Acoustic Forecasting

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Global scale 3D acoustics to estimate the coverage for the detection of explosive and seismic events.

Full 3D solution in complicated bathymetric environment.
Outline

- Overview
  - Underwater Sound Propagation
  - Ocean Acoustic Modelling

- Interesting Modeling Examples

- Ambient Noise Forecasting
  - Forward Problem
  - Source Signatures Levels
  - Temporal / Spatial Characteristics

- Measurements to help modeling

- Modeling to help measurements
Underwater Sound

- Sound travels exceedingly well underwater
  - Very little volume attenuation for frequencies below 2 kHz
  - Solar Heating at the surface refracts sound away from rough sea-surface boundary
  - Pressure in the deep ocean refracts sound away from the seafloor

- In European Seas - the sediment is the primary driver in propagation of sound to long ranges.

- Marine mammals, (and all ocean animals) have evolved and adapted to situation beneficial to sound propagation and immersed in ambient noise.
Ocean Acoustic Modeling - I

- Ray-tracing (from the 1940s)
  - Simple integration of Snell’s law - following refracting ray paths. Energy is determined by an integral along the rays, and summing up arriving rays (Gaussian beams)

- Normal Mode Modelling (from the 1970s)
  - Separation of variables of the wave-equation yields a vertical eigenvalue equation - which is solved for modes.
  - These modes can rapidly summed compute the full-field
  - Extensions to mildly range-dependent (adiabatic mode) and fully range dependent (coupled mode) are common.
Ocean Acoustic Modeling - II

- **Energy Flux Models**
  - Pioneered by Weston, these approaches are a combination of ray/modes - where energy bundles (groups of modes) are integrated. These models can be very fast.

- **Parabolic Equation Modelling**
  - The acoustic field is marched forward using a propagator from the outgoing only (parabolic) wave equation. This model is very efficient for range-dependent environments at lower frequencies.
  - This algorithm has been recently extended to include 3D effects.
Ambient Noise Forecasting: Sources

- The local ambient noise is an incoherent combination of all sources in a particular frequency band.

- Temporal Variability
  - Minutes (passing ships)
  - Hours (sea-state)
  - Diurnal (biologics)
  - Weekly (weather, seisms)
  - Seasonal

- Frequency Dependent Sources
  - Very Low frequency < 200 Hz
    - Ships, seismic surveys, baleen whales (Blue/Fin), Wind Farms, ice
  - Low Frequency (200-1 kHz)
    - Ships, Wind, Humpback Whales, Fish, ice cracking
  - Mid Frequency
    - Wind, Toothed Whales/Dolphins, Pile-Driving, Navy Sonars
  - High Frequency > 10 kHz
    - Snapping Shrimp, dolphins, ?
Ambient Noise Forecasting: Propagation

- Acoustic propagation conditions can effect the local ambient noise
  - Sound speed profile - surface ducts can trap sound from shallow sources
  - Wind can lead to rough surface, which reduces long-range sound propagation
  - Soft/hard sediments can act as acoustic sponges/mirrors.
Interesting Modelling/Measurement Examples

- Seismic Airgun Modeling
- CTBTO Crozet Study
- Surface Shipping Noise (Data/Model)
- CTBTO Acoustic Coverage Study
Airgun Modelling

- Coherent combination of seismic source out to far-field.

**Example Airgun Array**

**Peak Sound Pressure 200-500Hz**
Basin Scale Seismic Source Modelling

a) NRL Ensemble Forecast

b) Single Source 2D SEL (7-1kHz)

c) Airgun Array 2D SEL

d) Single Source 3D Acoustics
HA04 Replacement Study

• In view of the re-establishment of the Crozet Islands hydrophone station (HA04), CTBTO initiated a number of studies

• Oceanographic and Acoustic Studies were performed to investigate the optimal placement for survivability, coverage and cost

• For the acoustic study, the OASIS code (Peregrine-3D) was used to investigate the impact of local bathymetric and distant island/guyots/seamounts shielding on global coverage
In order to evaluate candidate sites, a metric was chosen to be the % of the earth covered as a function of Figure of Merit. (FOM = TL (with positive Signal excess) = -(SL - AN)

For large sources (earthquakes, explosions) the 3D predicted earth coverage is significantly larger (~ 3%) than the 2D

- 3D Diffraction Gain from seamounts, ridges
- Relative 14% Increase in Coverage
- 3D refraction loss from local features
Shipping Dominated Environment

- Data taken of Ft. Lauderdale USA
Shipping Noise Modelling Example

Shipping Noise Computed from AIS in Skagerrak (PE @ 60 Hz)
3/7/2013 1400Z

a) [Map of shipping routes]

b) [Map showing noise levels]
CTBTO Soundscapes
“Active Acoustic Space”

- Working w/ Jen Miksis-Olds @ ARL-PSU we are examining the seasonal effects of an active acoustic space.

This work addresses how far mammals can detect other mammals. Future work will involve how far in space we can extrapolate noise measurements.
Measurements can help the modelling

- Modelling with historical databases for SVP, sediment can lead to very poor prediction capabilities.

- The recent development of data-assimilative ocean models has with short time scales (~ 3 hour) and short spatial scales (~3 km) has greatly improved acoustic forecasting.

- High resolution Bathymetry can be critical in shallow water environments

- Direct (or inferred) measurements of the seafloor type are a requirement of accurate acoustic prediction.

- A shipping source level database would be very useful.

- POINT! - Make a Transmission Loss measurement part of the ambient noise measurement system.
Modelling can help the measurements

• Modelling can be done prior to the measurements of ambient noise to determine best locations for limited observations.

• Modelling can be used after long-term ambient noise measurements to extrapolate to different positions.
Conclusions / Knowledge Gaps

- Propagation in underwater acoustics is critically dependent upon the local environment
  - Sound Speed
  - Bathymetry
  - Sediment Type

- Area of the ocean \( (\pi r^2) \) means errors in long-range attenuation leads to vast differences in area/volume illuminated

\[ 16 \log R \]

- With a few simple measurements and current oceanographic modelling capabilities we can reliably estimate the ambient noise field. (Sources Level Calibrations)

- FINAL POINT:
  - Propagation in the ocean is really complicated
  - Propagation in the ocean isn’t too hard to do reliably