Three Main Acoustic Themes

- Detection of seafloor earthquake & volcanic activity for discovery of new hydrothermal vent ecosystems
- Marine mammal identification
- Ambient sound measurements
Relevance of Ocean Acoustics

Acoustic monitoring can contribute in a significant way to numerous NOAA and other U.S. government agency missions including:

- Seafloor earthquake and volcano detection and monitoring
- Marine mammal assessment (for threatened and endangered species under MMPA and ESA)
- Ocean exploration
- Seismic, volcano and tsunami hazard research
- Ocean ambient noise assessment (ecosystem characterization)
- Meteorological monitoring (e.g. hurricanes, rainfall, windspeeds)
- Iceberg tracking (effects shipping, possibly related to climate change)
- Nuclear Test Ban Treaty verification (Dept of Energy)
- Identification of illegal fishing-trawler activity
Why is passive acoustics ideal for ocean monitoring?

Physics of sound propagation in ocean:

- Sound travels faster in water (1500 m/s) than in air (340 m/s)
- Existence of an ocean sound channel (SOFAR channel):
  - Low sound velocity zone (typically 1 km deep), refracts sound waves toward minimum speed, acts as a wave guide
- Sound waves travel long distances underwater with little energy loss
How Does PMEL Use Ocean Acoustics?

- Use special underwater microphone, called hydrophone, deployed in sound channel
- Record ocean sound to study geophysical and biological phenomena.
U. S. Navy SOund SUrveillance System: SOSUS Hydrophone Arrays

- Billion $ cold-war era hydrophone system:
  - Bottom-mounted hydrophones
  - Deployed in sound channel throughout north Pacific Ocean
  - Used in anti-submarine warfare

- PMEL Acoustics Project accessed hydrophone data in 1991:
  - Navy looking for environmental applications for their assets
  - Only civilian research group with access to SOSUS real-time data
  - Data sent via encrypted phone line from Whidbey Island NAS to Newport

- Vast improvement for ocean seismic detection over land-based networks:
  - Detect magnitude ~2 compared to ~4
  - Much more accurate event locations
10 times more offshore earthquakes detected by SOSUS, located more accurately due to better sound-speed models and station coverage.
PMEL SOSUS Project: Volcanic event detection

- **Since Project began in 1991** –
  - SOSUS detected 7 major seafloor spreading & magmatic events on Juan de Fuca Ridge system

- **During events, research vessels:**
  - Observed release of massive volumes of hydrothermal fluid into ocean
  - Eruption of lava onto seafloor

- **Partner with NSF ocean science community**
  - Mobilize vessels to investigate sites

- **Use past observations:**
  - To better forecast future seafloor spreading events
Recent earthquake swarm (April 2008) detected in Juan de Fuca plate by SOSUS

- More than 3000 earthquakes detected (10x more than land-based seismic nets)
- Progression of seismicity from midplate, to transform, to magma intrusion at ridge
- Water samples (stars) analysis consistent with tectonic event within intraplate, possible hydrothermal fluid release at ridge
- Press release carried by >200 media outlets worldwide, 3rd highest hits on Google News.
Hydrophone Mooring

With success of SOSUS, PMEL developed portable hydrophone.
PMEL Autonomous Hydrophones: Global Reach

- EPR: 5 Hill's, 250Hz
- MAR: 4 Hill's, 250Hz
- Antarctica: 5 Hill's, 250Hz
- IO: 3 Hill's, 250Hz
- ICE: 5 Hill's, 250Hz
- Axial OBH: 4 OBH, 250Hz
- Davis Strait: 4 Hill's, 2KHz
- NW Rota Volcano 1 Hill, 250Hz
- Bering Sea: 2 Hill's, 2KHz

Brothers Volcano 3 OBH's, 250Hz
Mariana Islands: NW Rota submarine volcano explosive eruption

First video and sound of deep ocean eruption

Sponsors: NOAA OE Program and US Coast Guard

Frequency

450 Hz

1 Hz

Hydrophone ~100 m from eruption vent

Time

minutes

Hydrophone ~100 m from eruption vent
Kermadec Arc - New Zealand:

Brothers volcano - A volcano that resonates

Harmonic resonance from movement of fluid/magma inside volcano

Sponsors: NOAA Ocean Exploration Program and GNS New Zealand
Walvis Ridge – South Atlantic:

- Far-field records of explosive volcanic activity
- Detected across the Atlantic Ocean basin, range of ~5,200 km

Sponsors: National Science Foundation and CNRS, France
Volcanic Seismicity and Ice-quakes in Bransfield Strait, Antarctica

Volcanic Earthquake Swarms – planned ROV investigations in 2011

Hydroacoustic Observations, Antarctica
Global ocean ambient noise has increased 10 dB in the past 30 yrs, mainly from anthropogenic sources (e.g. increased container shipping).

Antarctica and New Zealand volcano have highest noise levels, higher than mid-Atlantic shipping lanes, influenced by wind, ice, tectonic activity.

No other lab is monitoring this issue globally, may have profound effects on marine animals and ecosystems that use sound for navigation/communication.
Acoustic Marine Mammal Detection

**Why?**
- Basic research
  - migration patterns
  - feeding habitats
  - trophic interactions
- Find endangered species
  - e.g., only ~350 right whales left in North Atlantic
  - even fewer in N. Pacific
  - finding seasonal distributions is critical

**How?**
- Develop quality detection algorithms to find whale vocalizations in hydrophone data
  - efficient
  - robust to noise
- ...for
  - baleen whale moans (15 species)
  - toothed whale/dolphin clicks (70 species)
Established presence of 6 endangered species
Developing New Acoustic Technologies

SIREN: Seafloor Incident Reporting and Evaluation Network

New strategy for acoustic monitoring of marine ecosystems

- Combine hydrophones on:
  - Satellite mooring
  - autonomous vehicles (vertical profiler & sea-glider)

Provide near-real-time acoustic monitoring network

Sponsors: NOAA/PMEL and ONR
Future Goals of Acoustic Program Research:

- Acoustics Provides insights into wide variety of topics:
  - Destruction/creation of seafloor hydrothermal ecosystems
  - Seismic/volcanic hazard for coastal communities
  - Distribution of endangered marine mammals species
  - Increase in global ocean noise due to anthropogenic and climate change effects

- Future project goals:
  - Develop PMEL hydrophone assets into an integrated, global observing system
    Applied to various ocean research issues (ocean noise, fisheries, marine mammals and climate change).

  - Cultivate alternative acoustic monitoring technologies
    real-time hydrophone communication (autonomous floats, buoys or cabled hydrophone arrays)

  - Continue current and develop new international collaborations
    (e.g. France, South Korea, Iceland, New Zealand, South Africa)
Thank you
Resonating Icebergs

Recorded unique harmonic signals off Antarctica

Satellite confirmed iceberg signal source location

Iceberg ~5x10 km

Iceberg uk-213 (61.34 S, 54.38 W)
**Ecosystem Research Program 5-year Goal to:**

“Study ocean phenomena to ascertain the potential for generating coastal earthquakes and tsunamis and the extent to which these phenomena alter existing and create new and/or unique ecosystems.”

**Ecosystems Observations Program Goal of:**

“Assessment of living marine resources (i.e. marine mammals under ESA and MMPA).”
PMEL/Vents Ecosystem Research:
Linkages to NOAA Research Plan and Strategic Plan

NOAA Strategic Plan - Performance Objective:
3-5 year milestone to estimate ambient noise budgets in at least one regional ecosystem by characterizing the nominal acoustic environments

NOAA Research Plan - Research Area:
Advancing Understanding of Ecosystems to Improve Resource Management
Massive, long-term seafloor eruptions have occurred many times in Earth’s history, and will occur again. May play major role in volatile flux in ocean, and volcano/tsunami hazard.
Developing (near) Real-time Hydrophone Technologies:

- Tether-free QUasi-Eulerian float
- Remains on seafloor for long-term monitoring
- Detects event, makes multiple trips seafloor to surface
- Near real-time, short satellite data transmission
- Portable, expendable, low power
- 1-year life time (up to 12 ascent/descent cycles)
- Minimum drift from rapid ascent/descent
- Modified for chemical or water-column measurements
Ambient sound correlated with global wind field

Freeze and thaw of pack ice contributes to Antarctic noise.
Ambient Noise and Global Economic Trends
1950-2000

- World GDP (dB re 1 international 1990 mega $) with a growth rate of 3.33 dB/decade and an R² of 0.9816.
- Ambient Noise (dB re 1 microPascal**2/Hz) with a growth rate of 3.26 dB/decade and an R² of 0.945.
- World Fleet Gross Tonnage (dB re 1000 GT) with a growth rate of 3.20 dB/decade and an R² of 1.
**Example earthquake swarm:**
*Axial Volcano, Juan de Fuca Ridge, January 1998*

Earthquakes begin in summit caldera, migrate 60 km down rift-zone over a 2 day period.

In situ instruments detect water-temperature anomalies, seafloor subsidence, and are buried in lava!

Evidence of eruption at summit and injection of magma down the volcano at speeds of 0.2 - 1.0 m s⁻¹