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Full Chain In-Situ Calibration of Hydroacoustic Hydrophone Stations

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CTBTO / IMS / ED

CTBTO PREPARATORY COMMISSION

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Content

- CTBTO - Hydroacoustic Network
- Overview of Calibration Capabilities at Hydrophone Stations
- Importance of Full Chain In-Situ Calibration
- Review of Past Studies
- Envisaged In-Situ Calibration Methodologies
- Key Challenges
- Future Actions

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IMS Network

4 Monitoring Technologies

3 Waveform Technologies

- 11 hydroacoustic stations (all stations certified)
- 50 primary and 120 auxiliary seismic stations (155 stations certified)
- 60 infrasound stations (54 stations certified)

Radionuclide Technology (Particulate & Noble Gas)

- 80 radionuclide stations + 16 radionuclide laboratories (73 stations and 14 laboratories certified)
- 40 radionuclide stations also have noble gas monitoring capability (26 stations certified)

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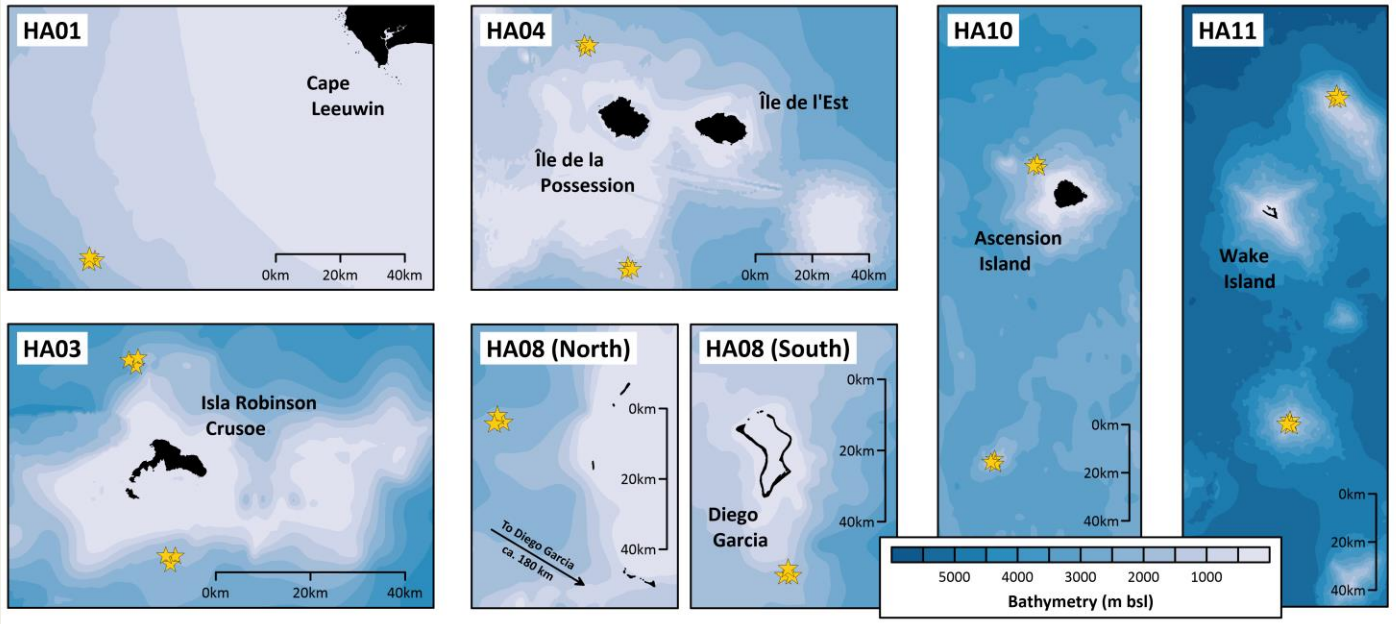
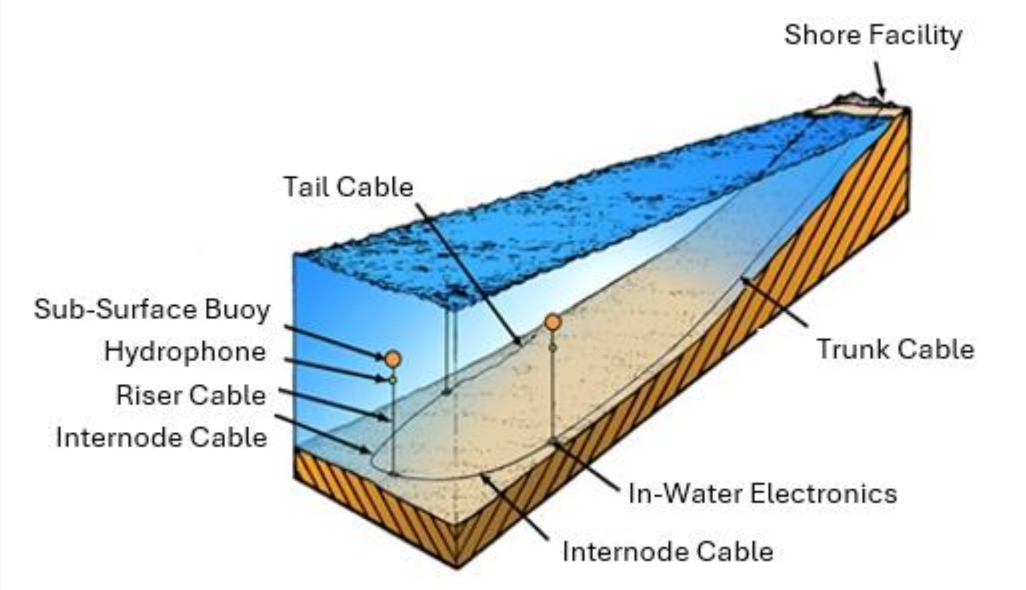
Hydroacoustic Network





Schematic outline of an IMS hydrophone station – Not to Scale

6 Hydrophone Stations
Bottom-moored triplets of hydrophones at SOFAR depth, which are very sensitive to acoustic pressure variations in ocean, detect signals traveling in the ocean.

5 T-Phase Stations
Land-based seismometers, which are more sensitive to ground vibrations, detect hydroacoustic waves transmitted through the Earth's crust.

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Overview of Calibration Capability at Hydrophone Stations

- Initial Calibration – Before Deployment: **“Full chain”** system calibration during the acceptance tests under operation depth and temperature.
  - Hydrophone (including preamp) in low frequency **tank facility**
  - UWS digitizer electronics: input from riser cable to laser output **in the laboratory**
- After Deployment: UWS digitizer electronics calibration is performed from the CRF, it **does not include** the contribution of the analog part that contains information related to the hydrophone and the riser cable.

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Overview of Calibration Capability at Hydrophone Stations

UWS Digitizer Electronics Calibration in-situ – After Deployment.

Hydrophone

↓

Pre-amplifier

↓

1) A command from the CRF triggers the system for calibration and switches it into calibration mode. →

<u>Electronic Bottle</u>

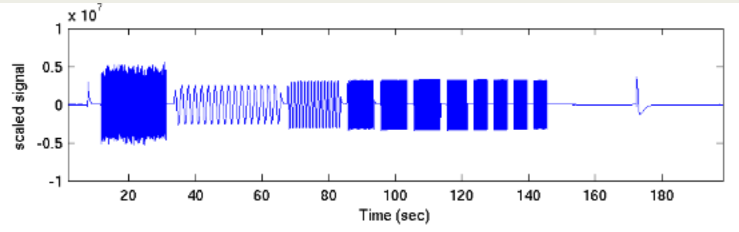
High Pass Filter

Low Pass Filter

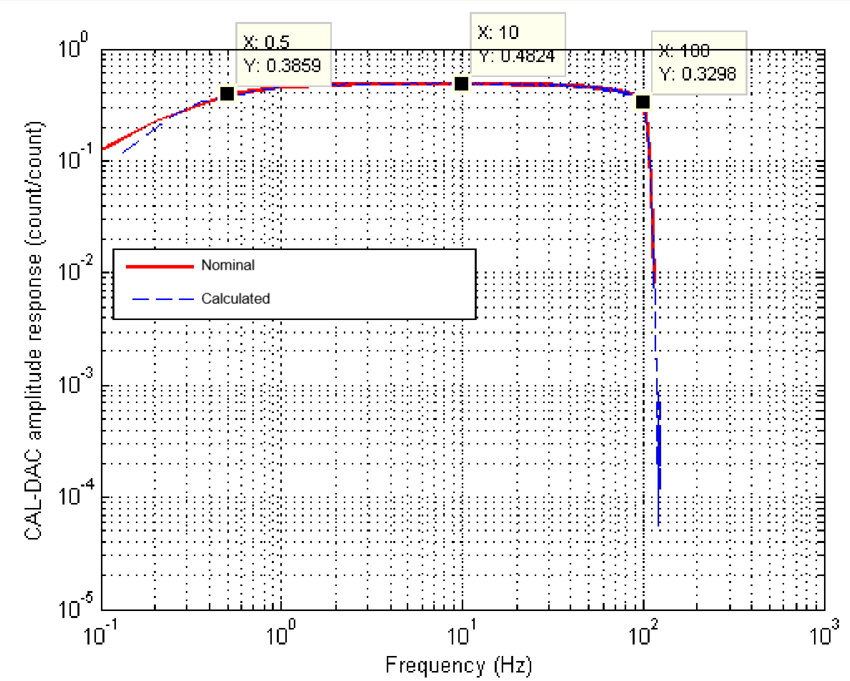
A/D Convertor

2) Known pre-stored analog waveform is injected via a D/A converter.
Sequence consists of:

- Pseudo-random noise (RBC)
- CW sinusoid chirps



3) Data received at the shore and sent to Vienna via the satellite link. Processed to check if there are changes in the response over time.



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Importance of Full Chain In-Situ Calibration

- **Hydrophone** is the primary sensing element, and its acoustic performance is **critical**. Potential source of hydrophone instability: Sensor material ageing, electronic component degradation, water ingress, external impact.
- The **analog part** of the system (hydrophone and riser cable) **may degrade over time**, and this potential degradation is currently not accounted for in the system's traceability.
- This is **particularly important** as IMS sustainment foresees operating HA Hydrophone stations well beyond **their design life,** as full chain calibration can help in early identification of underwater system issues/aging.
- Assessing the state of health of the **full signal chain** through in-situ calibration from the hydrophone to the on-land electronics **would help** us evaluate station sustainability and maintenance needs.
- It would be a key check to ensure the **performance consistency** and **long-term reliability** of the hydroacoustic network.

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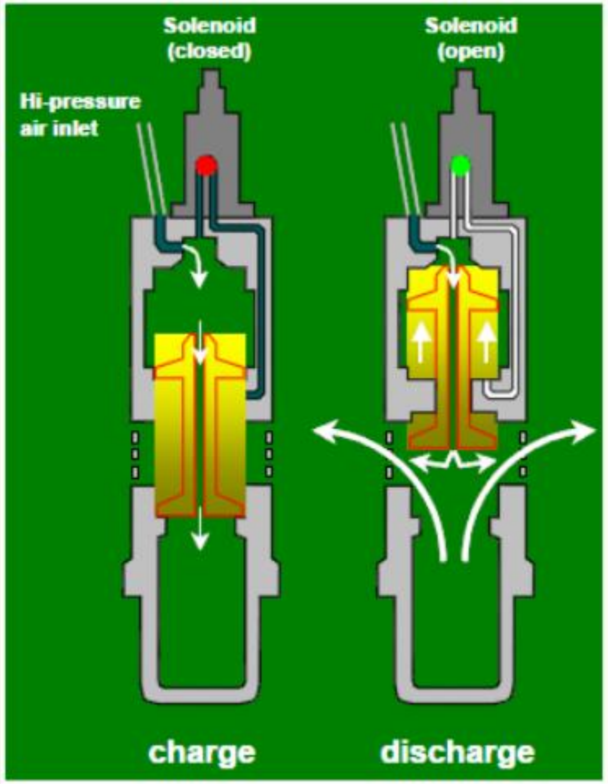
Review of Past Studies - 1 & 2

Air gun survey, Ascension Island, May 1999, *J.C. Ross*

Purpose: Calibrate & locate **3 existing hydrophones** (installed 1957)

Direct arrival phase, contaminated by **bottom reflections** & **scattering, clipped received signals**

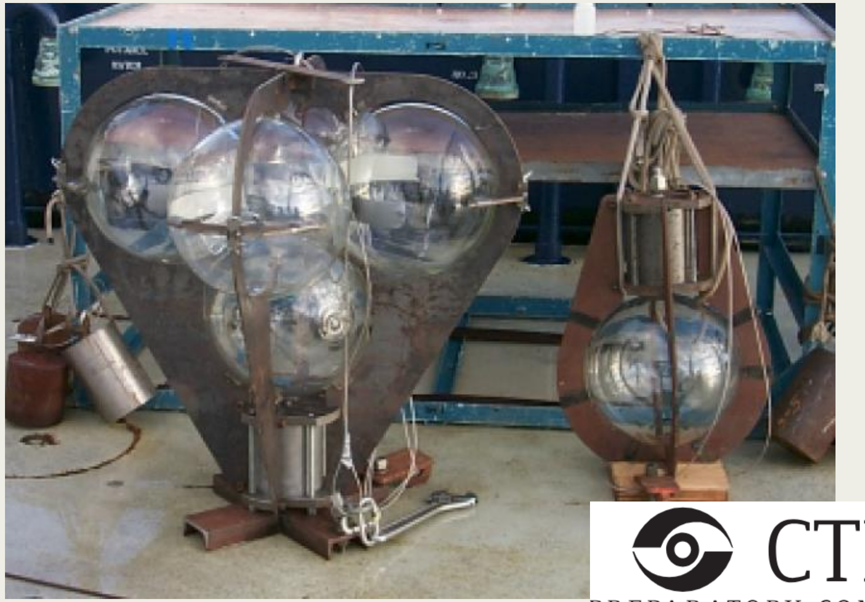
Seismic air guns, designed for **near-surface operation,** may **not couple** into **SOFAR channel**



Imploding spheres, alternative method to energize **SOFAR channel**

Signal spectra, broad peak **200–800 Hz**

Source frequencies higher than **hydrophone network sensitivity** (1–100 Hz) → **low frequencies absent**



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Calibration Methodologies – IEC 60565 – 1: 2020

- **Free Field three transducer spherical wave reciprocity calibration – Primary Method**
  - Requires 3 transducers at least one of which must be reciprocal (receiver ⇔ projector).
  - **Not easy to conduct** under ocean conditions due to detailed calibration procedure (At least 3 pairs of electrical transfer impedance (Z) measurements).
  - Lowest possible measurement uncertainty (most accurate result) due to being the primary method.
- **Free Field calibration by comparison with an acoustic reference device – Secondary Method**
  - 3 Types of comparison calibration method
    - **Hydrophone calibration by comparison with a reference hydrophone.**
    - **Hydrophone calibration using a calibrated projector**.
    - Projector calibration using a calibrated hydrophone.
  - Much easier to conduct; however, it has higher measurement uncertainty compared to the primary method.

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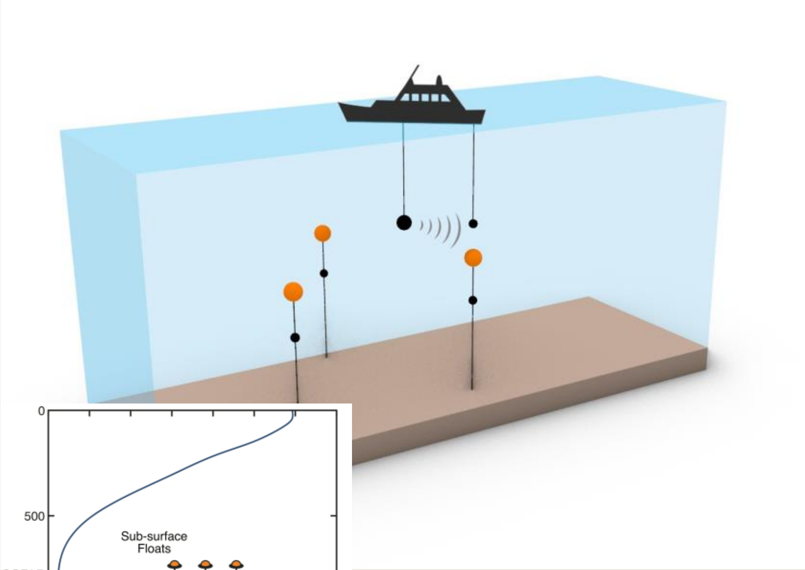
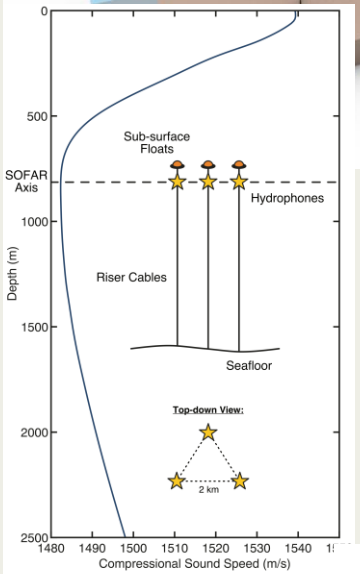
Envisaged In-Situ Calibration Methodologies - 1

Hydrophone calibration using a calibrated projector

- **Calibration of the projector** at the frequency of interest is **essential**. Very low frequencies can be challenging.
- **Sound propagation** in the measurement site should be carefully considered. **Models** can be used to predict how sound travels in situ.
- Measurements are **highly dependent on the distance** between the projector and the hydrophone under test, **unless** an additional monitoring hydrophone is moored from a second platform near the known position of the hydrophone triplet.
- This method **requires only one platform** during the measurement process, which holds both the projector and the hydrophone (for monitoring).





$$M_H = \frac{d \times V_{PH}}{S_{VP} \times V_P}$$

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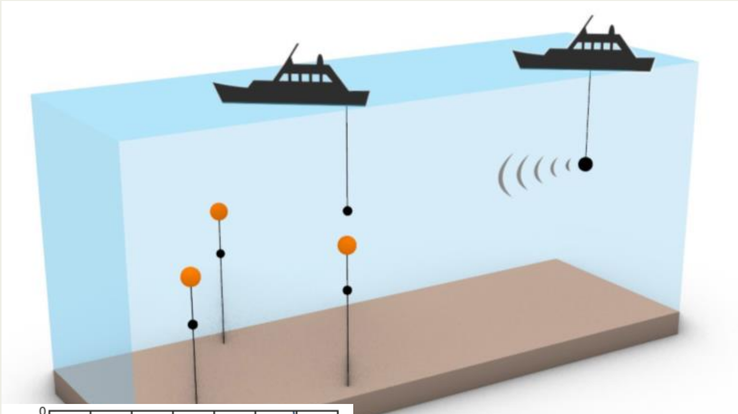
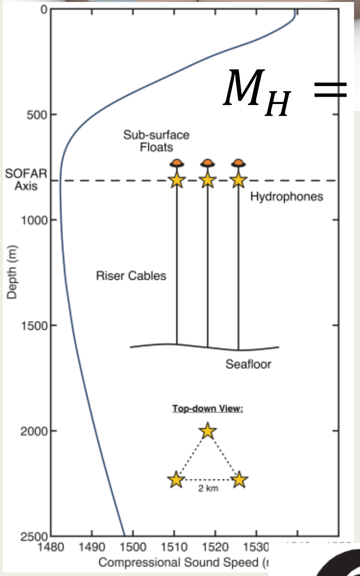
Envisaged In-Situ Calibration Methodologies - 2

Hydrophone calibration by comparison with a reference hydrophone.

- The **sound source** used for the calibration **does not need** to be a calibrated device. However, a **calibrated hydrophone** is still required for comparison measurements.
- Calibration of a **reference hydrophone** at very low frequency is generally challenging.
- This method **depends** on whether both the hydrophone under test and the calibrated hydrophone are exposed to the **same acoustic field**.
- This method may offer **more stability** of the measurement under open ocean conditions.
- This method requires two platforms during the calibration process. This adds additional **logistical and financial burdens**.





$$M_H = \frac{V_H}{V_{Ref,H}} \times M_{Ref,H}$$

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Key Challenges of In Situ Calibration

- Calibration at very low frequencies (**1–100 Hz**); **availability and metrological traceability** of the projectors and hydrophones are **limited**.
- The lower number of oscillations at the hydrophone side without any overlap due to reflections require the use of **signal processing techniques** to reconstruct a sufficiently long waveform for identifying the signal's amplitude and phase, especially at frequencies below 20 Hz or adaptation of such a method.
- Deep-water deployment (**up to 1400 m**); the measurement platform must be properly equipped to deploy instruments to the SOFAR channel depth.
- There are **no standard calibration procedures** for in-situ deep ocean underwater acoustic calibration methods.
- Accurate knowledge of the **coordinates of the hydrophone triplet** and variability from ocean currents.
- Open **ocean** ambient and propagation conditions.
- **Remote** station locations and associated **logistical challenges and cost**.

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Future Actions

Feasibility / Preparation

- **Cooperation and joint work** with other institutions operating in offshore marine areas: contributing to calibration efforts, providing logistical support at remote stations, and addressing station-specific permitting issues.
- **Exploration of equipment** and their proper calibrations. A custom-designed product may be necessary to meet the frequency and the operational depth specifications.
- Establishment of a **calibration methodology and procedure**.

Sea Test

- Open **sea test** in realistic conditions at an accessible location, collaboration with partners would be necessary before testing it in remote locations.

Calibration Work

- **HA01** Cape Leeuwin (Australia) is the most accessible HA hydrophone station in this sense.

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THANK YOU