Impact of shelfbreak fronts on long-range underwater sound propagation in the continental shelf area

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3-D feature of the Shelfbreak front off New Jersey

Field observations during the SW06 experiment

Sea Surface Temperature Satellite Image
2°x2° block centered at Hudson Canyon
The Coastal Ocean Observation Lab (COOL) at Rutgers University, NJ

Vertical Structure
Scanfish sound speed data
Glen Gawarkiewicz, WHOI
3-D acoustic effects from shelfbreak fronts

Idealized model study:  
**3-D Rigid-Bottom Wedge with a Frontal Interface**

- Continuous wave signal propagation
  Source moves from the front to the wedge apex on the same $\theta$ angle, following the red line shown below.

*Slope angle* $1/10^\circ$ (~1.75/1000 slope)

*Water sound speed*
inside 1,500 m/s, outside 1,530 m/s

*Normalized Frequency* $1,500/\lambda_0$
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Objective map of the Scanfish data in the SW06 experiment

Water temperature at 40 m depth

Phase speed of acoustic Mode 1 at 200 Hz
Realistic model study: **4-D Ocean Acoustic Field Prediction**

- 4-D ocean fields from a data assimilation model (MIT - MSEAS) by P. F. J. Lermusiaux are employed.

- Acoustic normal mode wavenumbers are calculated, and the indices of modal refraction are presented in the lower-right two panels. The modal phase speeds in red areas are faster, which cause acoustic modes to refract away and propagate toward lower phase speed areas (blue and white areas).

Sep 4 to Sep 7
3-D Adiabatic mode solution

\[ \rho \left( \frac{\partial}{\partial y} \left( \frac{1}{\rho} \frac{\partial P}{\partial y} \right) \right) + k^2 \left( \frac{\partial}{\partial y} P \right) = -4\pi \delta(x) - \vec{r}_s \]

3-D wave equation

\[ P(\xi, y, z) = \sum_m \Gamma_m(\xi, y) \Psi_m(\xi, y, z) \]

vertical mode decomposition

vertical modes satisfy the next normal mode equation

\[ \rho \left( \frac{d}{dz} \left( \frac{1}{\rho} \frac{d}{dz} \Psi_m(\xi, y, z) \right) + \left( \frac{\omega^2}{c^2} - \xi_m^2(x, y) \right) \Psi_m(\xi, y, z) \right) = 0 \]

2-D wave equation for the modal amplitude

\[ \left( \frac{d^2}{dx^2} + \frac{d^2}{dy^2} \right) \Gamma_m + \xi_m^2 \Gamma_m = -4\pi \frac{\Psi_m(\xi_s, y_s, z_s)}{\rho(\xi_s)} \delta(x - x_s) \delta(y - y_s) \]

- Utilize 2-D PE to solve modal amplitude equation to include horizontal refraction

- WKB solution of neglecting horizontal refraction

\[ P(\xi) \approx \sqrt{\frac{2\pi}{k_n(\xi) r}} \cdot \frac{\Psi_m(\xi_s, y_s, z_s)}{\rho(\xi_s)} e^{i \frac{\pi}{4} + i \int_{k_n} \xi dr} \]
Modal TL Calculations
Case 1: SW06 Acoustic Site
Realistic model study: **4-D Ocean Acoustic Field Prediction**

- Modal intensities predicted by the vertical modes and horizontal PE approach

**CASE 1: SW06 Acoustic Site (Source Frequency 100 Hz)**

Mode 1 intensities (contours), plotted along with modal refractive index

- **Mode 1 TL (100.00 Hz), 04-Sep-2006 00:00:00**
- Red lines: 3D Adiabatic mode solution
- Black lines: 2D Adiabatic mode solution

Bathymetry contours: 40, 80, 100, 200, 500, 1000 and 1500 m

**TL dB contours (dark lines):** -60, -54, -48, -42 and -36 dB

150 km x 80 km on shore
Realistic model study: 4-D Ocean Acoustic Field Prediction

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![Diagram showing acoustic field prediction contours and refractive index](image)
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**Diagram Description:**
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**Graph Notes:**
- Data represents acoustic field prediction
- Contours indicate intensity levels
- Geographic position on shore

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**Legend:**
- Color scale indicates refractive index $n = k / k_{ref}$

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**Additional Information:**
- Source frequency: 100 Hz
- Date and time of measurement: 04-Sep-2006 00:00:00
- Geographical coordinates: Latitude and Longitude
Modal TL Calculations

Case 2: Cold Pool

- Sep 06 21:00
  Sea surface temperature
- Temperature along track
- Salinity along track
- Sound speed along track
- Index of Refraction of Mode 1 $n_1 = \frac{k_1}{k_{1,\text{ref}}}$ FREQ = 100Hz
- Index of Refraction of Mode 2 $n_2 = \frac{k_2}{k_{2,\text{ref}}}$ FREQ = 100Hz
Realistic model study: **4-D Ocean Acoustic Field Prediction**

- Modal intensities predicted by the vertical modes and horizontal PE approach

**CASE 2: Mesoscale Eddy (Source Frequency 100 Hz)**

Mode 1 intensities (contours), plotted along with modal refractive index

150 km x 70 km on shore
Realistic model study: 4-D Ocean Acoustic Field Prediction

- Modal intensities predicted by the vertical modes and horizontal PE approach

**CASE 3: Bottom (Source Frequency 100 Hz)**

Mode 1 intensities (contours), plotted along with modal refractive index

70 km x 100 km
Realistic model study: 4-D Ocean Acoustic Field Prediction

- Modal intensities predicted by the vertical modes and horizontal PE approach

**CASE 3: Bottom (Source Frequency 100 Hz)**

Mode 1 intensities (contours), plotted along with modal refractive index

on shore
Summary

• Joint 3-D acoustic effects from shelfbreak fronts and bathymetry/slope
• Realistic ocean model from the MIT-MSEAS has been employed, and an approach of vertical modes and horizontal PE enables us to investigate 3-D normal mode propagation on the continental shelf area.

Future work

• We need higher ocean model resolution.
• Full 3-D calculation to capture the 3-D mode coupling