Internal waves, intrusions, and coastal zone acoustics

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Causes of “synoptic” sound fluctuations: Deep ocean vs. coastal

• **Deep ocean**
  
  **Vertical stratification dominates** (some exceptions)
  
  – Principal anomalies: Linear internal gravity waves (IW)
  
  – Wide IW bandwidth in frequency, wavenumber
  
  – Horizontal isotropy (arguably)
  
  – *Stochastic modeling effective*

• **Coastal / shelf edge**

  **Strong horizontal gradients; Nonlinear internal waves and T/S variability.**
  
  – Anisotropic variation of seabed (shelf break and slope)
  
  – Tidal current amplification: Internal tides and short nonlinear IW result (directly forced by tide, or indirectly, via internal tide)
  
  – Surface fluxes, offshore forcing, seabed, and coastline all work to create contrasts (fronts) in the horizontal and lead to secondary submesoscale sound-speed anomalies (including intrusions) that directly affect acoustics
  
  – *Deterministic or stochastic modeling?*
Various uses of this terminology

“Intrusions”
1. Mesoscale
2. Sub-mesoscale (including inhomogeneous surface mixed layer, frontal processes, river plumes
3. Double-diffusive mixing related interleaving

“Internal Waves”
1. Steep and nonlinear (solitary, permanent form, or otherwise)
2. Long horizontal wavelength, unsteep, and linear.
3. Modal (on shelf, or in deep water far from sources)
4. Beam-like
Mesoscale Intrusions
Kuroshio Intrusion at Luzon Strait, South China Sea
Caruso, Gawarkiewicz and Beardsley (2006) images,
Many other articles on this.

Many other instances, including Gulf of Mex. Loop Current
NASA/JPL image, Topex/ERS-2
Quick review of internal wave effects.
- **Perpendicular acoust. prop.**: Mode coupling. **Parallel**: Refraction (focus, shadow)
- Broad range of acoustic signal variability.
- Intermittent or steady state effects depending on IW conditions, prop. range, etc.
- Periodic tidal forcing. Other factors are variable.
SW06, NJ Shelf, central site, ~ 80-m depth

0.05 day/tick = 4320 s

2760 m @ 0.8m/s
L = 300 m

SW06 Along-shelf Acoustic Observations: Transiting NLIW Groups

Above: Beam deflection and shortening of horizontal field coherence length (30 to 5 wave-length) at horiz. array as IW’s pass. Array gain changes also. 100 Hz.

Left: Typical max and min array gain curves vs aperture size. (w/o and with NLIW)

Coupled-mode situation: Intensity fluctuations. ASIAEX 2001 SCS.

Fronts (many scales) and sub-mesoscale processes

- **Sub-m:** Size scale smaller than Rossby radius of deformation, 
  \[ L_R = \frac{NH}{f}, \sim 20-30 \text{ km.} \]
- **Restratifying motions in response to lateral mixed-layer variations.** ... from heterogenous surface forcing.
  - Precipitation and evaporation (P-E)
  - Latent, radiative, and sensible heat fluxes
- **Wind-driven effects**
  - Coastal upwelling (Ekman)
  - Divergent Ekman transport (varying wind and wind curl, or mesoscale current variations leading to varying apparent wind and stress)
- **Instabilities** (ageostrophic acceleration)
- **Straining of large-scale features.**
- **Keys:** Front creation and existence.
Autumn

\[ T(x,z) \]

\[ S(x,z) \]

\textbf{MIT MSEAS Regional Ocean Model} (Pierre Lermusiaux group)

Summer

\[ T(x,z) \]

\[ S(x,z) \]
Large Intrusions at Fronts

Salty slope water (Evap in Atlantic, Med. ... salty abyssal water)

Internally density-compensated intrusions

WS - (relative) - CF

WF

CF

Fresh (Shelf ... rivers)

Salty
Small Double-Diffusive Intrusions

Level or sloped isopycnal (flow into page)

Warm Salty (Atlantic, slope water)

Salt finger conditions underneath WS intrusions, Diffusive layering conditions overlying them.

(Ask me offline about these double-diffusive instabilities)
Salt fingers dominant: “upward slope” of warm salty intrusion. Underside of Meddy.

6 Intrusions in 20 m depth. Intrusions and mixing processes not properly treated in models.
One intrusion: DD Layers (convective rolls?) on top; No microstructure axis of intrusion; Fingers below

Note spectral shapes (next slide)
Remote acoustic mapping?

Conductivity gradient spectra (T mostly) above, inside, and below intrusion.

Variance preserving form below left shows finger wavelength near 5 cm.

These spectra provide what is needed to predict backscatter strength.
Amplitude of Compressed Pulse Output (Relative Units)

ISW Rosey: 08-17-2006 Cast 87

- **Depth (m):**
  - Low (150-270 kHz)
  - Mid (220-330 kHz)
  - HL (330-470 kHz)
  - HH (450-590 kHz)

- **Time (GMT):**
  - 03:04 03:07 03:10 03:12 03:15 03:18 03:21 03:24 03:27

- **Noise Spike**

- **Shear-driven Turbulence**

- **Volume Scattering Strength (dB)**

- **Small zooplankton**

- **10 \log_{10} \sigma_v**

- **Frequency (kHz):** 0 50 100 150 200 250 300 350 400 450 500 550 600

- **Graphs illustrating the relationship between depth, time, and frequency.**
Modal wavenumber and phase-speed anomalies of large intrusions (Tying it all together, ... acoustics)

- The spatial scales differ from those of internal waves
- fronts/intr and IW have comparable modal $k$ and $C_p$ variances
- Degree of anisotropy poorly known; surmise that anisotropic fronts create anisotropic intrusions.
- Amenable to modal horizontal mode PE simulation
- Snellius:
  \[ \theta \text{ crit.} = \cos^{-1}\left( \frac{k + \Delta k}{k} \right) \]
  \[ = \cos^{-1}\left( \frac{C}{C + \Delta C} \right) \]
  \[ 4.7^\circ = \cos^{-1}\left(\frac{1500}{1505}\right) \]
Closing Remarks

• Horizontal anisotropy of internal waves and front-related features gives anisotropic acoustic variability.
• Have reviewed (many) observed and modeled Internal-wave effects.
• Intrusion-related microstructure barely ‘visible’ acoustically.
• Low-frequency: Small-scale intrusions have weak effects on modal $k$. These will smooth out the larger delta-$k$ effects of fronts and large intrusions.
• Physics of the smaller intrusions is not explicitly included in regional flow models; this may have acoustic prediction implications. (Nor are nonlinear internal waves)