

Curating hydroacoustic data to strengthen the implementation of environmental dimensions of the SDGs

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CTBT  **SDGs**

CTBT Innovation Challenge Towards
Securing Sustainable Development



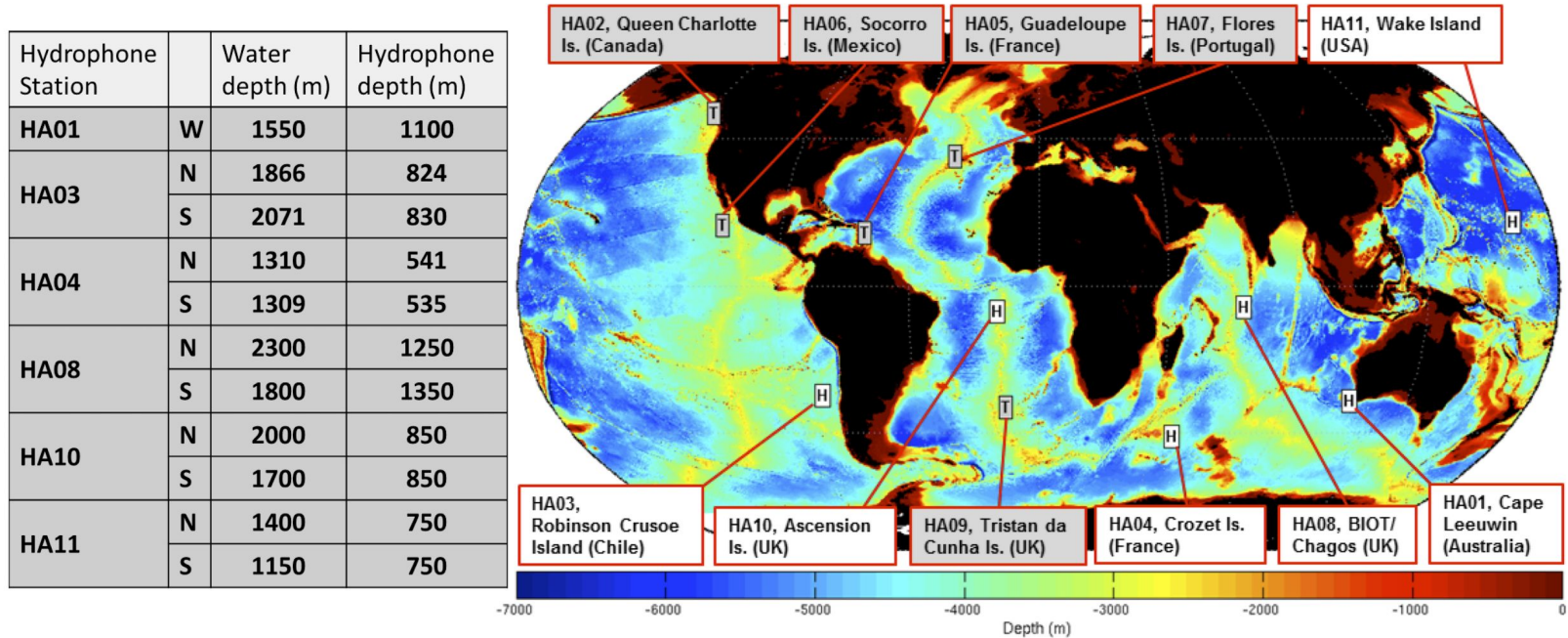
Presentation Outline

- Benefits of my project to the CTBTO
- Map -- Introduction of the CTBT International Monitoring System (IMS) Hydroacoustic (HA) network
- Big picture -- The IMS hydroacoustic network and the SDGs, what's the connection?
- Highlights -- Scientific and civil applications using IMS HA data relevant to SDGs
 - 13: Climate Action
 - 12: Responsible Production and Consumption
 - 14: Life Under Water
 - 11: Sustainable Cities and Communities
- Context -- Policy challenges, and integration of the CTBTO (IMS and IDC) into policy-ocean science frameworks
- Possible considerations and concluding remarks

Benefits of my project to the CTBTO

1. Highlight linkages between strengthening the environmental dimensions of SDGs 11, 12, 13, 14 and the work of the CTBTO, with regards to the hydroacoustic network in particular.
2. By using examples of scientific research and civil applications, synthesised the value of the IMS hydroacoustic network, including its data, infrastructure, expertise, users and arrangements with related parties.
3. Conduct a simple analysis on the vDEC hydroacoustic data contracts/projects to generate insights about user demographics, areas of ocean science that are enriched by IMS hydroacoustic data, and future outreach.
4. Consider existing UN frameworks and mechanisms with which the CTBTO could align to advance the Sustainable Development Goals, including the UN Decade of Ocean Science and the Sendai Framework for Disaster Risk Reduction.

The CTBT IMS Hydroacoustic Network



- (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 record hydroacoustic waves in the water column.

IMS/ED/HA/mz20180423

The IMS hydroacoustic network and the SDGs, what's the connection?

Comprehensive Nuclear Test-Ban Treaty Organisation (CTBTO)

International Monitoring System (IMS) + International Data Centre (IDC)

Hydroacoustic network

Marine ecosystems functions and processes

Establish monitoring baselines of ocean soundscapes



Variability in noise generation as a function of iceberg volume & rate of disintegration



Ocean and climate

Derive thermometry from sound speed of deep ocean ambient noise



Improve measurements of fine deep-ocean temperature variations



Ocean health

Verify acoustic disturbance levels in marine spatial planning



Use whale vocalisations to study whale population structure



Estimate fin whale density and distribution



Study reducing trends of noise as a marine pollutant



Ocean crust and marine geohazards

Assess, calibrate location & timing information of anthropogenic noise sources



Increase detection sensitivity of tsunami & earthquake events



Ocean technology

Guide hydrophone infrastructure placement for long-range passive ocean monitoring



Combine hydroacoustic technology with other spatial analysis & remote sensing techniques



Ocean observation and marine data

Provide real-time and continuous data to national tsunami warning centres



User analysis of vDEC platform based on present & past data contracts



SDG 13: Take urgent action to combat climate change and its impacts

Targets :

- 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.
- 13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities.

Context of concern :

- Oceans' role in absorbing atmospheric heat → measurements of temperature variations are necessary to quantify air-to-sea heat exchange, for calibrating climate change models and assess global warming trends.
- In contrast to ocean surface temperatures, deep ocean temperatures cannot be readily inferred from satellite-based remote sensing methods. One method of measurement is by sparse, free-drifting oceanographic floats, which provides limited spatial and temporal resolution.
- Monitoring baselines need to be established – in this case, the baseline of the ambient noise in the ocean soundscapes.

Improve measurement of fine deep-ocean temperature variations

13 CLIMATE ACTION



Goal 13.1. “Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.”

Connection: Used ambient noise from IMS HA records to develop passive acoustic thermometry, improving precision in the global monitoring of deep-ocean temperature variations and complementing existing remote sensing methods.

Ex. Woolfe K. F. *et al.* 2015. “Monitoring deep-ocean temperatures using acoustic ambient noise.” *Geophys. Res. Lett.* 42: 2878-2884.

- Long integration times in noise correlation processing was a challenge in acoustic thermometry studies conducted with active sources (e.g. fault zones), however, integration times could be shortened due to acoustic stability in deep-ocean propagation along the SOFAR channel.
- Used records of low frequency (~ 10 Hz) SOFAR arrival time variations at HA11 Wake and HA10 Ascension Islands.
- High correlation (0.8 coefficient) between two temperature measurement methodologies. (ARGO floats: estimates from spatial and temporal interpolation; passive thermometry: true sampling w/ no interpolation.)

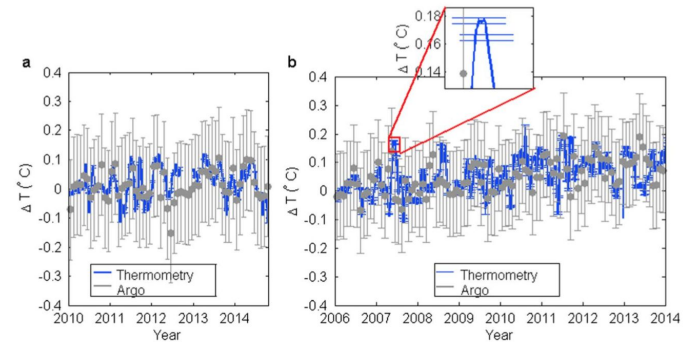


Figure 3. (a) Comparison of the deep-ocean temperature variations at the Wake Island site estimated from passive thermometry (blue line)—using the SOFAR arrival time variations shown in Figure 2a—with free-drifting profiling oceanographic Argo float measurements (grey dots), along with corresponding error bars (see supporting information Text S4). (b) Same as Figure 3a but for the Ascension Island site using the SOFAR arrival time variations shown in Figure 2d. Each ΔT data series is normalized so that a linear fit on the data would have a y intercept at zero (see Figure S4).

Guide infrastructure placement for long-range passive ocean monitoring

13 CLIMATE ACTION



Goal 13.b. “Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities.”

Connection: The existing IMS HA network could guide the placement of other arrays over the globe for future long-range passive ocean monitoring experiments.

Ex. Woolfe K. F. & K. G. Sabra. 2015. “Variability of the coherent arrivals extracted from low-frequency deep-ocean ambient noise correlations.” *J. Acoust. Soc. Am.* 138 (2): 521-532.

- Measured characteristics of low-frequency coherent arrivals from ambient noise fields differed depending on station configurations, including the orientation of hydrophone pairs with broadband sources.
- The scale of the HA station network makes it possible to carry out a systematic comparison of multiple deep water sites around the world, so that broad recommendations can be made for the deployment of future deep water hydrophone arrays for passive monitoring applications.

Establish monitoring baselines of ocean soundscapes

Noise generation as a function of iceberg volume and rate of disintegration

13 CLIMATE ACTION



Goal 13.1. “Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.”

Connection: Resilience and adaptive capacity to climate-related hazards can be strengthened by monitoring baselines of ocean soundscapes, and their variability associated with variations in natural events, such as the life cycle of Antarctic icebergs.

Ex. Matsumoto H. *et al.* 2014. “Antarctic icebergs: A significant natural ocean sound source in the Southern Hemisphere.” *Geochem. Geophys. Geosyst.* 15.

- Examined the sounds generated by the disintegrating icebergs, recorded by hydrophones at H03N at Juan Fernandez Islands, as well as long-term noise levels and trends at H01W Cape Leeuwin and H10S Ascension Island.
- Integrated multiple techniques for tracking iceberg movement and volume, including satellite-based imagery (iceberg > 5–6 km), and radar altimeter in sea-ice free areas (smaller icebergs of 0.1–2.8 km).



Combining time-spatial analysis with IMS hydroacoustic data

- Time-latitude Hovmüller diagram displaying iceberg volume and (black) sea-ice boundary
- Total iceberg volume north of the sea-ice edge
- Plot of noise levels in specific frequency bands, from IMS station HA10 Ascension Island

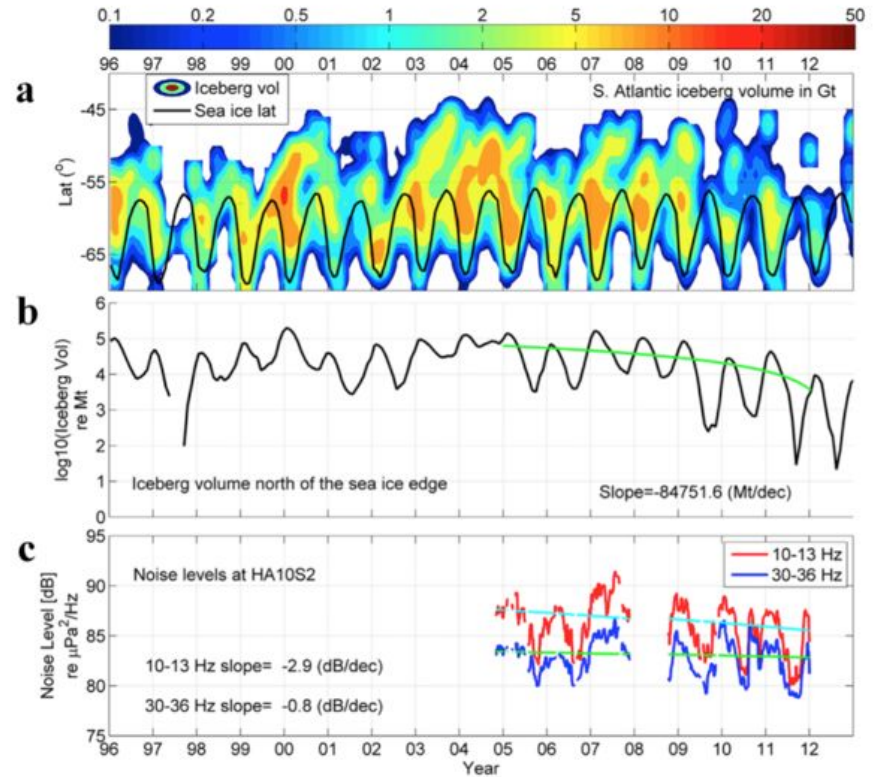


Figure 7. Iceberg volume and acoustic noise levels in the South Atlantic Ocean. (a) Time-latitude Hovmüller diagram of monthly iceberg volume (in Gt) in the South Atlantic region between 70°W and 30°E from 1996 through 2012. Solid black line is the sea-ice edge. (b) Logarithm of altimeter-derived volume of icebergs in megaton north of the sea-ice edge in the Indian-Antarctic waters, which shows a ~85 Gt/decade decrease from 2005 through 2012. (c) Noise levels at IMS Ascension Island station HA10S between 10–13 Hz (red) and 30–36 Hz (blue) from 2004 through 2012. The linear trend from 2004 through 2012 is -2.9 dB/decade in the 10–13 Hz and -0.8 dB/decade in the 30–36 Hz band.

“Antarctic icebergs: A significant natural ocean sound source in the Southern Hemisphere”

Matsumoto H. *et al.*, 2014. *Geochem. Geophys. Geosyst.*, 15.

SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Targets :

- 14.1 By 2025, prevent and significantly reduce [marine pollution of all kinds](#), in particular from land-based activities, including marine debris and nutrient pollution.
- 14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including [by strengthening their resilience and take action for their restoration](#) in order to achieve healthy and productive oceans.
- 14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and [based on the best available scientific information](#).
- 14.a [Increase scientific knowledge, develop research capacity and transfer marine technology](#), taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to [the development of developing countries](#), in particular small island developing States and least developed countries.

Verify acoustic disturbance levels in marine spatial planning



Goal 14.5 “By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information.”

Connection: IMS HA hydrophone stations, that are located in highly protected maritime nature reserve areas, can contribute to monitoring the ocean soundscapes, verifying that the noise levels in those oceans do not pose disturbance to whales and other noise-sensitive species.

About the parks, monuments and reserves where some hydroacoustic stations are located:

1. **Australia**, Ngari Capes Marine Park – HA01 Cape Leeuwin
2. **Chile**, Juan Fernández Archipelago National Park and UNESCO Biosphere Reserve – HA03 Juan Fernandez Islands
3. **TAAF (French Southern and Antarctic Lands)**, TAAF maritime reserve and UNESCO World Heritage Site applicant – HA04 Crozet Islands
4. **US Territory in the North-Western Pacific**, Pacific Remote Islands Marine National Monument – HA11 Wake Island

Use whale vocalisations to study whale population structure

14 LIFE BELOW WATER



Goal 14.2 & 14.a “By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including [by strengthening their resilience and take action for their restoration](#) in order to achieve healthy and productive oceans.”

“[Increase scientific knowledge, develop research capacity and transfer marine technology](#), taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to [the development of developing countries](#), in particular small island developing States and least developed countries.”

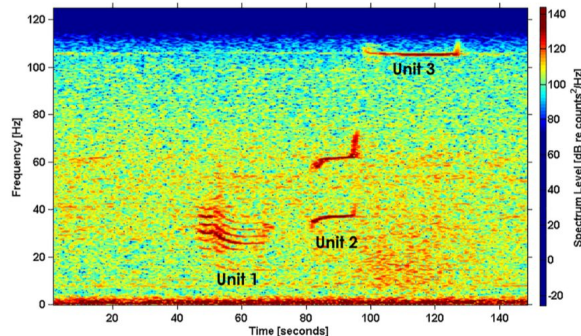


FIG. 1. (Color online) Sri Lankan pygmy blue whale call recorded from the CTBTO IMS station at Diego Garcia. The Unit 1 pulsive (1), Unit 2 frequency modulated upsweep (2), and Unit 3 tonal downsweep (3) components are labelled.

Connection: Use vocalisations as an identifier of whale population structure, revealing knowledge about demographics, identification and cultural transmission.

Ex. Miksis-Olds J. L. *et al.* 2018. “Two unit analysis of Sri Lankan pygmy blue whale song over a decade.” *J. Acoust. Soc. Am.* 144 (6): 3618-3626.

- Frequency changes to compensate for increased environmental noise have been observed before, but it was not identified as a driver of change in this case.
- High conformity and change in unison show social learning and cultural transmission within the Sri Lankan population in the Indian Ocean.

Estimate fin whale population density and distribution

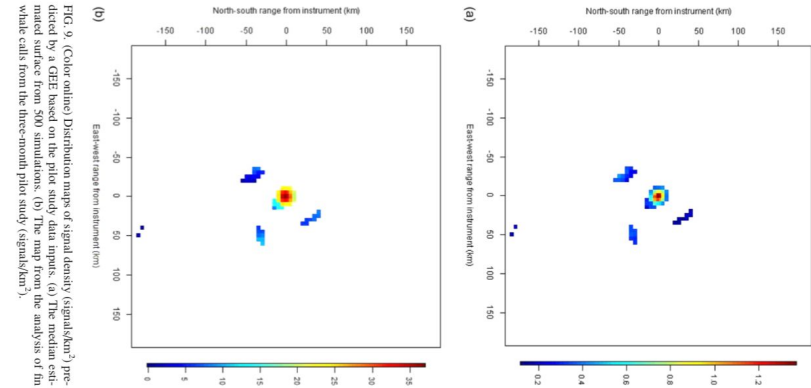
14 LIFE BELOW WATER



Selected research example:

Harris D. V. *et al.* 2018. “Fin whale density and distribution estimation using acoustic bearings are derived from sparse arrays.” *J. Acoust. Soc. Am.* 143 (5): 2980-2993.

- First time utilizing CTBTO data fully for cetacean density estimation – presented new method of using acoustic data to collect information about spatial distribution to improve population density estimation.
- Fin whales in the Pacific, the second largest cetacean and endangered (IUCN Red List); data collected from HA11 at Wake Island in the Equatorial Pacific.
- Used automatic detection on Ishmael, an open-access bioacoustic analysis software package.
- The monitored area at Wake Island was smaller than



anticipated, in comparison to detection ranges at other CTBTO sites – pilot study shows the importance of quantifying the size and shape of the monitored area.

Study reducing trends of noise as a marine pollutant

14 LIFE
BELOW WATER



Goal 14.1 “By 2025, prevent and significantly reduce [marine pollution of all kinds](#), in particular from land-based activities, including marine debris and nutrient pollution.”

Connection: Favourable and encouraging trends in reducing marine pollution of all kinds, including low-frequency (10-100 Hz) deep water ambient sound.

Ex. “Is low frequency ocean sound increasing globally?” Miksis-Olds J.L. & S.M. Nichols. 2016. *J. Acoust. Soc. Am.* 139 (1).

- Compared trends in the South Atlantic and Equatorial Pacific Oceans to trends identified in the Northeast Pacific and Indian Oceans.
- Decrease in the past 5-8 years in South Atlantic and Equatorial Pacific:
 - A stark contrast to increases in NE Pacific in 1960s to mid-1990s, and in Indian Ocean over the past decade;
 - Consistent with recent decreases in NE Pacific over the same approx. time period.

Ex. “A statistical method for the evaluation of long term trends in underwater noise measurements.” P. Harris *et al.* 2019. *J. Acoust. Soc. Am.* 145 (1).

- Confirms statistically decreasing trend in ocean noise using data collected at HA01 Cape Leeuwin (Australia).
- Foundation laid for causes of decreasing trends to be continually investigated.

SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable

Targets :

- 11.5 By 2030, significantly reduce the number of deaths and the number of affected people and decrease by% the economic losses relative to GDP caused by disasters, including water-related disasters, with the focus on protecting the poor and people in vulnerable situations.
- 11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.

Context of concern :

- Rapid estimation of the rupture process and the geographical extension of the rupture could be significant for tsunami warning systems.

Increase detection sensitivity of tsunami & earthquake events

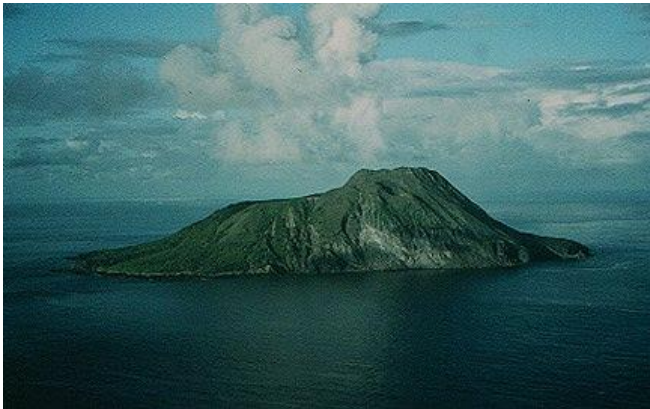
11 SUSTAINABLE CITIES
AND COMMUNITIES



Goal 11.5 “By 2030 significantly reduce the number of deaths and the number of affected people and decrease by % the economic losses relative to GDP caused by disasters, including water-related disasters, with the focus on protecting the poor and people in vulnerable situations.”

Connection: Hydroacoustic station data can contribute to the characterisation and study of tsunamigenic events, including those near small island developing States.

Selected research examples:



- **2004 Sumatra earthquake, Mw = 9.0**
Used data from H08S Diego Garcia hydroacoustic array to study rupture propagation. (Guilbert *et al.* 2005. *Geophys. Res. Lett.*, 32, L15310.)
- **2015 Chile earthquake, Mw = 8.3**
Used data from HA03 Juan Fernandez Islands to characterise T-phase and tsunami signals during the tsunamigenic earthquake, and assess tsunami detectability. (Matsumoto *et al.* 2016. *Geophys. Res. Lett.*, 43.)
- **2010 Sarigan underwater volcanic eruption in the Mariana Islands**
Used data from H11 Wake Island station (Heaney, Campbell & Snellen, 2013. *J. Acoust. Soc. Am.* 134 (4), Pt. 2.)

Provide real-time and continuous data to national tsunami warning centres

11 SUSTAINABLE CITIES AND COMMUNITIES

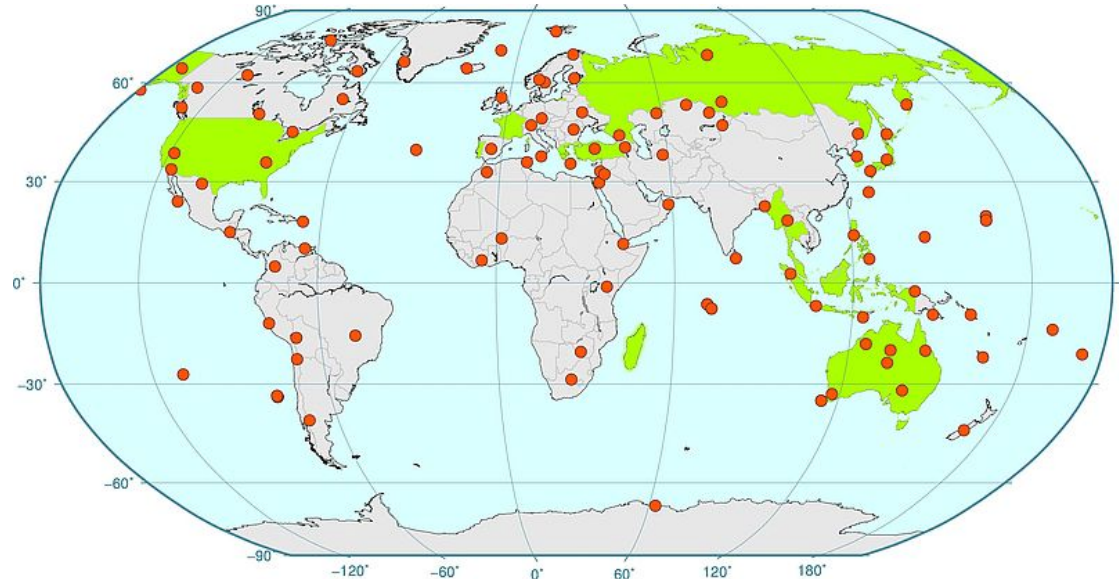


Goal 11.b “By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.”

Connection: Contributing to disaster risk reduction, CTBTO provides IMS data, including hydroacoustic data, to tsunami warning centres in 15 countries.

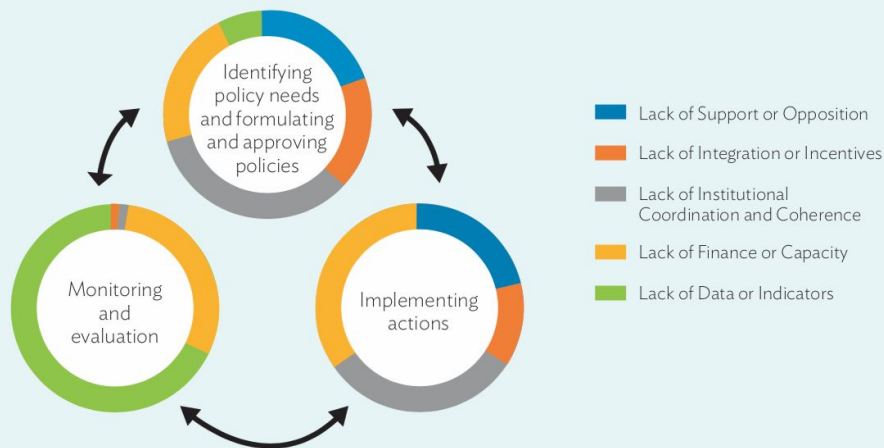
“Speed, quality and reliability” of the IMS data on tsunami warnings.

[\(https://www.ctbto.org/press-centre/highlights/2019/new-tsunami-warning-agreement-with-madagascar/\)](https://www.ctbto.org/press-centre/highlights/2019/new-tsunami-warning-agreement-with-madagascar/)



Integrating Environmental Dimensions of the SDGs, Challenges: “Lack of Data or Indicators” & “Lack of Finance or Capacity”

Figure 20: Identified Challenges at Different Stages of the Policy Cycle (N=14)



Source: Asian Development Bank.

Different barriers prove more challenging at different stages of the policy cycle. Most relevant to SDGs:

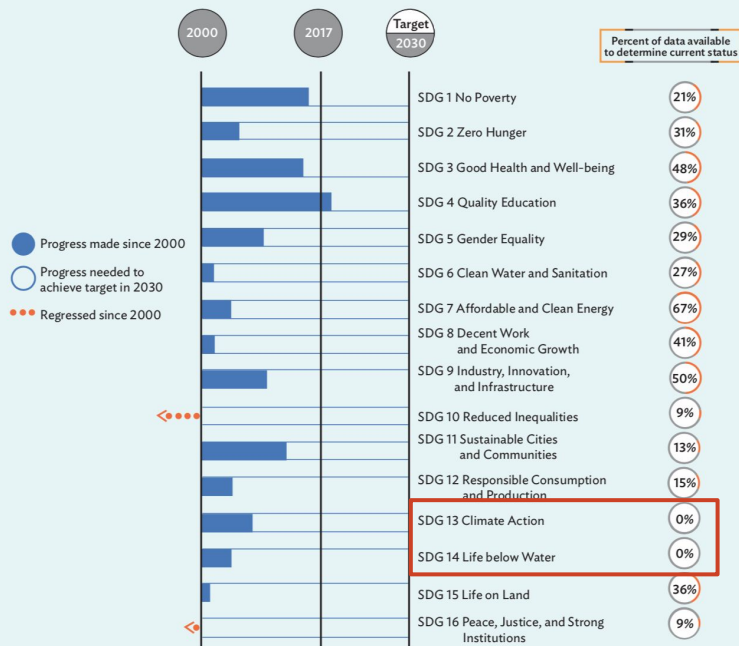
The costs of collecting environmental data (yellow) and the identification of appropriate monitoring indicators (green).

Many countries struggle to find suitable data for the environment-related targets. To deal with data gaps, some countries are using context-appropriate proxies based on different needs and circumstances. This is pragmatic, but proxies do not always capture the multiple dimensions of an issue in the same way that the official indicators intended.

Compared to the economic and social indicators, only a fraction of environmental indicators are indicators with established methodologies and data already regularly collected (“Tier 1”). The bulk of environmental indicators are “Tier 3.”

Regional Disparities and Data Availability to Determine Status of SDG Progress

Figure 8: Snapshot of Sustainable Development Goals Progress in Asia and the Pacific



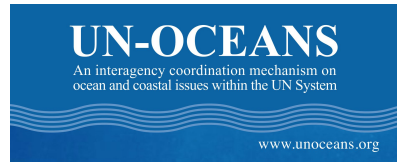
Source: United Nations Economic and Social Commission for Asia and the Pacific, 2017. *Asia and the Pacific SDG Progress Report 2017*. Bangkok. <https://www.unescap.org/publications/asia-and-pacific-sdg-progress-report-2017>



2021 United Nations Decade
2030 of Ocean Science
for Sustainable Development



SENDAI FRAMEWORK
FOR DISASTER RISK REDUCTION 2015-2030



The Current Status
of Ocean Science
around the World



SDG-Ocean Science Framework – UN Decade of Ocean Science (2021–2030)

- UN Decade of Ocean Science (2021–2030)
 - Intergovernmental Oceanographic Commission (IOC) of UNESCO
- Preparation:
 - 2018-2020: Planning Phase to develop an Implementation Plan for the Decade.
 - 2017: The Global Ocean Science Report (GOSR): *The Current Status of Ocean Science around the World*.
 - Eight defined ocean science categories.
 - Identifies and quantifies the elements that drive productivity and performance of ocean science, including workforce, infrastructure, resources, networks and outputs.

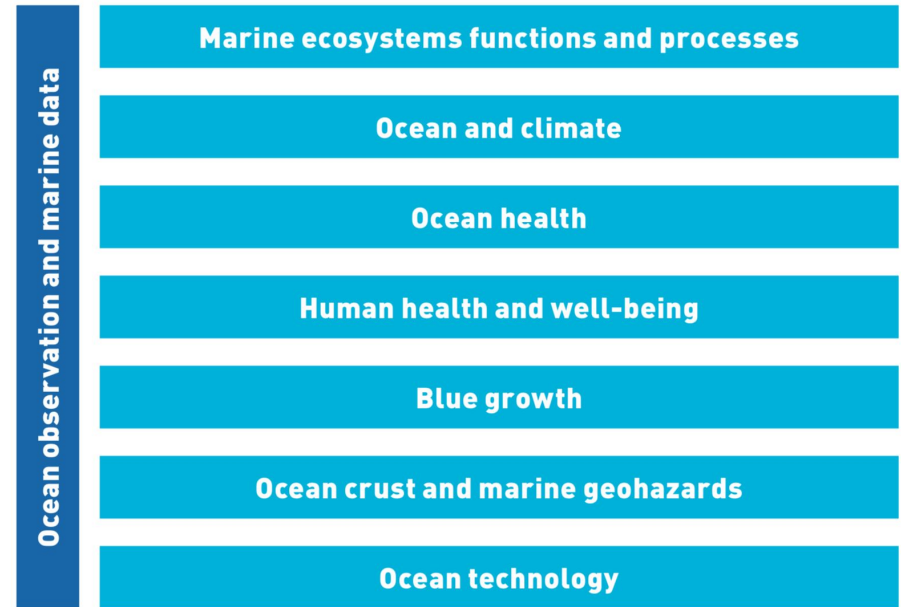


Figure ES1. Ocean science categories considered in the Global Ocean Science Report.

Ocean Science Community and Policy-Ocean Science Framework

State of Ocean Science:

- Scientific output and productivity
USA, Canada, Australia, UK, Germany, France are the top producers of scientific publications.
- Gender
Female scientists represent on average 38 % of the researchers in ocean science, about 10 % higher than in science overall.
- Expenditure
Accounts for between 0.1 % and 21 % of natural science expenditure and between < 0.04 % and 4 % of total research and development expenditure across regions and countries.
- Evolution in marine spatial planning (MSP) and ocean zoning
Ecosystem-based, managing the diversifying & multiple use for marine space.

Policy-Ocean Science Framework:

- Principle of “ensuring that no one is left behind”
- Sustainable Development Goals 2015-2030
- UN Decade of Ocean Science 2021-2030
- Sendai Framework for Disaster Risk Reduction 2015–2030

Analysing existing vDEC hydroacoustic contracts – info management & user analysis

- Which aspects of user analysis?
 - Demographics of data users & their respective research institutes
 - Occurrences and repetition of collaboration (# of researchers per publication + renewal of vDEC data contract)
 - Which areas of ocean science, as defined in the *Global Ocean Science Report*, have been enriched by IMS hydroacoustic data

- Corresponding insights?
 - Scientific output and productivity from CTBTO hydroacoustic data are still led by users from the 6 countries mentioned, mirroring the top producers of overall ocean science publications
 - Repeated collaboration and contract renewal = signs of trust in research partnerships and reliable data quality
 - 6 out of 8 areas of ocean science enriched using existing data

- Possible action?
 - Align outreach efforts with SDG goal to diversify demographics involved in ocean science
 - Establish feedback loops with existing users to improve vDEC user experience
 - Organise vDEC contract database to:
 - Index contracts according to the 8 ocean science categories considered for UN Decade of Ocean Science
 - Assess what missing information about users and research outcomes could be collected to measure progress of the CTBTO in advancing SDG agenda

Oceanographic data, information management and exchange – from the Global Ocean Science Report (2017)

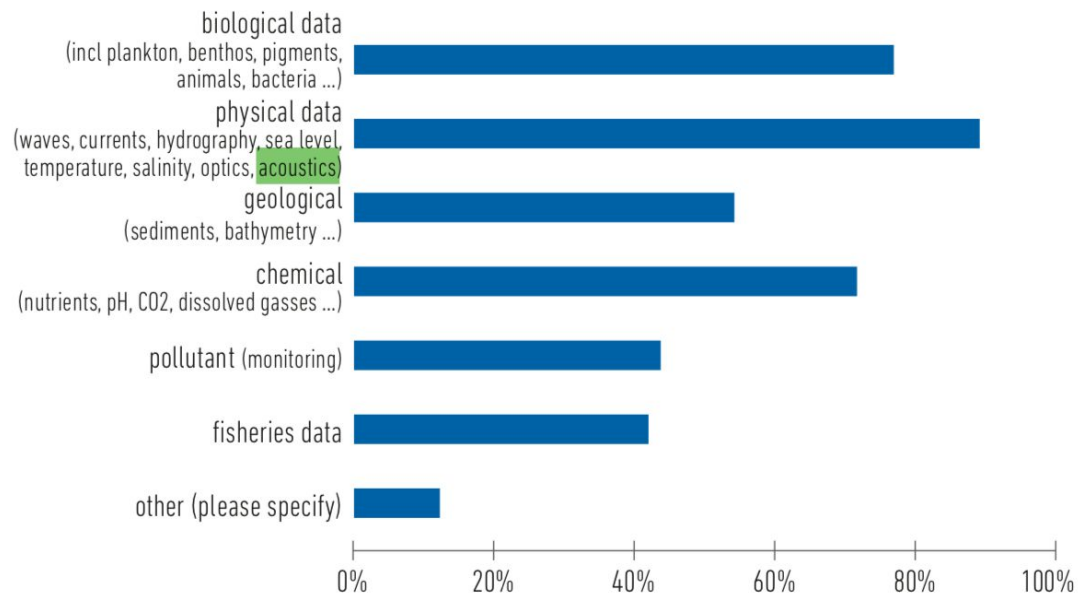
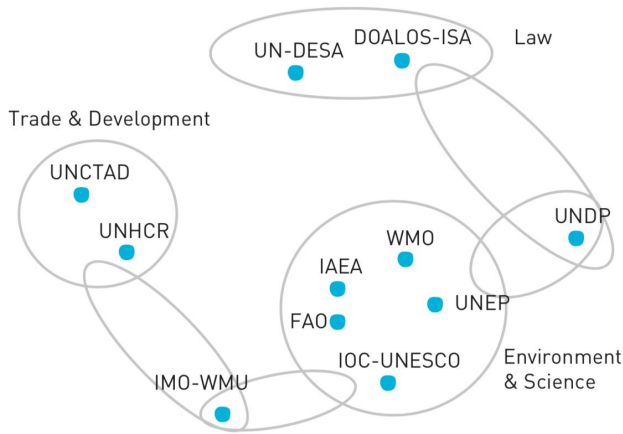


Figure 6.7. Observational data types regularly collected and managed by national data centres as a percentage of respondents.
Source: IODE survey, 2016 (answered by 57 focal points).

International organisations supporting ocean science under the UN umbrella – from the Global Ocean Science Report (2017)



“UN-Oceans”: composed of 16 relevant programmes, was established by the UN High-Level Committee on Programmes in 2003.

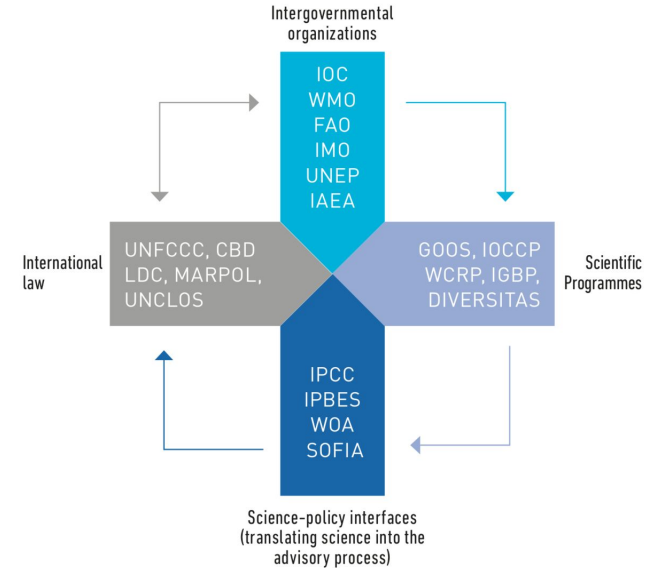


Table 7.1. Areas of activity declared by the UN-Oceans organizations in 2014 (adapted from Valdés, 2017).

	IOC-UNESCO	WMO	FAO	UNEP-CBD	UNDP	IMO-WMU	IAEA	UNHCR	UNCTAD	DOALOS-ISA	UN DESA
Sustainable development											
Science											
Marine environment											
Marine biodiversity											
Fisheries											
Exploitation non-living resources											
Cables & pipelines											
Marine safety & security											
People at sea and education											
Underwater cultural heritage											

Figure 7.1. Quadruple helix model showing the UN architecture for ocean science knowledge and environmental governance (the list of organizations and entities shown here is not exhaustive). Source: redrawn from Valdés (2017).

Stronger involvement of CTBTO as an organisation contributing to ocean science and management could be mutually beneficial.

Possible Considerations from the CTBTO



2021
2030 United Nations Decade
of Ocean Science
for Sustainable Development

- Consider the Global Ocean Science Report, especially sections on:
 - Ocean science institutions, marine laboratories and field stations (3.3)
 - Integration of IMS hydroacoustic station network infrastructure [Infrastructure]
 - Research profiles (5.3) + Collaboration patterns and capacity development (5.4)
 - Expert support + collaboration between countries and institutes + relationships w/ existing and future hydroacoustic data users [Capacity to support research]
 - Data management (6.2) + Data policy and data access restrictions (6.5.5)
 - Collaboration with regional data centres + feedback about user experience w/ vDEC and NDCs [Data and User experience]
 - International organisations and processes relevant to ocean science and management (7.2) + UN-Oceans and UN constraints to lead ocean science and policy assessment (7.3)
 - Stronger involvement of CTBTO as a UN organisation contributing to ocean science and management [Organisation]
- In the context of the UN Decade of Ocean Science framework:
 - Exploring potential involvement of CTBTO hydroacoustic network in UN-Oceans could be mutually beneficial.

Concluding Remarks

In order of priority and emphasis,

- Community (user relationships, interagency coordination, reciprocity, inclusion, outreach)
- Context (technical level: data presentation on vDEC platform & CTBTO website;
policy level: SDG and other UN frameworks)
- Position (“tree diagram”; leverage unique value during potential organisational alignment)
 - Capacity (the whole IMS HA network in full visibility)