SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

CTBTO
PREPARATORY COMMISSION

The CTBT Hydroacoustic Network at 25 years

Martin Lawrence
(Sydney Institute of Marine Science, formerly CTBTO)

Georgios Haralabus, Mario Zampolli, Peter Nielsen, Jerry Stanley
(CTBTO)

Invited Presentation

I02-718

ORAL PRESENTATION

Structure of presentation

- History of hydroacoustics in test ban monitoring discussions
- The hydroacoustic network of the International Monitoring System of CTBT
- A unique global observatory

Early Test Ban Treaty Negotiations

- First nuclear weapon test: 1945
- First discussion of test bans: 1954
- Partial Test Ban Treaty: 1963
  allowed underground testing
- Discussions of a comprehensive test ban treaty continued .....
  Monitoring regarded as essential
  There were concerns about monitoring underground tests
  Establishment of GSE (Group of Scientific Experts)
  to further investigate seismic technology
- Leading to negotiations on a CTBT commencing in 1993

CTBT Negotiations

- In the preliminary negotiating session in 1993, four monitoring technologies were selected for greater consideration:
  seismic, hydroacoustic, infrasound and radionuclide
- Formal negotiations of the Conference on Disarmament took place 1994-1995
  In Geneva, Switzerland
  Two-week periods separated by a few months
- There were many working documents, but only one final document:
  The CTBT treaty text.

Why hydroacoustic monitoring?

- Testing has occurred in the ocean
- Completeness of environments
- Synergy of technologies
  ➔ increased difficulties for potential evader
- Quality of hydroacoustic signals
  very sensitive
  very clean signal (for in-water path)
  very high Signal-to-Noise Ratio (SNR)

Hydroacoustics in CTBT negotiations - 1

- States put forward individual visions of a hydroacoustic network
- Following plenary discussion, a working team was established to report back to the plenary group
- Basic issue 1: Purpose of network:
  - ➢ discrimination only
  - ➢ discrimination & location ✓
- Basic issue 2: Geographical coverage
  - ➢ all oceans
  - ➢ emphasis on Southern Ocean
  - ➢ all oceans except Arctic Ocean ✓

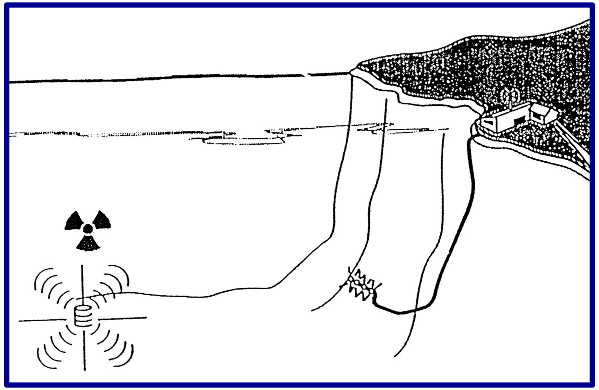
Hydroacoustics in CTBT negotiations - 2

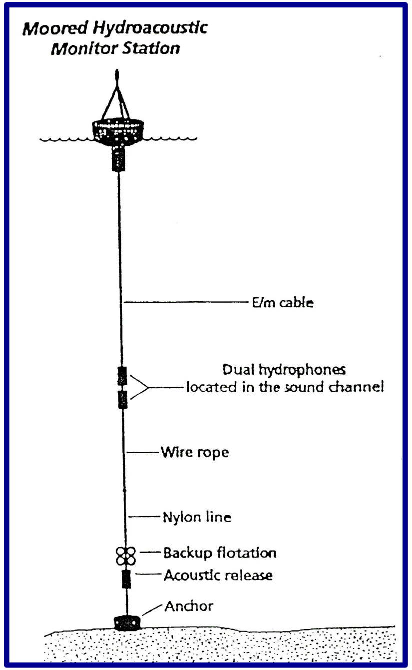
- Basic issue 3: Type of hydroacoustic station
  - ➢ hydrophones cabled back to shore, sending real time data ✓
  - ➢ autonomous buoys, periodically sending event characteristics (not waveform)

- Cabled network:

  Provides better data quality & availability.

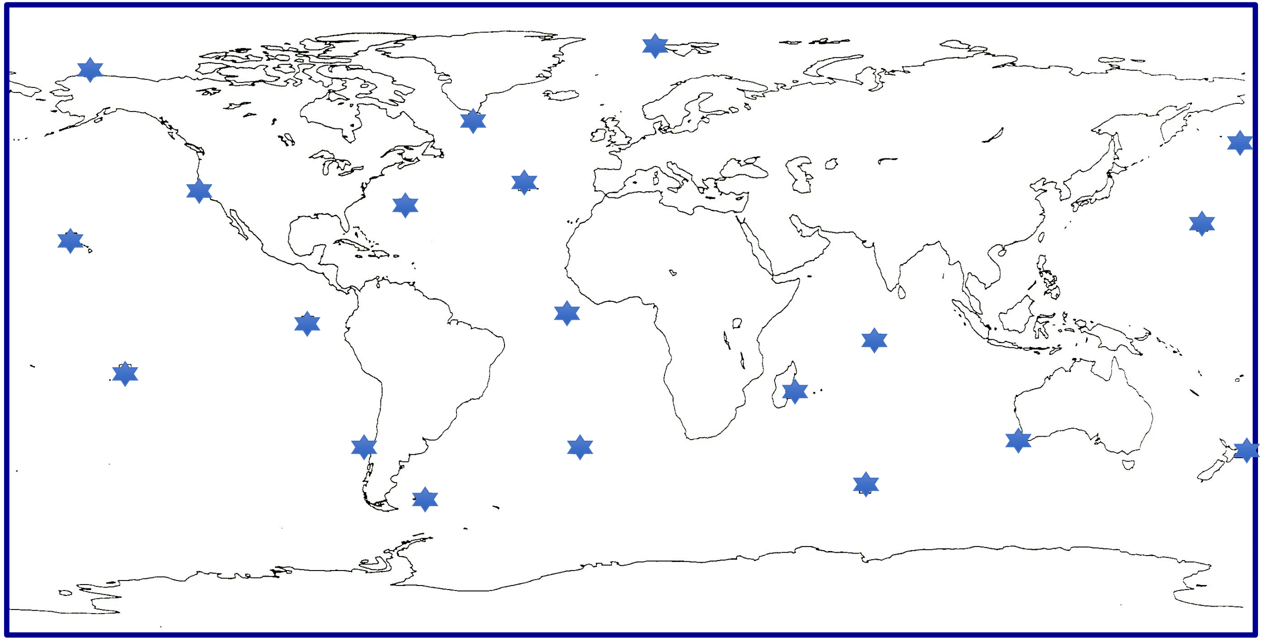
  Initially more expensive, lower ongoing cost.





Number & Location of Hydroacoustic stations

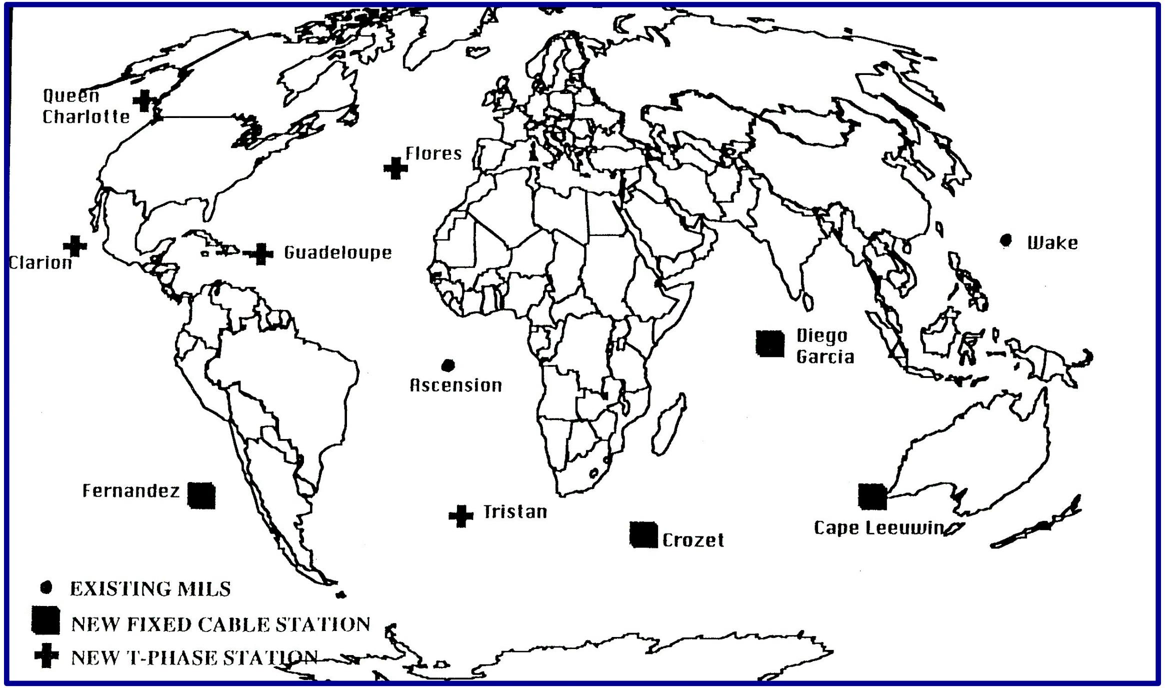
The network first proposed involved 20 cabled stations



Number, Type & Location of Hydroacoustic stations

- 20 station network was deemed to be too expensive.
  Next proposal had 11 cabled hydrophone stations
  (with locations approximately as now in Treaty)
- The concept of 11 stations was agreed by plenary.
  But the team was instructed to reduce the cost
- The next proposal (accepted by plenary) was:
  6 cabled hydrophone stations
  5 seismic stations using T-phase signals
- The basic specifications of stations were agreed,
  as well as the location of stations
- Station locations were chosen by examination of modeling studies

Map of hydroacoustic network – Dec 1995



MILS (missile Impact Locating Stations), existing U.S. hydrophone stations made available for preliminary use.

They have now been totally replaced by stations that meet CTBT standards.

Specifications of hydroacoustic stations

- Hydrophone stations:
  - ➢ Passband up to 100 Hz
    (covers bubble pulse of underwater nuclear explosion)
  - ➢ Up to 2 cables
  - ➢ 1 operational sensor with 2 back-up sensors per cable

- T-phase stations:
  - ➢ Passband higher than for seismic stations
    (utilizes the higher frequency information in ocean signals)

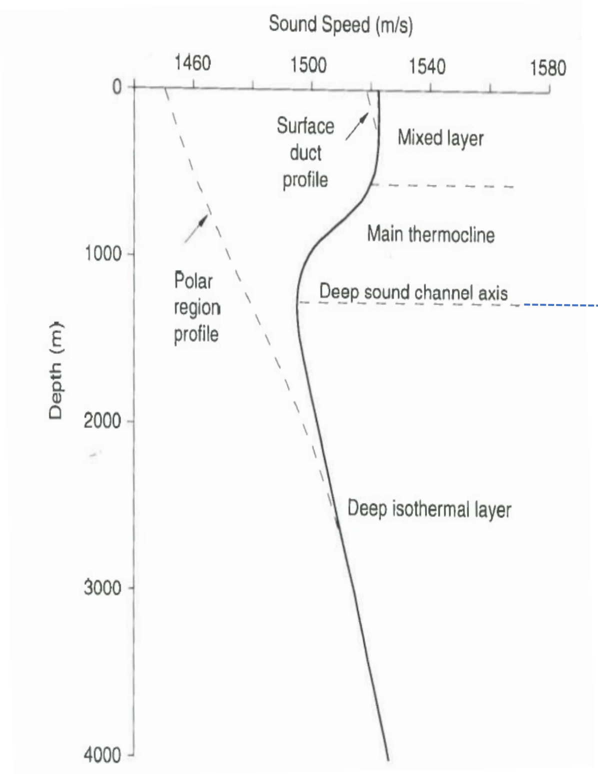
Development of detailed specifications

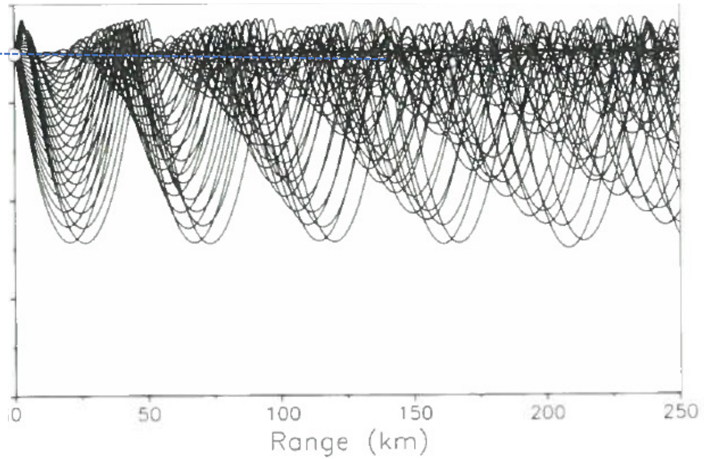
- WGB had responsibility for developing detailed specifications for stations.
  {Hydroacoustic workshops were used to provide advice to WGB on clarification of the HA specifications.}
- This process led to design of hydrophone stations with 3 horizontally separated hydrophones.
  This provides directional information.
- Sampling rates of data were chosen to be:

Hydrophone stations	250 samples/second
T-stations	100 samples/second

The CTBTO Hydroacoustic Network at 25 years

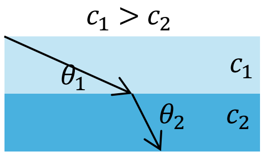
Underwater sound propagation - the SOFAR channel

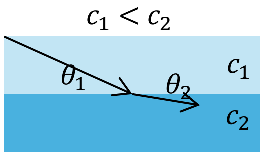




Snell's law:

$$\frac{\cos\theta_1}{c_1} = \frac{\cos\theta_2}{c_2}$$





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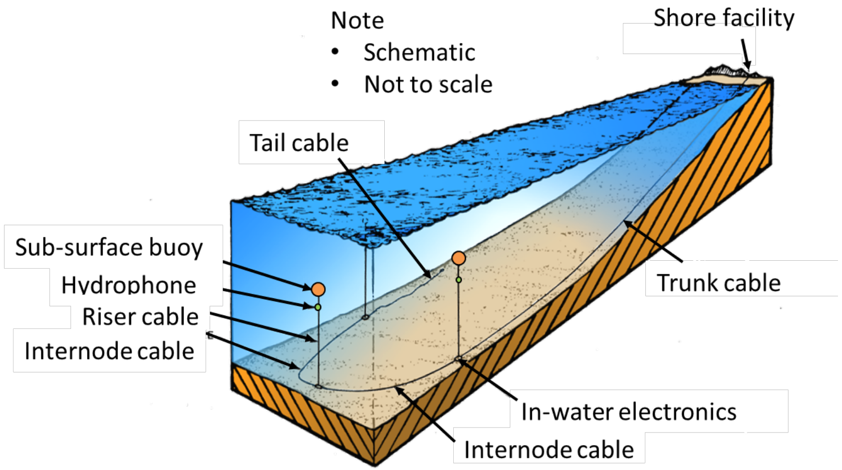
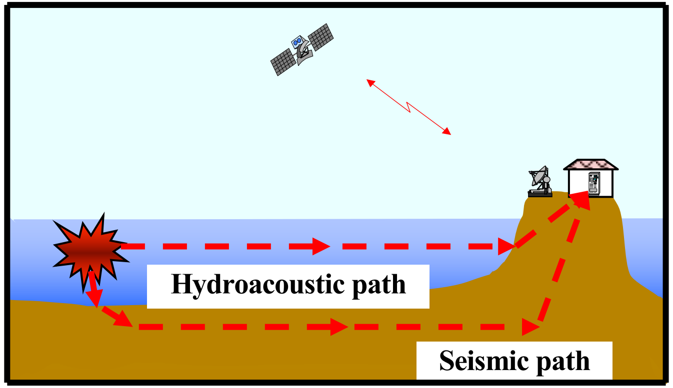
The two types of IMS hydroacoustic station

Hydrophone station – triplet

Hydrophone station – triplet



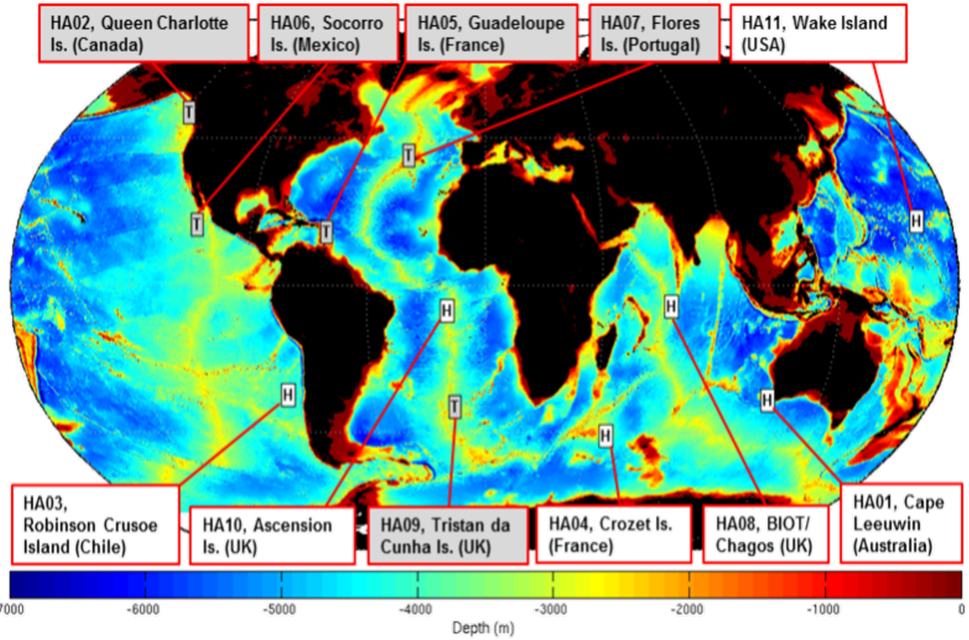
T-phase seismometer



The CTBTO Hydroacoustic Network at 25 years

The CTBT IMS hydroacoustic network

Station	Installation	Certification	Type
HA08	MAR-2000	18-DEC-2000	Hydrophone
HA05	SEP-2000	30-JAN-2002	T-station
HA01	MAR-2001	10-DEC-2001	Hydrophone
HA03	JAN-2003 *Tsunami 2010* Re-established: FEB-2014	14-NOV-2003	Hydrophone
HA10	JAN-2004	15-DEC-2004	Hydrophone
HA09	MAR-2004	22-DEC-2004	T-station
HA06	JUN-2004	22-DEC-2005	T-station
HA07	SEP-2004	21-NOV-2005	T-station
HA02	NOV-2006	20-DEC-2006	T-station
HA11	FEB-2007	08-JUN-2007	Hydrophone
HA04	DEC-2016	19-JUN-2017	Hydrophone



- (Grey boxes) 5 T-phase stations: near-shore seismometers, which record waterborne hydroacoustic waves coupled upslope into the earth’s crust.
- (White boxes) 6 Hydrophone stations: moored hydrophones pick up hydroacoustic waves in the water column.

Hydrophone depth at each station

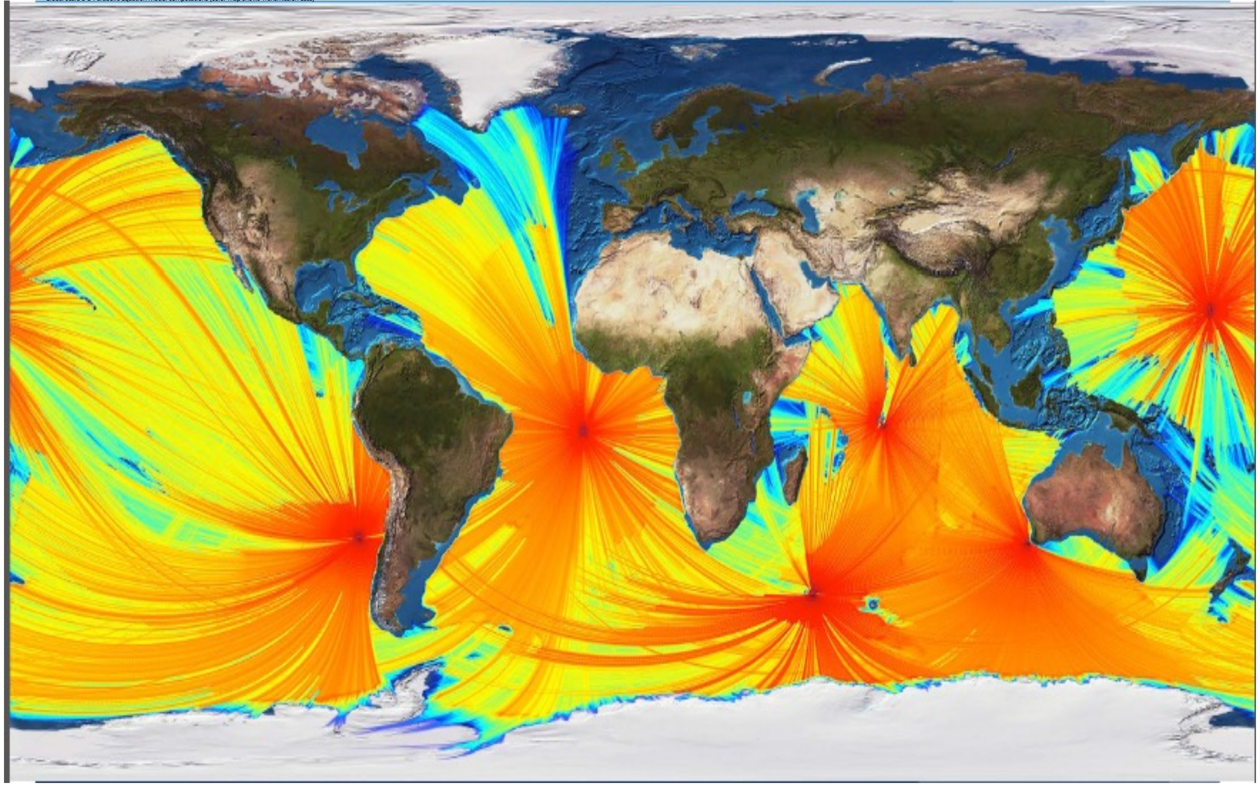
Hydrophone Station		Water depth (m)	Hydrophone depth (m)
HA01	**W**	**1550**	**1100**
HA03	**N**	**1866**	**824**
	S	**2071**	**830**
HA04	**N**	**1310**	**541**
	S	**1309**	**535**
HA08	**N**	**2300**	**1250**
	S	**1800**	**1350**
HA10	**N**	**2000**	**850**
	S	**1700**	**850**
HA11	**N**	**1400**	**750**
	S	**1150**	**750**

- Hydrophone depth is roughly at the axis of the SOFAR channel.
- Deeper near the equator.

The CTBTO Hydroacoustic Network at 25 years

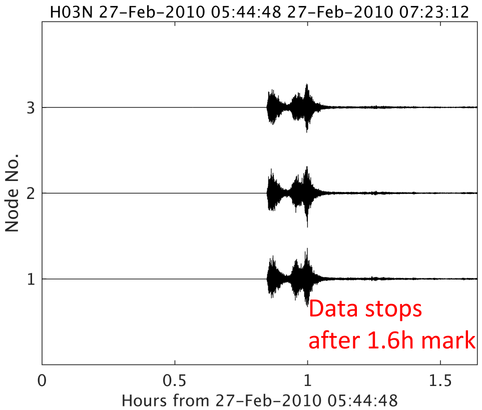
Acoustic coverage by IMS hydrophone stations

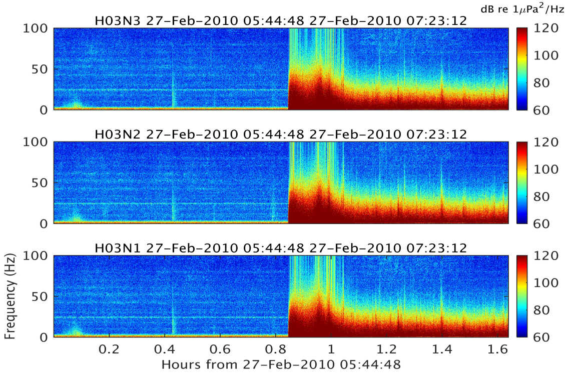
Global scale 3-D Parabolic Equation Model computations (color-map shows Transmission Loss)



K.D. Heaney, R.L. Campbell (OASIS Inc., USA), presented at International Hydroacoustics Workshop, CTBTO, (June 2015).

The 2010 Chile tsunami





A disaster for Robinson Crusoe Island & HA03

27th February 2010, 8.8 moment magnitude earthquake recorded at HA03 (Chile)

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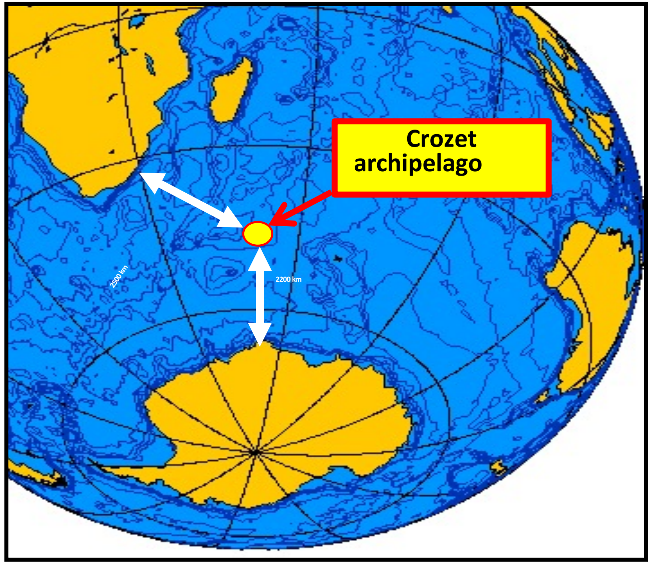
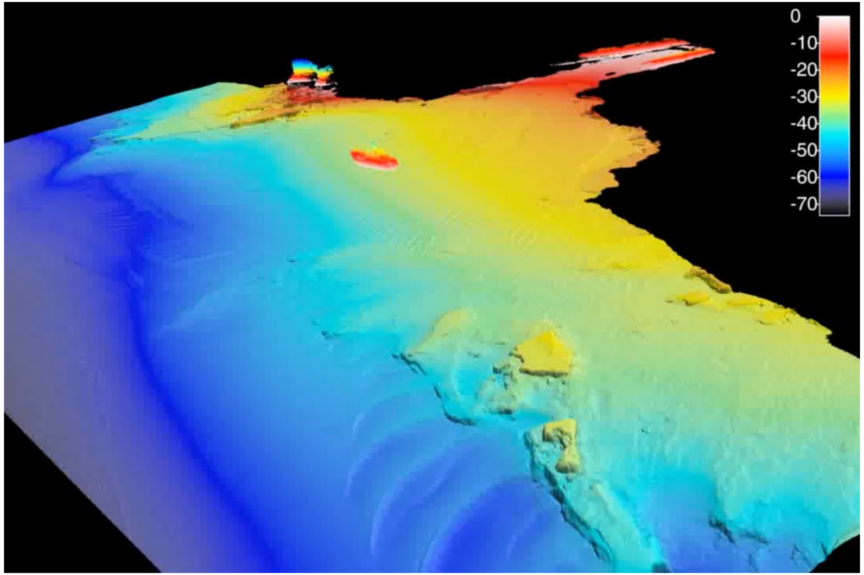
Site survey, Aug 2010, to assess tsunami damage

The CTBTO Hydroacoustic Network at 25 years

HA04 Crozet Islands (France) - 1



Extremely remote location



Survey

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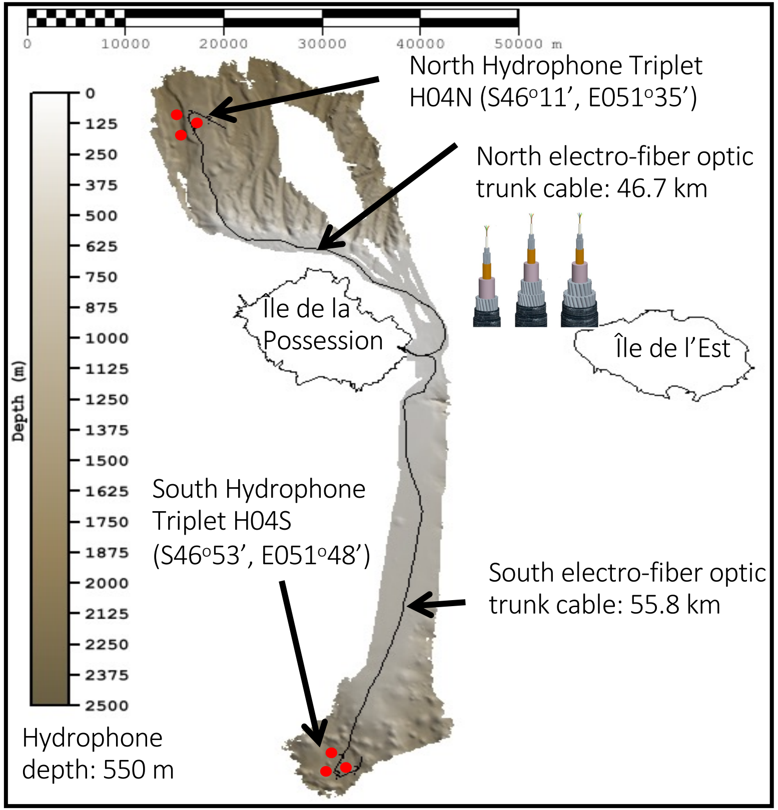
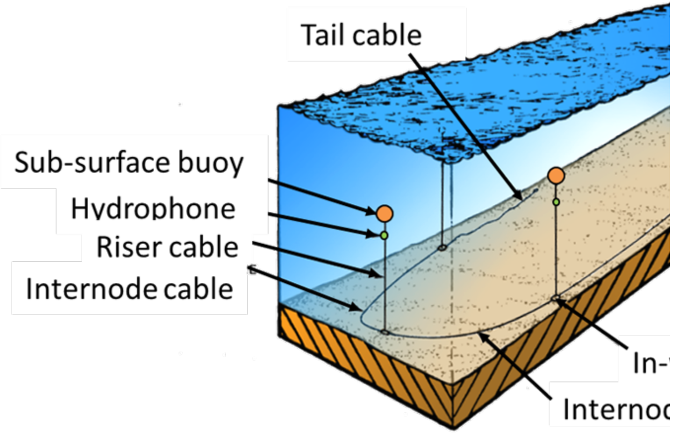
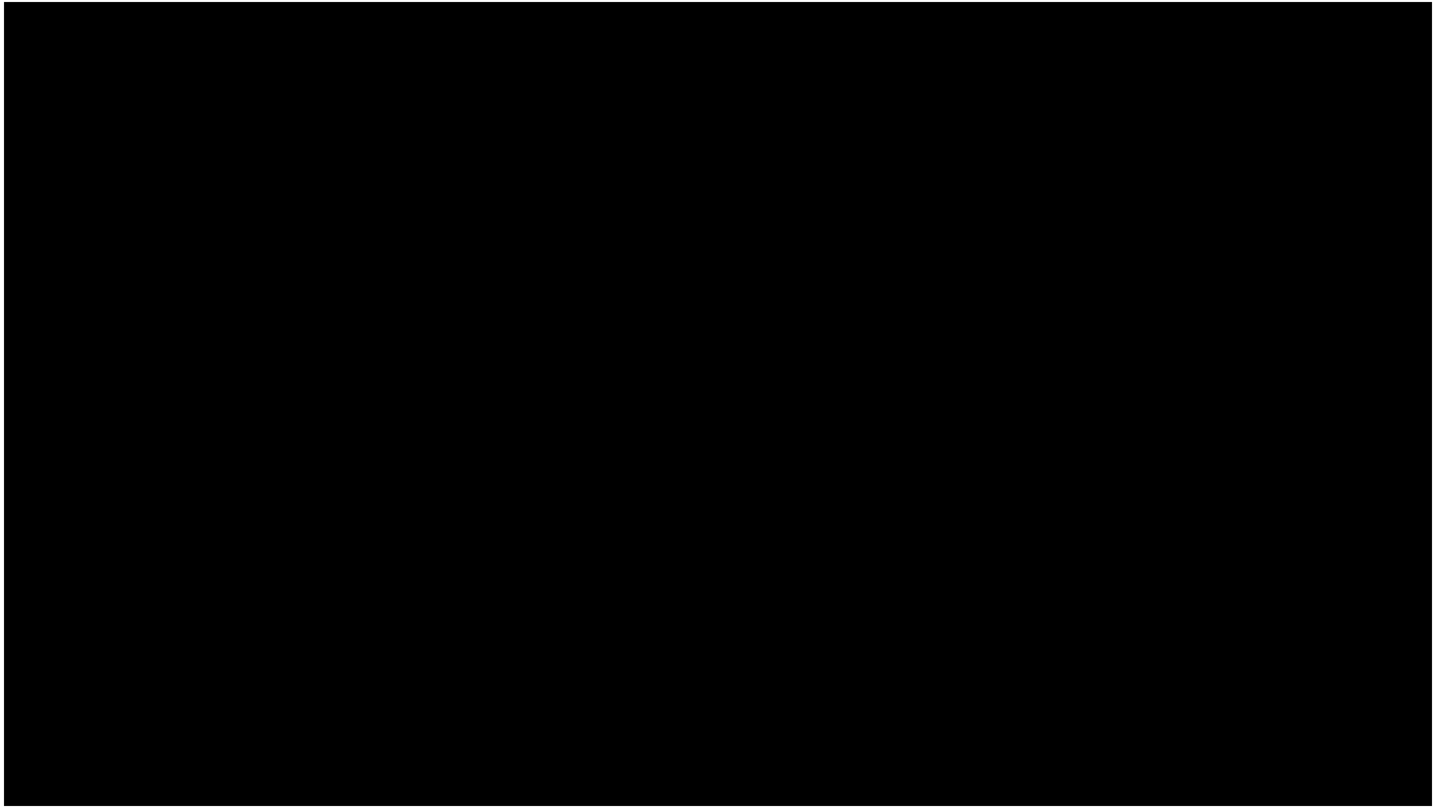
HA04 Crozet Islands (France) - 2



Note
- Schematic
- Not to scale

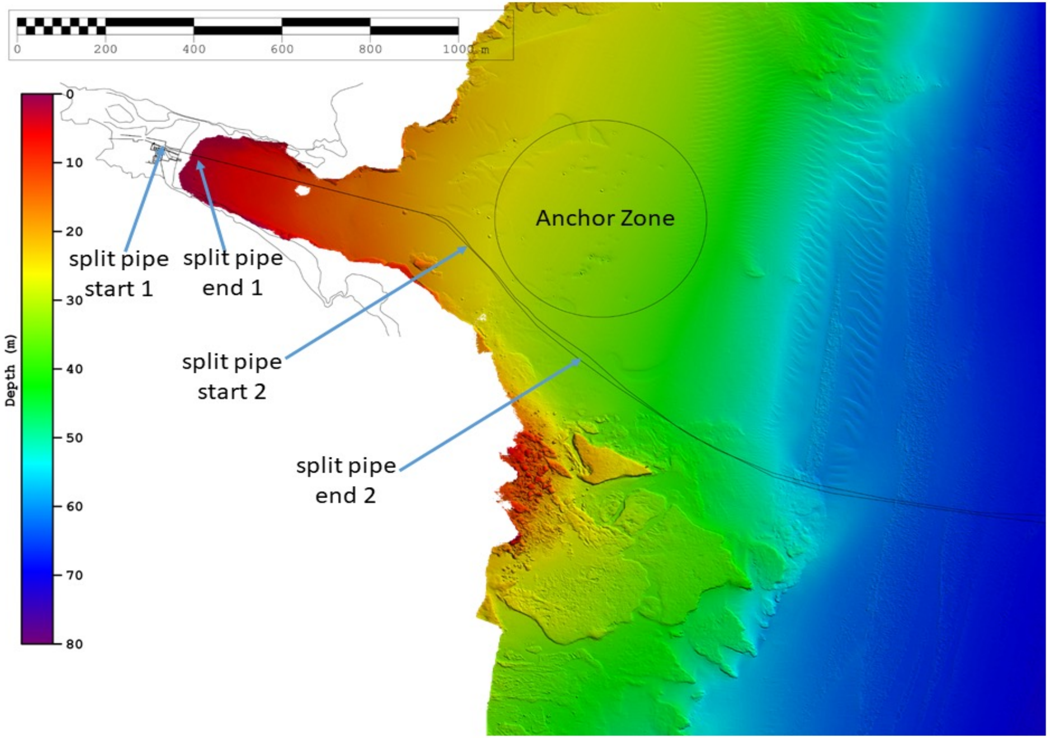


HA04 Crozet installation – time lapse



HA04S Crozet shore landing – video

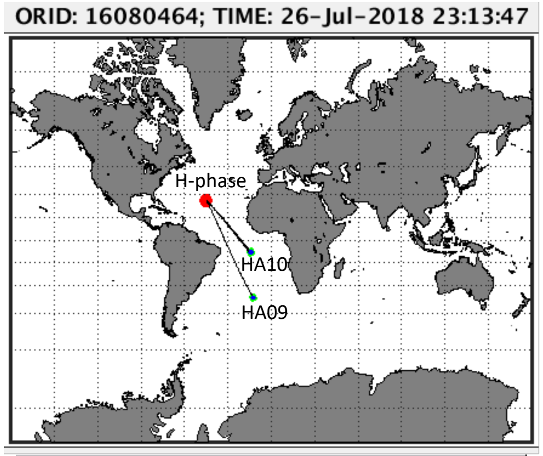
HA04S Crozet shore landing – layout

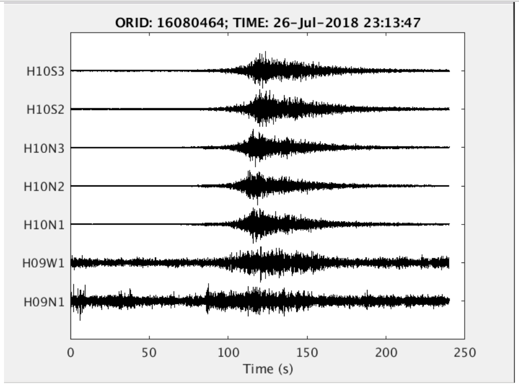


The CTBTO Hydroacoustic Network at 25 years

Performance comparison of Hydrophone & T-stations

- Hydrophone stations - 250 samples per second
- T-stations - 100 samples per second
- T-stations are much noisier than hydrophone stations
- T-phases *cannot be a defining phase*, i.e., cannot contribute to event localization using arrival time and back azimuth – they are *only associated* to an event
- Back azimuth estimates are more uncertain for T-stations than hydrophone stations
- Very limited number of detections characterized as H-phases at hydrophone stations are also detected either as H- or T-phases at T-stations.





- H-phase recorded at hydrophone station HA10 extracted from the Reviewed Event Bulletin (REB) by analysts
- The ORID (ORigin IDentifier) number identifies the event associated to detections at both hydrophone station HA10 and T-station HA09

Civil and scientific applications

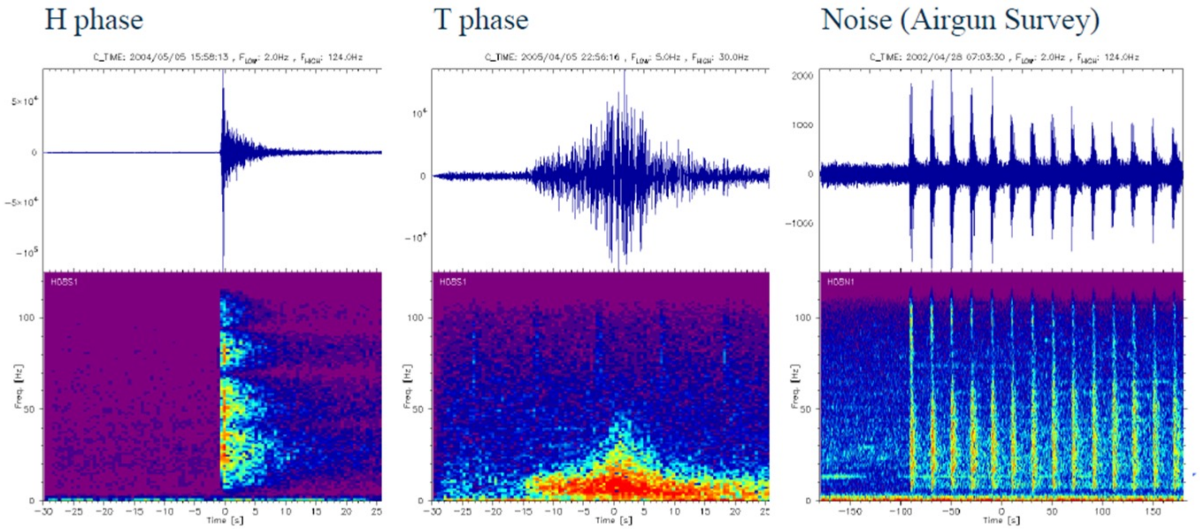
- Data to tsunami warning centers (18 agreements with 17 countries)
- Marine mammal vocalizations
- Iceberg calving, ice-quakes & seasonal ice-sheet noise
- Underwater volcanoes
- Undersea soundscape and long-term ambient noise
- Ocean acoustic thermometry
- Underwater acoustic anomalies & humanitarian assistance in emergency cases
  – *e.g.* the search for Argentinian submarine ARA San Juan

Sounds recorded by IMS hydrophone stations - 1

Classification of sounds

Possible hydroacoustic phase names:

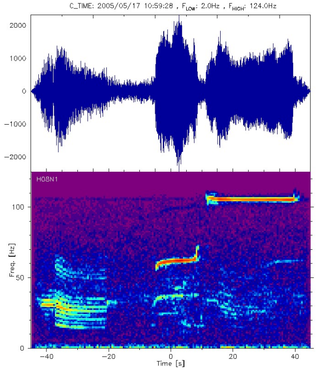
- **H** Originating from (explosive) in water sources
- **T** Ground-coupled hydroacoustic phase (from earthquakes)
- **N** Noise (all other signals)



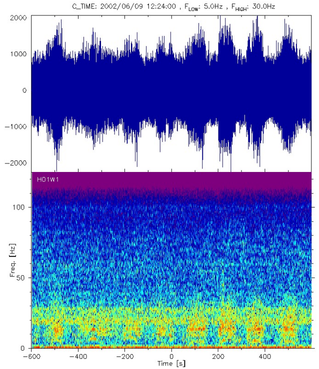
Sounds recorded by IMS hydrophone stations - 2

Sounds from various sources

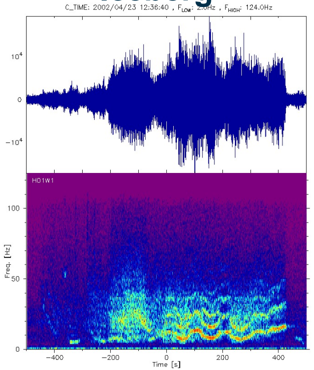
Whale Call



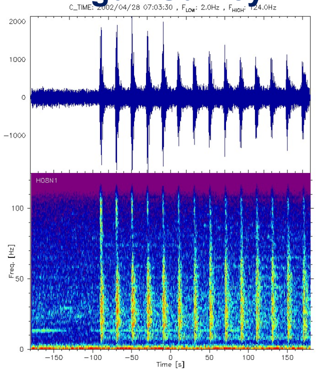
Underwater Volcano



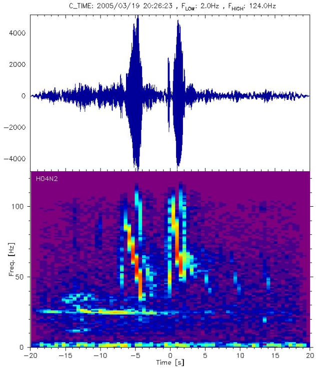
Iceberg



Airgun Survey

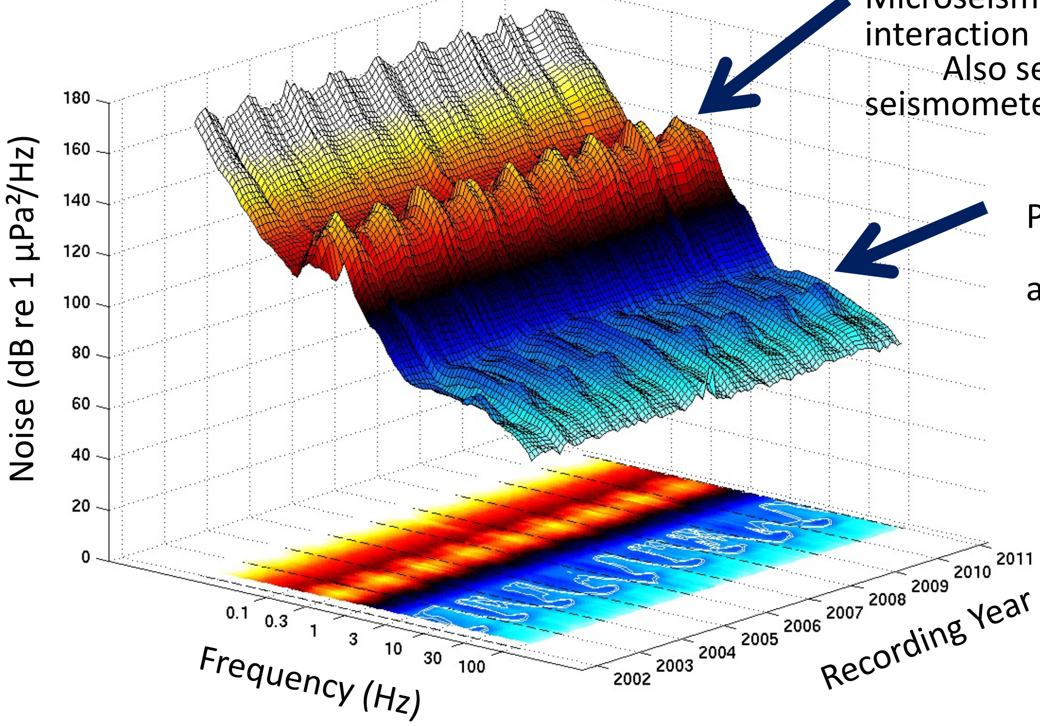


Unknown Source



Decadal soundscape recorded by an IMS hydrophone

Hydrophone at HA01 Cape Leeuwin, Australia.



Microseismic peak caused by non-linear interaction between ocean surface waves.
Also seen throughout the world on seismometers and infrasound arrays.

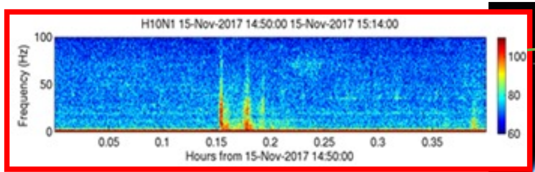
Peaks centred around 20Hz.
Present during (austral) summer, absent during winter.
Caused by fin whales.

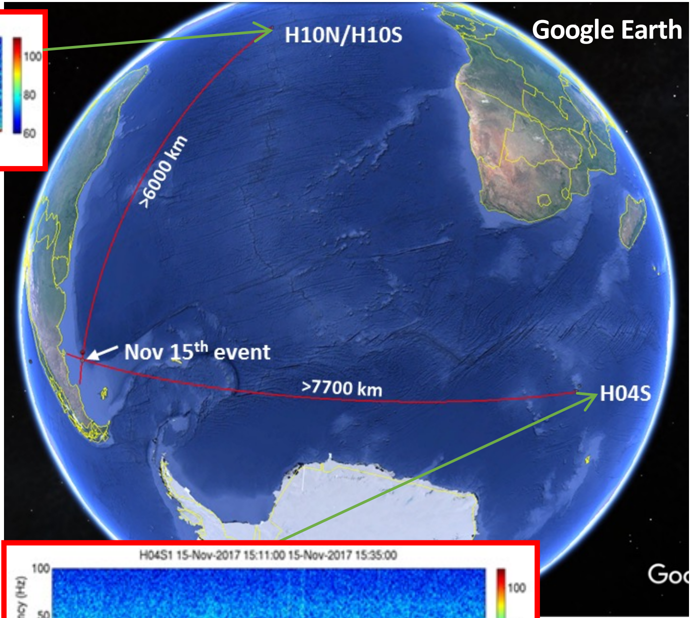
The CTBTO Hydroacoustic Network at 25 years

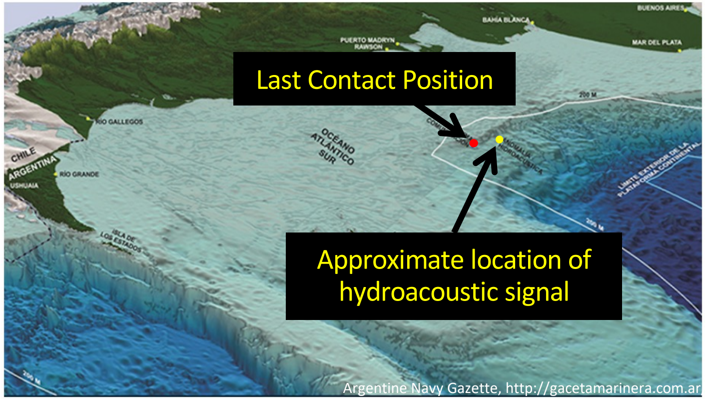
Notable IMS hydrophone station recording

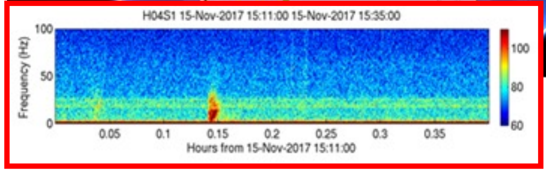
Hydroacoustic signal originating from a source in vicinity of last known location of Argentinian submarine ARA San Juan.

Nielsen et al, "CTBTO's Data and Analysis Pertaining to the Search for the Missing Argentine Submarine ARA San Juan", *Pure and Appl. Geophysics* (2020).



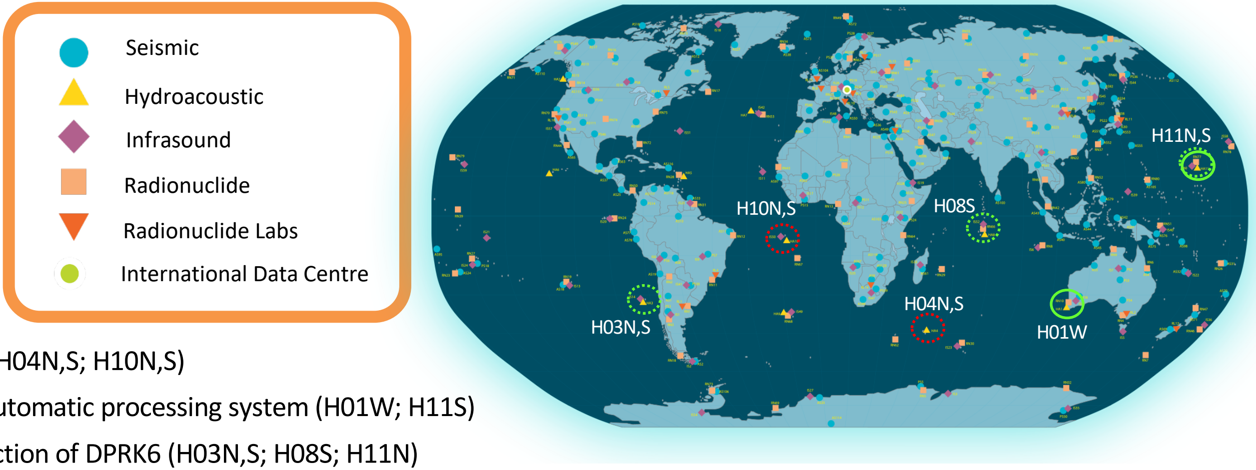






The CTBTO Hydroacoustic Network at 25 years

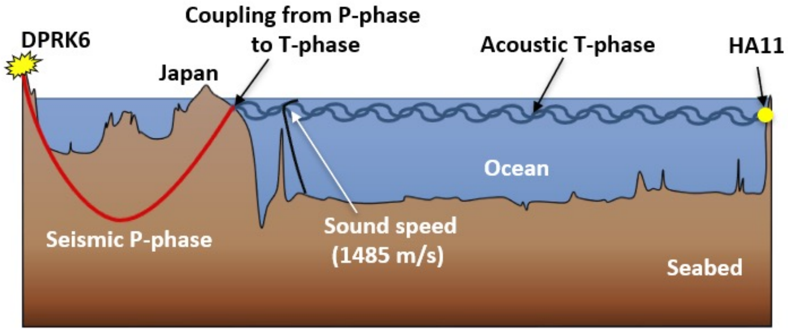
DPRK6 (2017) nuclear test on hydrophone stations



Seismic p-phases detected:

- Hydrophone triplets not detecting DPRK6 (H04N,S; H10N,S)
- Hydrophone triplets detecting DPRK6 by automatic processing system (H01W; H11S)
- Hydrophone triplets used for manual detection of DPRK6 (H03N,S; H08S; H11N)

... and a T-phase on the HA11 Wake Island Hydrophones:



[SnT2021 presentation OT2.1-275, by M. Zampolli, P. Nielsen, R. Le Bras, P. Bittner, G. Haralabus, J. Stanley]

Data accessible for scientific & civilian applications

The CTBTO virtual Data Exploitation Centre (vDEC):

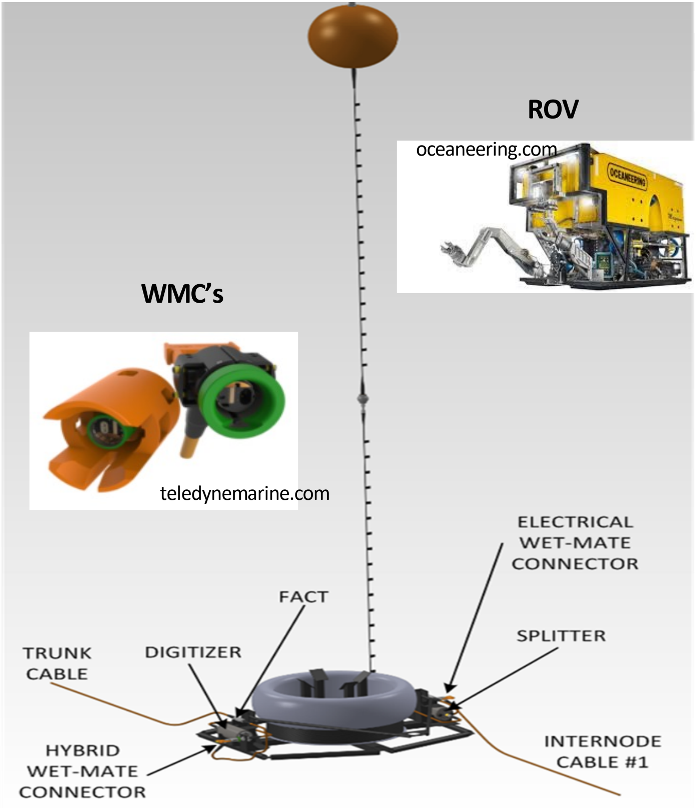
- Available at zero-cost to researchers and institutes from member states
- Archived time-synchronized raw data (hydroacoustic, seismic, infrasound and radionuclide)
- Generally, lag time of a few months
- To apply for vDEC please visit https://www.ctbto.org/specials/vdec/

Sustainability – Modular design

Sustainability challenges and safeguarding the investment.
Technology foresight: Modular design

- Very expensive to repair existing hydrophone stations.
- Current design of underwater system is for 20-year life with no maintenance.
- It uses linear deployment (highly efficient & reliable).
- Alternative is hydrophone triplet using modular components.
- Then replacement of a failed component could be carried out in situ - Much less expensive.
- Underway, a modular design that maintains the initial linear deployment of the current system.

Modular design – What is it?

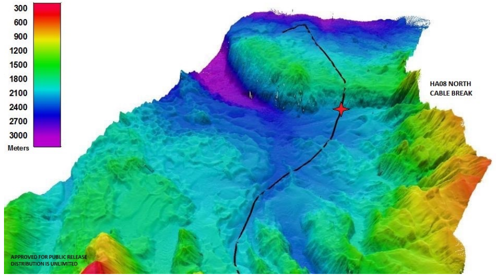


- Hybrid Modular HA node: All components attached on a common load-transfer frame.
- Triplet is deployable in one continuous string, like the present HA triplets.
- A modular version of the current linear triplet topology, as key components are connected by Wet-Mate Connector (WMC) to enable individual node and component-level reparability.
- No Remotely Operated Vehicle (ROV) required for first installation. Proven linear deployment.
- ROV required for repair.
- Possibility to augment with additional scientific equipment (e.g. seismometers).

[see also ePoster P1.3-270 by M. Zampolli, G. Haralabus, J. Stanley]

Current issues in the HA network

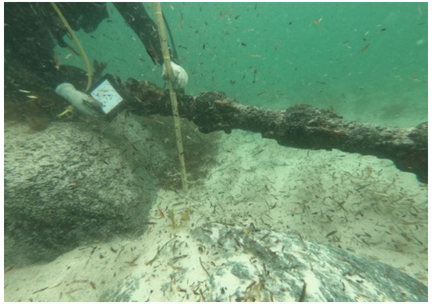
- Hydrophone station HA08, at Diego Garcia, was installed in 2000. In March 2014, the north triplet stopped sending data. Optical Time-Domain Reflectometer (OTDR) test shows cable fault at 189 km from shore. South triplet still working well.



HA08 bathymetry and fault indication
[see also ePoster P4.4-276 by G. Haralabus, J. Stanley, M. Zampolli]

- One hydrophone of south HA10 triplet (Ascension Island) has failed.
- Nearshore surveys and navigational buoy maintenance required at HA03.
- Nearshore split-pipe and cable preventative sustainment for HA01.

HA01 near-shore survey
[see also ePoster P4.4-323 by J. Stanley, G. Haralabus, M. Zampolli]



A Unique Global Observatory - 1

- **Unique global resource**
  - ➢ Provides data 24/7, with extremely high data availability, stored for many years.
  - ➢ High quality GPS synchronized acoustic data.
  - ➢ High operational readiness level.
  - ➢ Spatial and temporal acoustic coverage of the Oceans.
- **Challenges**
  - ➢ The wet end of the hydrophone stations cannot be easily serviced.
  - ➢ Installation or repair of a hydrophone station is much more expensive than for any other CTBT IMS station.
  - ➢ Repair will be required, at unpredictable intervals.

Value of the hydroacoustic network

- **Valuable for CTBT monitoring**
  - ➢ Excellent quality of signal (and directionality) for events in or near ocean
  - ➢ Synergy with other technologies.
  - ➢ It is the only CTBT IMS technology that is complete.
- **Valuable for civil applications**
  - ➢ Tsunami warning
  - ➢ Humanitarian assistance
- **Valuable for scientific studies**
  - ➢ Earth processes, such as rupture progression during an earthquake
  - ➢ Marine mammals
  - ➢ Iceberg and icesheet studies
  - ➢ Ocean acoustic thermometry (for global climate change studies)