPAWAR; Andy Read, Pat Halpin, & Larry Crowder; Duke University
  - **Animal Diving, Movements, and Behavior**: Dan Costa, Scott Shaffer, UC Santa Cruz; Dorian Houser, Biomimetica Corp., Jim Finneran, SPAWAR Systems Center.
  - **Hearing and Physical Responses to Sound**: Darlene Ketten, Harvard Medical School and WHOI; David Mountain & Allyn Hubbard, Boston University
  - **Model Integration, User Interfaces**: Roger Hillson, Haw-Jye Shyu; Naval Research Lab

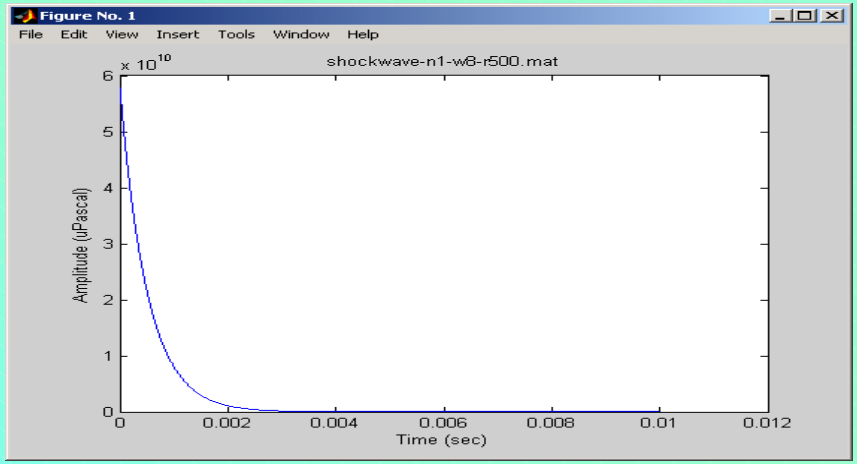
ESME Sample Menu Screen

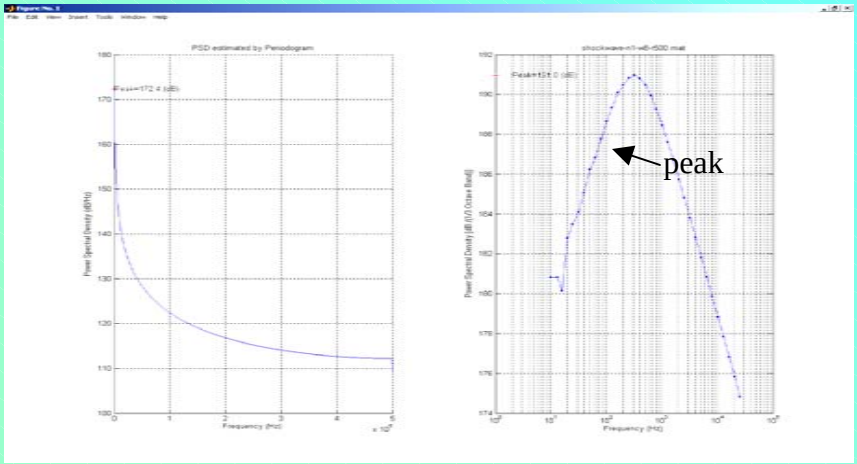
- The User Interface for the ESME Work bench consists of 5 major parts:
  1. Main menus – select major actions for running the workbench.
  2. Pull-down menus in the main menu – for selecting different sub-actions within a main menu.
  3. Option menus in a pull-down menu – select different options for sub-actions.
  4. Pop-up menus in an option menu – prompt the user for parameters.
  5. Graphics Context menu – mouse driven plotting and data entry.



The graphics context menu

8 pounds of TNT, at a range of 500 meters

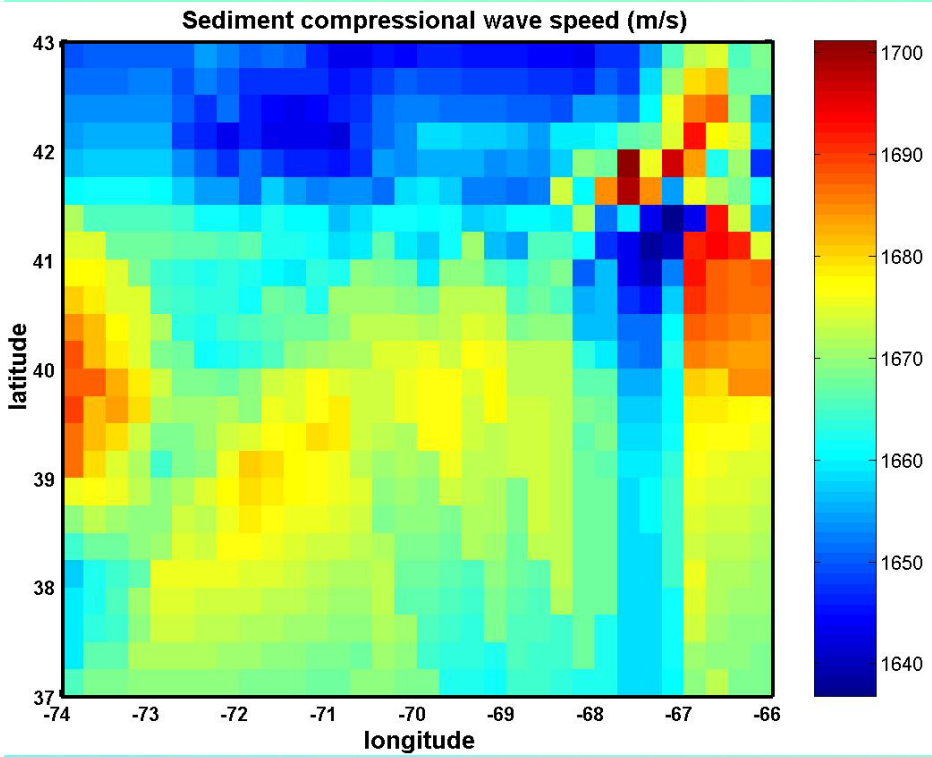


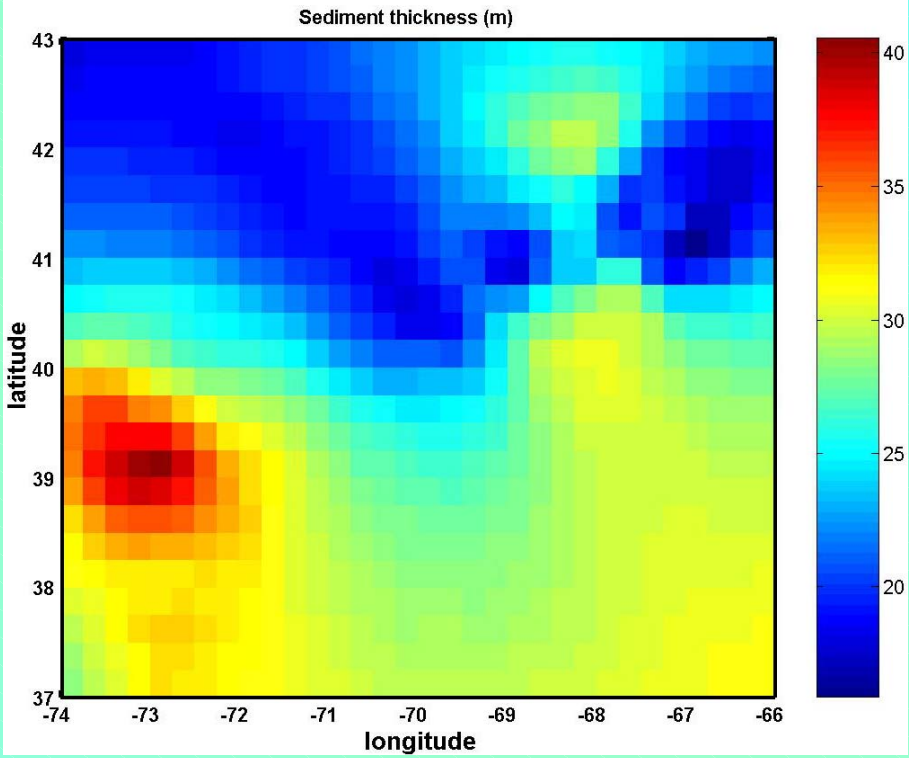


- Left – Simulated shock wave (based on Arons' shock wave equation).
- Right – power spectrum in linear frequency scale and Energy Flux Density in 1/3-Octave bands in logarithmic frequency scale. Maximum Energy is 191 dB at 300 Hz.

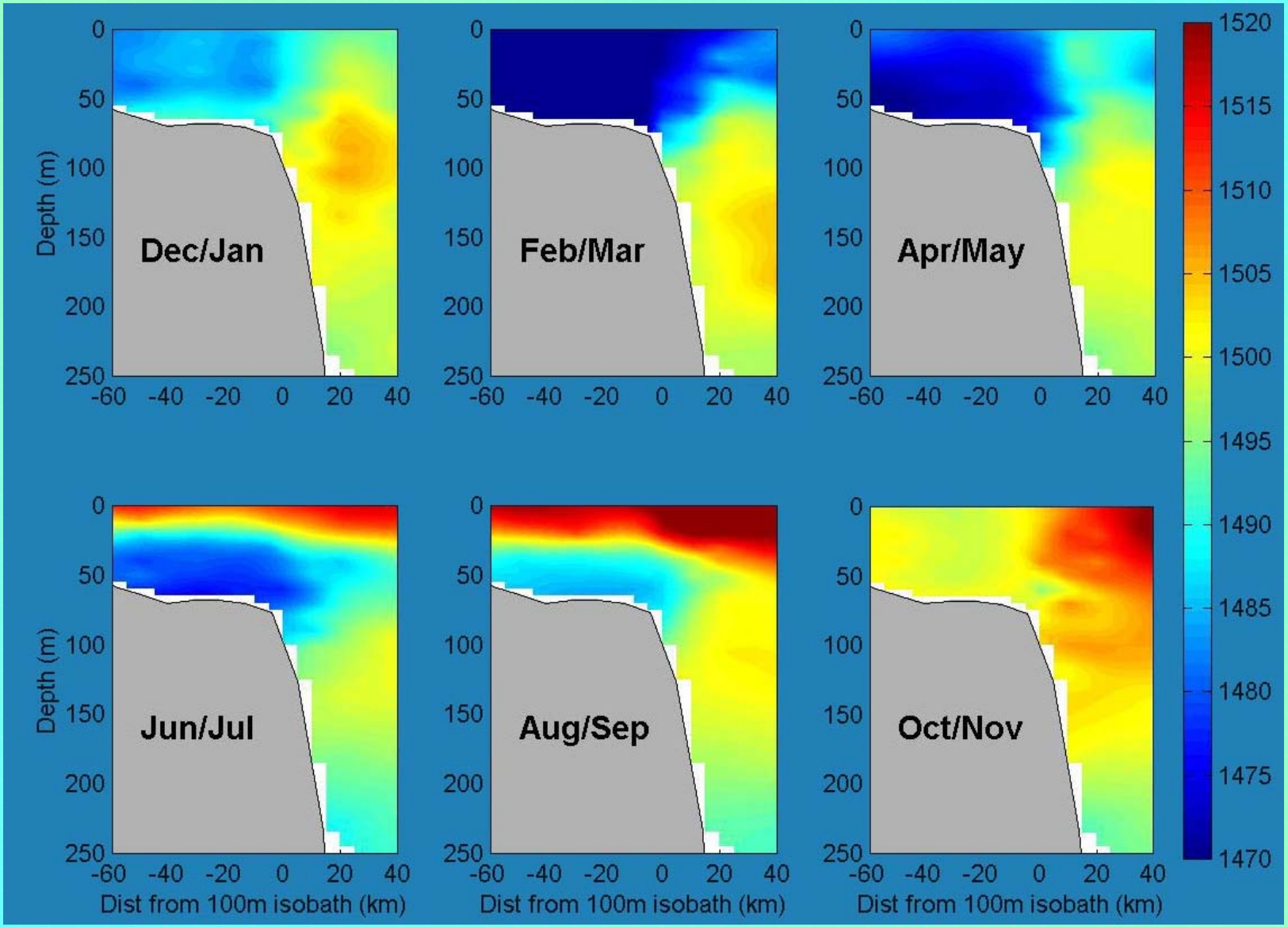
Sediment Compressional Wave Speed
(Middle Atlantic Bight Region)

Compressional wave speed and sediment thickness generated using the ESME geoacoustic module.





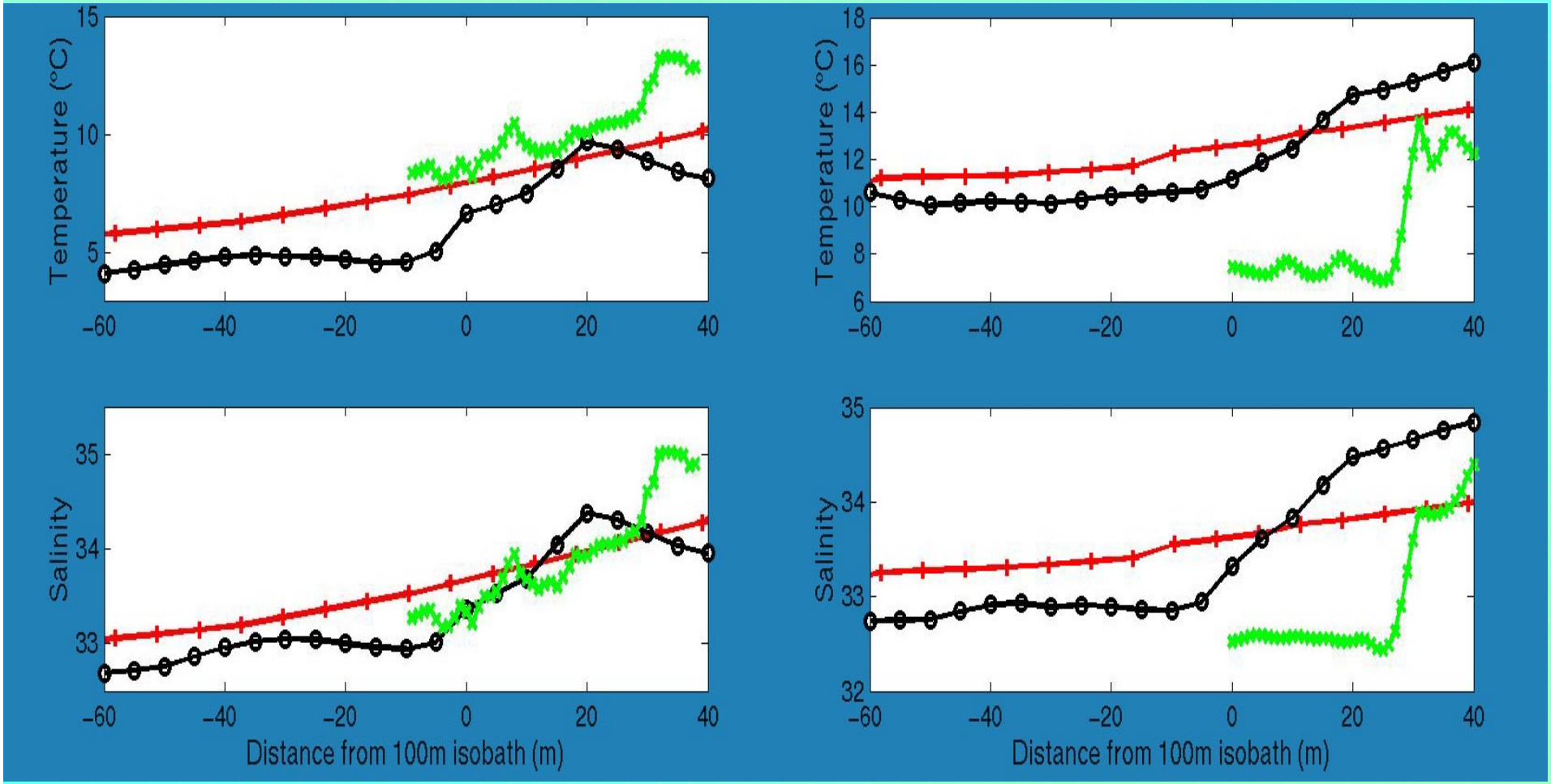
MAB "Feature Model"



MODAS / Model / PRIMER

(MAB cross-frontal T,S @ 40m)

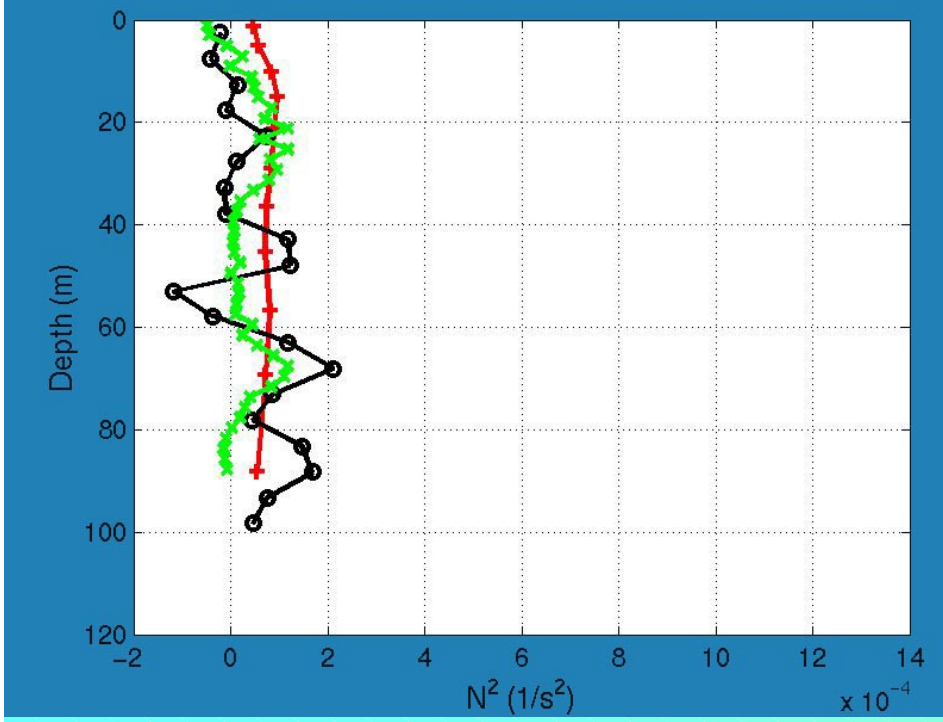
Feb/Mar Aug/Sep



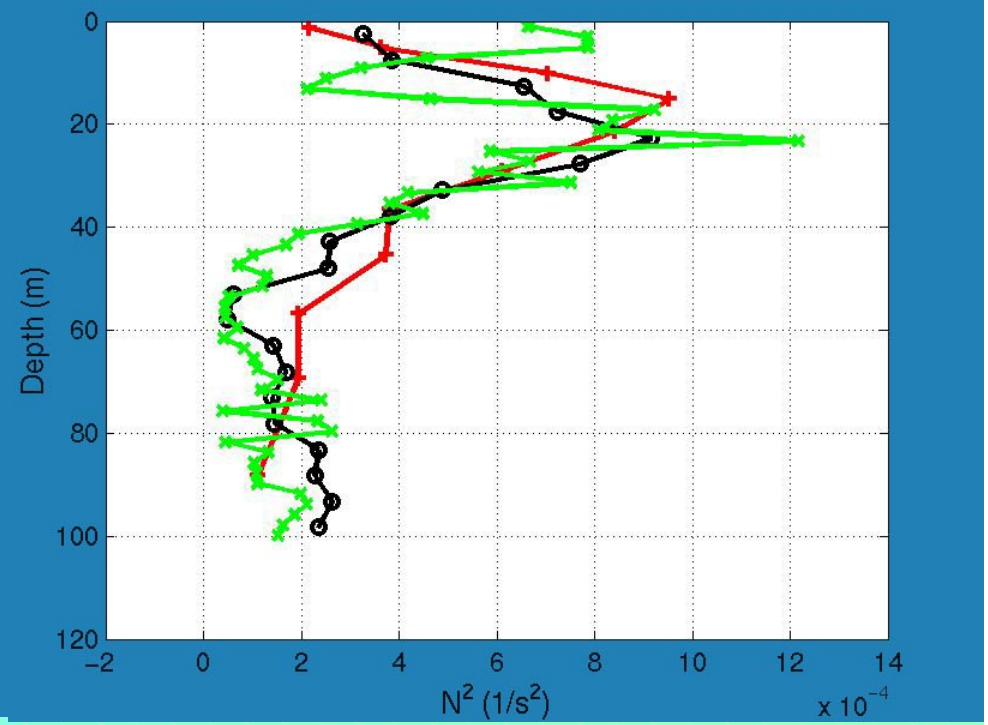
MODAS / Model / PRIMER

(stratification @ 100m isobath)

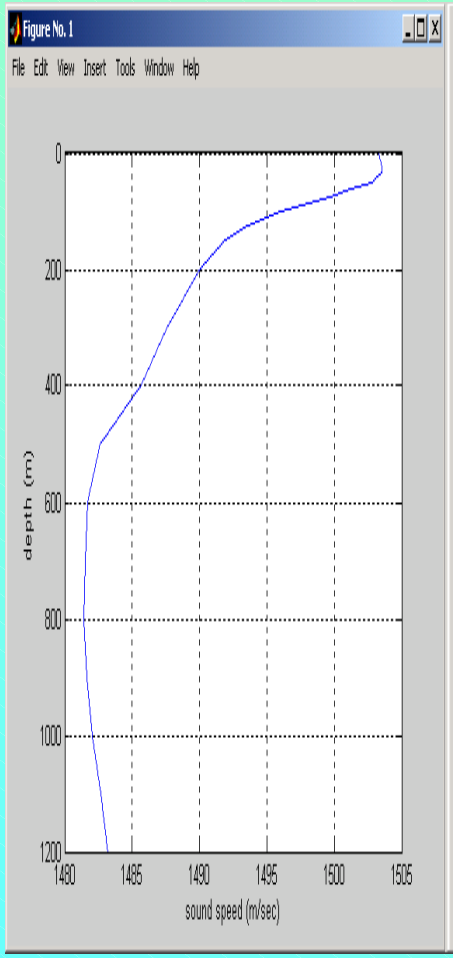
Feb/Mar



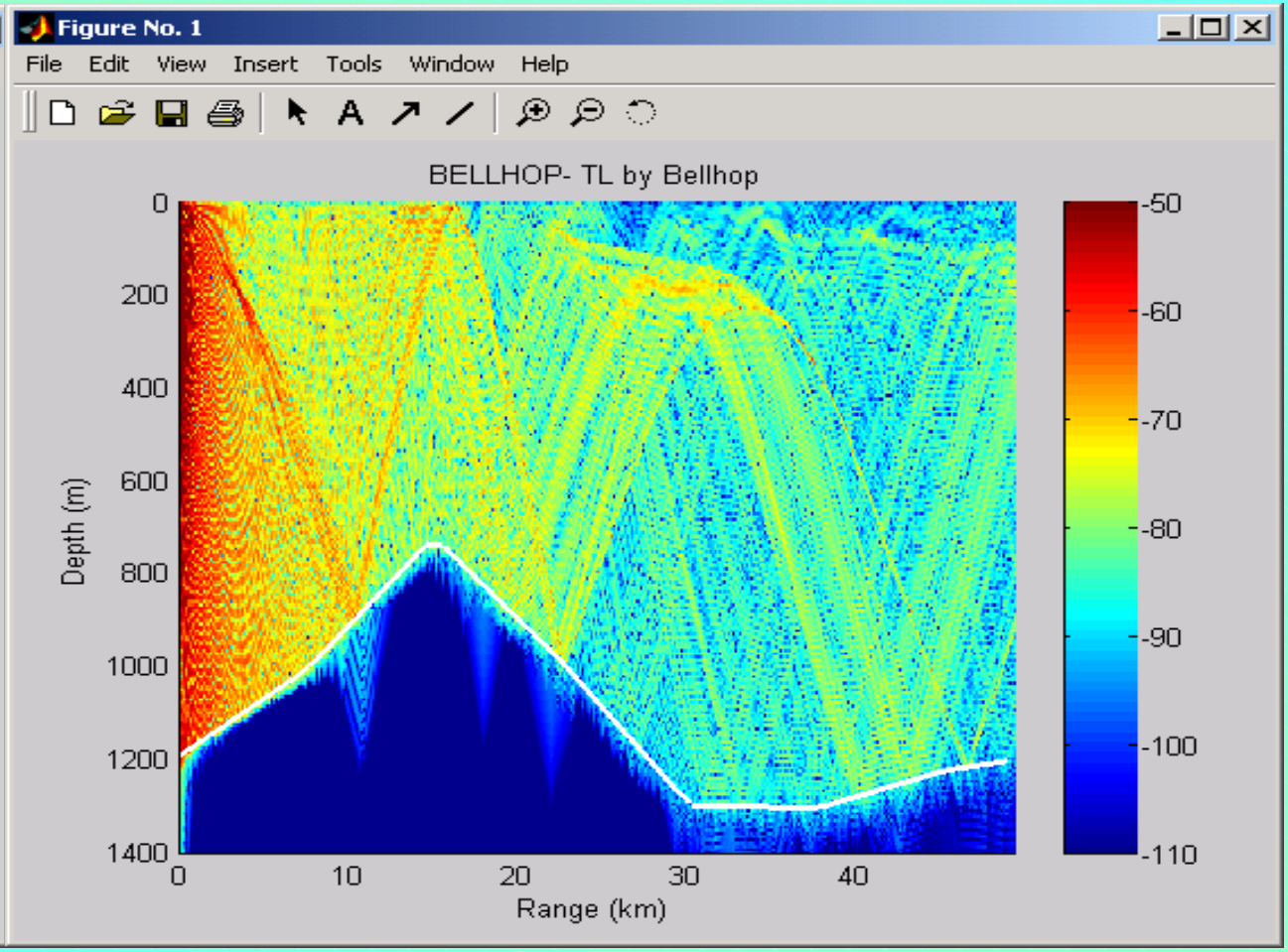
Aug/Sep



Underwater Acoustic Propagation

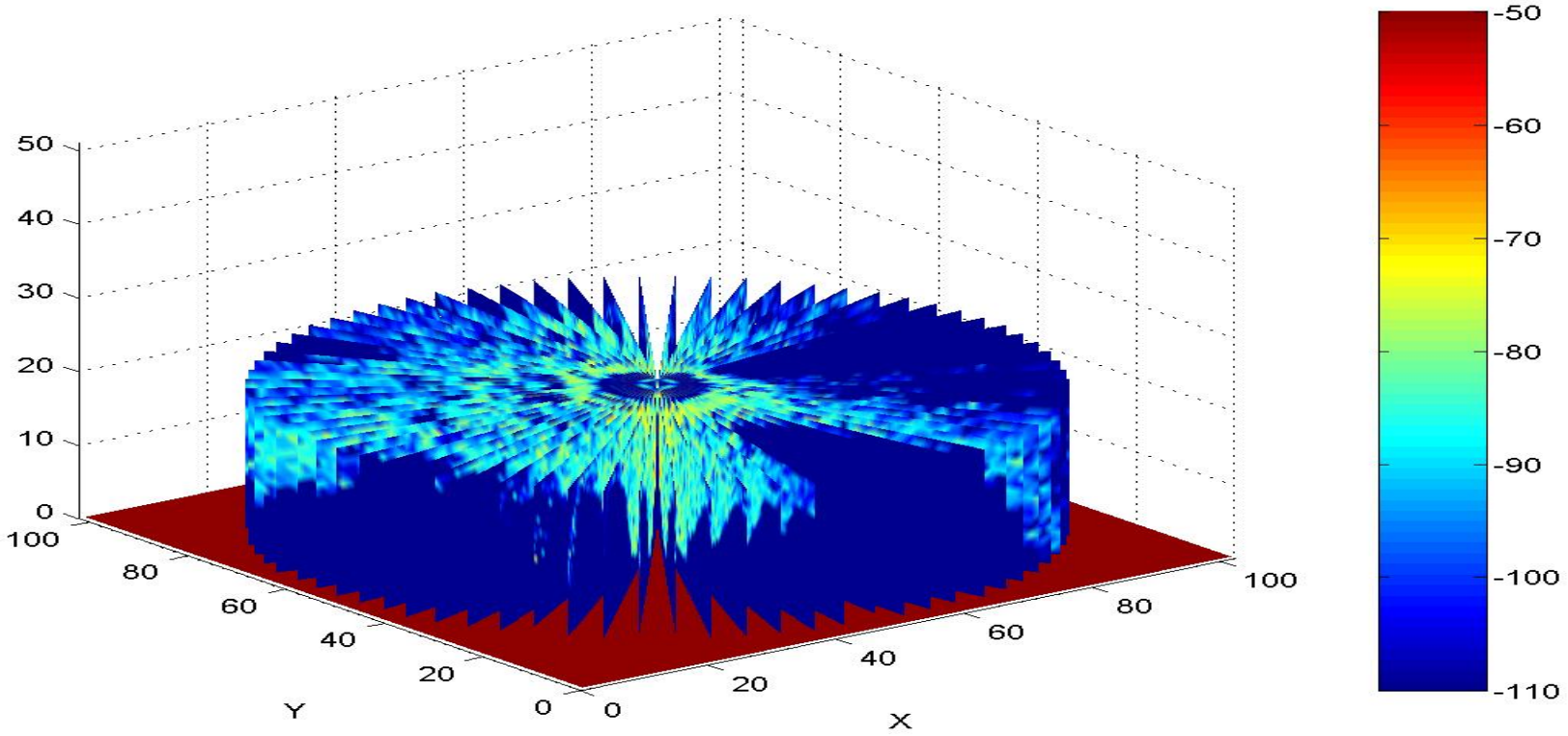


Sound speed profile

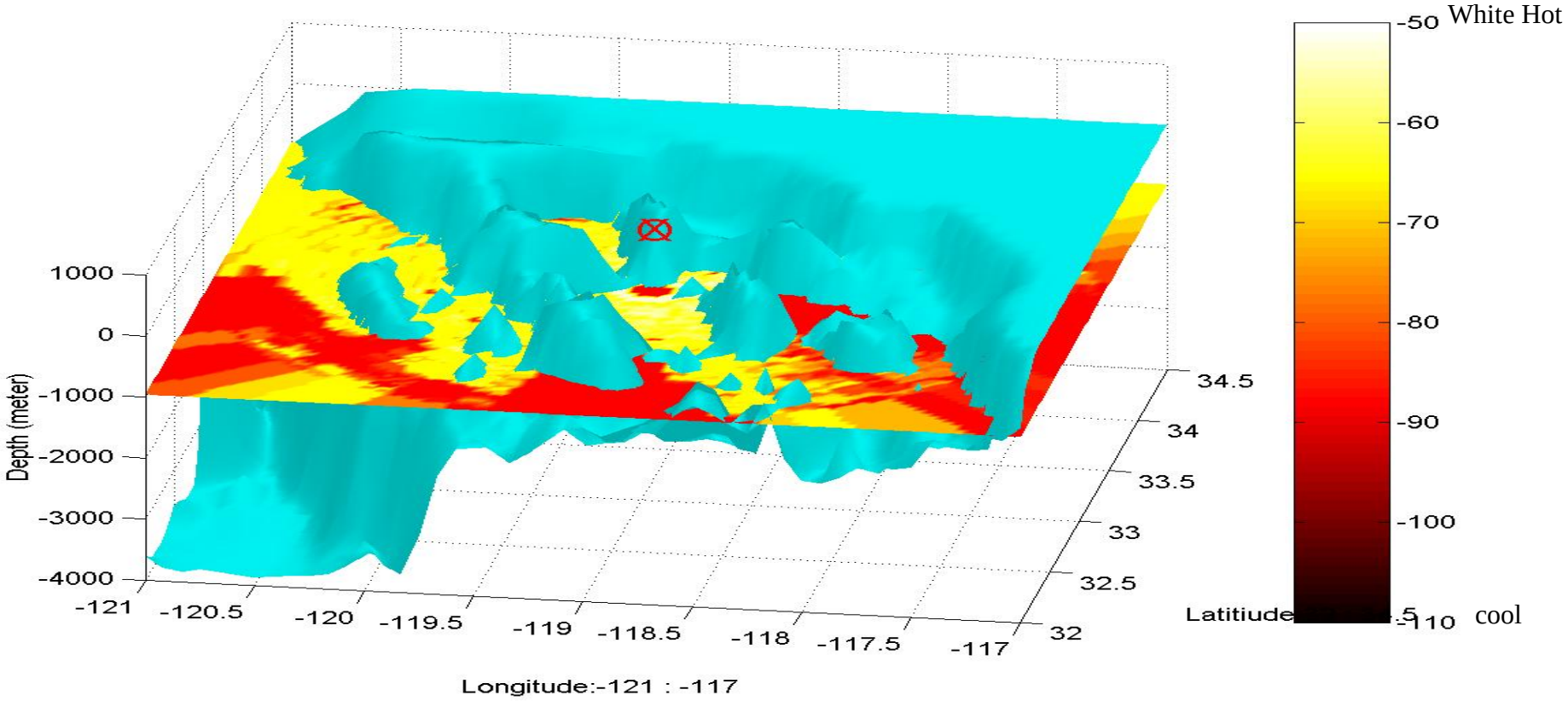


for a look at various TL models visit http://oalib.saic.com/

A 3-D display of Transmission Plot



Horizontal Slice with Bathymetry



The kinds of problems we talk about in ESME

- Roger:

- I have encounter several cases that are not suitable for Bellhop. One of the example is a shallow surface duct (with depth of 20 m) and sound source with frequency of 400 Hz (i.e. wavelength is about 3.75 m).

- According to Mike, Bellhop requires 10 wavelength in the water column.
- When the surface duct is about 20 m deep, the lowest frequency to run
- with Bellhop will be 750 Hz. Yet, I saw many surface duct cases with
- even shallower depth in all of the three test sites (Virginia Capes, Mid
- Atlantic Bight, and Southern California Bight).

- Currently, Bellhop is the only propagation code that we used to generate
- received time series. Clearly, we need a second method to compliment
- Bellhop; otherwise, the result on TTS estimation will not be reliable. The second method will be using Fourier Synthesis with either Kraken or PE.

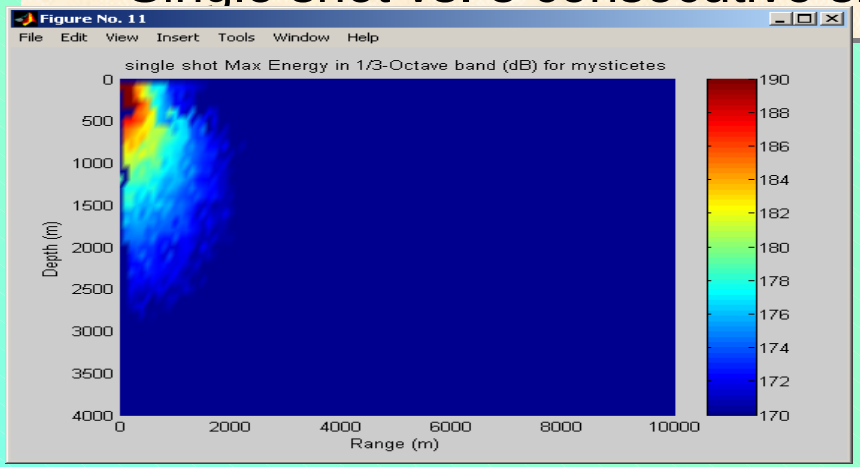
- Mike and Martin are working on a tool that will automatically pcik the
- proper propagation model for ESME. But, that will not solve the problem
- of producing received time series. I need their support to do so.

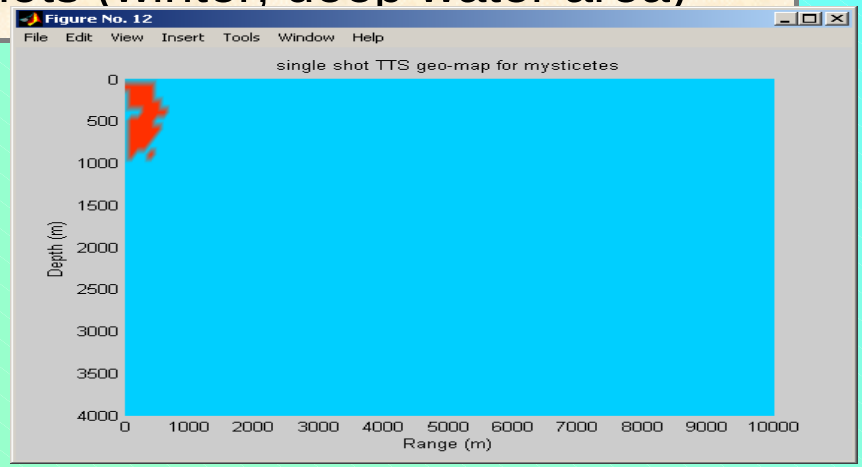
- Fortunately, in our paper, the case that we shown has a surface duct of
- 200 m deep and we are using 3500 Hz of sound source.

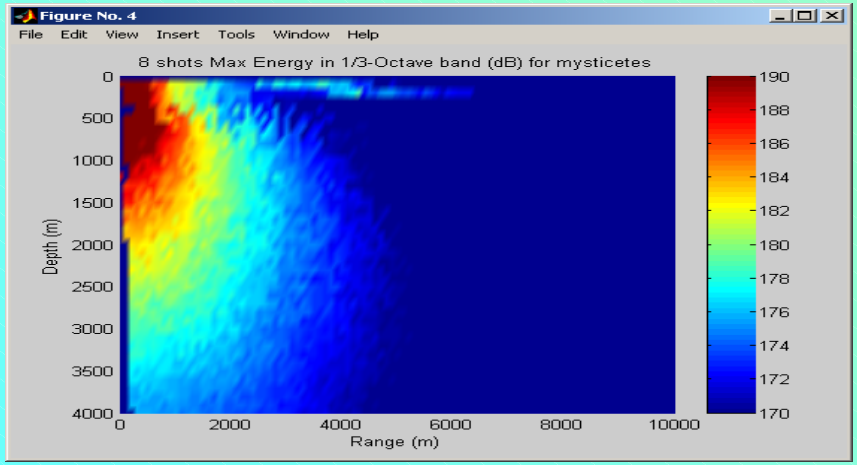
- Haw-Jye

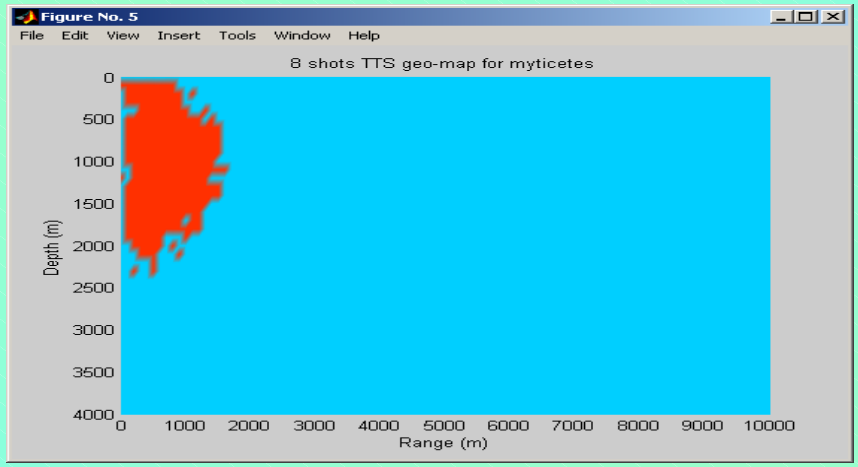
Model Predicted Sound Field

Single shot vs. 8 consecutive shots (winter; deep water area)







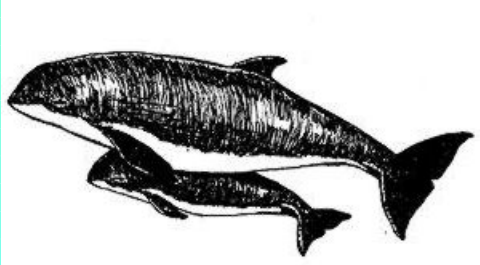


Red area indicates predicted ZOI of TTS.

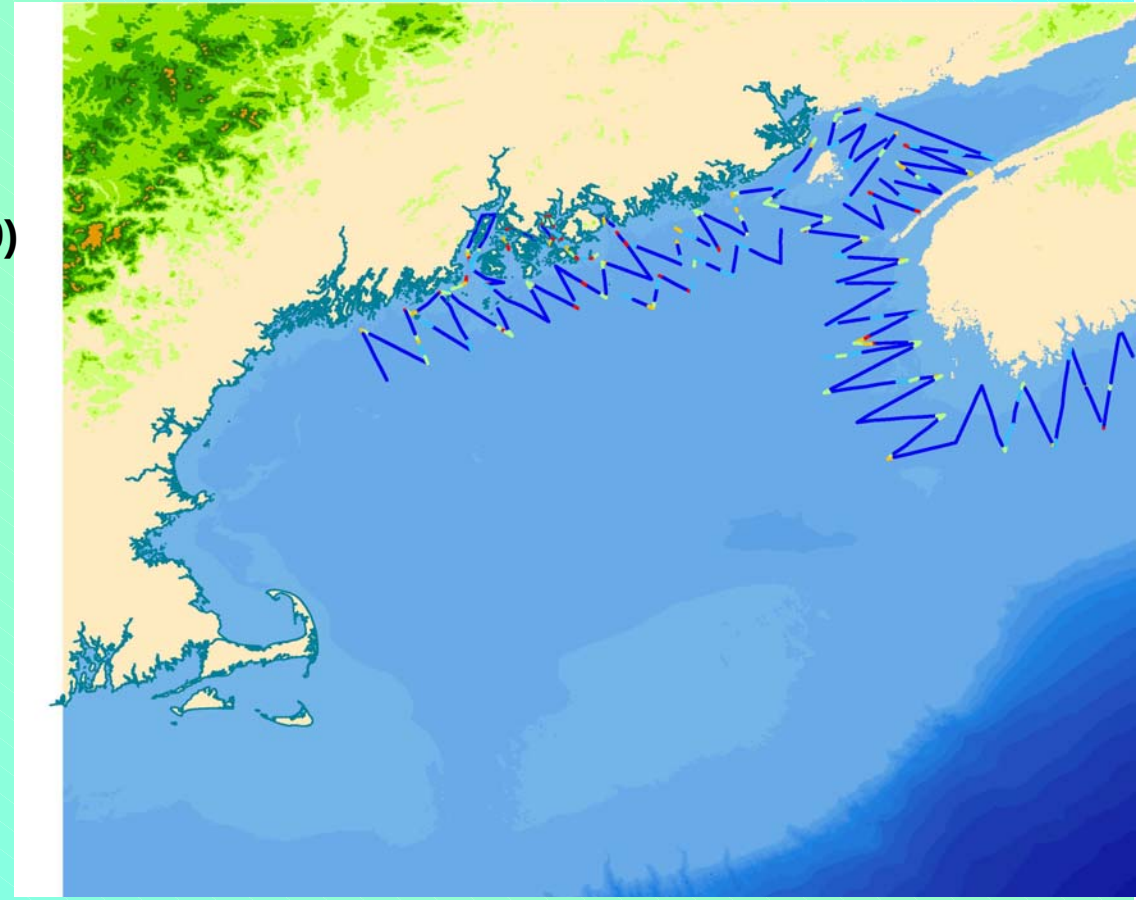
Example Data: Cruise Survey

Effort Data

Time duration effort (Fall 1999)

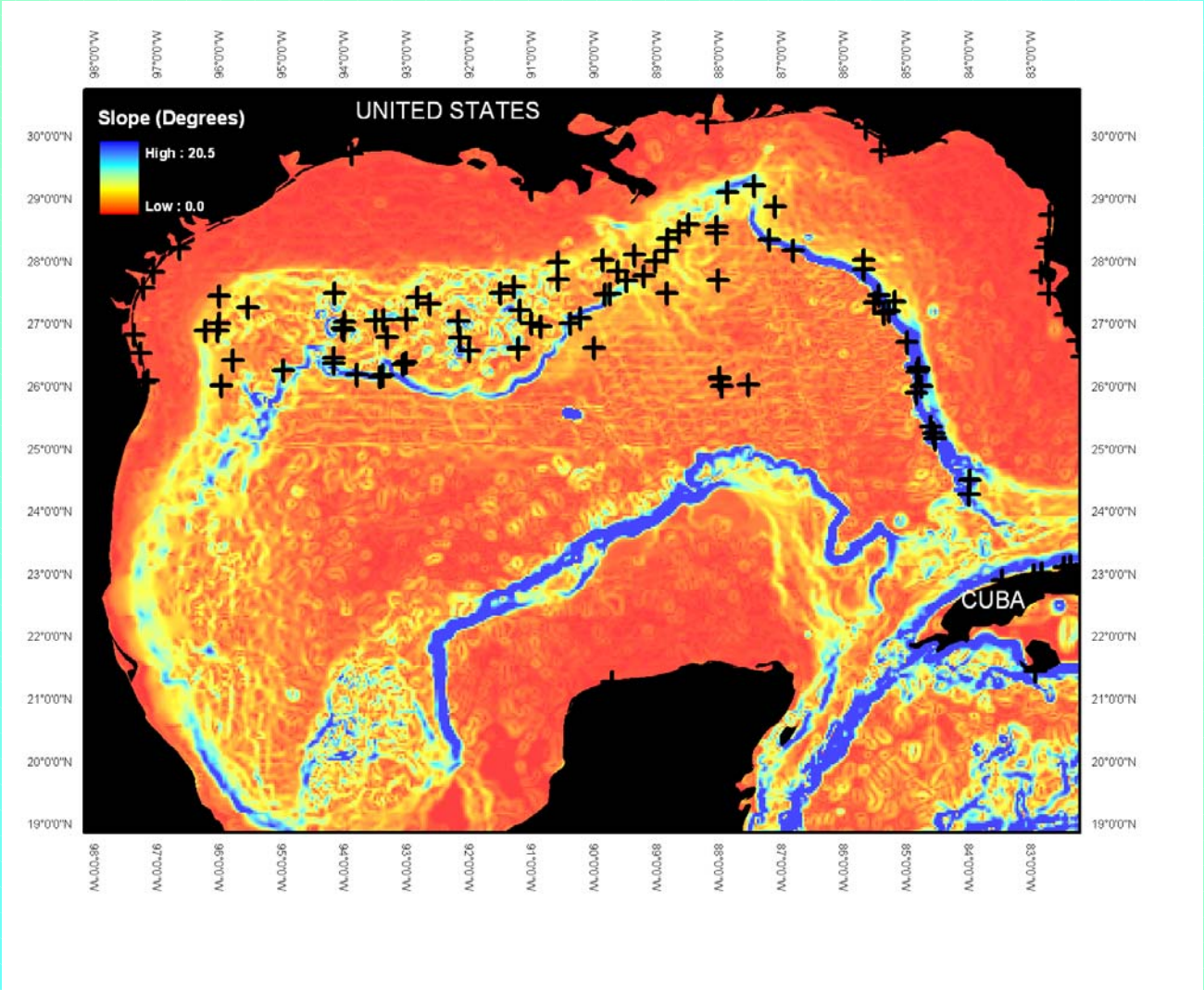


Ancillary data on effort, and survey conditions are necessary to allow for the proper statistical treatment of the data



Data source: Debi Palka, NMFS

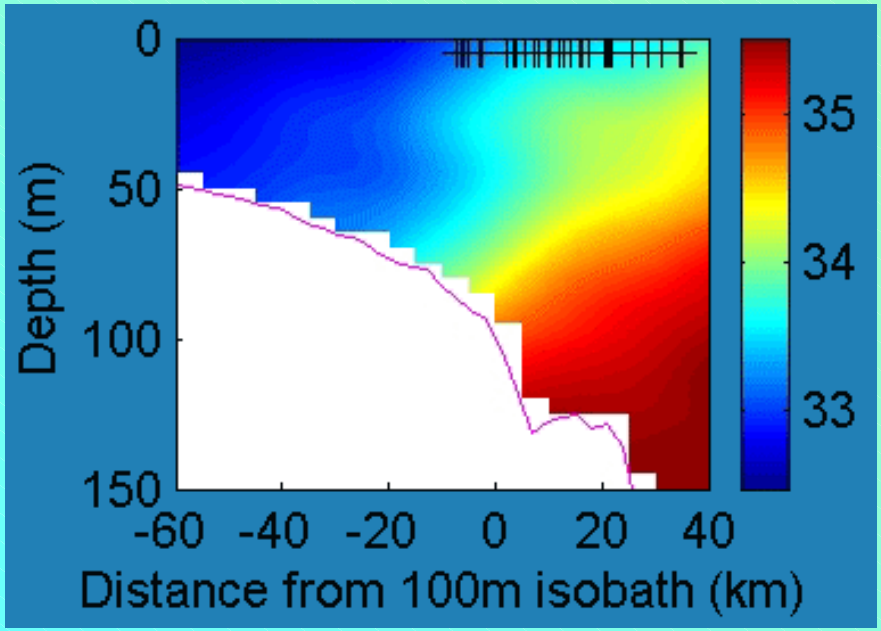
Application of Beaked Whale Data to Environment
Gulf of Mexico - Slope



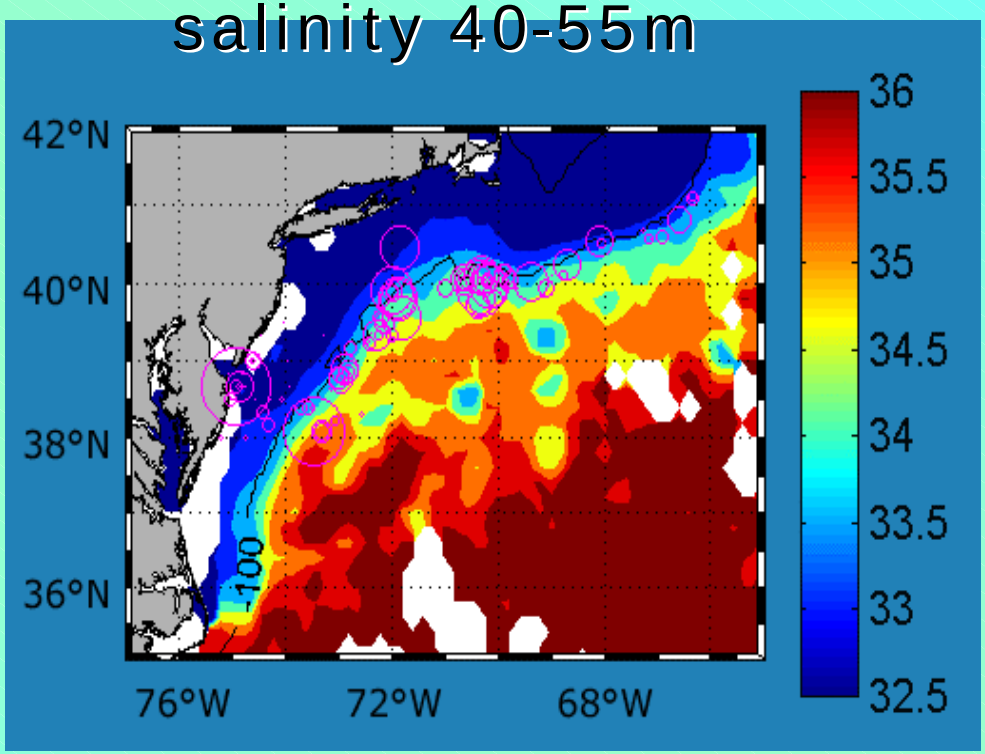
Tursiops positions from D Palka

1998 July-August sighting survey

Cross-section mean salinity

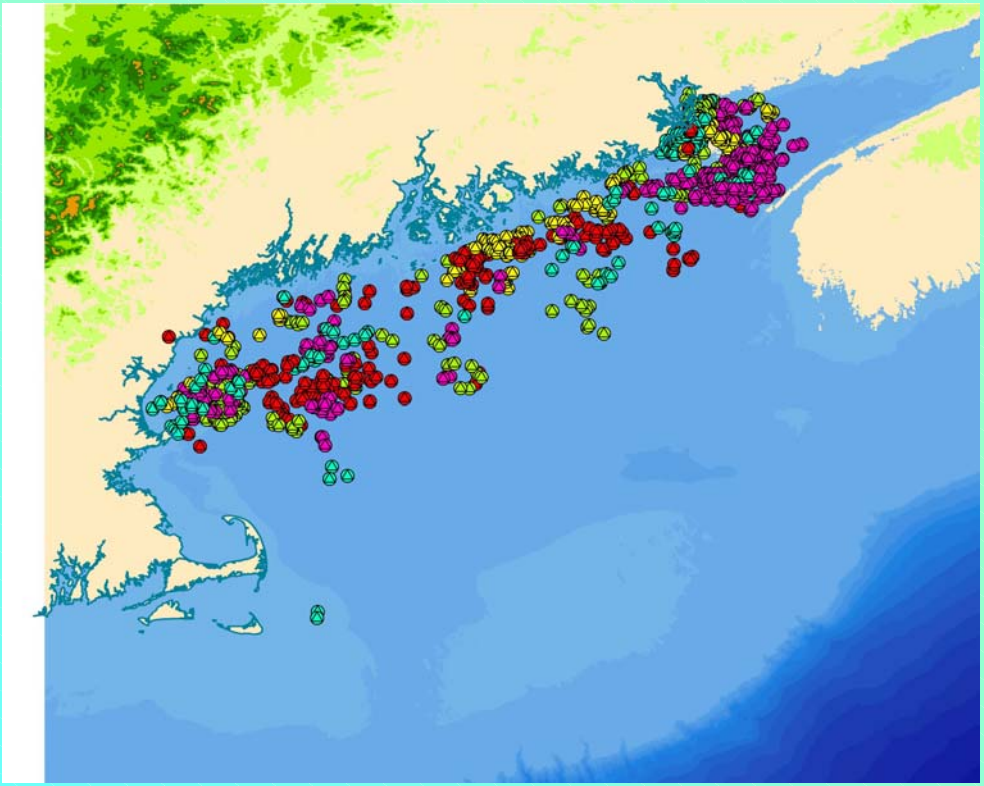


Planview mean salinity 40-55m



Example Data: Telemetry

Harbor Porpoise



Visualization

- ***points***
- ***inferred tracks***
- ***animation***

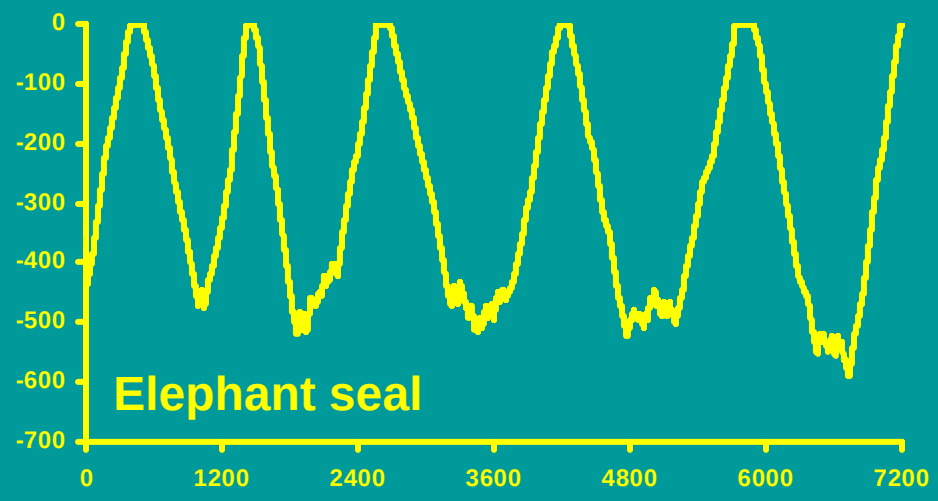
Data QC (Argos)

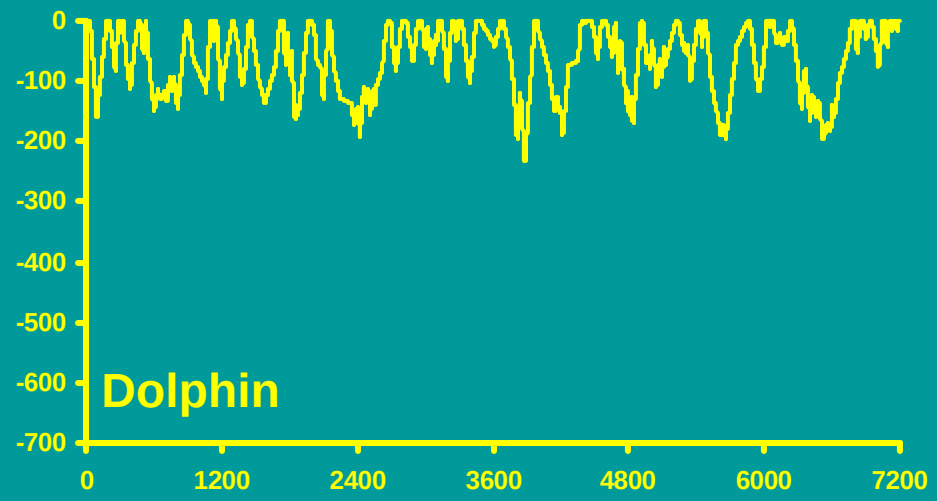
3 = <150m
2 = >150 - < 350m
1 = >300 - < 1000m
0 = > 1000m

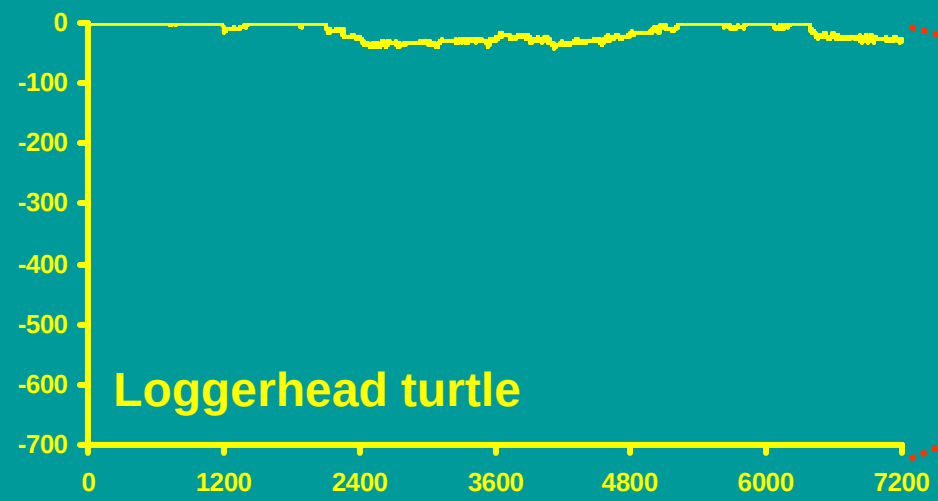
5 animals tracked as point observations over time (Fall 1999).

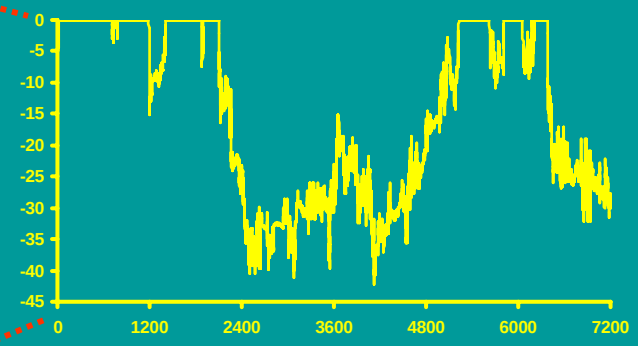
Data source: Read and Westgate, Duke University

Dive Emulation

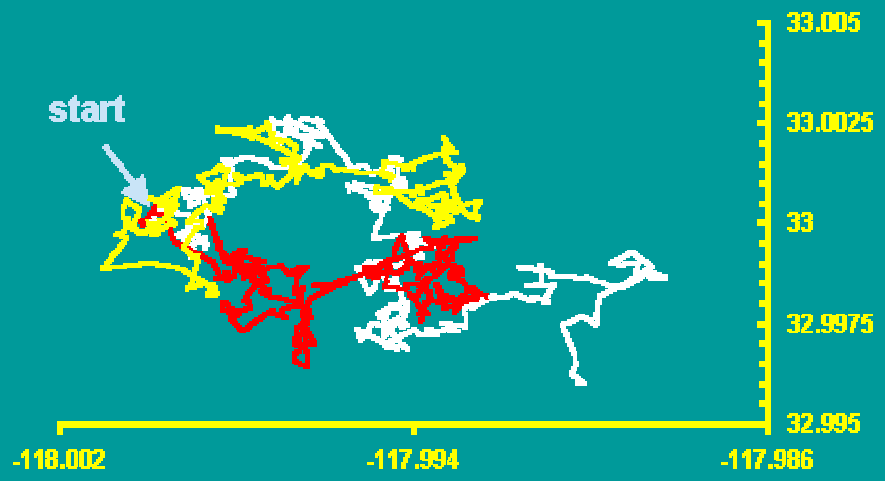






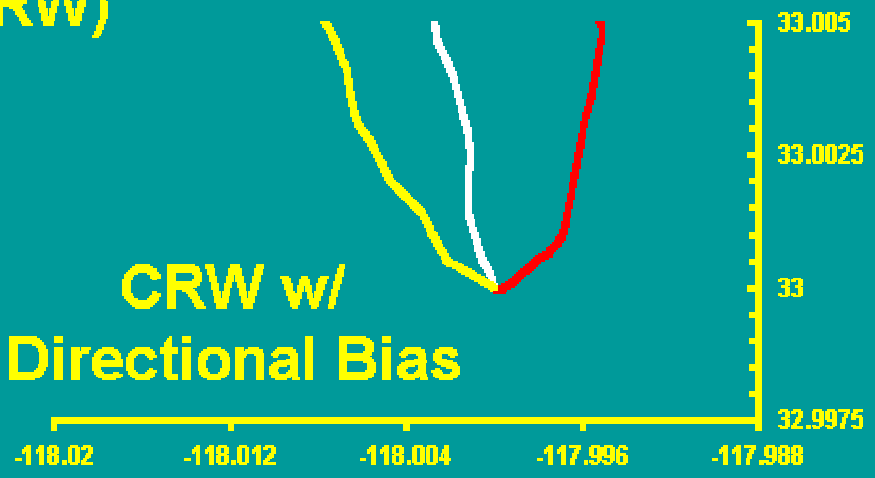


Directional Travel



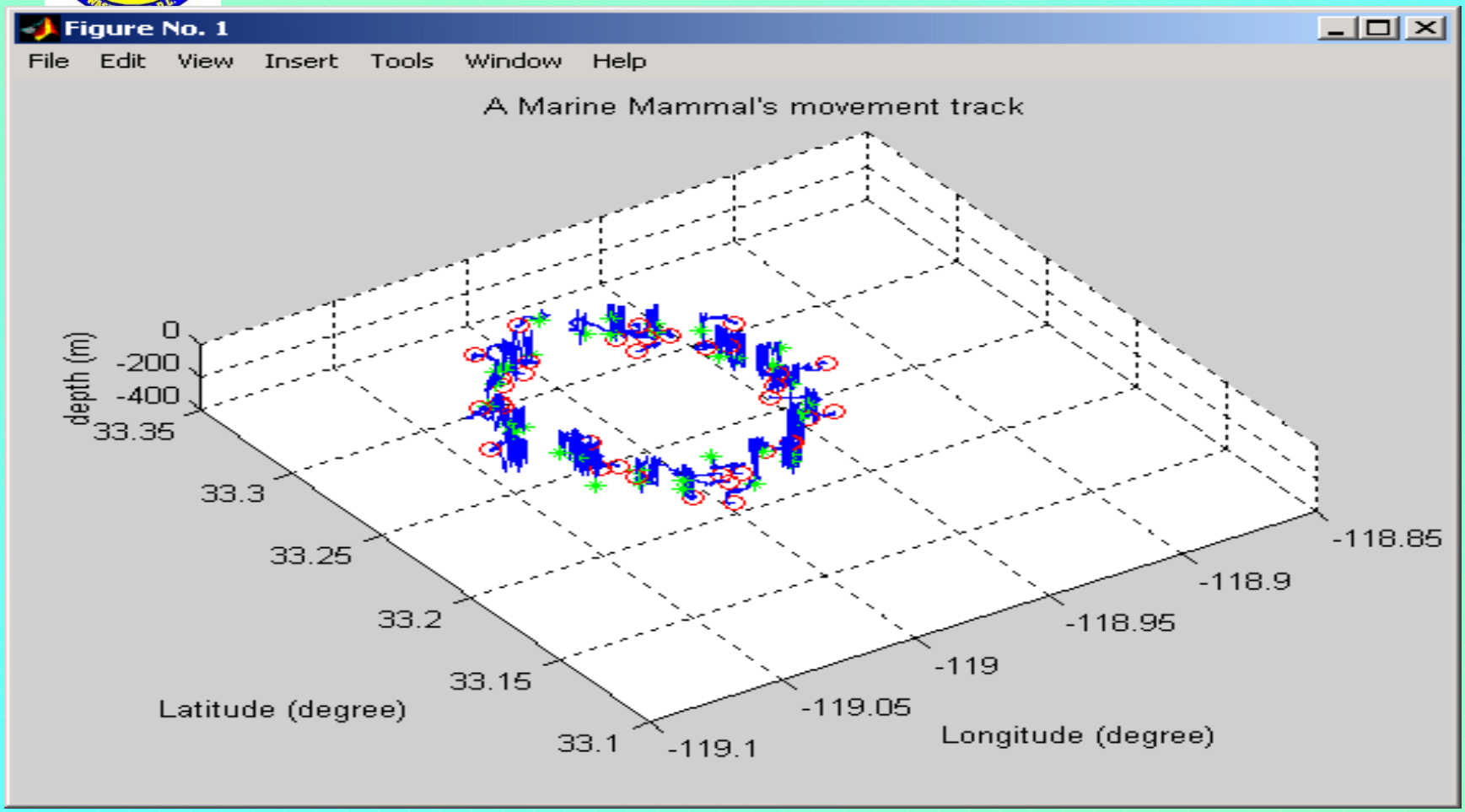
Random Walk (RW)

Correlated RW (CRW)

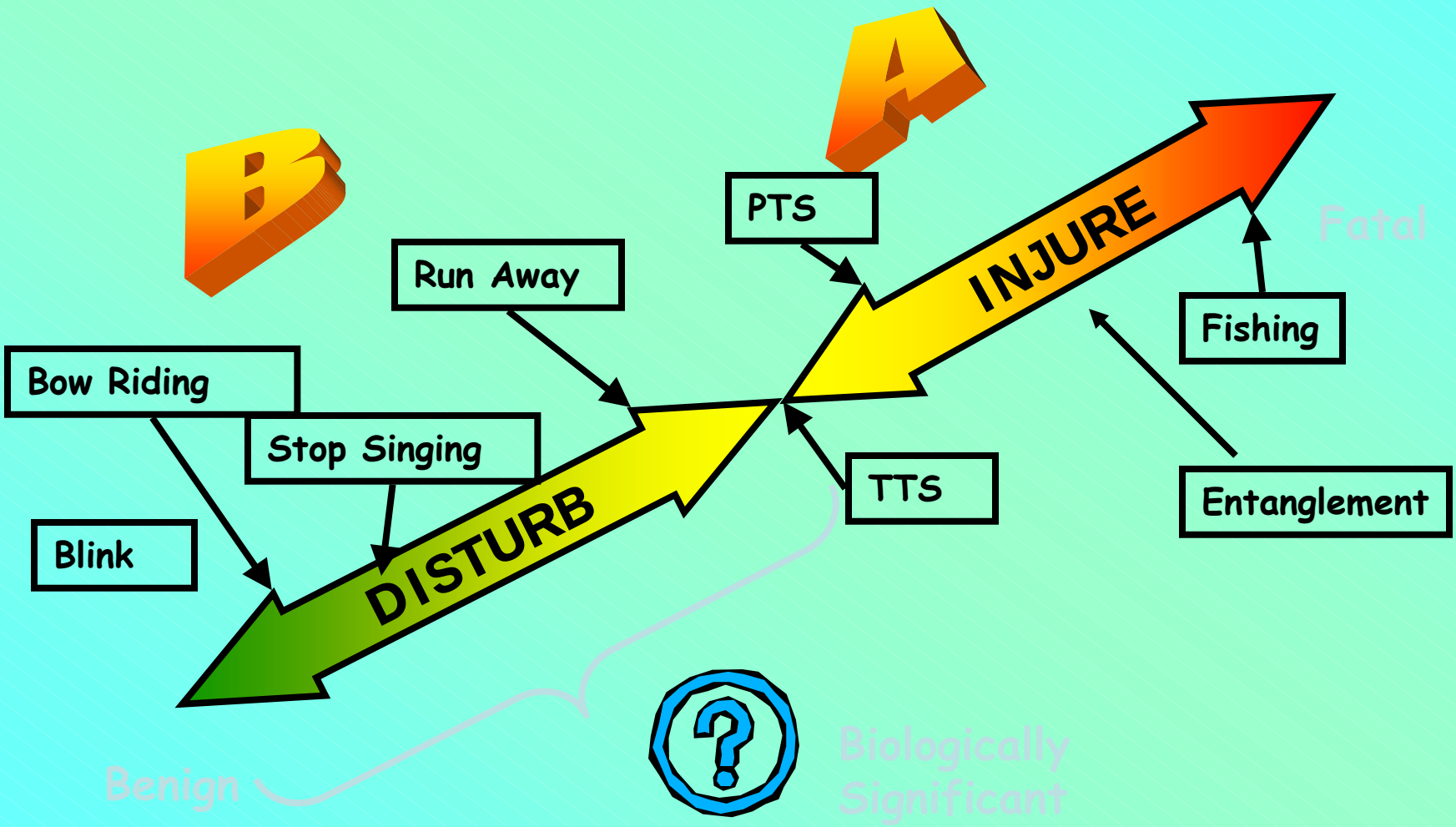


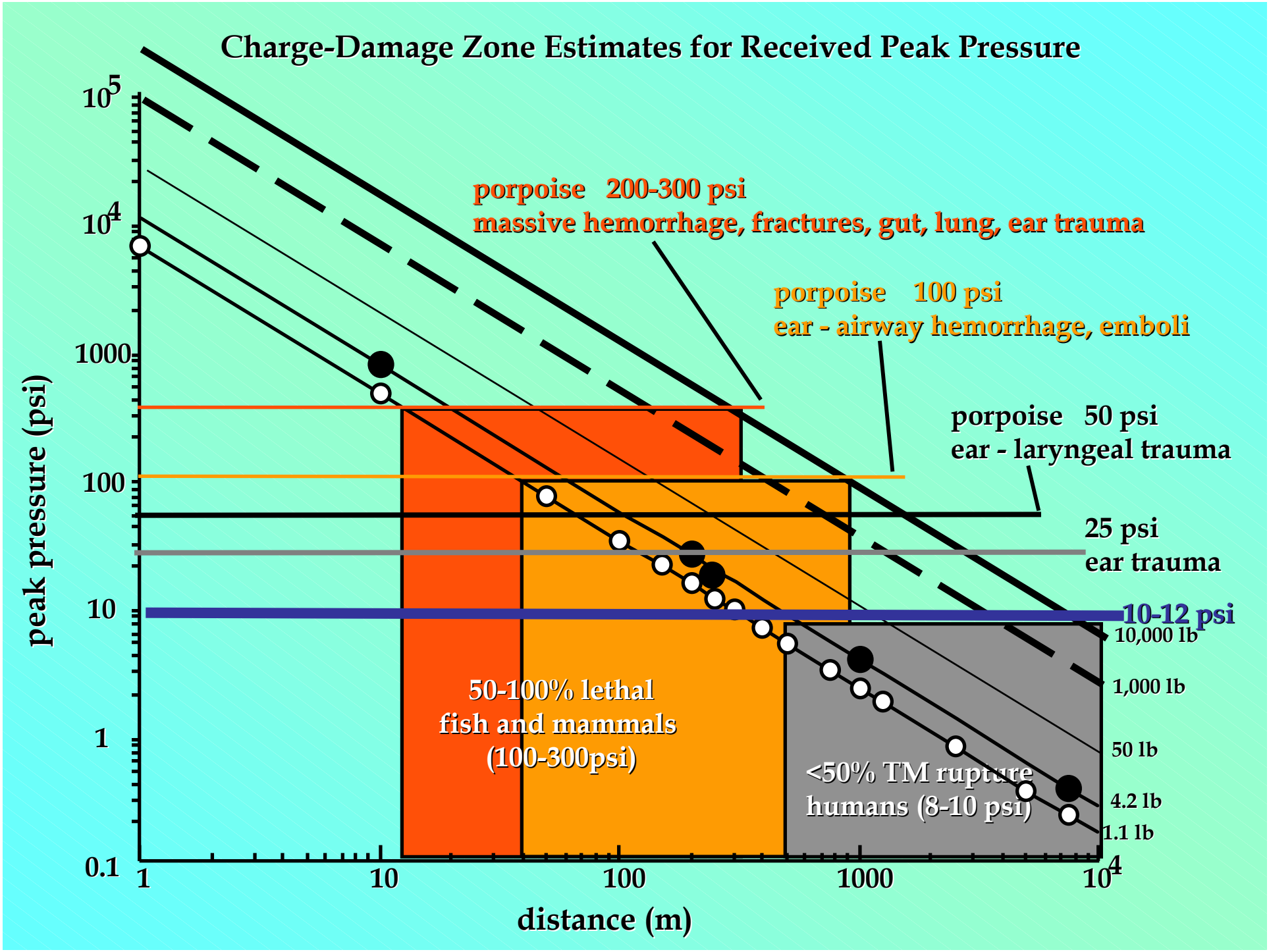
CRW w/ Directional Bias

Another 3-D plot of the simulated marine mammal tracks (random movement)

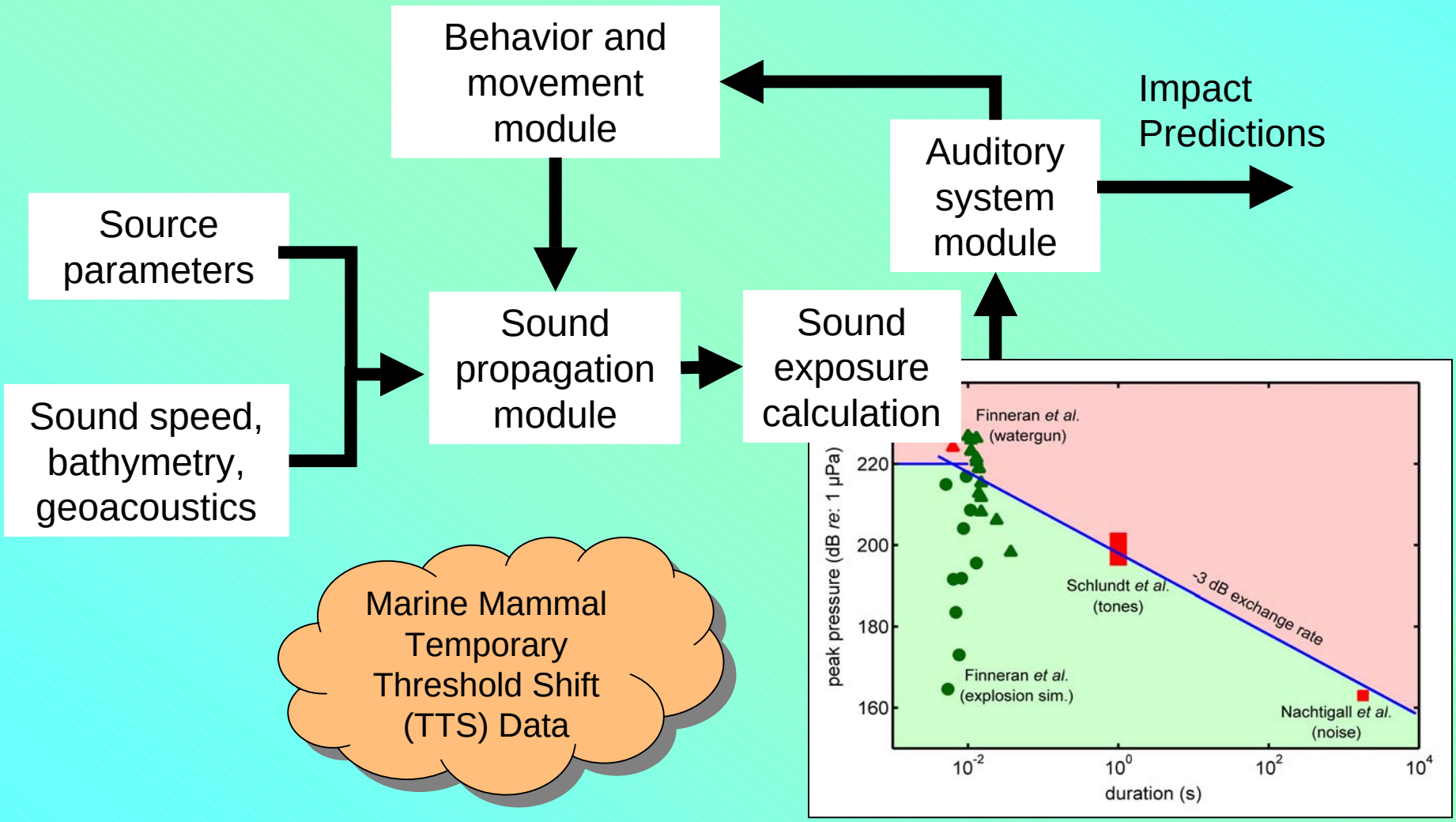


Harassment Continuum



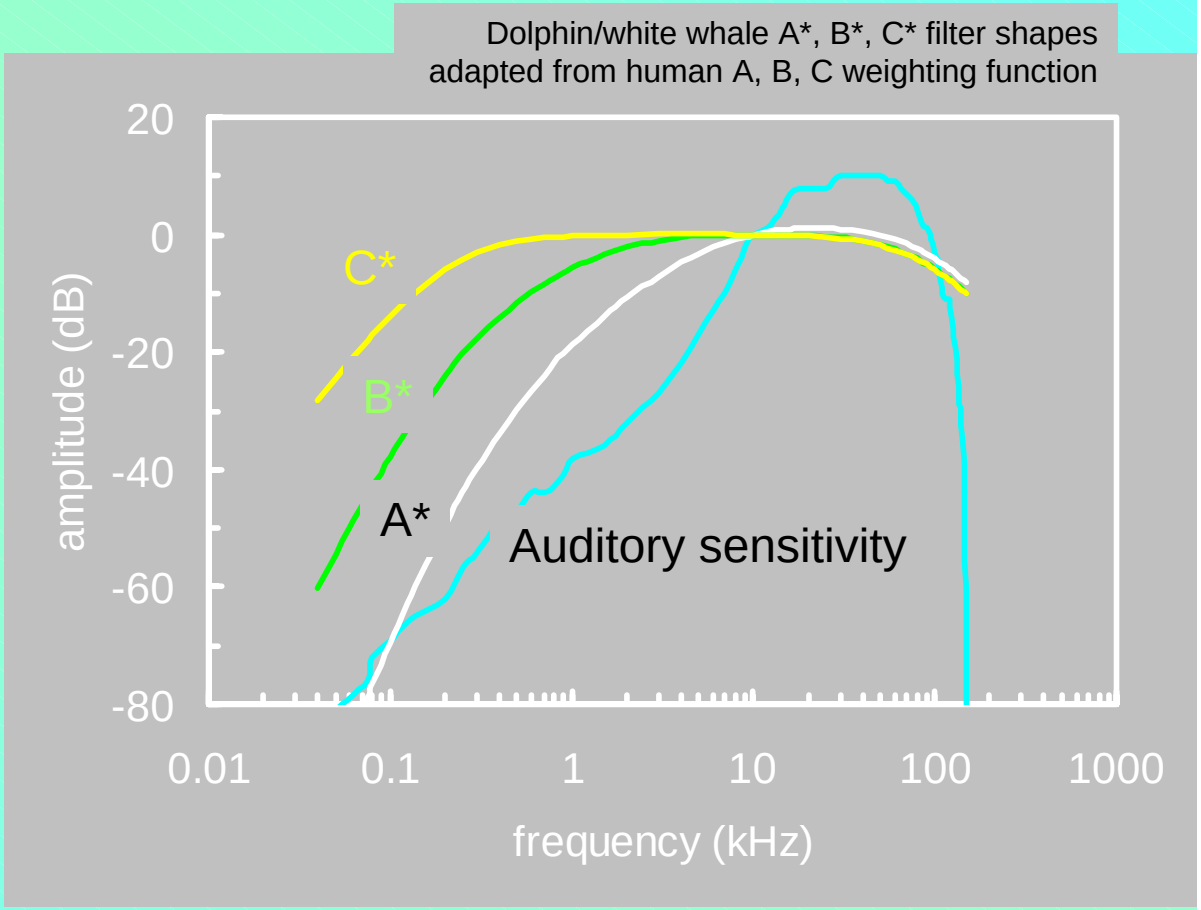

Charge-Damage Zone Estimates for Received Peak Pressure
porpoise 200-300 psi
massive hemorrhage, fractures, gut, lung, ear trauma
porpoise 100 psi
ear - airway hemorrhage, emboli
porpoise 50 psi
ear - laryngeal trauma
25 psi
ear trauma
10-12 psi
50-100% lethal
fish and mammals
(100-300psi)
<50% TM rupture
humans (8-10 psi)
10,000 lb
1,000 lb
50 lb
4.2 lb
1.1 lb
peak pressure (psi)
distance (m)
0.1
1
10
100
1000
10^4
10^5

Effects of Sound on the Marine Environment (ESME) Components



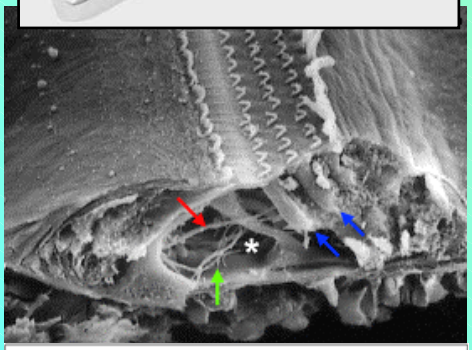
Potential Weighting Functions

- Adapt human A, B, C-weighting functions?
  - Compare human audiogram with dolphin/white whale audiograms
  - Derive frequency scaling parameters
  - Example, C-weighting parameters
    - Human = 20.6 Hz, 12.2 kHz
    - *Tt*, *Dl* = 200 Hz, 100 kHz
  - Normalize to 10 kHz

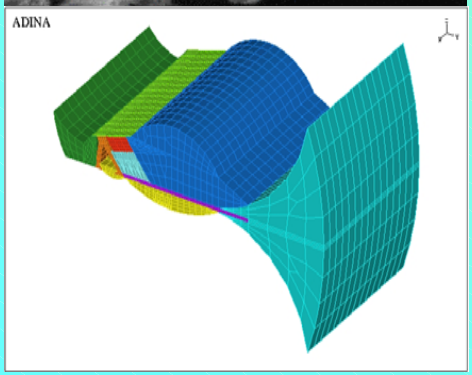


Ear Modeling
(Ketten, Mountain, Hubbard)

CT scan and 3-D imaging

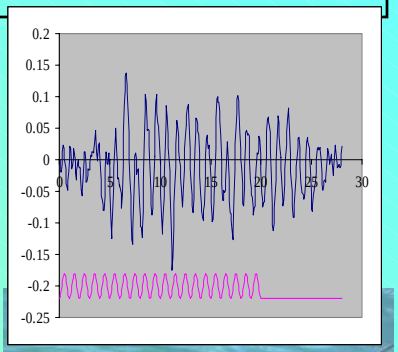


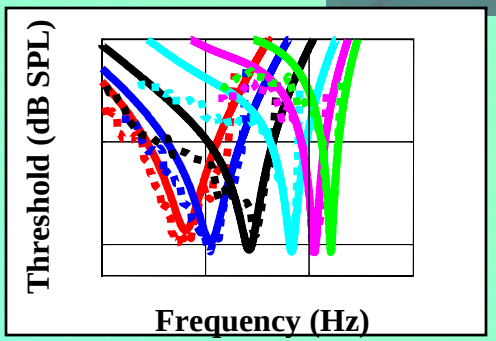
Measurement of fine structure of the inner ear



Mathematical models of auditory transduction based on measured anatomy and comparison with other species

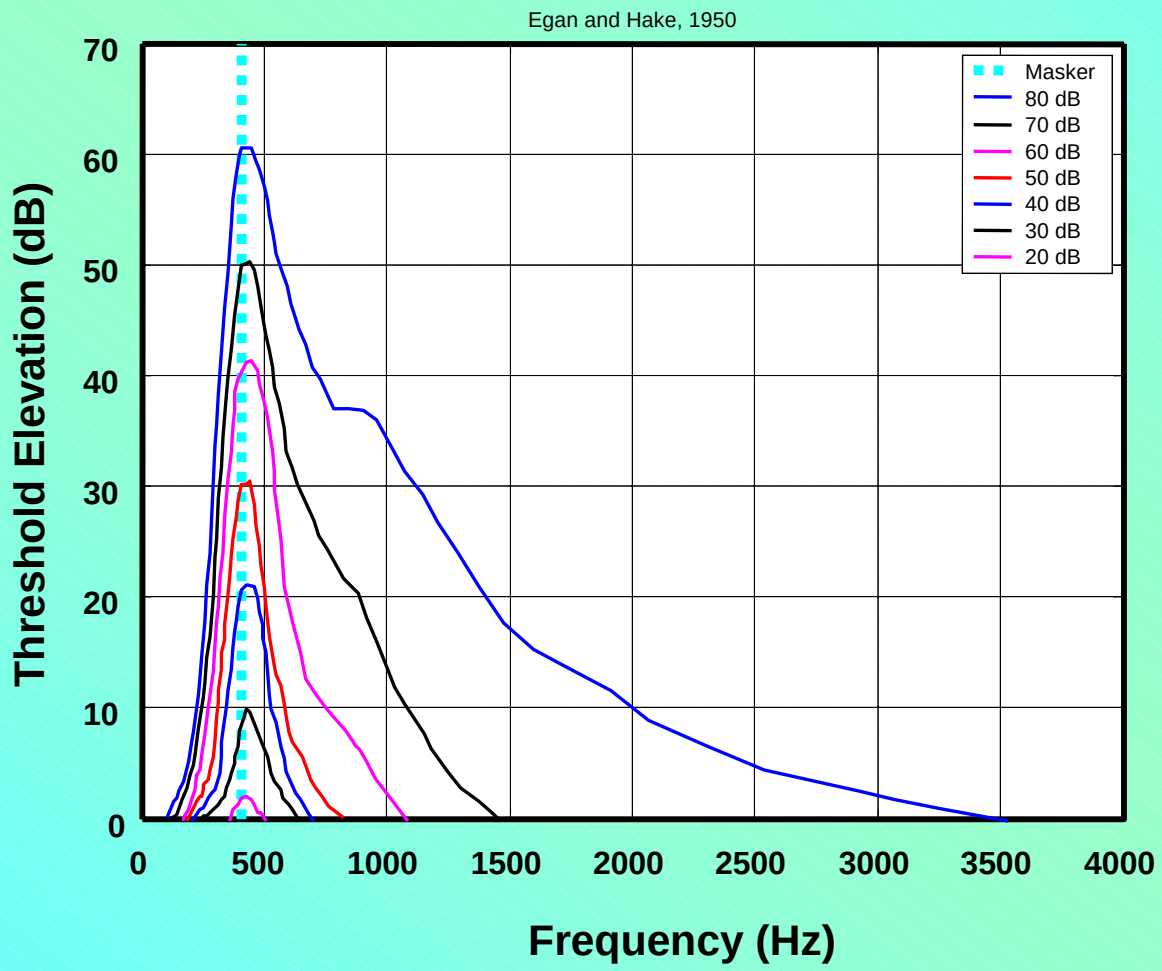
Measures of hearing from auditory evoked potential methods



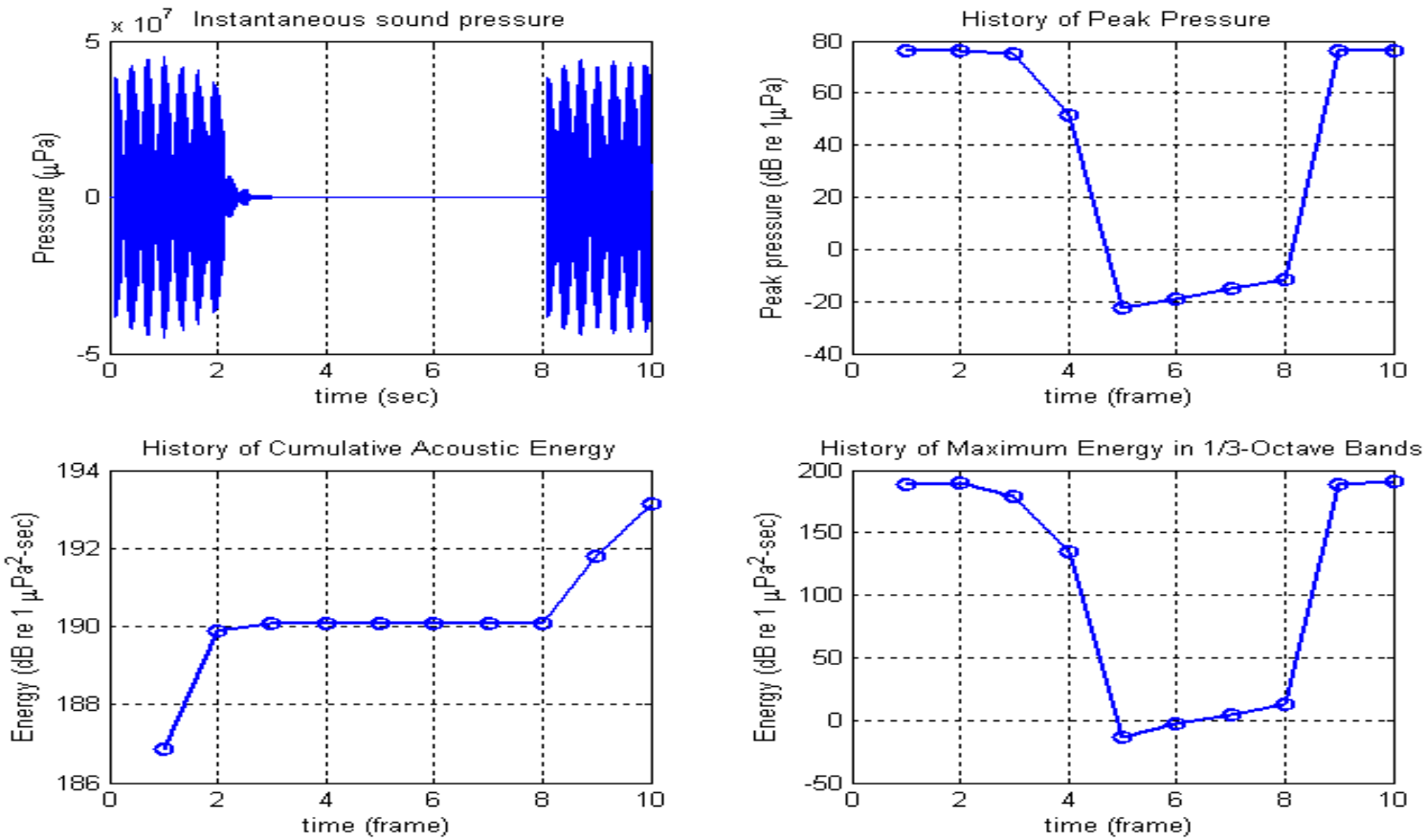


Upward Spread of Masking

Fixed Masker Frequency



Display of the Acoustic History



Challenges

- Databases
  - physical databases for acoustic tranmission loss modeling are well developed and readily accessible
  - biological databases are incomplete, scattered and hard to access
    - distribution and abundance data
    - animal diving, movements and behavior data
    - libraries of manmade and animal sounds
- Uncertainty
  - physical models typically use mean values for a day, week, month or season
    - measured variance is increasingly recognized as an important factor in model forecasting, especially in shallow water (less than 1000 meters depth)
  - uncertainty or variance in biological data is a major obstacle to planning to minimize risk
- What are the relevant risk metrics for model output?
  - Hearing?
  - Other physiological effects?
  - Behavior?

Future directions - ESME

- Scientific Peer Review
  - 2004 Special Issue of Journal of Ocean Engineering
- Assessment of Navy Applicability
  - 2003-2004 modeling of environmental risk for VAST exercises
- Preparation for Transfer/Transition
  - 2004 – ESME Good/Better/Next development roadmap completed
  - 2005 – benchmark ESME model distributed on CD with entire software code text, metadata definitions, documentation of software, and users manual.
  - 2006 – transfer or terminate.
    - CNO evaluation and decision on ESME future in FY06.