Introduction to ocean technologies for ocean observation and monitoring

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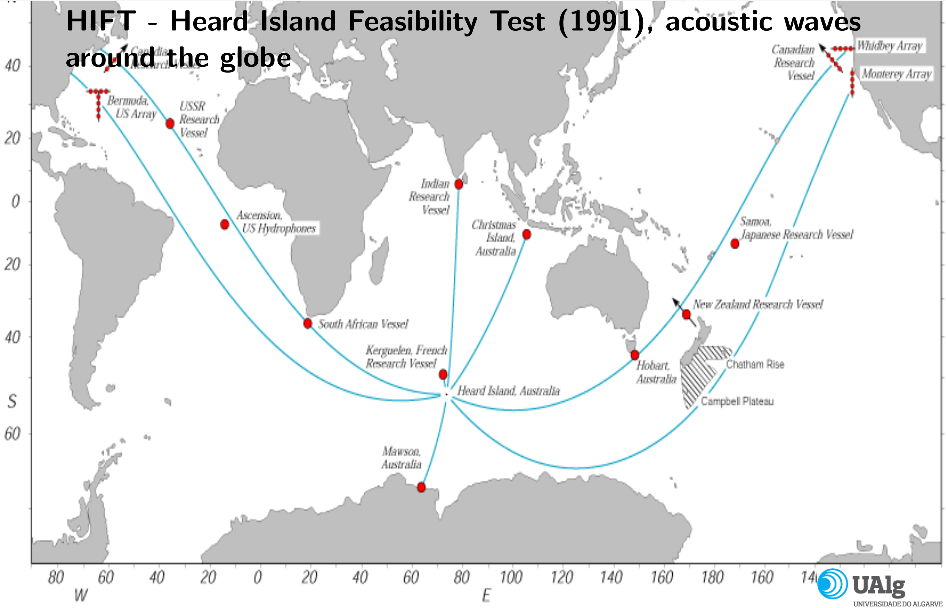
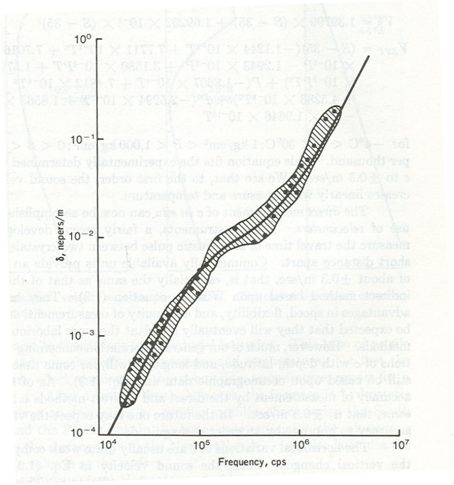
Outline

1. **Why acoustics and its role in ocean observation**
2. **Applications**

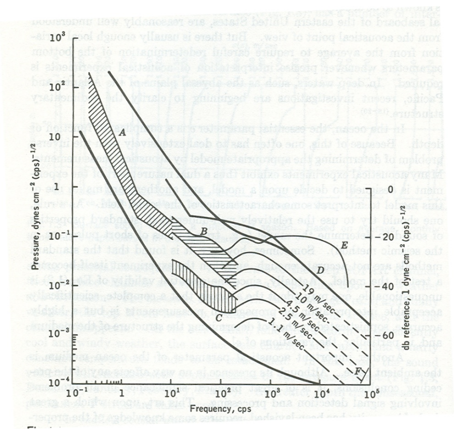
   active and passive sonar, echosounding and fishing, geotechnical and oil exploration, ocean thermometry and tomography, marine mammal monitoring, underwater communications, localization and navigation, port and waterway protection

HIFT - Heard Island Feasibility Test (1991), acoustic waves around the globe

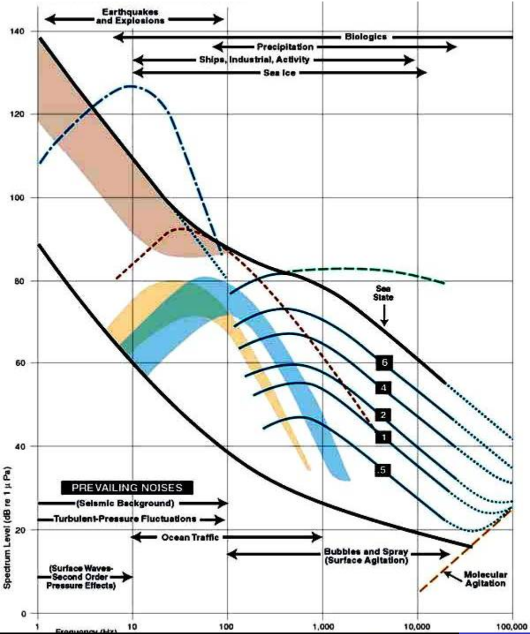




Sound attenuation at high freq
($T = 25°$C, $S = 35$ ppt)
(Tolstoy & Clay, AIP, New York, 1987)



Ambient noise power due to:
seismic noise, thermic agitation
rain, surface noise, etc.



Ambient noise and interferences

- frequency dependance
- ground noise
  - earthquakes
  - explosions
  - construction
- biological
- shipping noise
  - distant shipping
  - man-made activity
- wind, waves, ice

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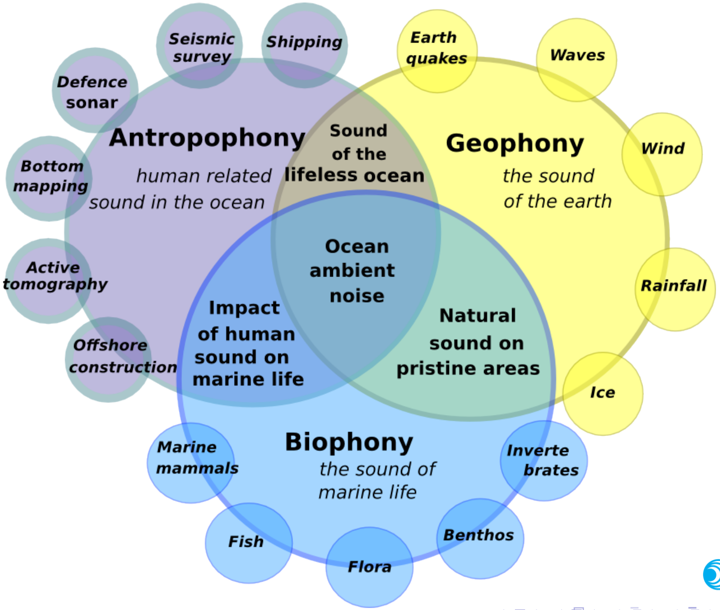

Seismic survey
Shipping
Defence sonar
Earth quakes
Waves
Antropophony
human related sound in the ocean
Sound of the lifeless ocean
Geophony
the sound of the earth
Wind
Bottom mapping
Active tomography
Ocean ambient noise
Rainfall
Impact of human sound on marine life
Natural sound on pristine areas
Offshore construction
Ice
Biophony
the sound of marine life
Marine mammals
Inverte brates
Fish
Flora
Benthos

man-made noise

environmental sound

biological sound

↘

→

↗

⇒ **Image**

separate effects

infer quantities

Sound propagation in the ocean

Most important factors in ocean sound wave propagation

1. the (variation) of sound speed
2. water depth
3. media interface type
4. sound frequency $\lambda = \frac{c}{f}$

Sound speed in the ocean

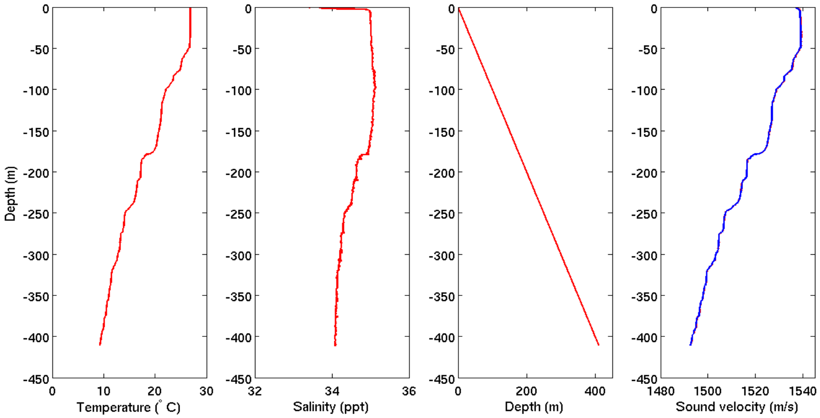
the speed of sound in the ocean was measured for the first time by Colladon and Sturm in 1827, in the lake of Geneva, Switzerland, having a value close to 1500 m/s, but varying with pressure (depth), with temperature and with salinity according to an empirical formula given by:

$$\mathbf{c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.010T)}$$
$$\mathbf{(S - 35) + 0.016z}$$

where

c = sound speed (m/s)
T = temperature (°C)
S = salinity (ppt)
z = depth (m)

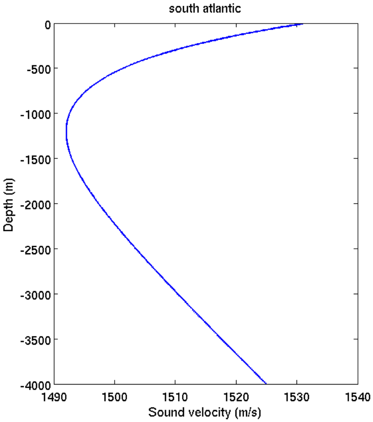
Calculating the sound speed profile



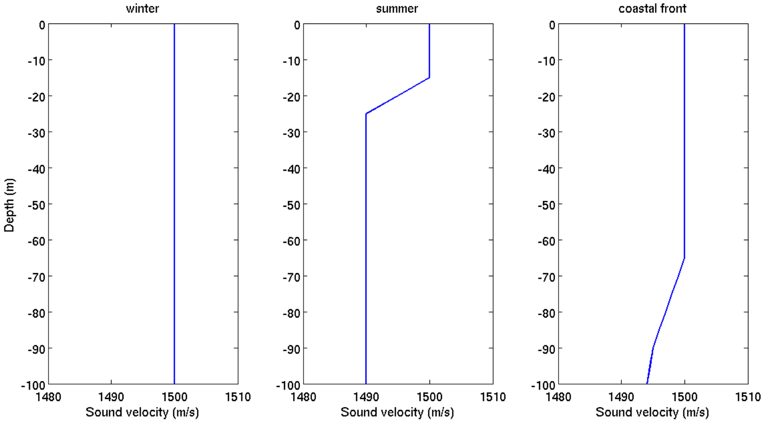
Sound speed variability :

- latitude
- year season
- ocean agitation
- currents/fronts/topography

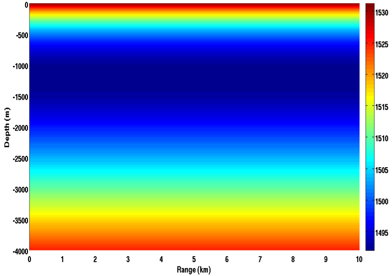
Typical sound speed profiles (1)



Typical sound speed profiles (2)



Ocean stratification

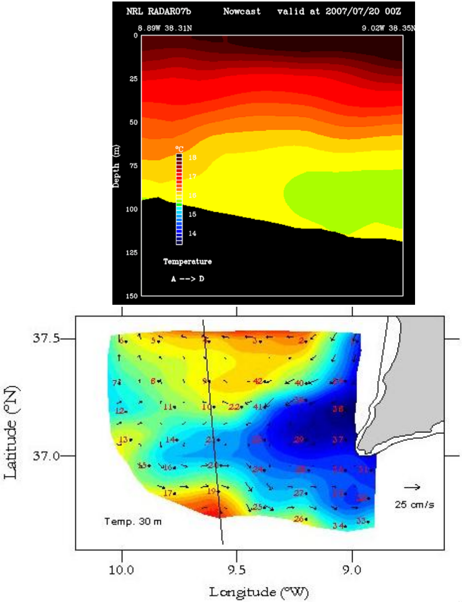


- high variability of sound speed in the vertical but relatively constant in the horizontal
- forming a deep sound channel propagation (DSC = deep sound channel) associated with the minimum of the sound speed profile
- variation of the DSC with latitude
- disapearing of DSC in coastal areas with energy redistribution

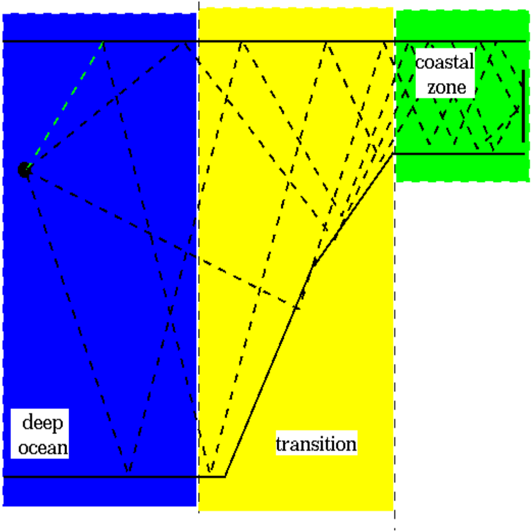
Ocean 4D variability

Sound speed variability

- depends on density: temperature, pressure and salinity
- non-isotropic media
- in depth
  - strongly stratified
  - rapidly varying
- in range-cross range
  - slow variability
  - region latitude
  - eddies, fronts, upwelling
  - salinity (rivers)
  - bathymetry effects on T

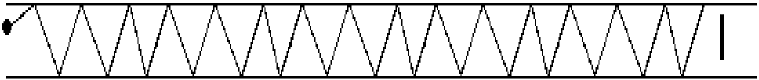


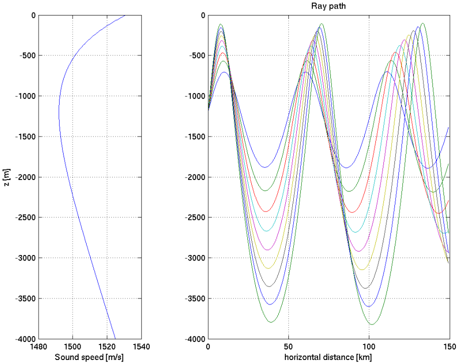
Transition zone



- topography effect
- currents and tide
- internal tides
- energy concentration

The effect of water depth





shallow water

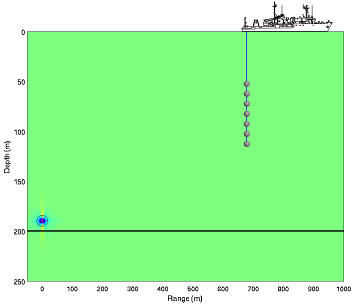
- guided wave
- interaction with boundaries
- nature of boundaries
- frequency

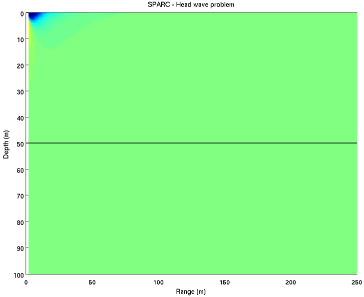
deep water

- refraction
- dependence from water column
- close to free space

Boundary reflections

- reverberation/multipath
- surface effects
  - surface waves
  - surface scattering
- bottom reflections
  - multiple layers
  - sound speed gradient
  - high-speed





Sound pressure level and transmission loss

Sound Pressure Level (SPL)

$$\mathrm{SPL}_{\mathrm{dB}} = 10 \log_{10} \frac{p_{\mathrm{rms}}^2}{p_{\mathrm{ref}}^2}$$

where $p_{\mathrm{ref}} = 1\mu$ Pa (20 μPa in the air) and

$$p_{\mathrm{rms}}^2 = \frac{1}{T} \int_t^{t+T} p^2(\tau) d\tau$$

Transmission loss (TL) calculation is given by:

$$\mathrm{TL}_{\mathrm{dB}} = 10 \log_{10} \frac{\mathrm{p}_{\mathrm{source}}^2}{\mathrm{p}_{\mathrm{receiver}}^2}$$

- in shallow water $\Rightarrow$ by border interaction
- in deep water $\Rightarrow$ by cylindrical attenuation with distance

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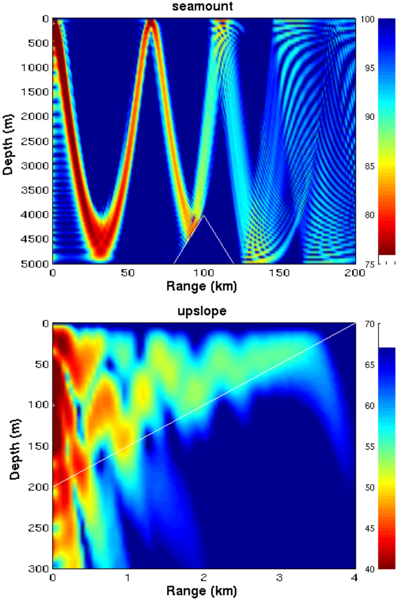
Signal attenuation with distance

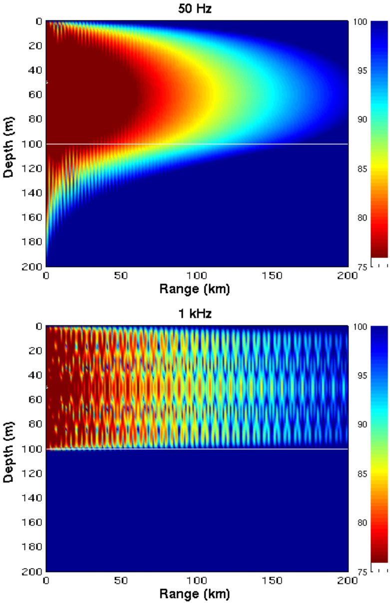
Sound absorption

- cylindrical spreading
  - with distance
  - frequency
  - bottom interaction
- bottom effects
  - along range bathymetry
  - bottom type
  - bottom layering
- with frequency

Model: C-Snap; F=50 Hz (seamount),
F=25 Hz (upslope)



Sound propagation: frequency dependence



Sonar equation (1)

SONAR *SOund NAvigation and Ranging*: the sonar equation has the objective to provide a simple method for determining the detection level of a given target in real conditions.

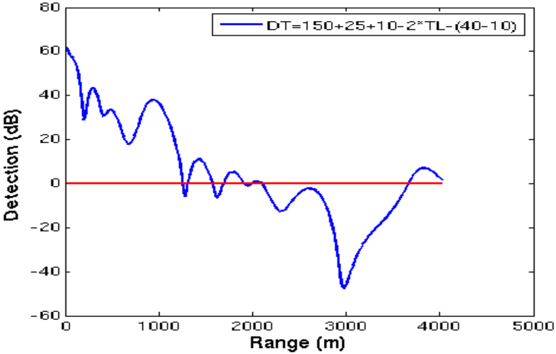
Active sonar in noise	**DT = SL + DIt + TS - 2TL - (NL-DI)**
Active sonar in reverberation	**DT = SL + DIt + TS - 2TL - RL**
Passive sonar	**DT = SL + DIs -TL - (NL-DI)**

DT	= detection threshold
SL	= source level
DIt/s	= target/source directivity index
TS	= target strength
TL	= transmission loss
NL	= noise level
RL	= reverberation level
DI	= directivity index (receiver)

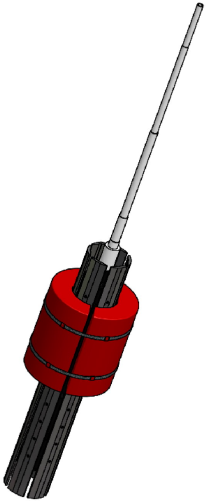
Sonar equation (2)

Example: we want to detect a target with an active sonar with a transmit power of SL = 150 dB, a directivity index of the receiver DI = 10 dB, a TS = 10 dB, and a DIt=25 dB in an ambient noise NL = 40 dB,

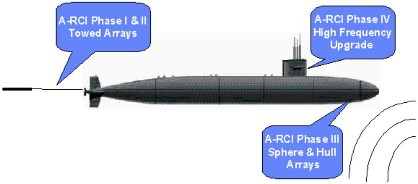
Active sonar in noise **DT = SL + DIt + TS - 2TL - (NL-DI)**

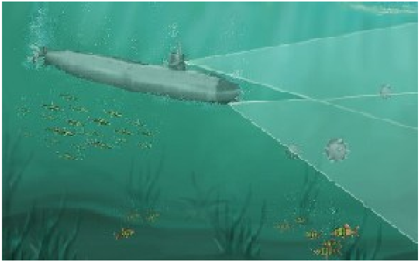


- active and passive sonar
- sidescan and multibeam sonar
- echosounding and fishing
- oil and geotechnical exploration
- ocean thermometry and tomography
- monitoring of marine mammals
- underwater communications
- target navigation and localization
- port and waterway protection



Sonar for military usage





LF sonar: 400 - 1000 Hz

- 10 - 50 km
- long range detection
- towed or hull mounted array

MF sonar: 3000 Hz

- $<$ 5 km
- hull sonar (*conformal*)

HF sonar: $>$ 100 kHz

- 100 - 250 m
- mine detection
- bottom exploration

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Submarine detection

USS Key West

- **passive sonar:**

extremely difficult

- **active sonar:**

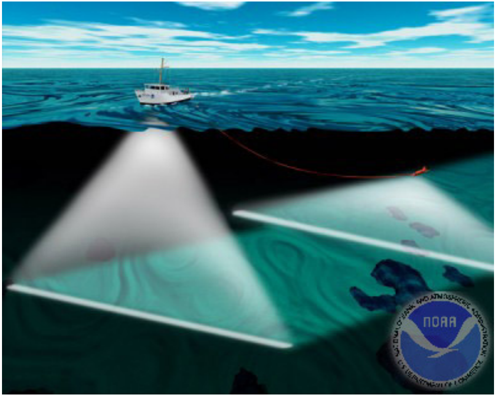
traditional, short range

SURTASS - LFA, upto 10 km

- **sonobuoys:**

(LOFAR)

- active / passive
- triangulation
- mono and multisensor



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multibeam sonar

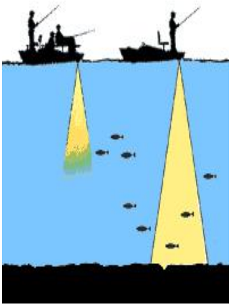
- sweep beam
- two way travel time
- depends on depth

sidescan sonar

- towed
- records intensity
- difficult to navigate

Sounding and fishing (1)

Hobby echosounding : 5 - 50 kHz, variable power; submerged objects and bottom type.
Hobby echosounding for fish detection: 20 - 200 kHz, angle and variable power.



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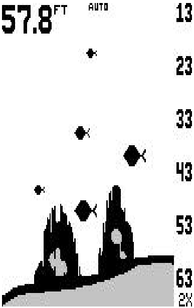


swim bladder

- resonant element
- density difference
- volume

propagation conditions

- thermocline
- muddy bottom/rock/algae
- water salinity
- dissolved particles

Sounding and fishing (2)

Objective

- to intimidate or attract fish schools

Between species

- frequency: 0.1 - 60 kHz
- sensitivity: 100 - 160 dB

(re 1μ P/Hz)

Studies

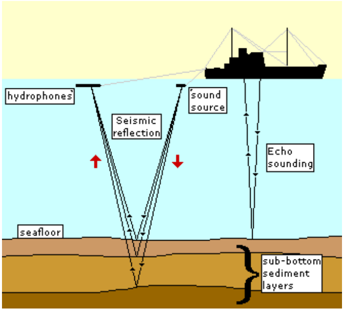
- comportamental
- *in situ*, invasive

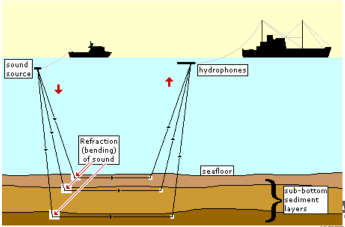
Kastelein et al. "Startle response of captive North Sea fish species to underwater tones between 0.1 and 64 kHz"

Marine Environmental Research, Elsevier, No. 65, p.369-377, 2008

anchored or towed systems

- horizontal or vertical arrays
- impulsive (sparker/uniboom)
- reflection analysis
- *full-field* inversion
- geological or seismic studies
- sediment study

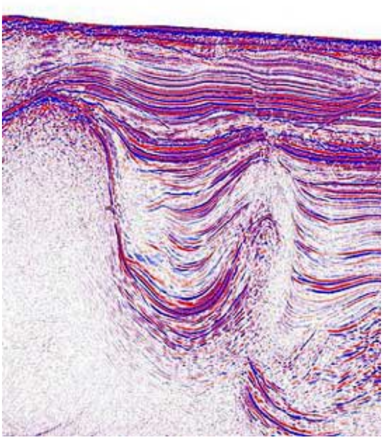




Geotechnical and oil exploration (2)

towed systems

- very long arrays (> 1 km)
- impulsive source / low freq
- reflection analysis
- geological studies
- bottom sampling
- (*cores*)



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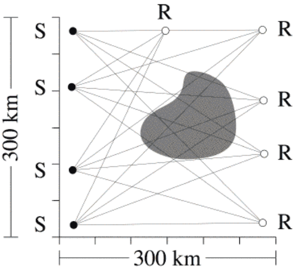
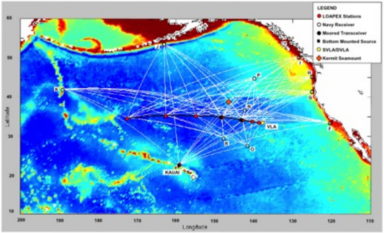
Ocean thermometry and tomography





from NPAL website

principle of medical CAT

- to "illuminate" an object from multiple points
- reconstruction of the object from the received signals (inversion)

global monitoring

- mean temperature in depth and range
- resolution: 0.01 °C
- scale: 3000 - 5000 km

initiatives

- HIFT: 1991
- ATOC: 1997-1999
- NPAL: 2002-

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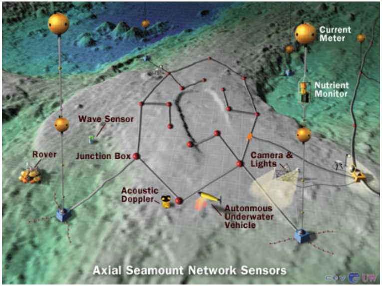
Ocean observation

Observation network NEPTUNE: Canada & U.S.A.



deep water observatories

- biology, geophysics, oceanography
- T wave observation
- communications

ESONET observation network: european network (2007 - 2011)

stations in 10 countries from Norway to Turkey

- 35 partners (in Portugal: UAc, FCUL, CINTAL, UALg)
- Azores: geothermal sources

Monitoring of marine mammals

- **frequency band**

100 Hz - 200 kHz

- **sound level**

from 140 to 230 dB re μPA

- **localization**

passive, active and visual

- **sensitivity**

frequency range and

acoustic power

- **impact**

tomography (ATOC)

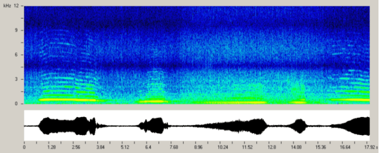
navy sonar (SURTASS-LF)

Orca

Pilot

Humpback

solmar.saclantc.nato.int



Underwater communications

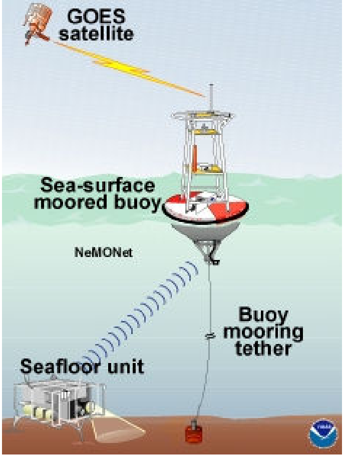
- communication between subs
- communication sub-surface
- shallow water:

$\Rightarrow$ $<$ 5 km, $<$ 8 kbits/s

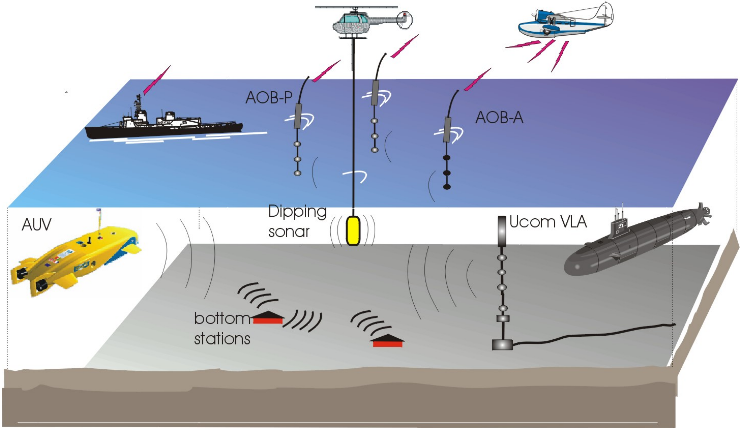
- or deep water

$\Rightarrow$ $<$ 20 km, $<$ 15 kbits/s

- control and command of autonomous vehicles

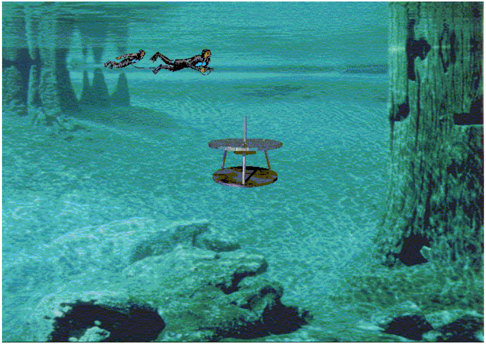


Tracking and navigation of cooperative underwater targets: AUVs



Port and waterway protection

- detection of underwater vehicles of small dimension
- diver detection
- shallow water
- network based sensor system



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MakaiEx Sea Trial - Kauai I., Hawai (EUA), September 2005.

Examples of acoustic signals (2)

Source: testbed/Lubell 1424

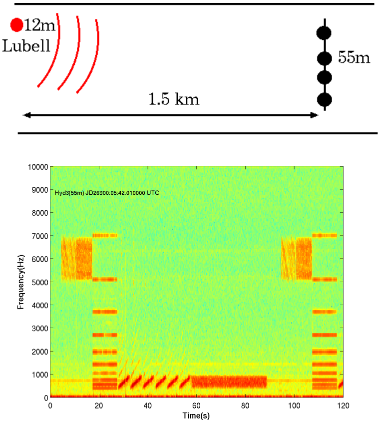
8-14 kHz 

1 -8 kHz 

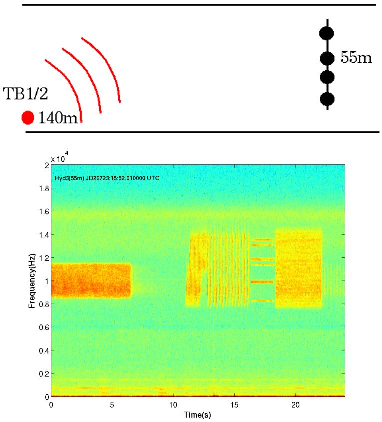
Receiver: AOB2

SiPLAB acoustic array: 8 hidrophones, 10 - 75 m, Band: 50 Hz - 16 kHz

Examples of acoustic signals (3)



hid3-55m



hid3-55m

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