Acoustic detection of high energy neutrinos in sea water: status and prospects

or: the road to KM3NeT

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Outline

- Introduction: sound in water and acoustic neutrino detection
- The “first generation” of acoustic neutrino test setups
- Results and lessons learned
- Conclusions and outlook

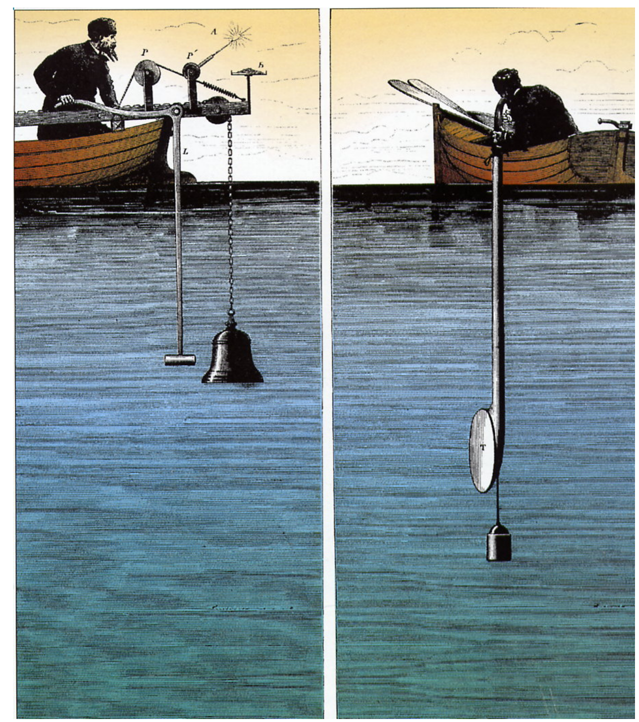
Sound in water

“Of all the forms of radiation known, sound travels through the sea the best”

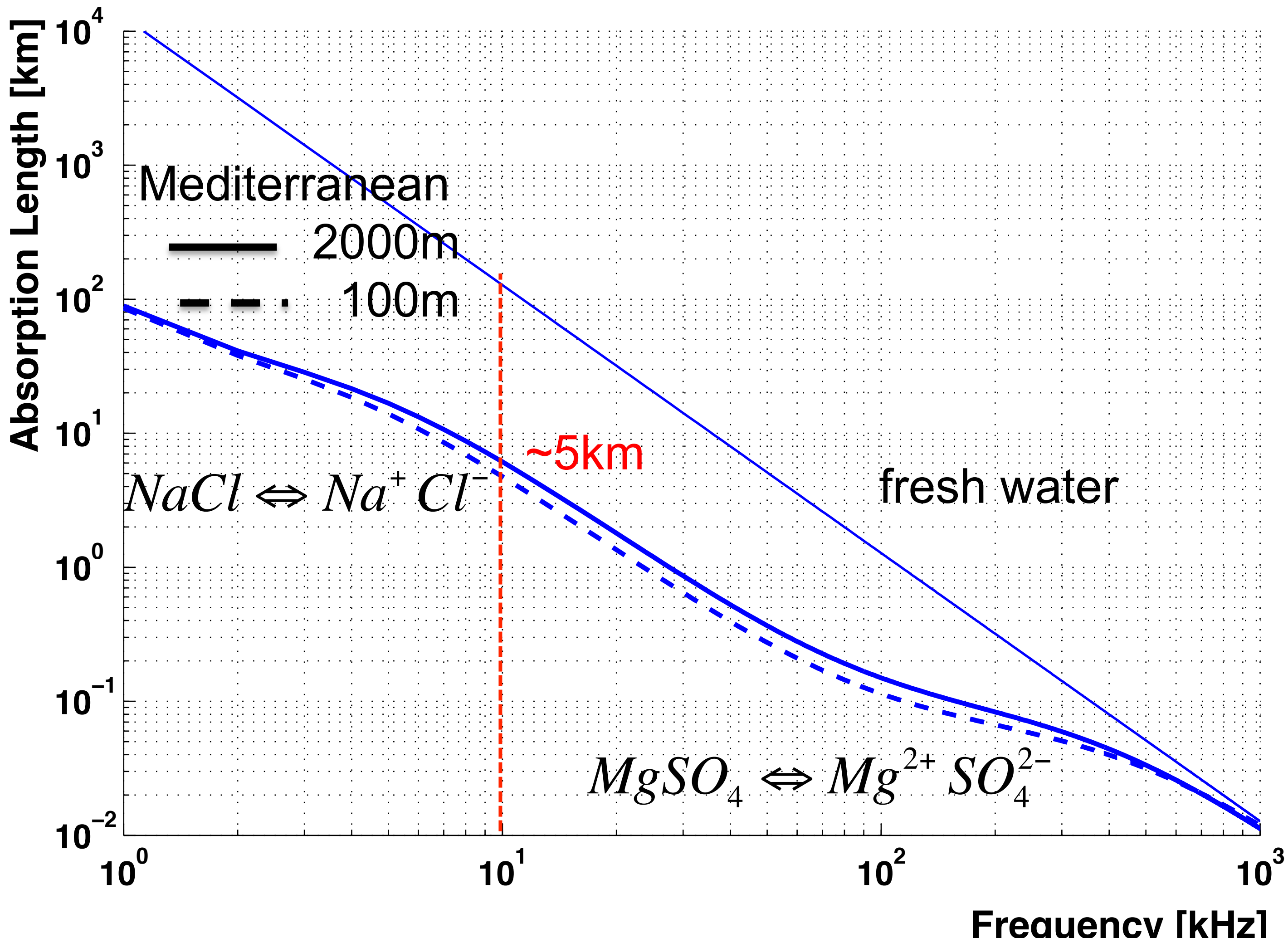
(R. Urick, Principles of Underwater Sound, 3rd edition, 1967)

Used by marine animals and humans for communication and positioning

Speed of sound in water investigated (at least) since 1826 (from title page of “Physics Today”, Oct. 2004, experiment in Lake Geneva)



Sound absorption length in water



Acoustic signals of neutrino interactions in water I

Thermo-acoustic effect: (Askariyan 1979)
energy deposition ⇨ local heating (~µK) ⇨ expansion ⇨ pressure signal

Wave equation for the pressure p for deposition of an energy density ε :

$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = -\frac{\alpha}{C_p}\frac{\partial^2 \varepsilon}{\partial t^2}$$

α = Volume expansion coefficient

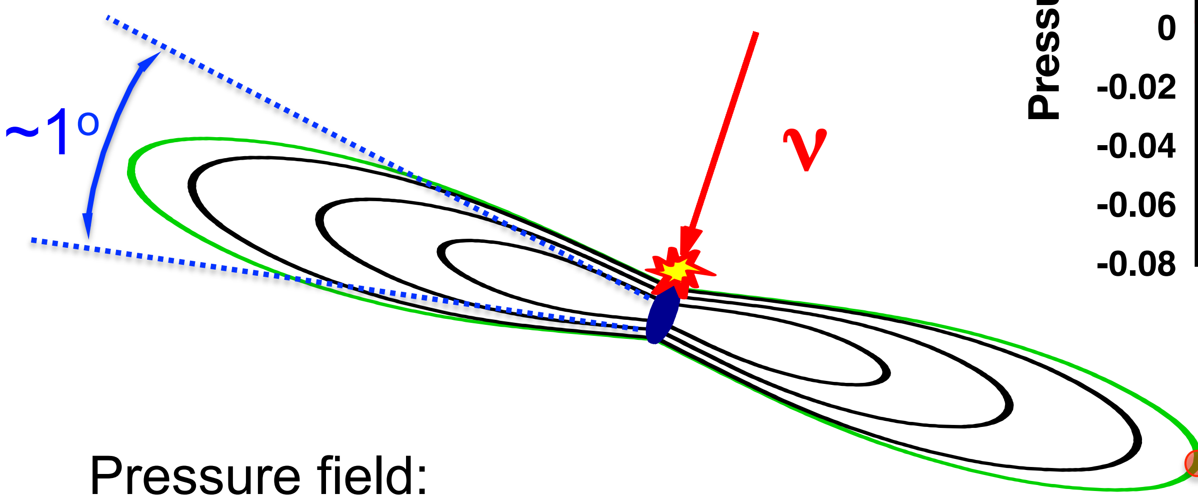
C_P = specific heat capacity (at constant pressure)

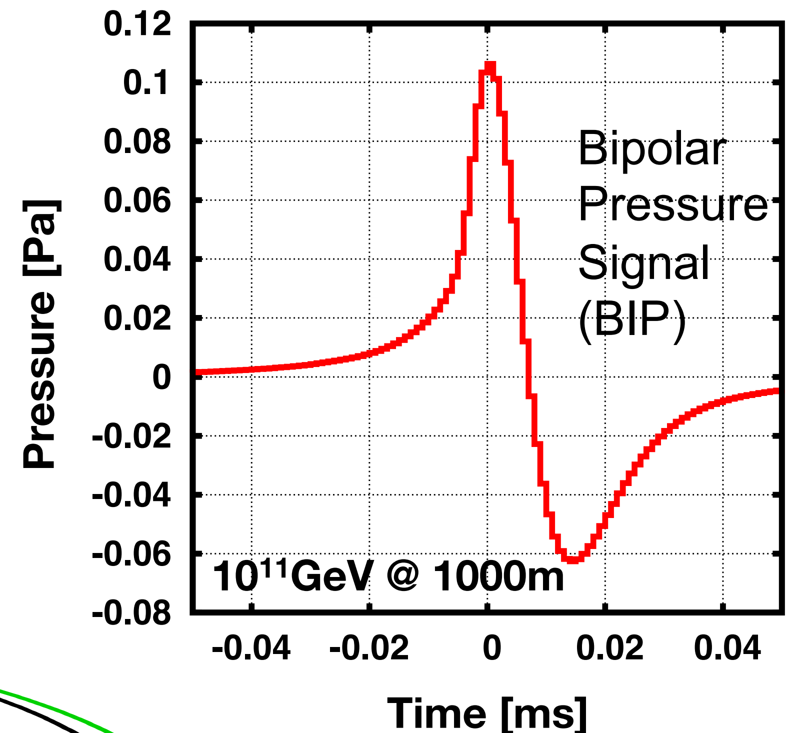
c = speed of sound in water (ca. 1500 m/s)

Solution (analytical/numerical) with assumption of an instantaneous energy deposition

Acoustic signals of neutrino interactions in water II

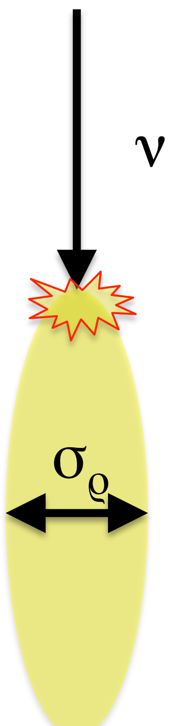
Hadronic cascade:
~10m length, few cm radius
(simulations by ACoRNE Coll.)





Pressure field:
Characteristic "pancake" pattern
Long attenuation length (~5 km @ 10 kHz)

The bipolar pulse

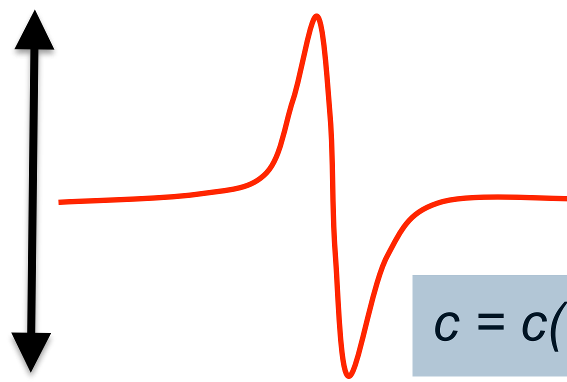


$$E_0 = \int \varepsilon \, dV$$

Analytical calculation of a signal in the far field for a Gaussian energy density

$$p_{\max} \propto \gamma_G \frac{E_0}{\sigma_\rho^2}$$

$2p_{\max}$



$$\gamma_G = \frac{c^2 \alpha}{C_P}$$

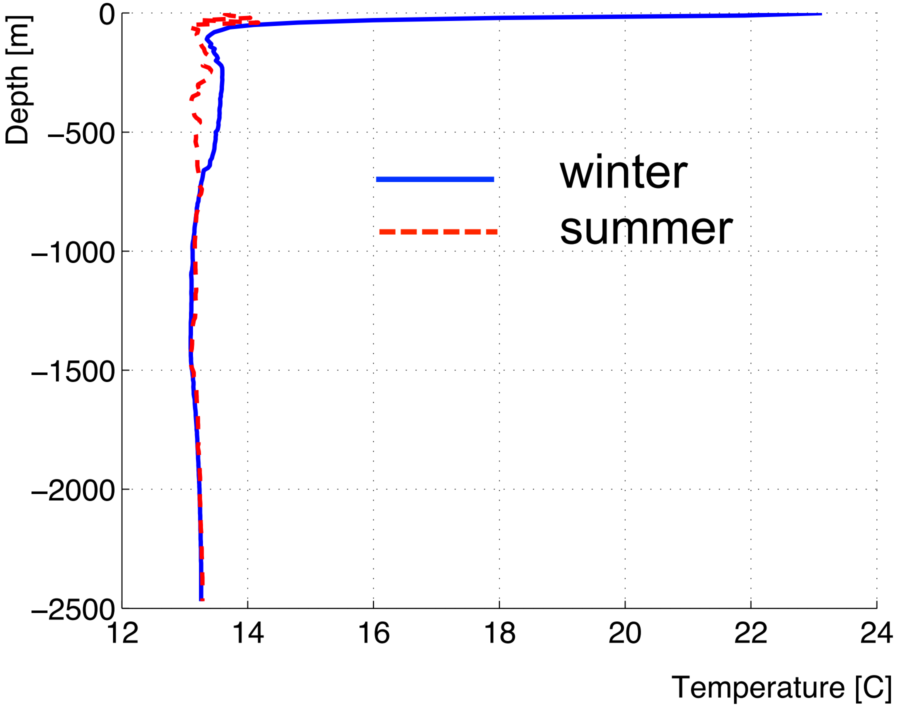
c = c(temp, pressure, salinity)

α = Volume expansion coefficient

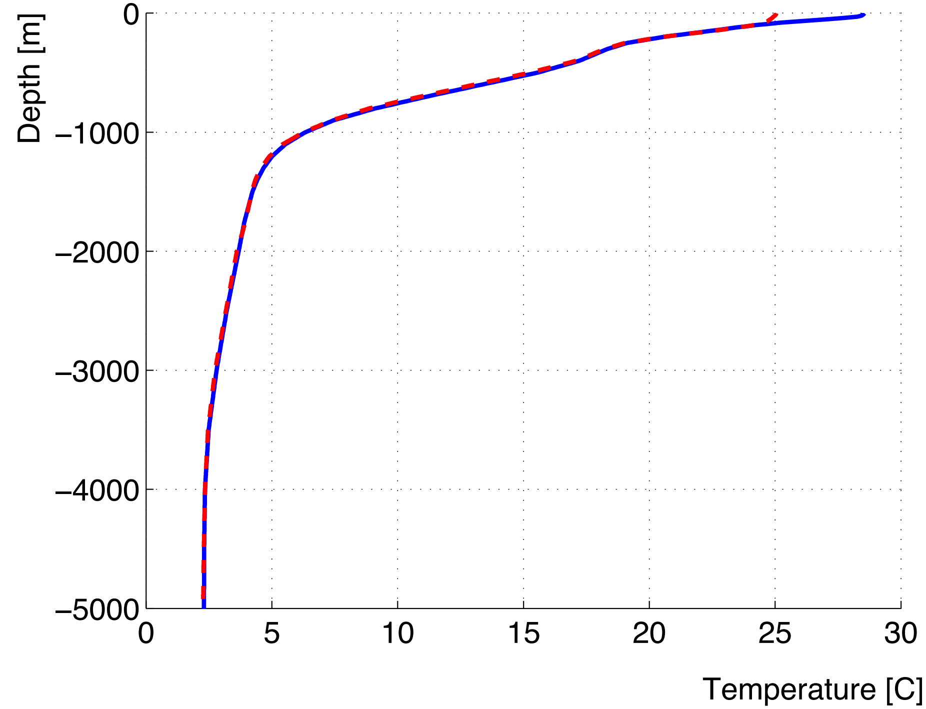
C_P = specific heat capacity (at constant pressure)

c = speed of sound in water (ca. 1500 m/s)

Temperature profile

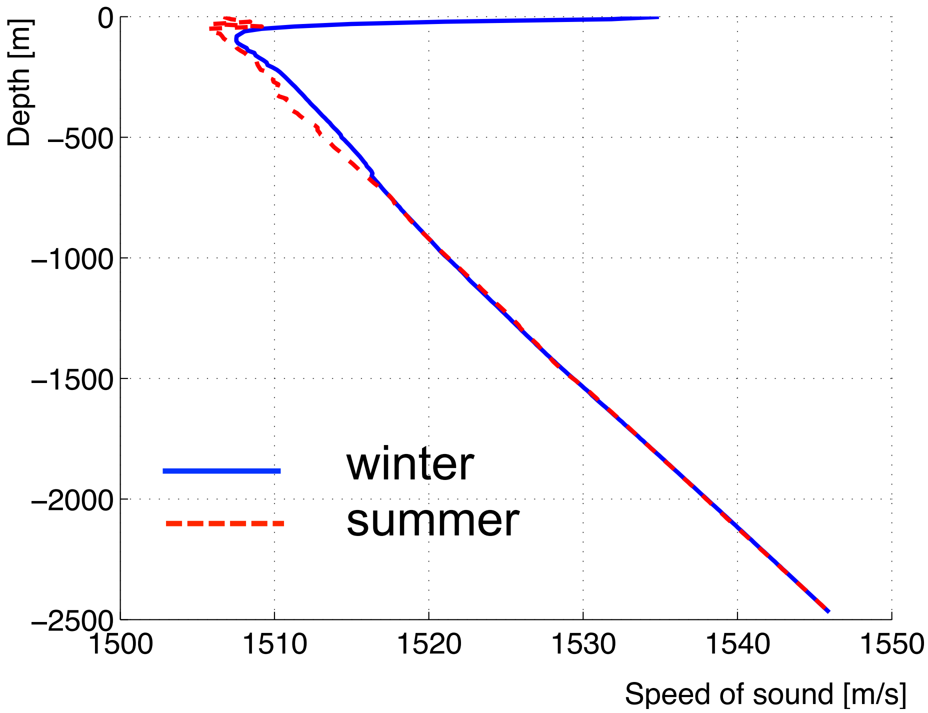


Mediterranean Sea

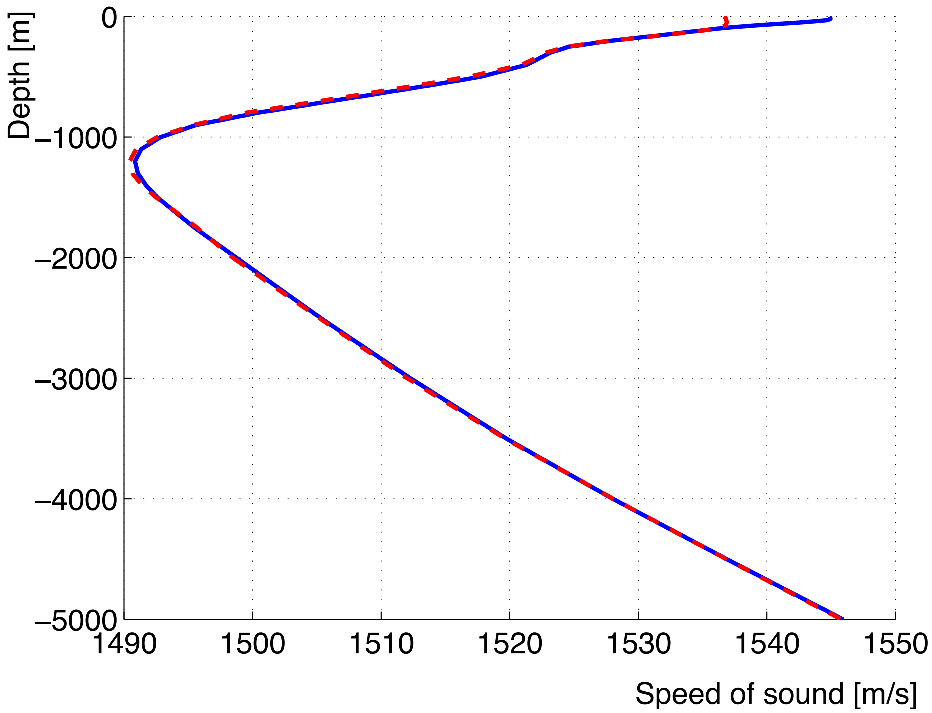


Tropical Ocean
24°30'N and 72°30'W

Speed of sound vs. depth

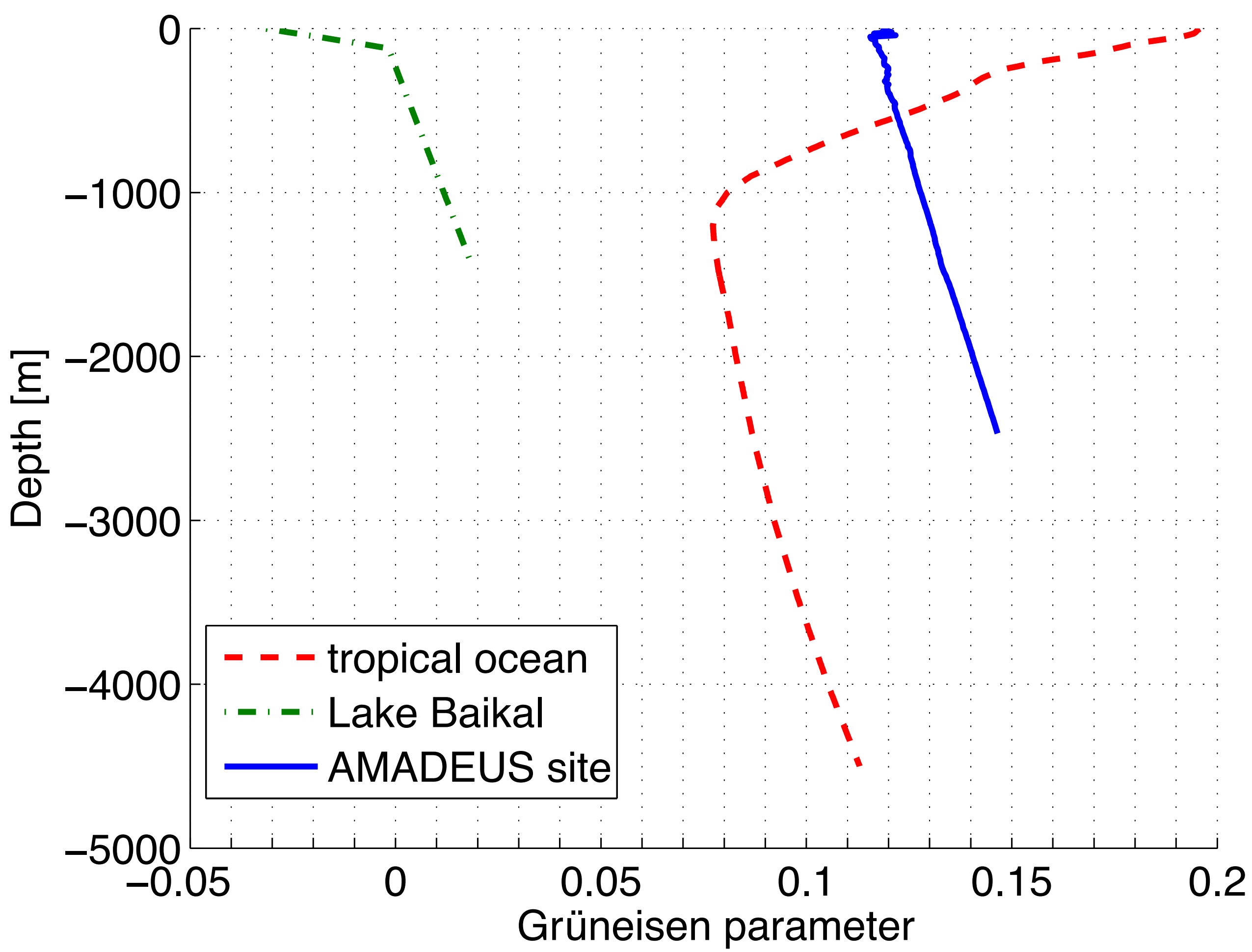


Mediterranean Sea



Tropical Ocean
24°30'N and 72°30'W

Grüneisen parameter



Acoustic detection test setups

First generation acoustic test setups for feasibility studies (background), developing techniques/algorithms

Two “philosophies”:

- “We can get access to an acoustic array; why not use it for some tests for acoustic particle detection?”
- “We have a neutrino telescope infrastructure; why not install some acoustic sensors to test acoustic particle detection?”

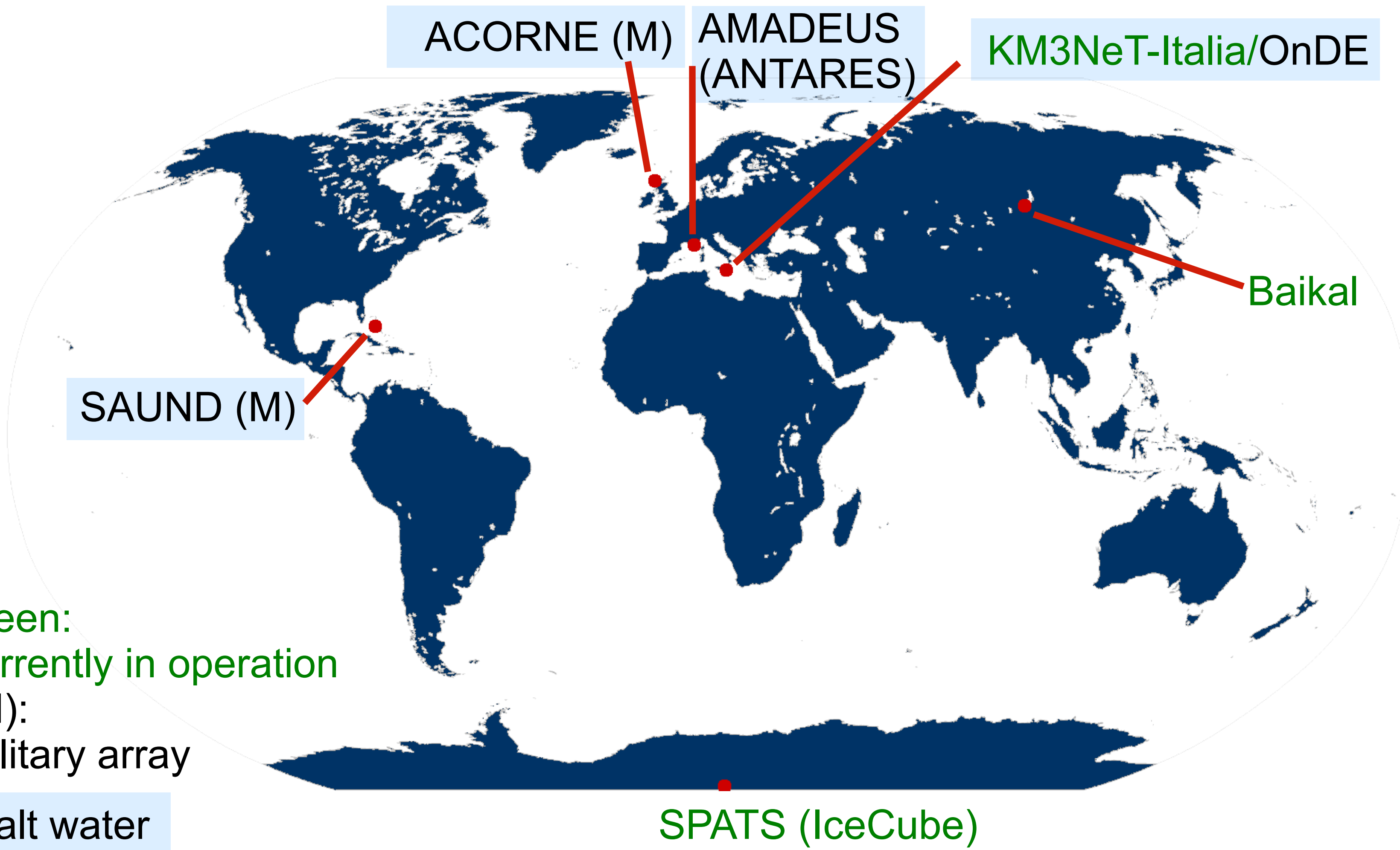
Technology:

Hydrophones (in water) and glaciophones (in ice) using piezo ceramics

Array size:

O(10) sensors

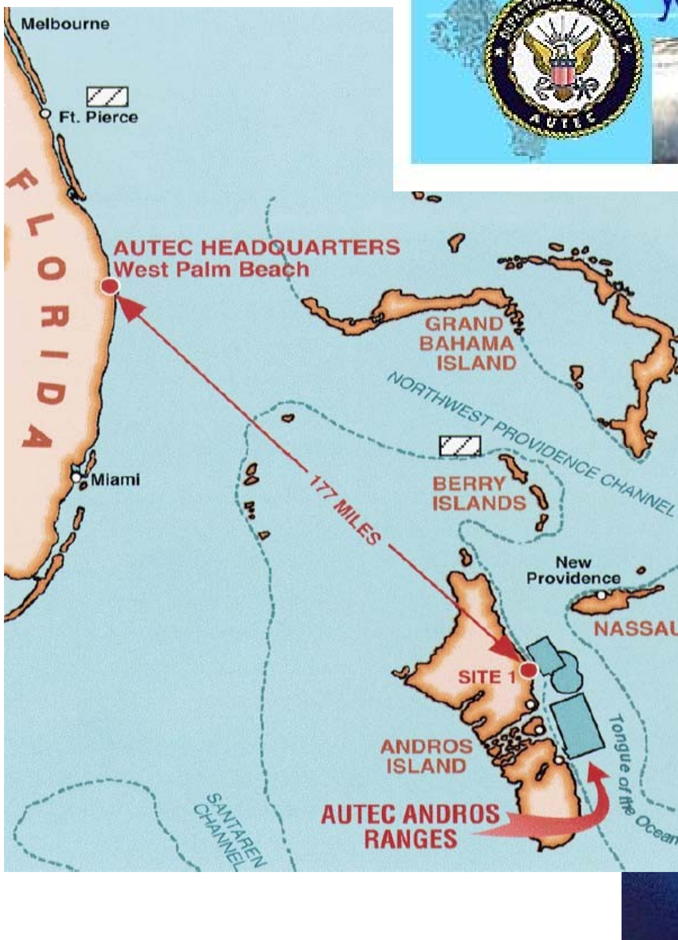
Test Setups in ice and water

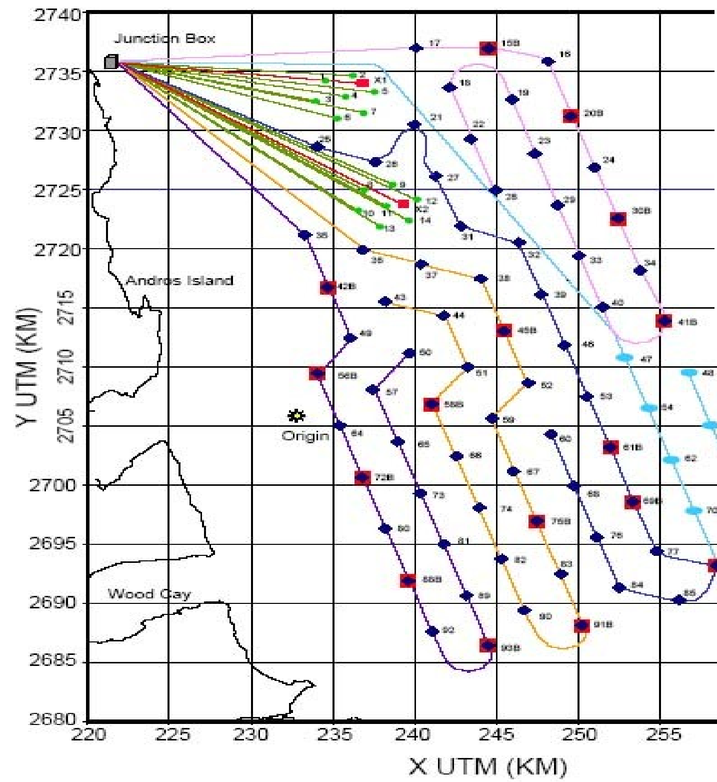


green:
currently in operation
(M):
military array

salt water

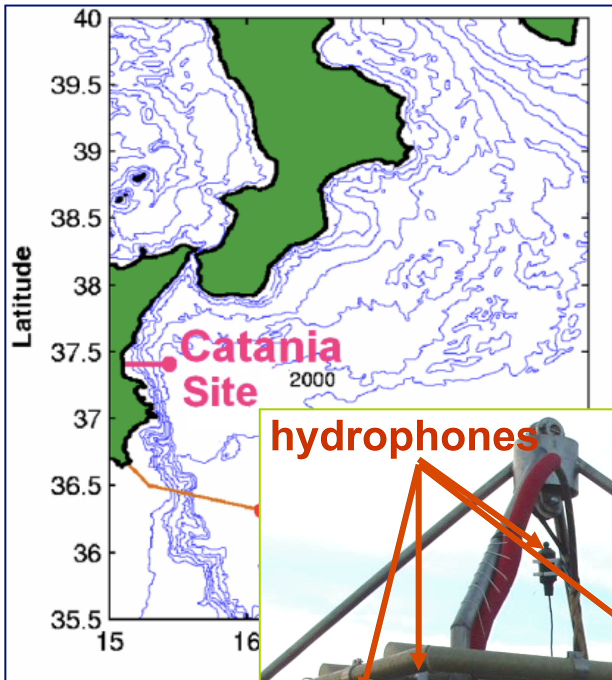
SAUND and AUTEC

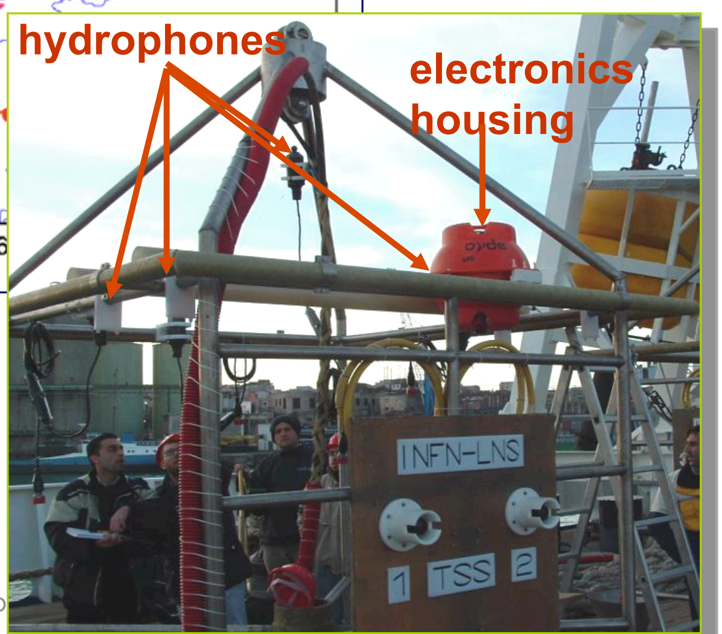




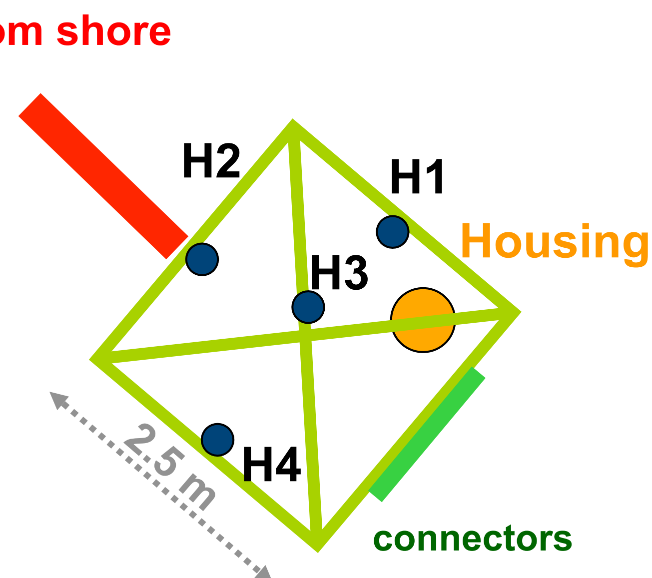
SAUND II :
49 hydrophones
on
20km x 50km
array

OnDE and KM3NeT-Italia





- Test Site at 2000 m depth, 25 km offshore Catania
- Operation of test setup OnDE (4 hydrophones) from 2005 -2006



Height from seabed :

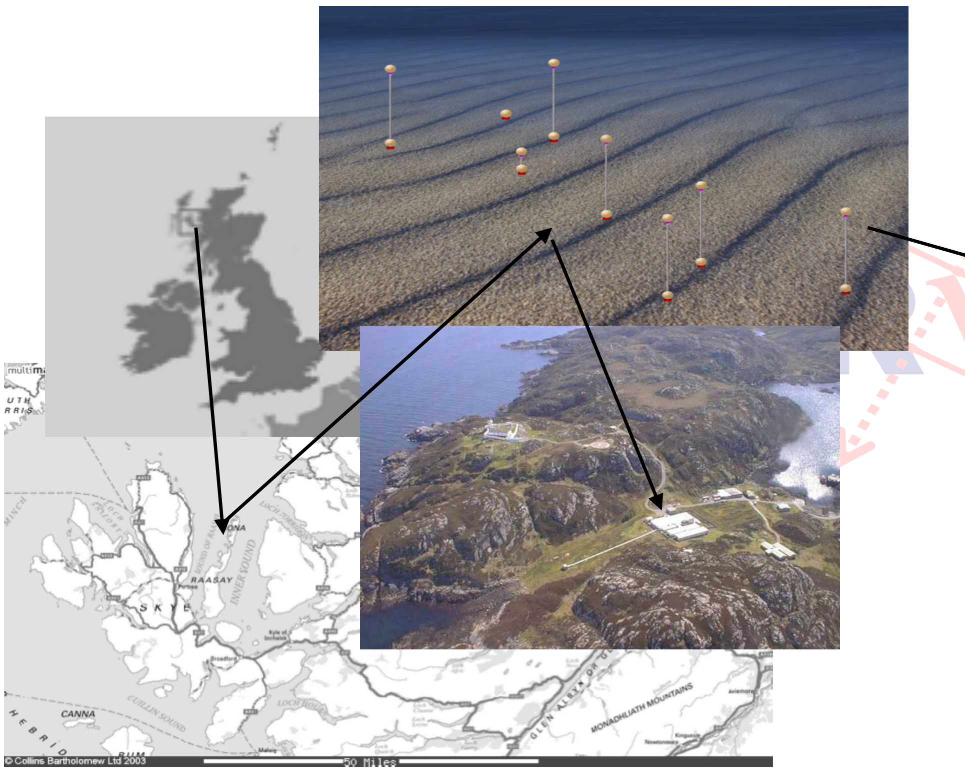
H1, H2, H4: ~ 2.6 m H3: ~ 3.2 m

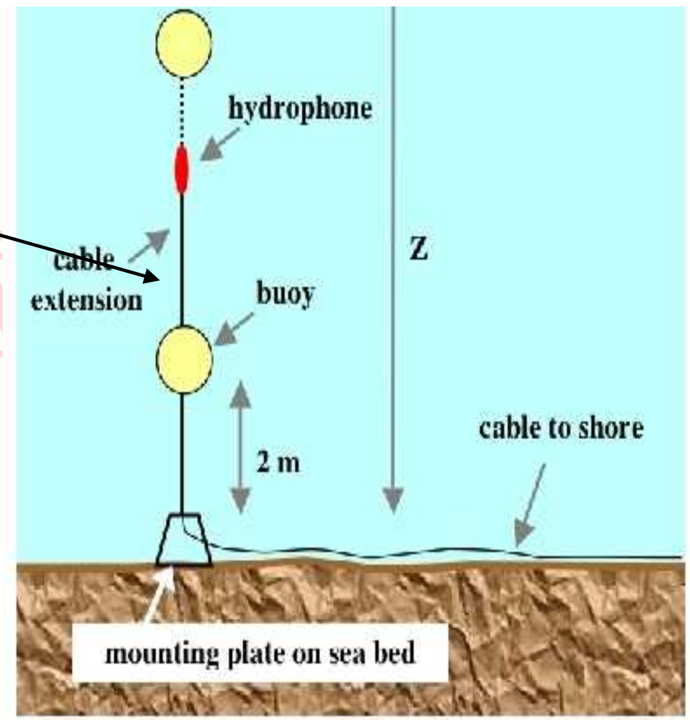
KM3Net-Italia activities covered by F. Simeone

The Rona Array (ACoRNE Collaboration)

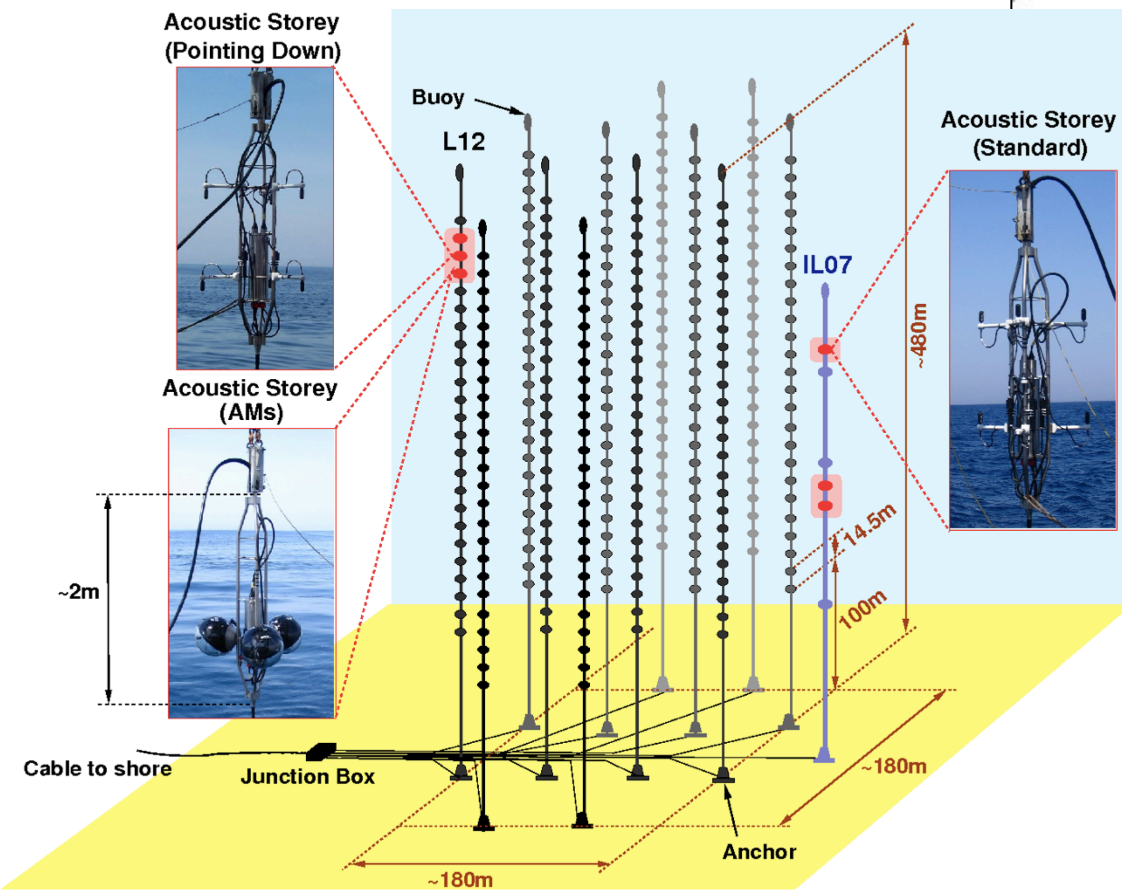
Off the Isle of Skye, 8 sensors

total cable length =
2m + cable extension + cable to shore





AMADEUS – ANTARES



Operational 2007-15

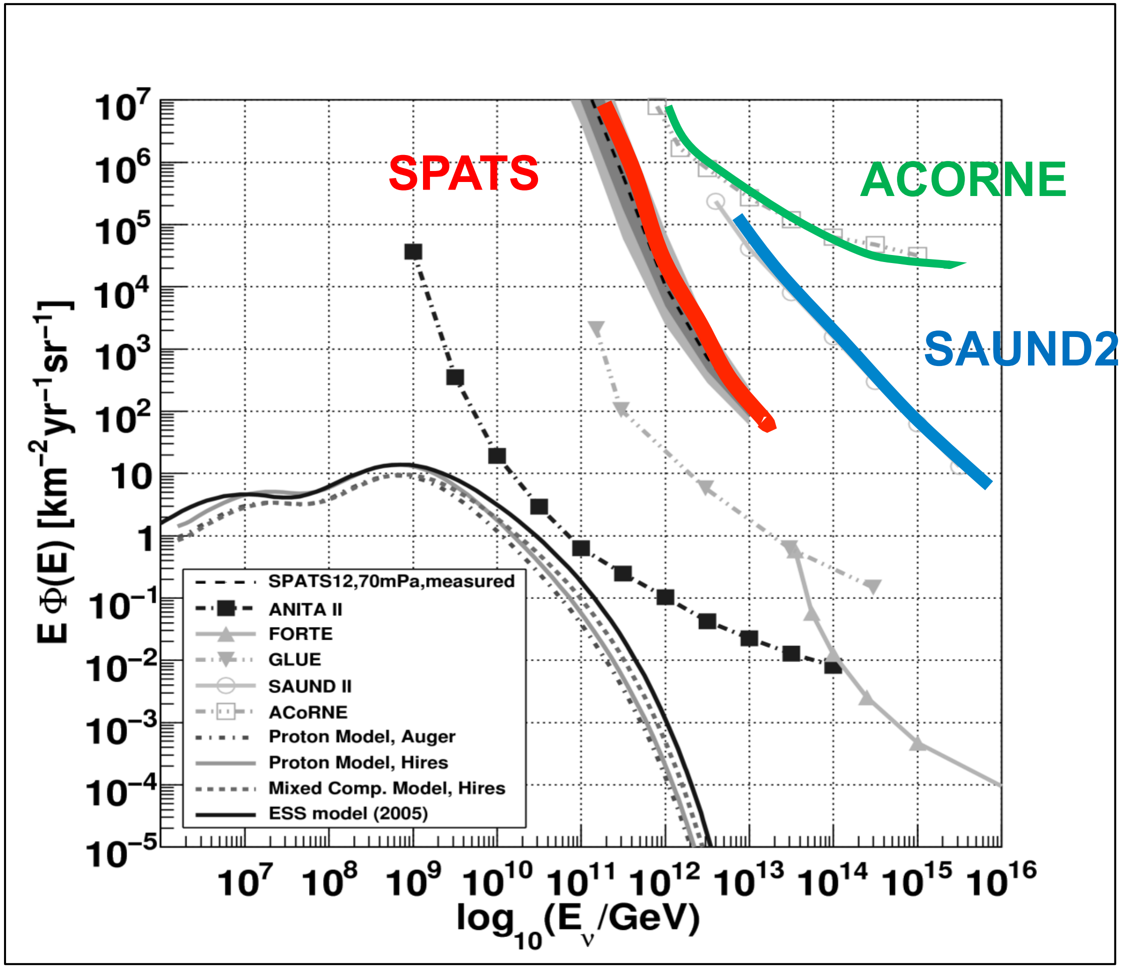
36 acoustic sensors on 6 stories

Local clusters for direction reconstruction

Depth 2300 – 2100 m

Limits on UHE neutrino flux

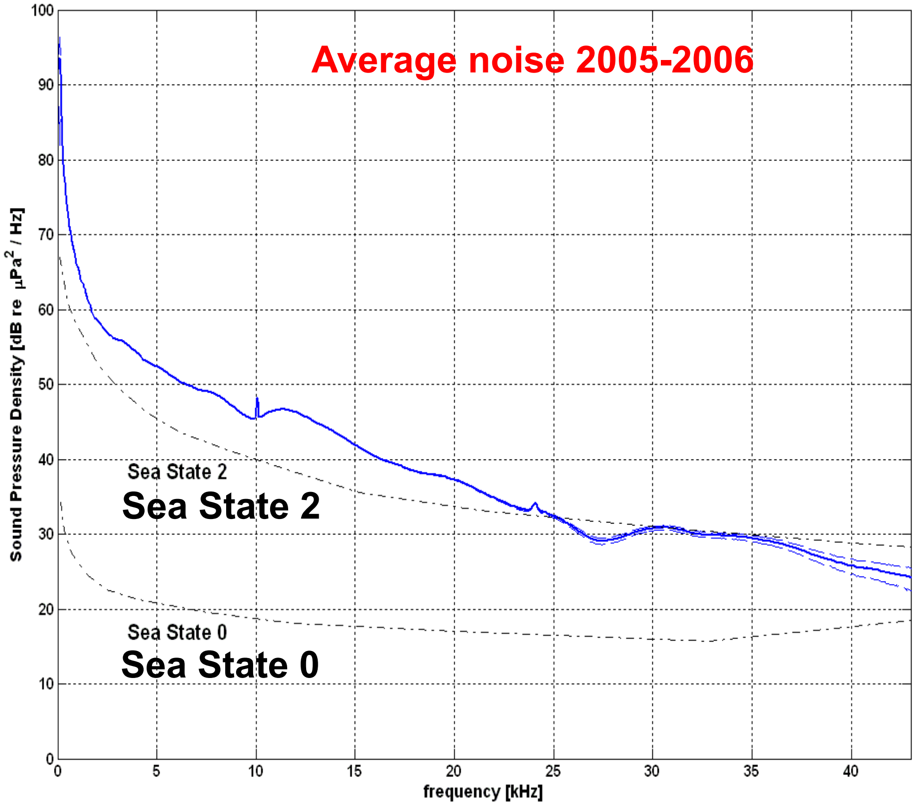
SPATS, ARENA 2012

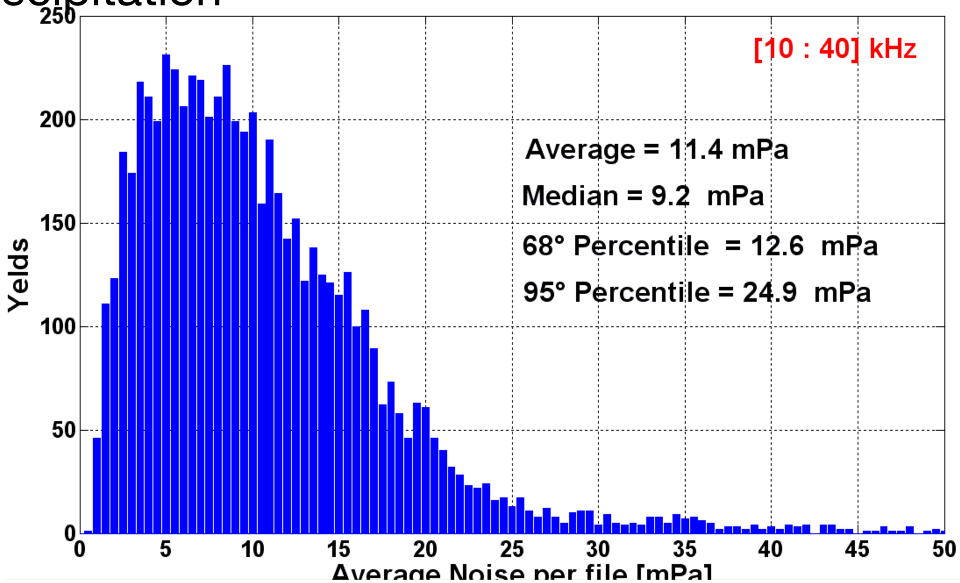


R. Abbasi et al.,arXiv:astro-ph/1103.1216

OnDE ambient noise (ARENA 2008)

Main source: Surface agitation and precipitation





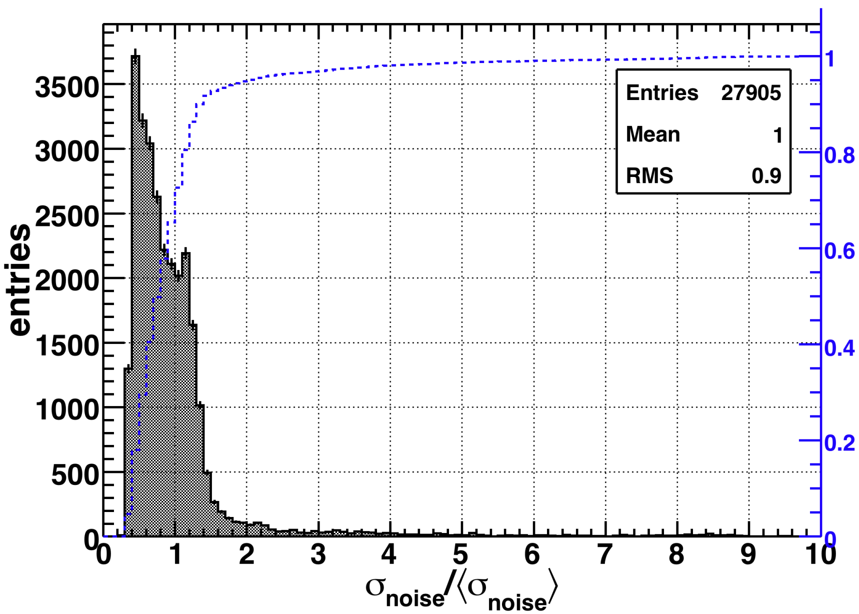
astro/ph 0804.2913

$$A_p(f_1, f_2) = \left[\int_{f_1}^{f_2} PSD \cdot (f) df\right]^{\frac{1}{2}}$$

The average noise in the [20:43] kHz band is $5.4 \pm 2.2_{stat} \pm 0.3_{syst}$ mPa

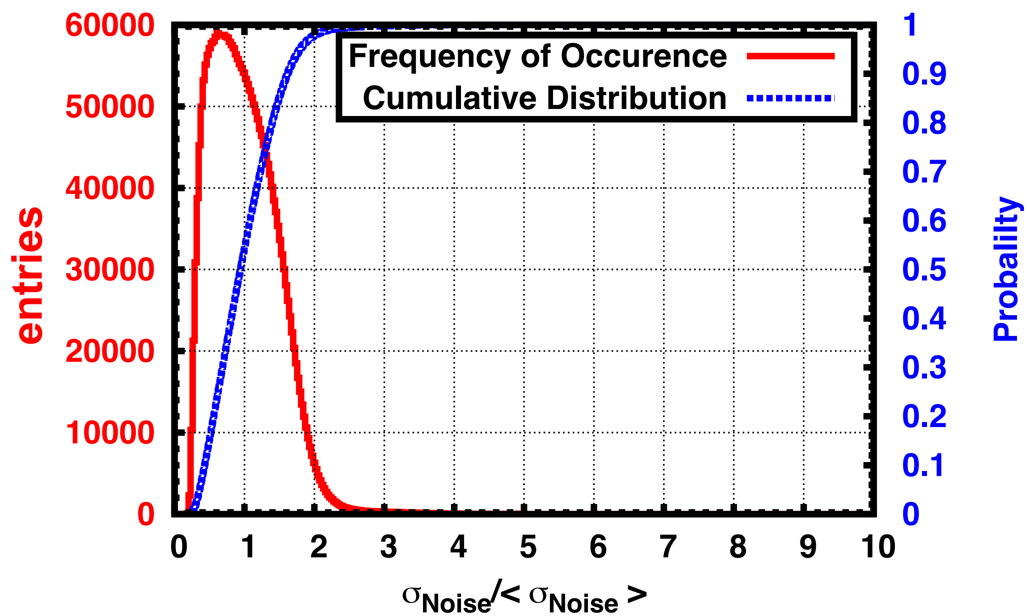
AMADEUS ambient noise

Measurement



Data of 2008-2010

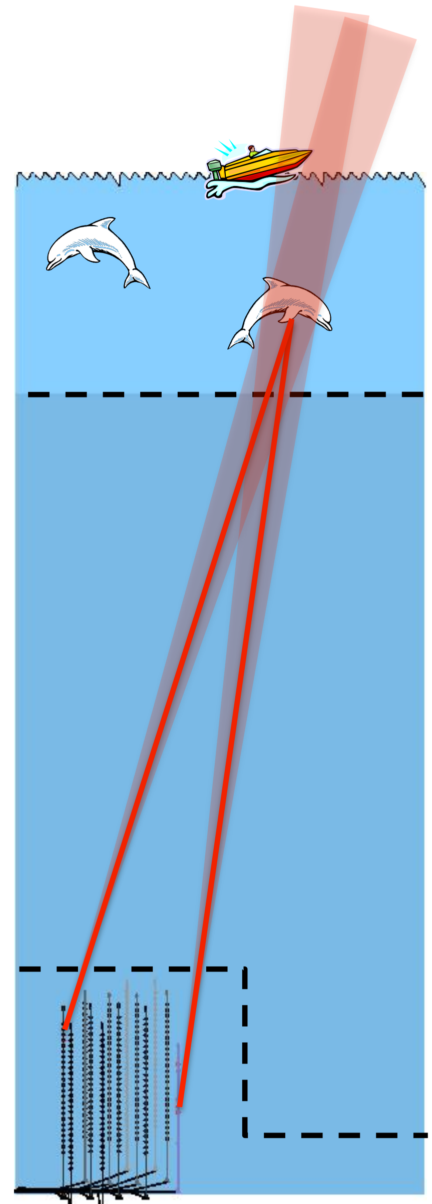
Simulation



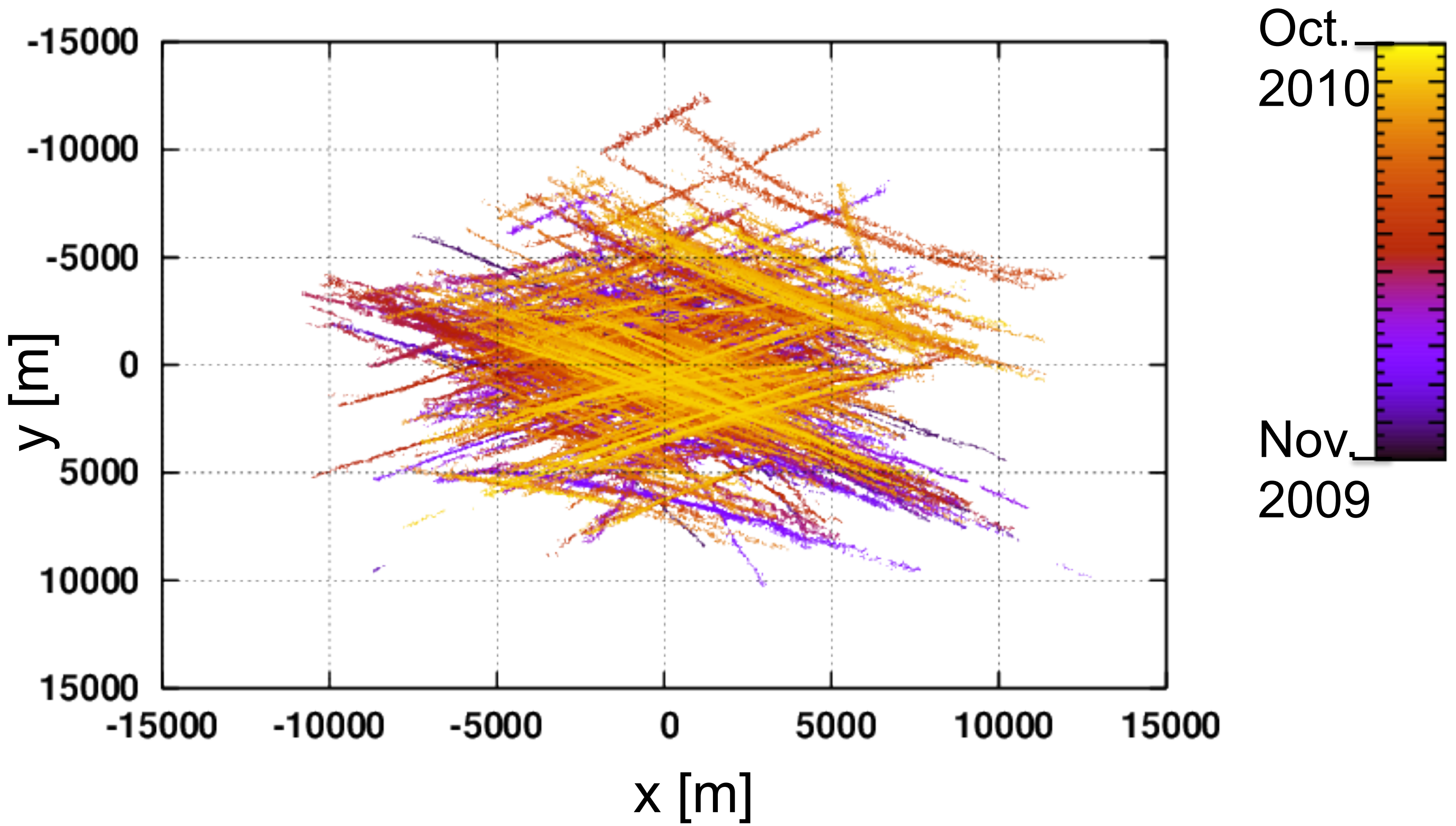
$<\sigma_{noise}>$ is about 10 mPa (10-50 kHz) and 95% of the time below $2<\sigma_{noise}>$

Transient background

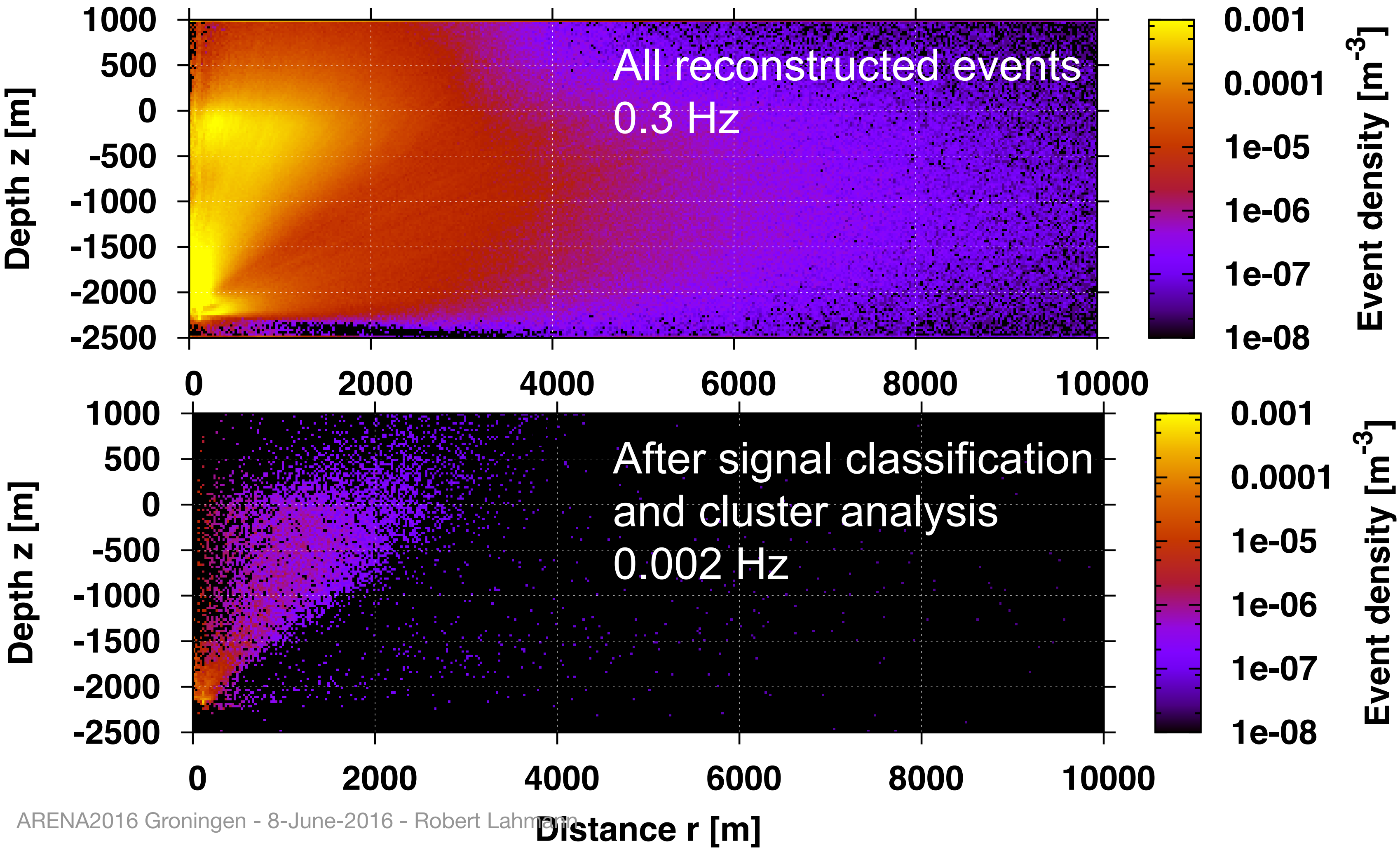
- Sources: Very diverse;
  Shipping traffic, marine mammals, …
  ⇨ Mostly originating from near surface
- Suppression:
  - signal classification
  - Project reconstructed signals to surface, perform clustering



Cluster analysis of moving sound emitting objects



Spatial distribution of transient background



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First generation setups: lessons learned

- Ambient background:
  Background low and stable, reduction of SNR for signal detection crucial
- Transient noise in the Mediterranean:
  High level of background (mainly dolphins);
  High level of reduction already achieved with AMADEUS, recognition of “acoustic pancake” crucial (talk by Dominik Kiessling)

The ~~road~~ open water ahead

- Second generation acoustic neutrino detection test setup (in Sea Water):
  "KM3NeT will have a huge array of acoustic sensors for position calibration; why not use it to implement what we have learned with the first generation setups?"
  (see following talk by Francesco Simeone)
- Third generation acoustic neutrino detector:
  KM3NeT can be extended with acoustic sensors using new and innovative technology (see talk by Ernst-Jan Buis).
  Results will be presented at ARENA 20XX

Conclusions and outlook

- “First generation” acoustic arrays have been used to investigate neutrino detection methods and provide input for simulations
- Working on methods to reduce SNR, recognize “pancake”
- The future of acoustics in sea water is KM3NeT

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