A Portable Experimental Buoy for Coastal Acoustic Monitoring as a Potential Complement to the IMS Hydroacoustic Network: Applications on the Argentinian Continental Shelf

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Argentinian Navy Research Office & UNIDEF (CONICET)

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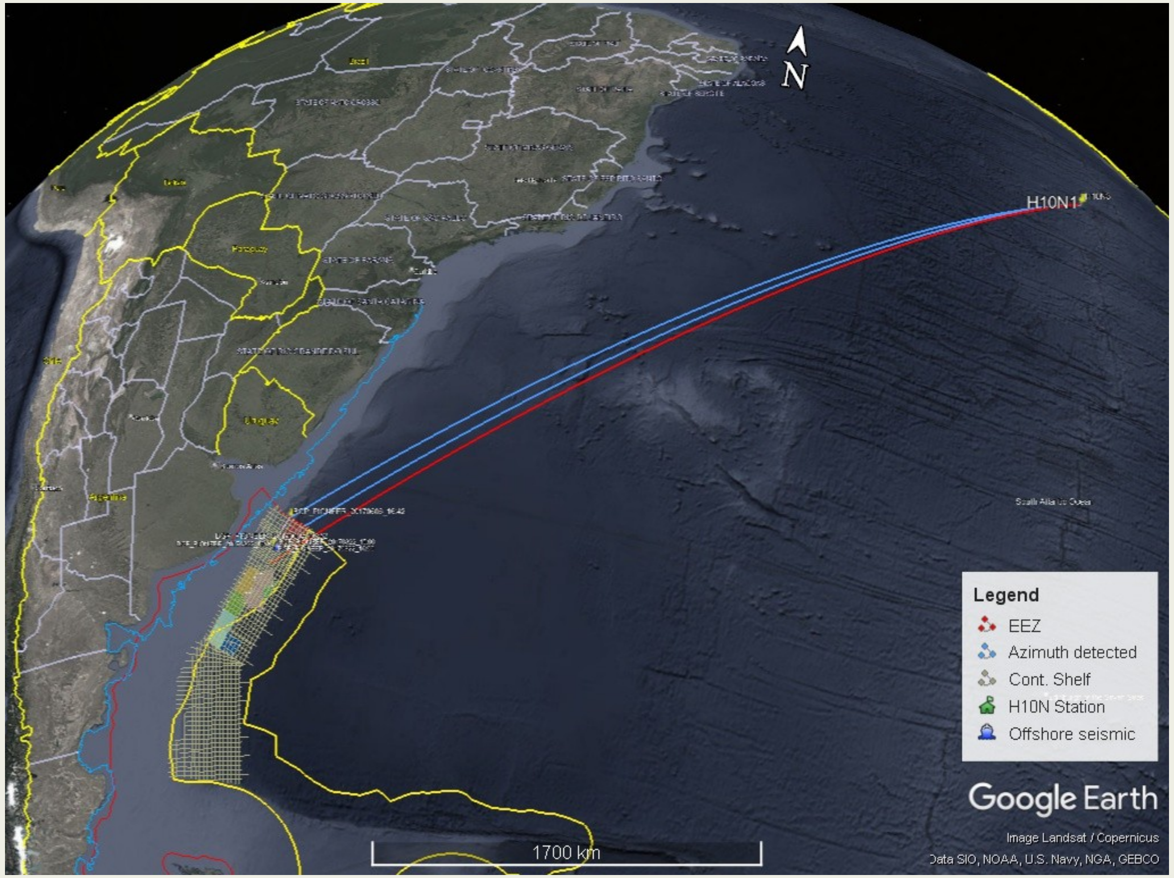
Background

Airgun array used in seismic surveys generate high amplitude sound pulses 5 Hz –60 Hz that can propagate over ocean-basin scales.

- Under favourable conditions, signals reach CTBT IMS hydroacoustic (HA) stations with high SNR.
- On the Argentinian Continental Shelf, airgun signals detected at H10N can be used to validate long-range propagation models [(1)].
- Limitations: highly directional sources and shallow-water propagation reduce detectability.
- Challenge: synchronize ground-truth airgun shots with H10N recordings, actual Source Levels.



[(1)] SnT2021 P1.3-494 An inverse problem approach for acoustic Transmission Loss estimation from the analysis of signals generated by seismic air-gun arrays.
SnT2023 O1.3-536 Analysis of bathymetric effects on long-range acoustic propagation using 2D and 3D Transmission Loss models in signals generated by airgun arrays.

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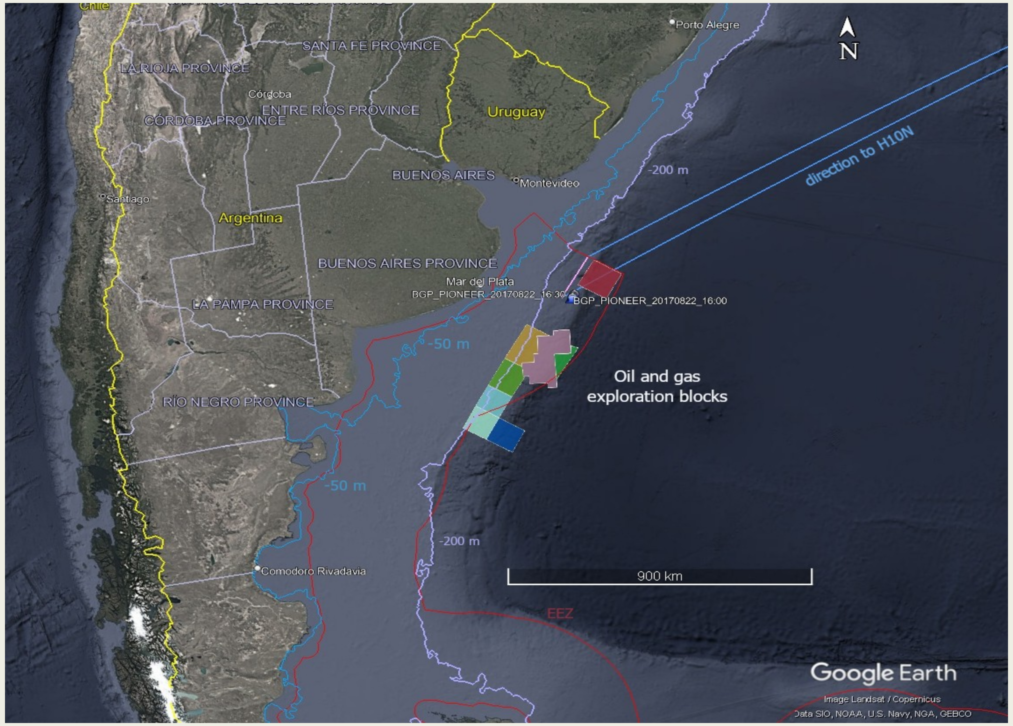
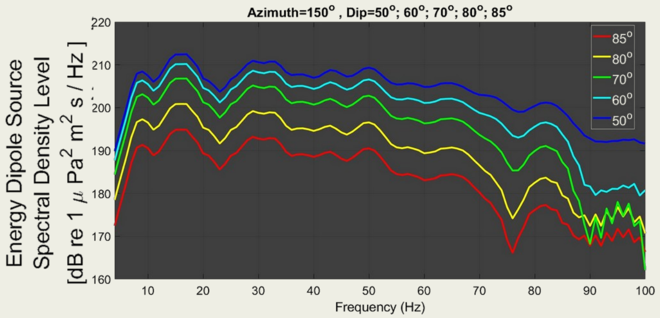
Motivation





- Seismic surveys are conducted in offshore oil & gas exploration blocks.
- Large dataset of high-amplitude impulsive signals ► basin-scale propagation analysis.
- Airgun array source levels simulated with an open-source airgun modelling software(2): Energy source level ~ 190 - 210 dB re 1μPa^{2}m^{2}s within 5 Hz – 70 Hz band (HA10 direction).
- Need for local measurement of airgun shots signals or other underwater noise sources on the Continental Shelf ► **selection of semi-permanent sites for buoy-deployed hydrophones**.

(2) Sertlek, H. O., and Ainslie, M. A. (2015). “AGORA: Airgun Source Signature Model: Its application for the Dutch Seismic Survey,” in Proceedings of Underwater Acoustics Conference and Exhibition, Crete, Greece, pp. 439–446,

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Current acoustic coverage in Argentinian Continental Shelf

- **Goal**: identify candidate shallow-water sites (depth z < 200 m) for improved local monitoring.
- **Acoustic coverage areas of the HA10 station:** preliminary analysis using 2D Parabolic Equation (PE) model RAM (Range-dependent Acoustic Model, Julia implementation).
- **Acoustic scenario:**
  - Oceanographic databases: T, S profiles from Copernicus; bathymetry from GEBCO.
  - Frequencies band analyzed: 2 Hz < f < 100 Hz.
  - Transmission Loss (TL) computed along Nx2D radial transects from H10N.
  - Source depth = 8 m (typical for airgun array).
- **Maximum coverage analysis**: High impulsive source levels[(3)]; TL < 200 dB; NL ~ 80 dB re 1μPa².

N geodesic radial lines from H10N for TL modeling

(3) Dekeling, R.P.A., et al. Monitoring Guidance for Underwater Noise in European Seas, Part III

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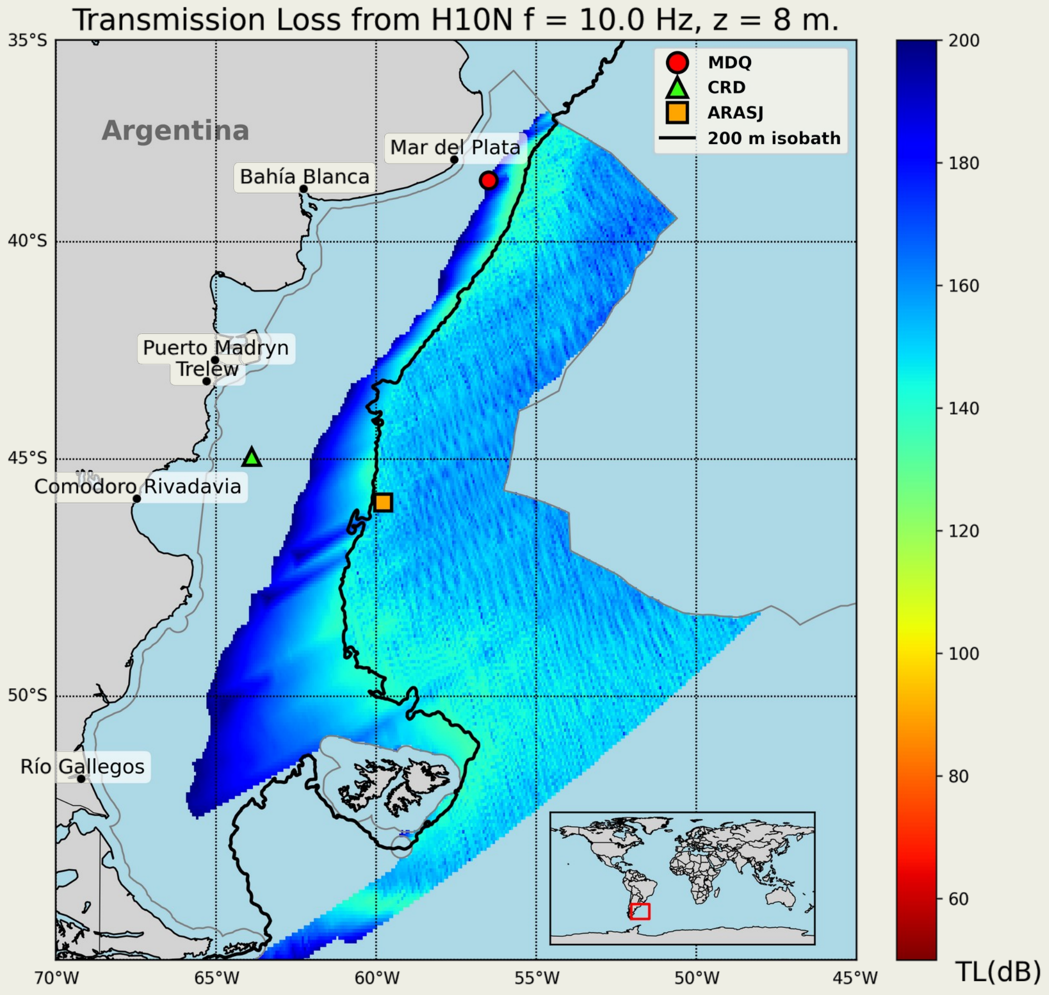
Offshore Argentina coverage of Ascension station H10N



- Strong frequency dependence:
  - Low frequencies (f < 10 Hz): coastal shadow zones, TL > 200 dB.
  - Higher frequencies (10 Hz < f < 80 Hz): partial coverage, but limited in shallow waters.
- Argentinian continental slope acts as an acoustic filter.
- Coastal coverage gaps: long-range IMS hydroacoustic stations miss nearshore regions.
- Local minima of TL in the continental slope (ARA San Juan wreckage, signal of 2017 implosion event was detected in two IMS-HA stations[4])
- Offshore candidate sites identified: 1-MDQ, 2-CRD

(4) Prario, I., Cinquini, M., Marques Rojo, R. *et al.* Characterization of the Acoustic Event Associated with the Loss of the ARA San Juan Submarine Based on Long-Range Measurements by CTBTO's Hydrophone Stations. *Pure Appl. Geophys.* **180**, 1317–1342 (2023). https://doi.org/10.1007/s00024-022-03090-0.

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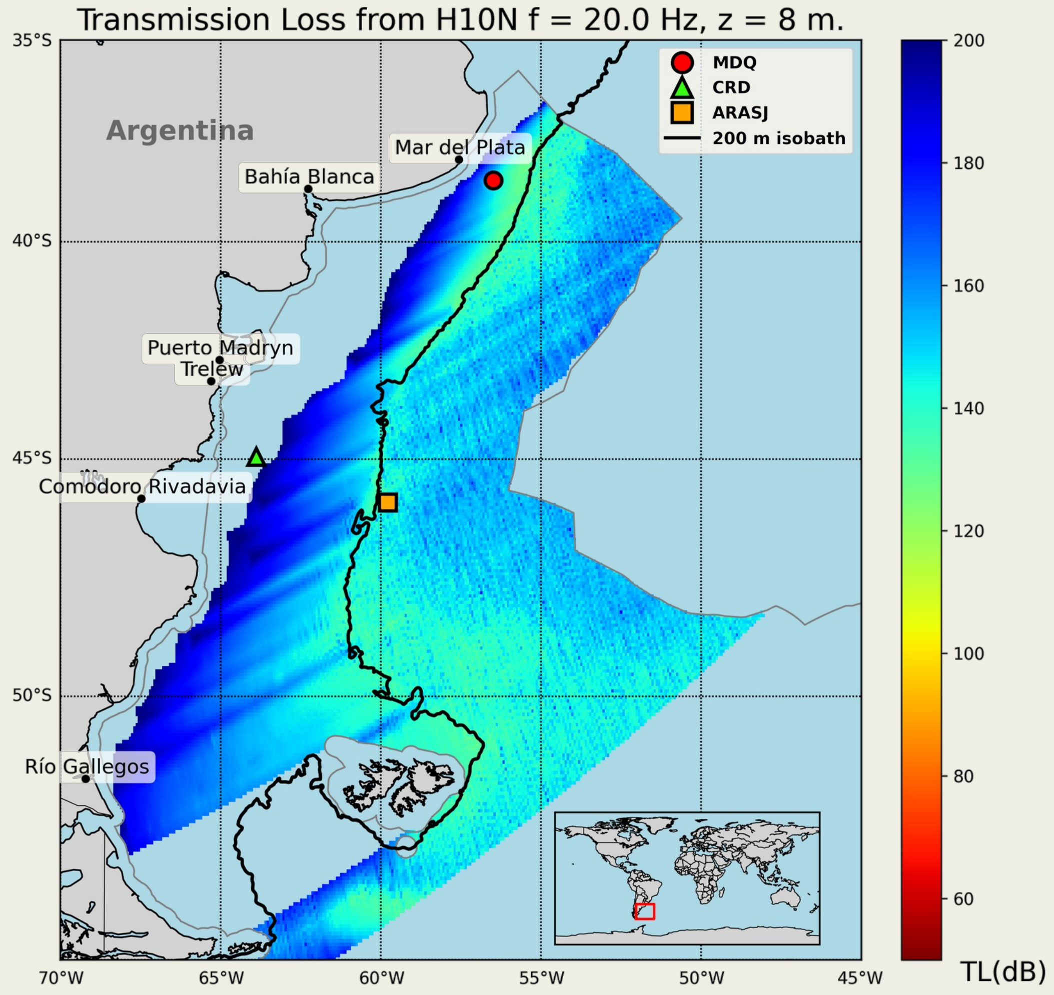

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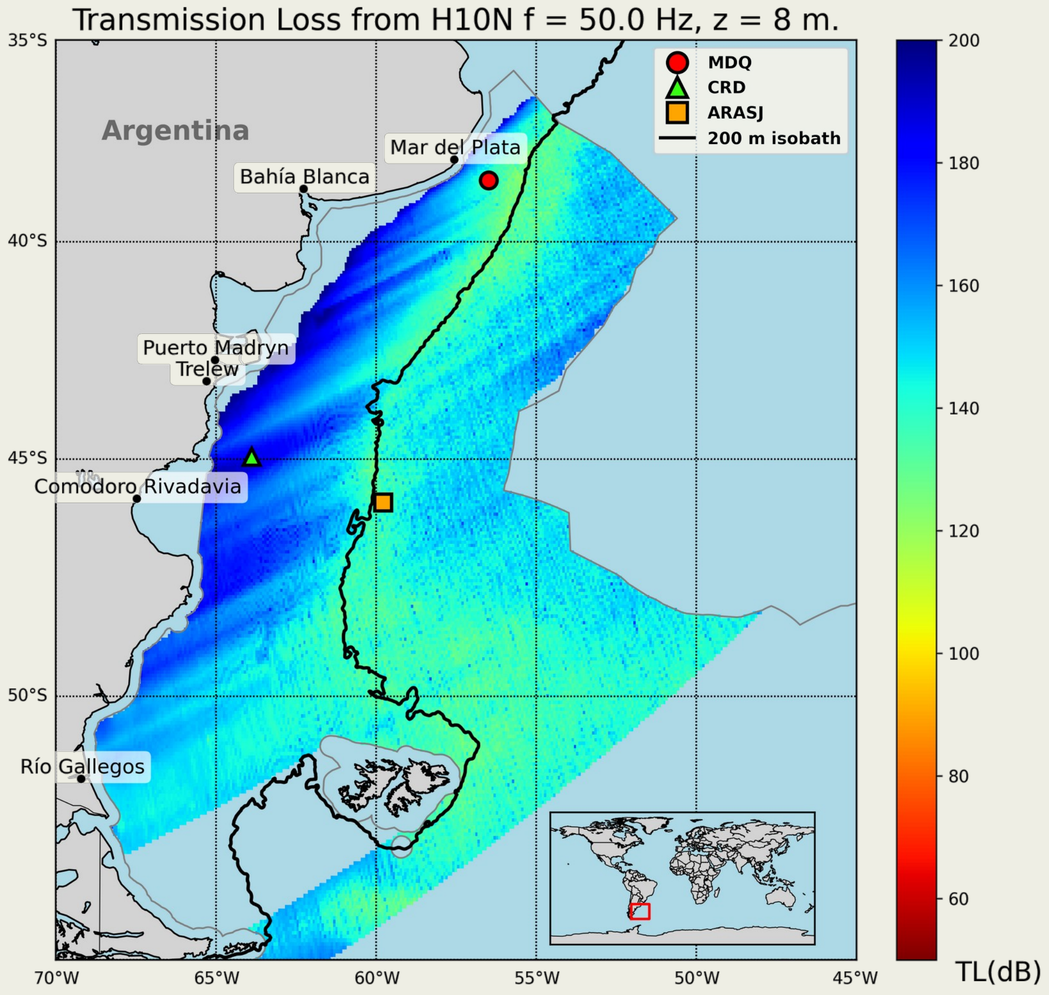

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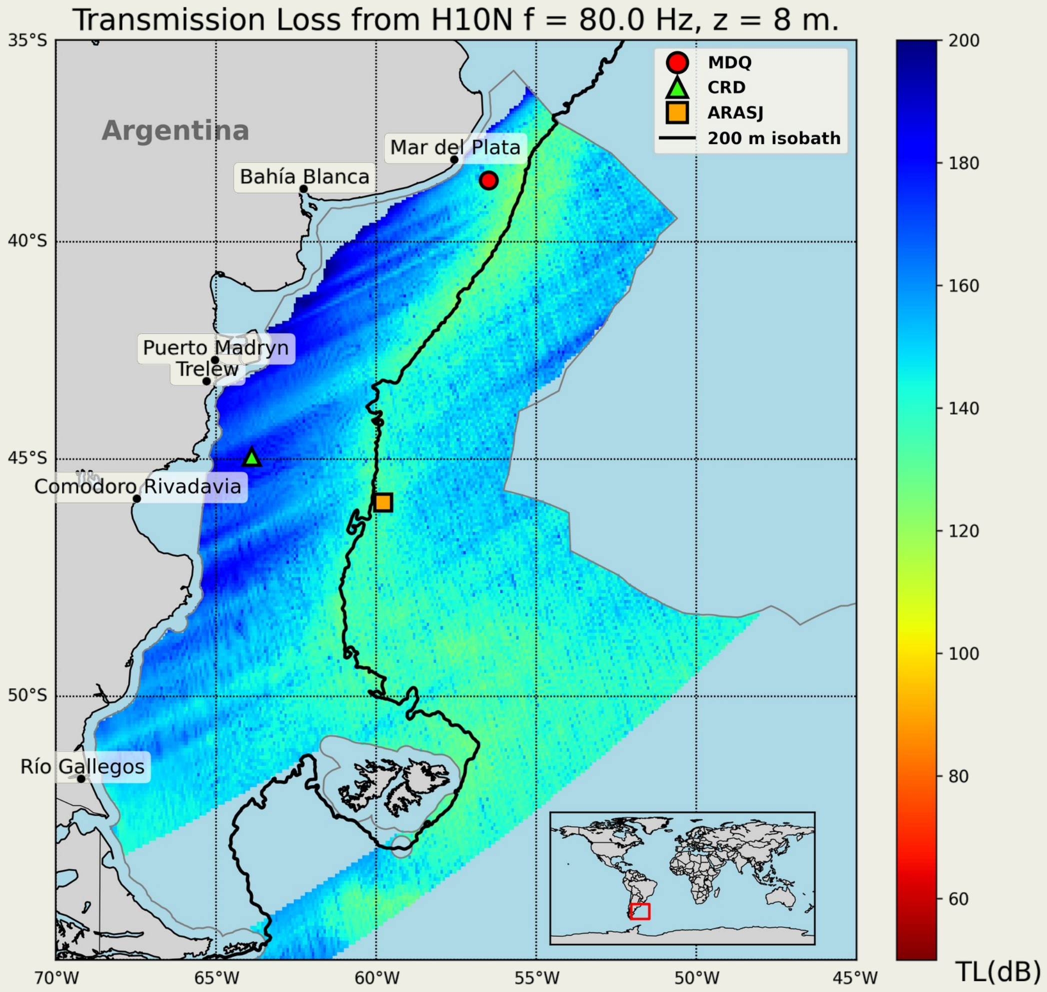

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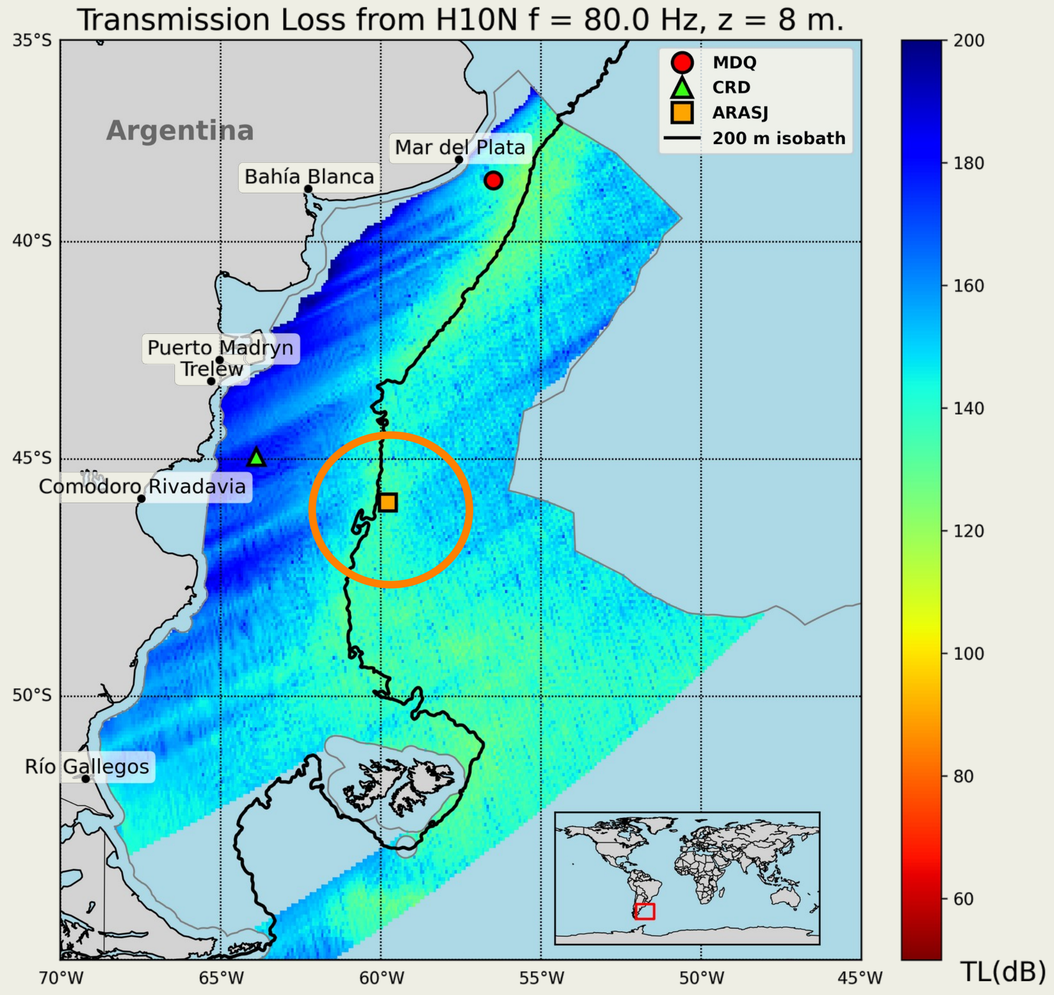

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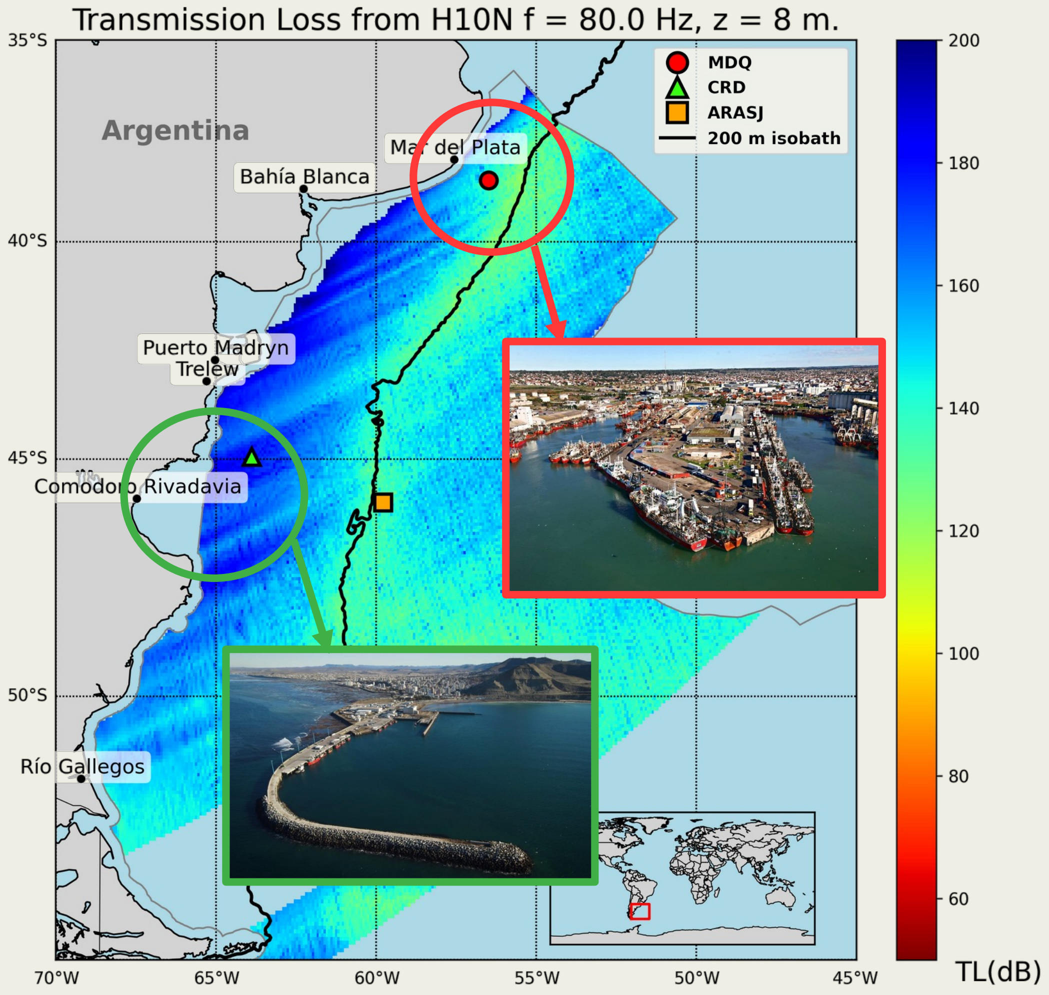

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Coverage of candidate 1 station (offshore Mar del Plata - MDQ)

- **Specific goal:**
  - Assess acoustic coverage over the continental shelf and adjacent waters.
- **Acoustic scenario:**
  - Frequency range: 2 Hz – 100 Hz (results shown at 10, 20, 50, 80 Hz).
  - Source depth = 8 m (typical airgun tow depth).
  - Receiver depth (hydrophone) = 40 m.
  - T, S profiles from Copernicus.
  - Bathymetry from GEBCO database.
  - Seabed properties from *Jensen et al.*
  - NL~80-85 dB re 1μPa^2
- **Simulation:**
  - 2D PE with RAM.jl.
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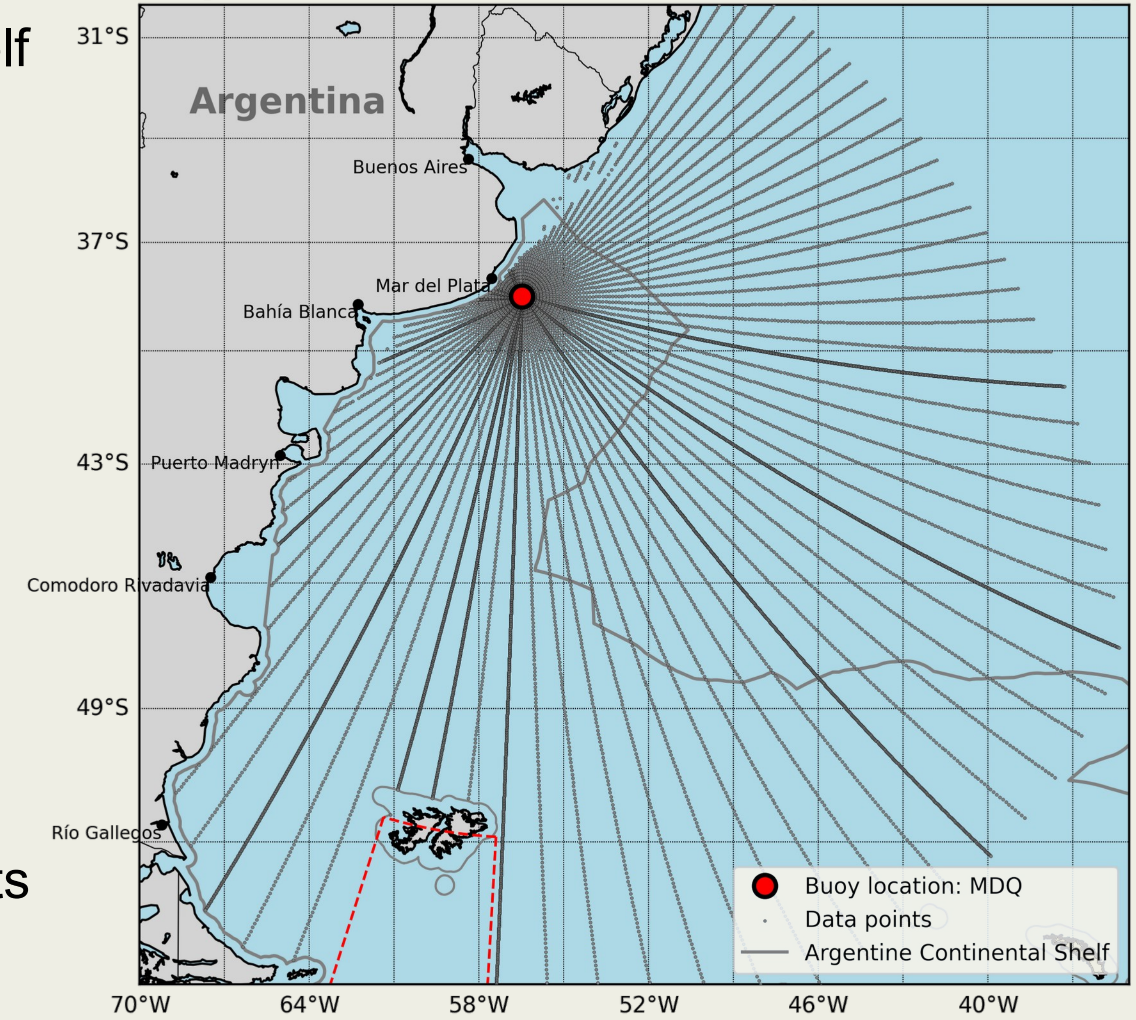
N geodesic radial lines from the buoy for TL modeling



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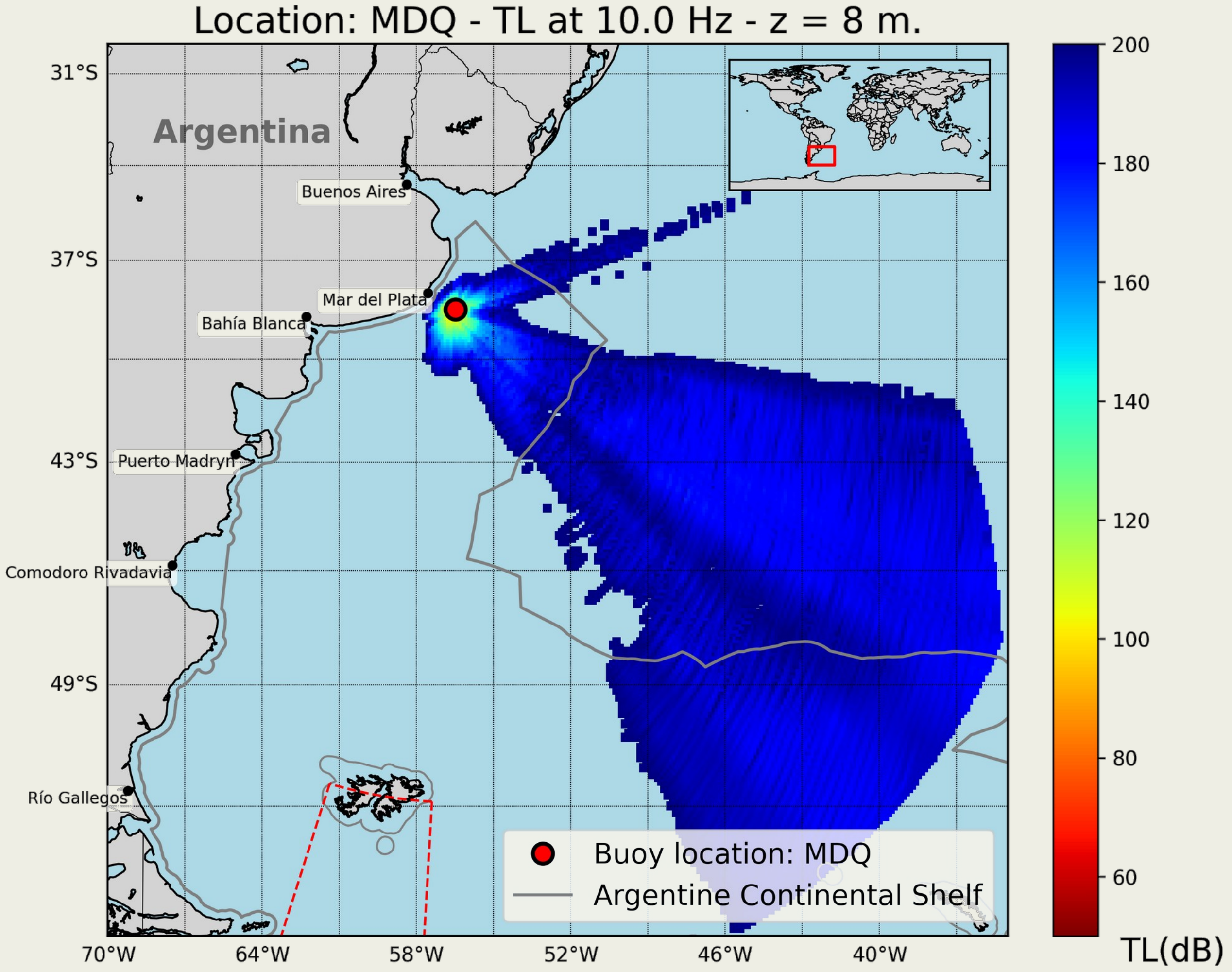

- Strong frequency dependence: low frequencies (f < 10 Hz) show larger shadow zones.
- Filtering effect: continental slope reduces transmission at low frequencies (f < 20 Hz).
- Improved coverage at 50 Hz < f < 80 Hz band across shelf and slope.
- Shallow-water gap: limited detectability close to the coast (depth z < 200 m).
- Implication: buoy-deployed hydrophones at MDQ station enhances monitoring in northern shelf region.

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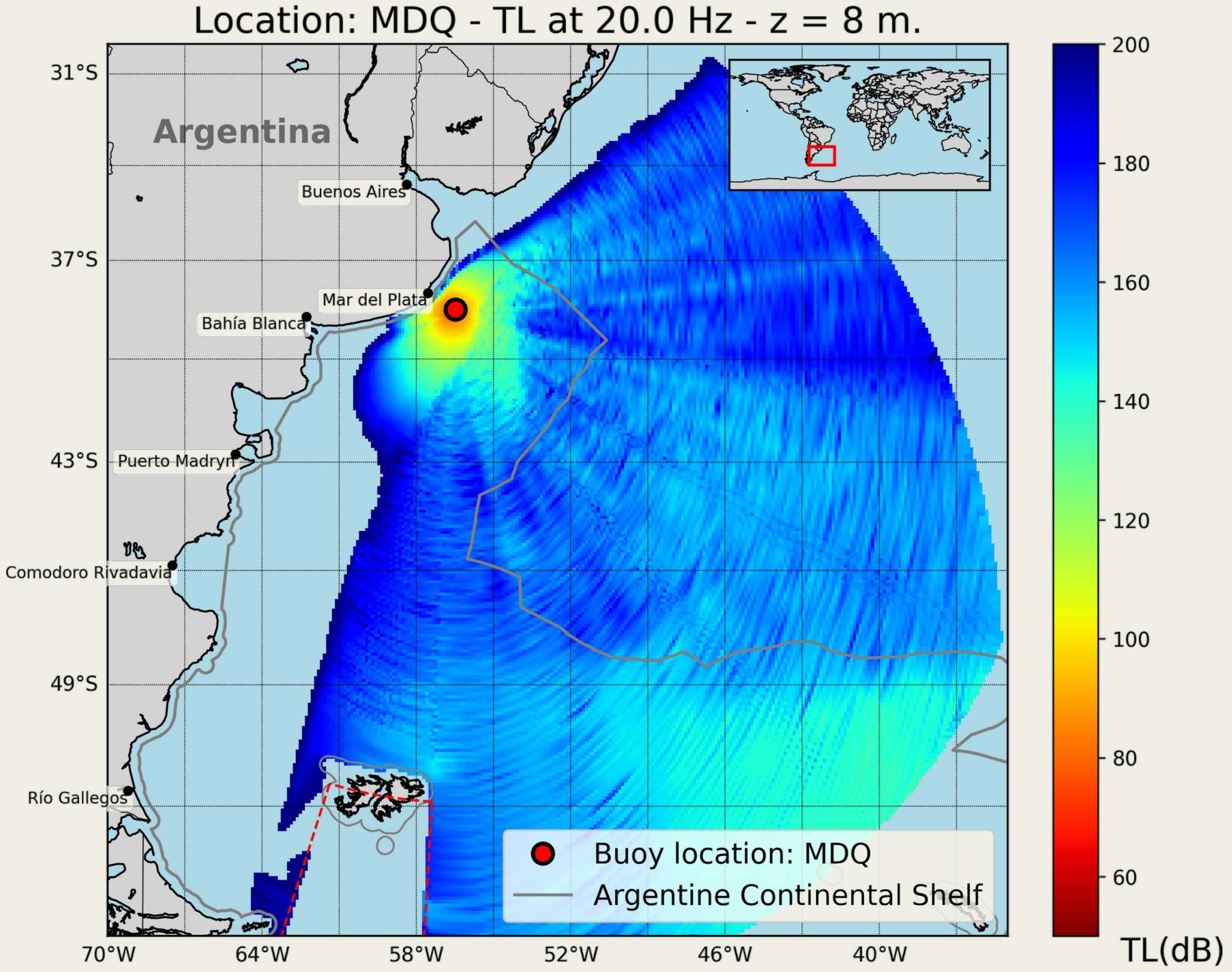

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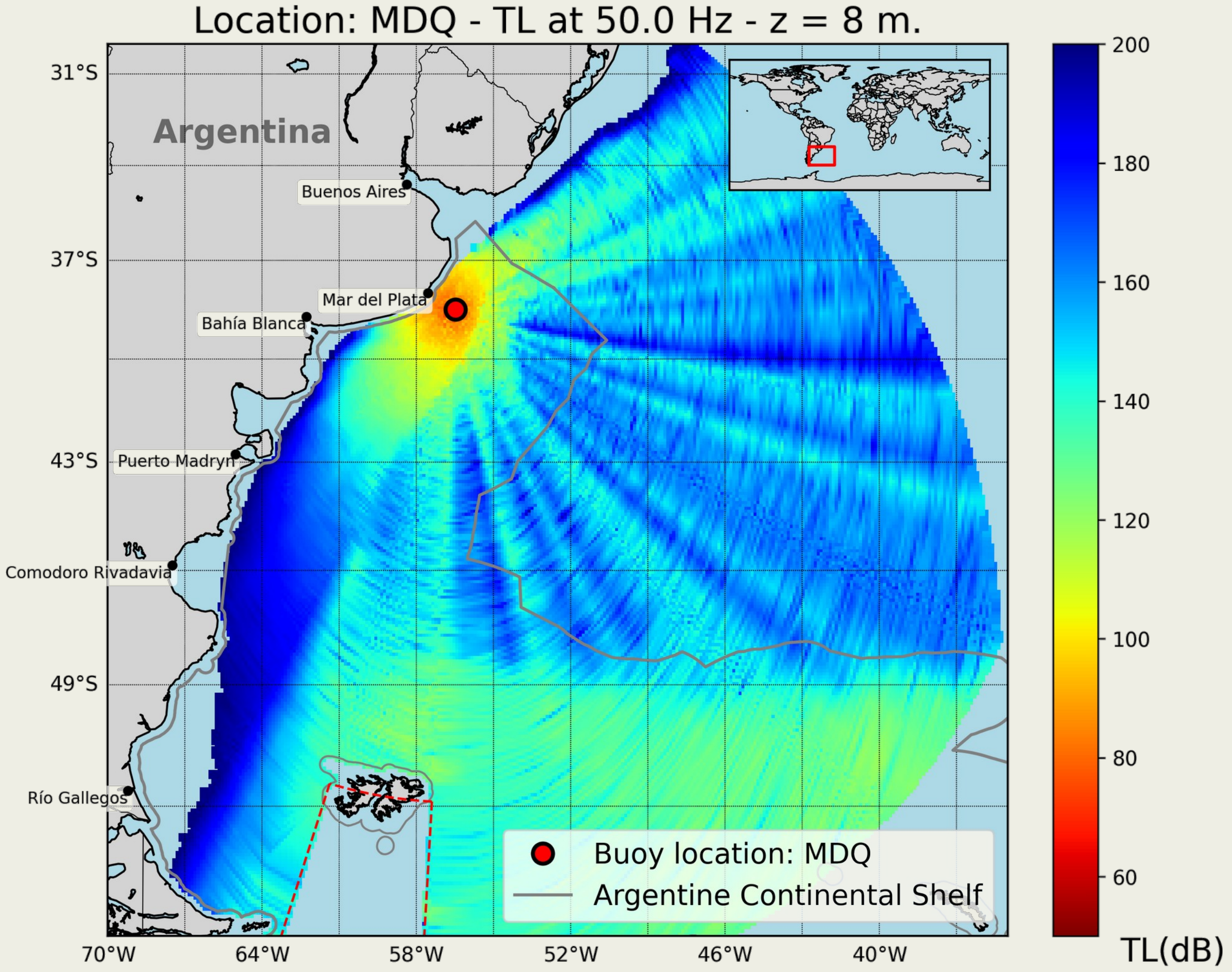

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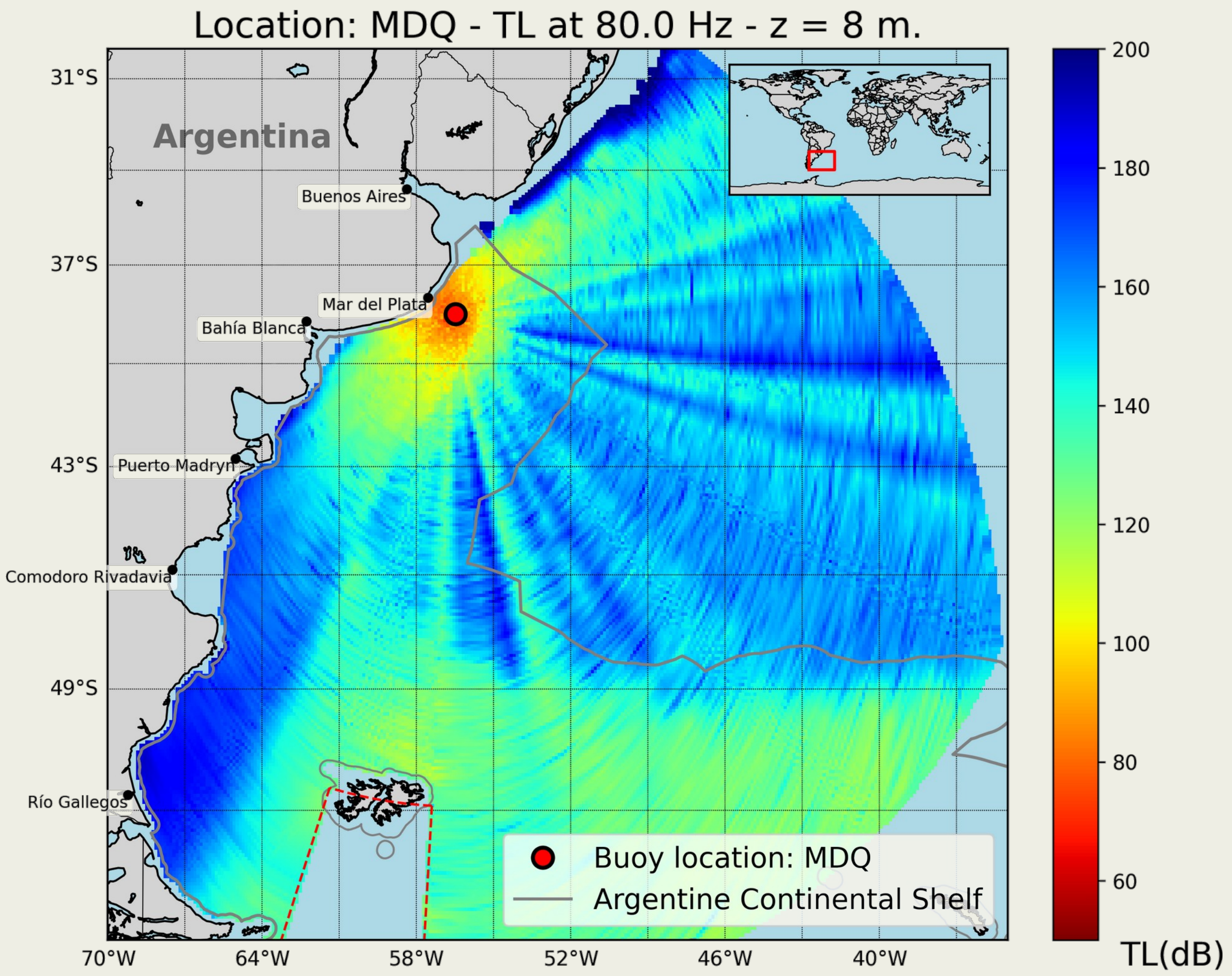

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Coverage of candidate 2 station (offshore Comodoro Rivadavia - CRD)

- **Specific goal:**
  - Assess acoustic coverage over the continental shelf and adjacent waters.
- **Acoustic scenario:**
  - Frequency range: 2 Hz – 100 Hz (results shown at 10, 20, 50, 80 Hz).
  - Source depth = 8 m (typical airgun tow depth).
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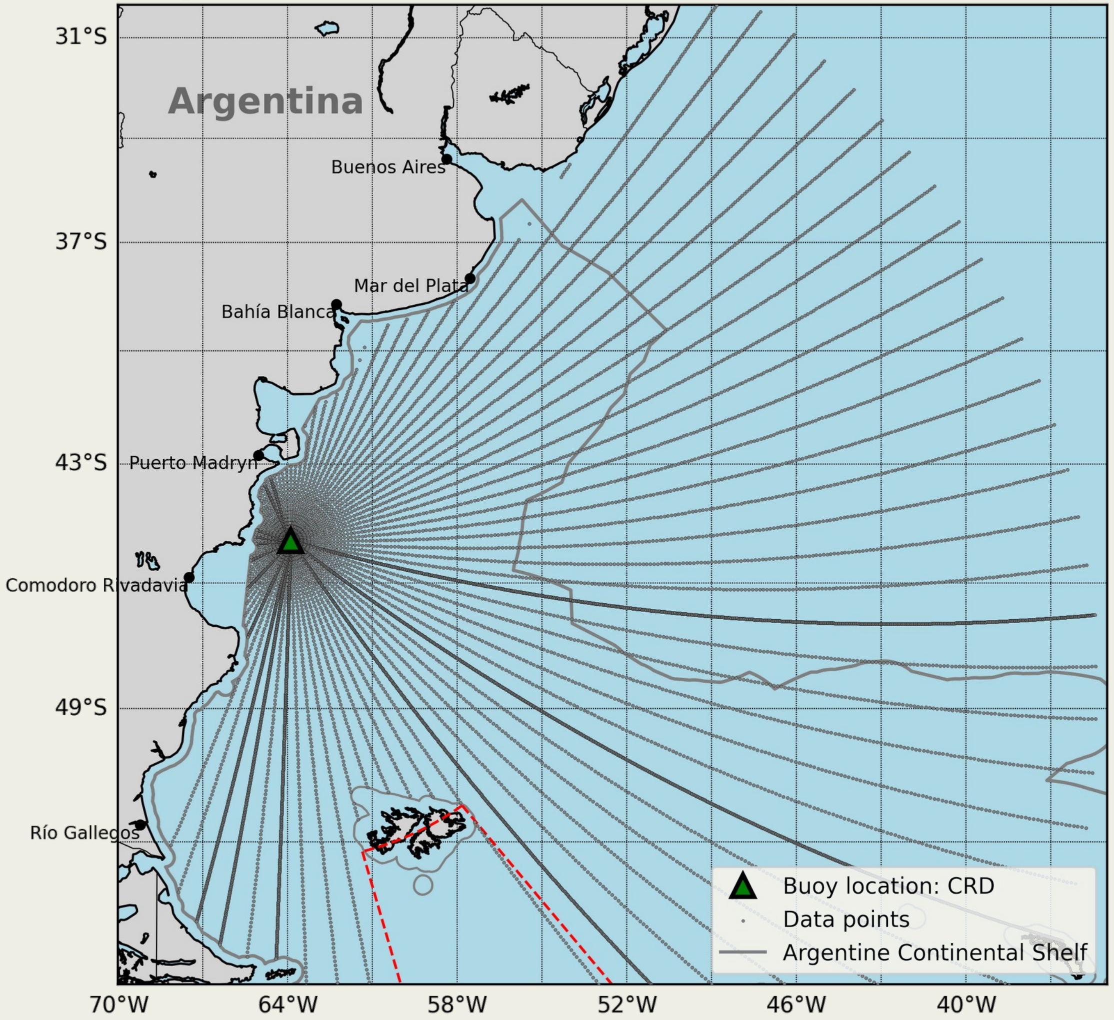

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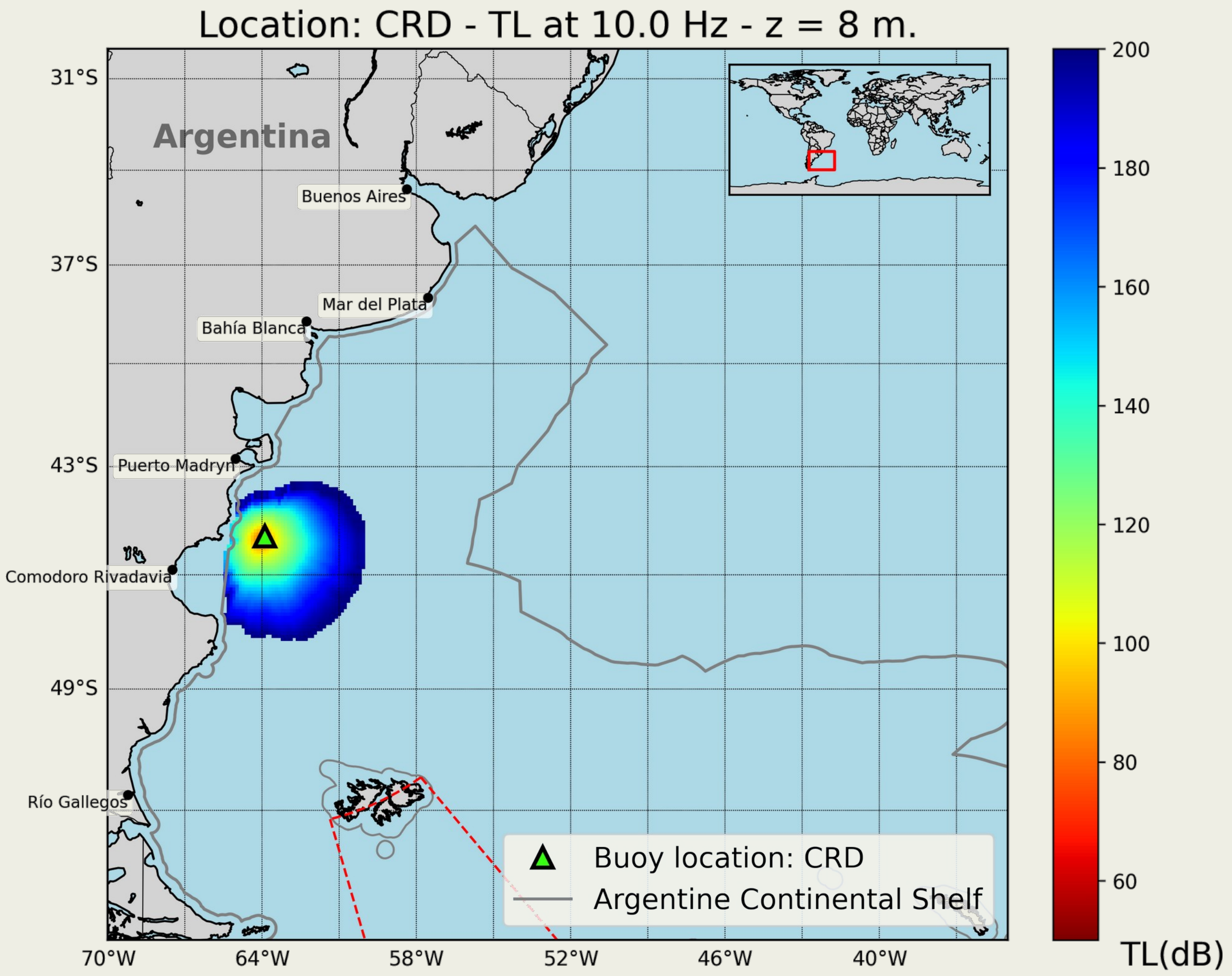

- Marked frequency variation: stronger propagation loss at 10 Hz – 20 Hz band rather than at 50 Hz – 80 Hz band.
- Continental slope creates coastal shadow zones at low frequencies.
- Broader mid-frequency coverage compared to MDQ station, extending farther offshore.
- Shallow-water limitations remain near coastlines.
- Implication: buoy-deployed hydrophones at CRD station can improve coverage in southern shelf and can complement MDQ station.

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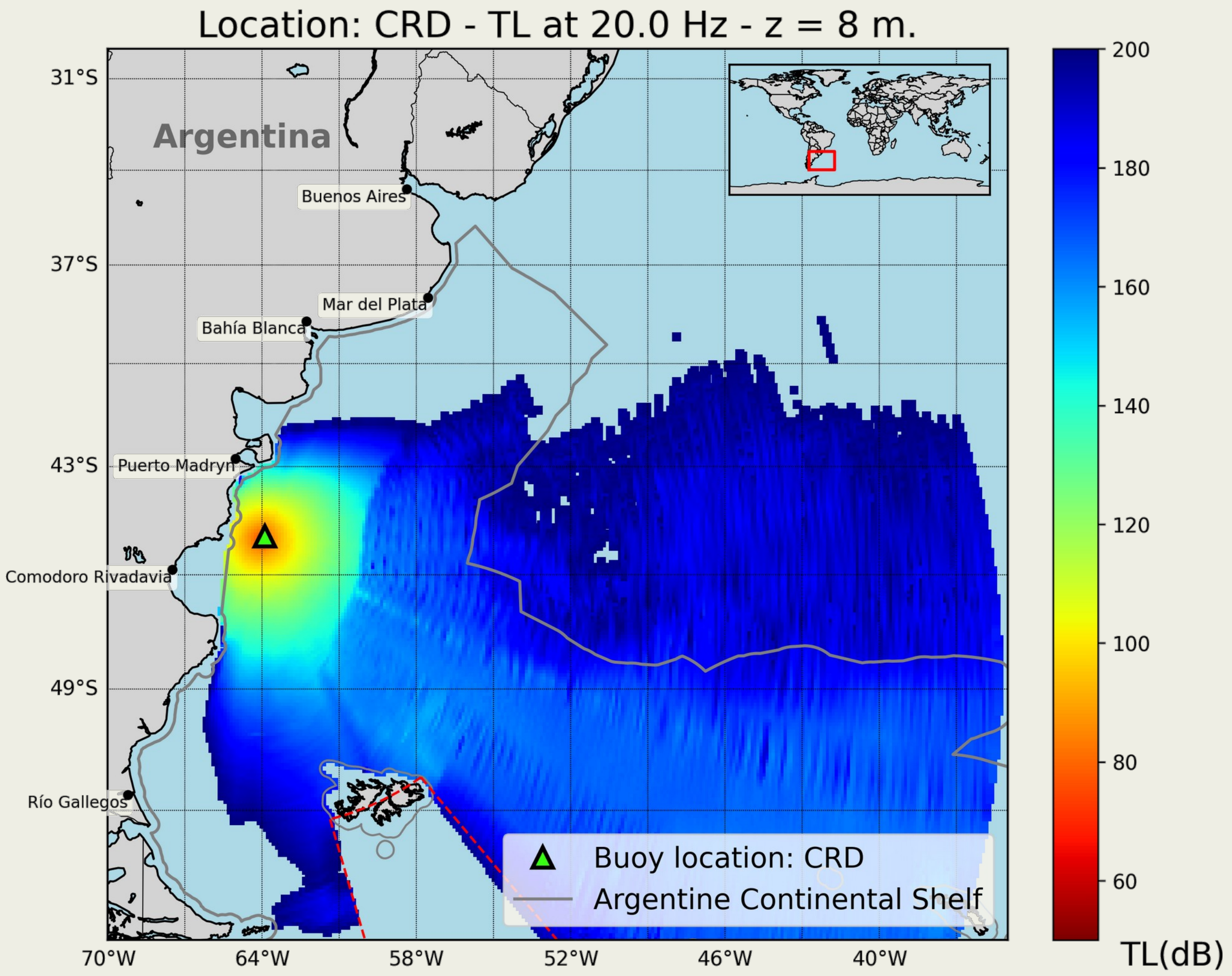

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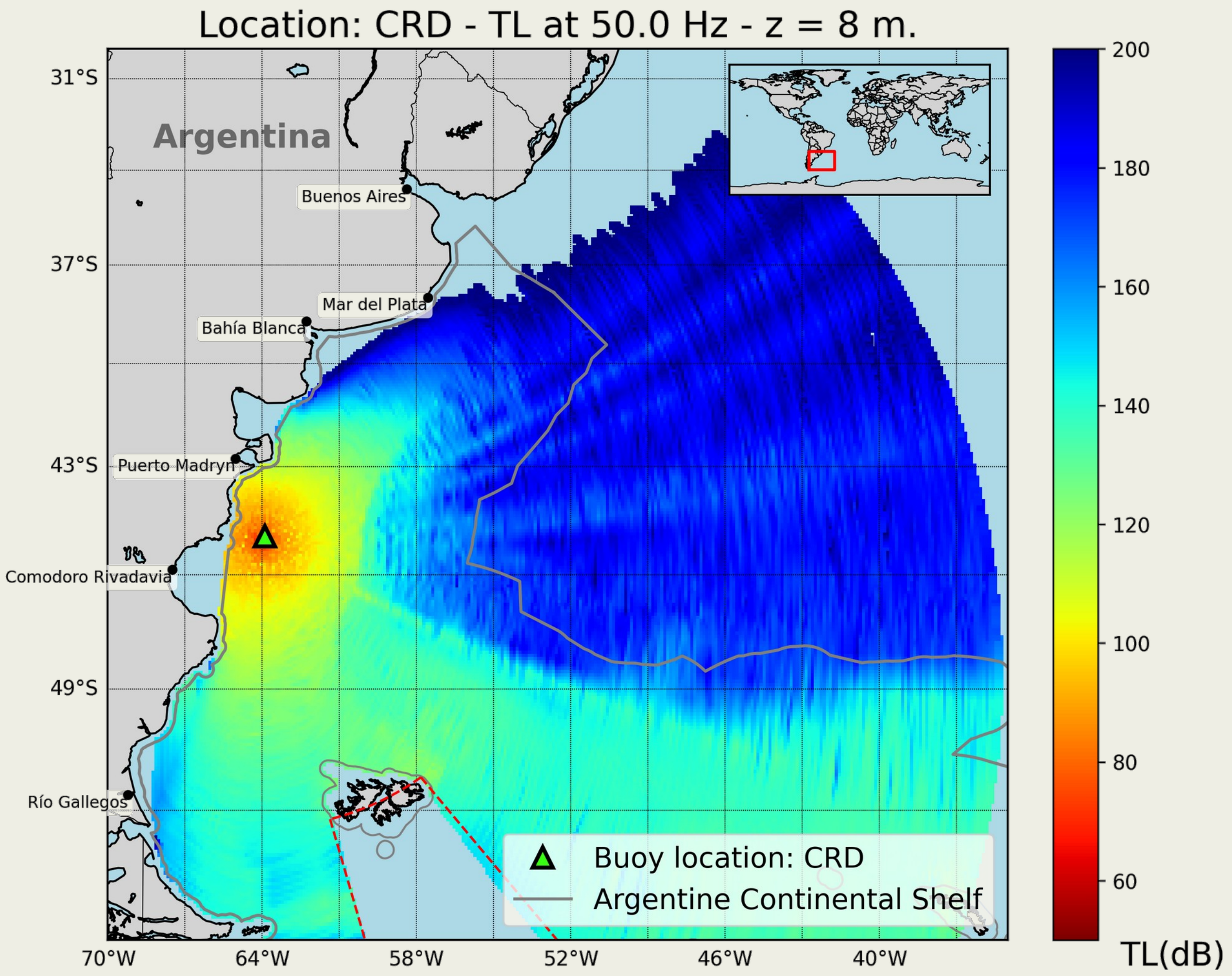

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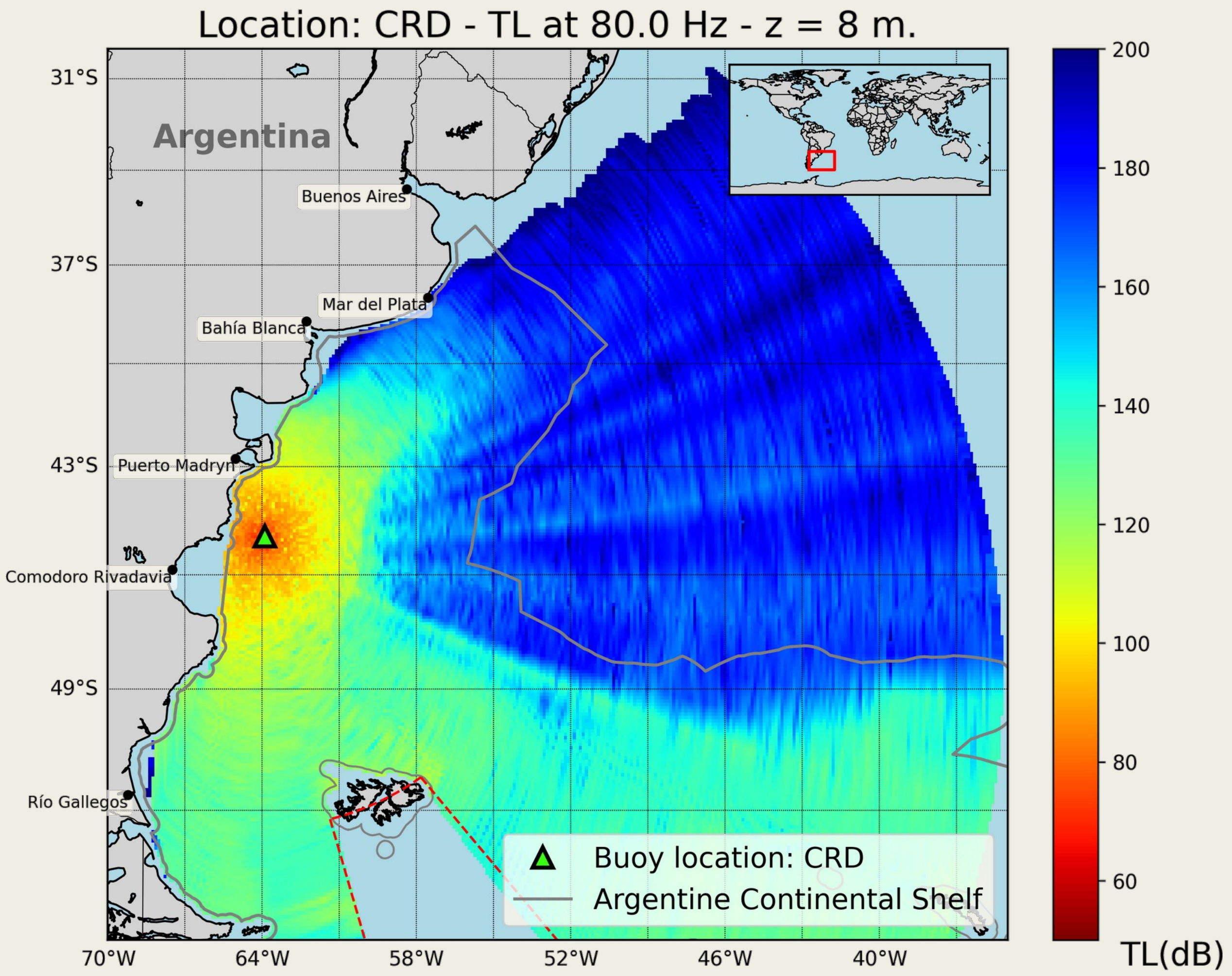

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Buoy Platform design for hydrophones deployment in selected stations

Main objetives:

- Characterization of ambient noise or underwater sound sources on the Argentinian continental shelf.
- Contributing to the understanding of shallow-water acoustic propagation.
- Potentially contribute to the understanding of long-range propagation using additional data from IMS-HA network.

This custom-designed buoy is a prototype platform developed for the deployment of hydrophone array at near-shore semi-permanent stations.

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Buoy Platform design for hydrophones deployment in selected stations

Features:

- A Glass-Reinforced Plastic hull for corrosion resistance and lightweight performance.
- 3 mooring lines for stable position.
- Stand-alone operation with solar power system.
- A sealed electronics compartment and a central mast for sensors, antennas, satellite transmission and GPS.
- Harsh marine conditions: strong currents and waves up to 4 meters.

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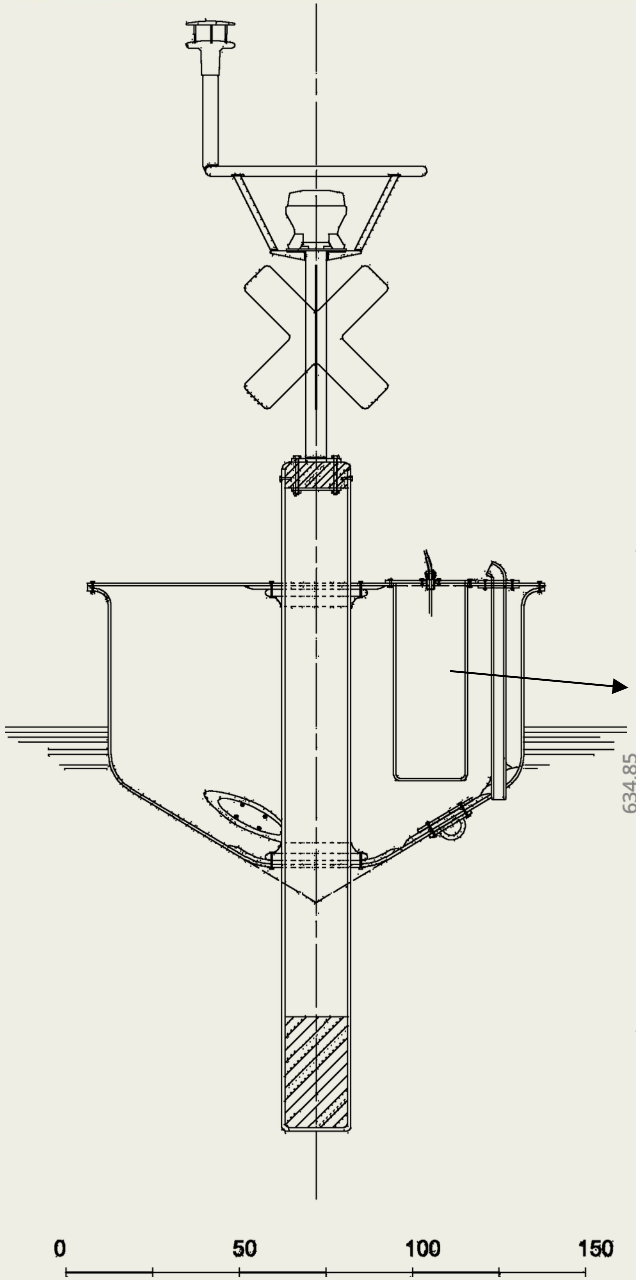
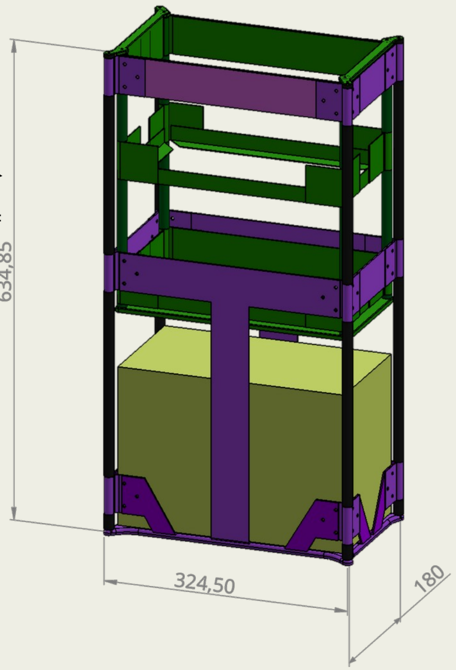
Buoy Electronics Rack





Removable, lift-out aluminum rack houses:

- Fanless embedded computer
- 24-bit audio interface for broadband hydrophone digitization
- Low-noise hydrophone preamplifiers
- AIS-AtoN (Automatic Identification System)
- Satellite modem for telemetry and command
- Deep-cycle battery with solar charge controller

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Layered Architecture of the Embedded System

Orchestrator Layer

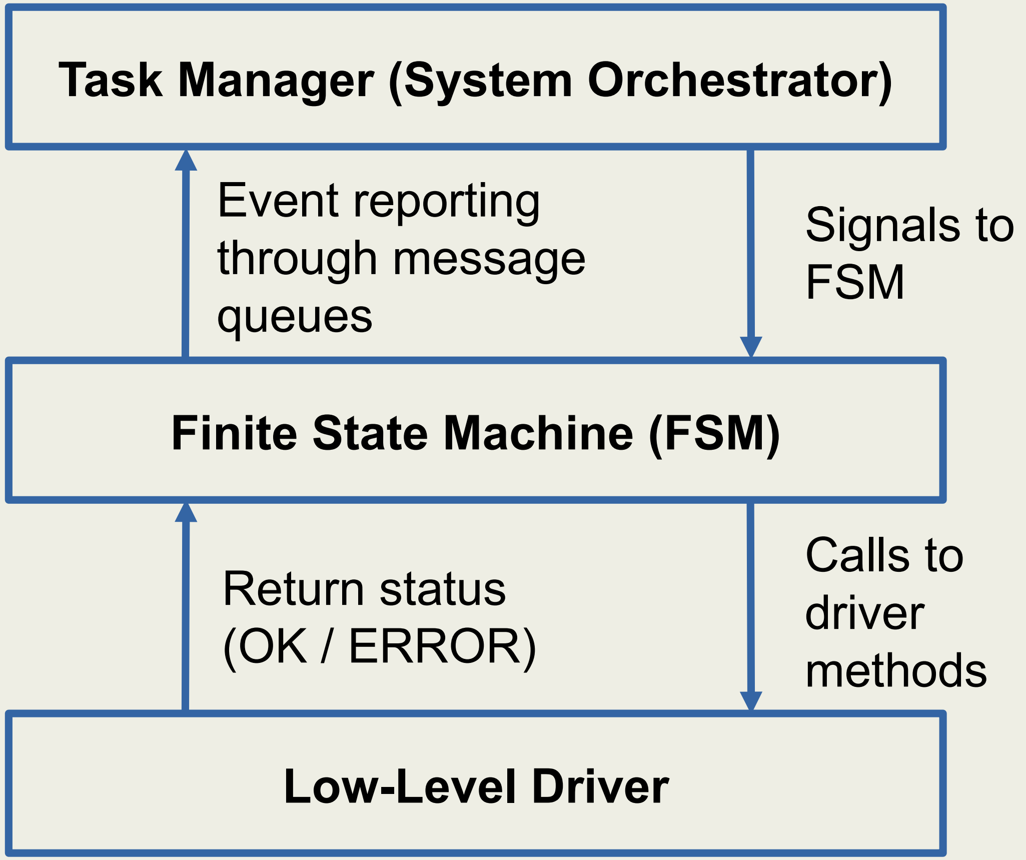
- Coordinates overall system flow.
- Decides which FSM to activate and when.
- Handles high-level internal and external events.

State Machine Layer (FSM)

- Manages module behaviour based on current state.
- React to events, executes actions, changes states.

Low-Level Driver Layer

- Interfaces directly with hardware.
- Performs device I/O and peripheral configuration.



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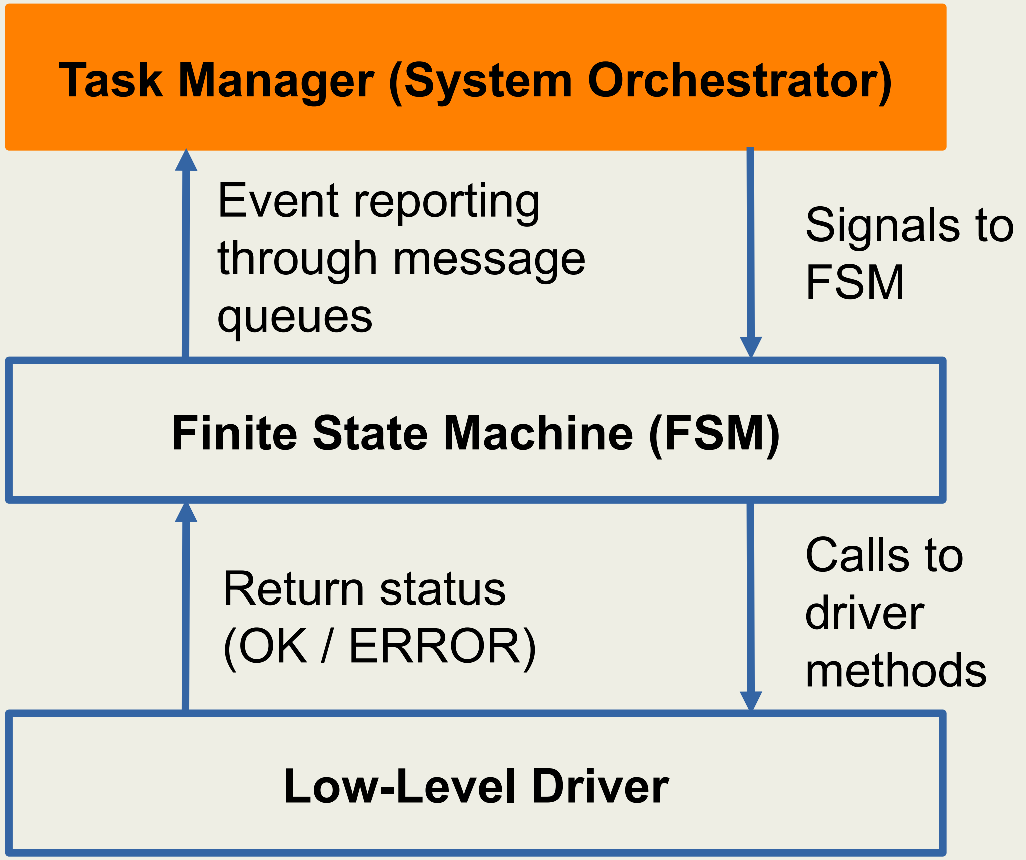

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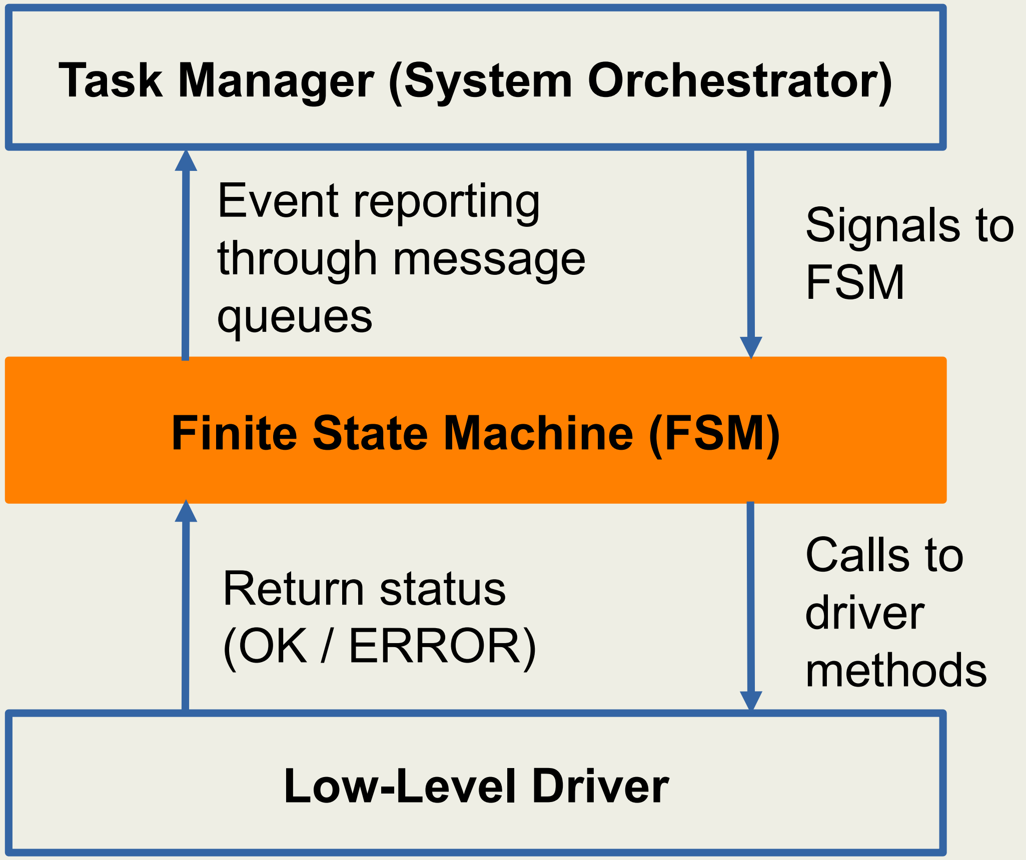

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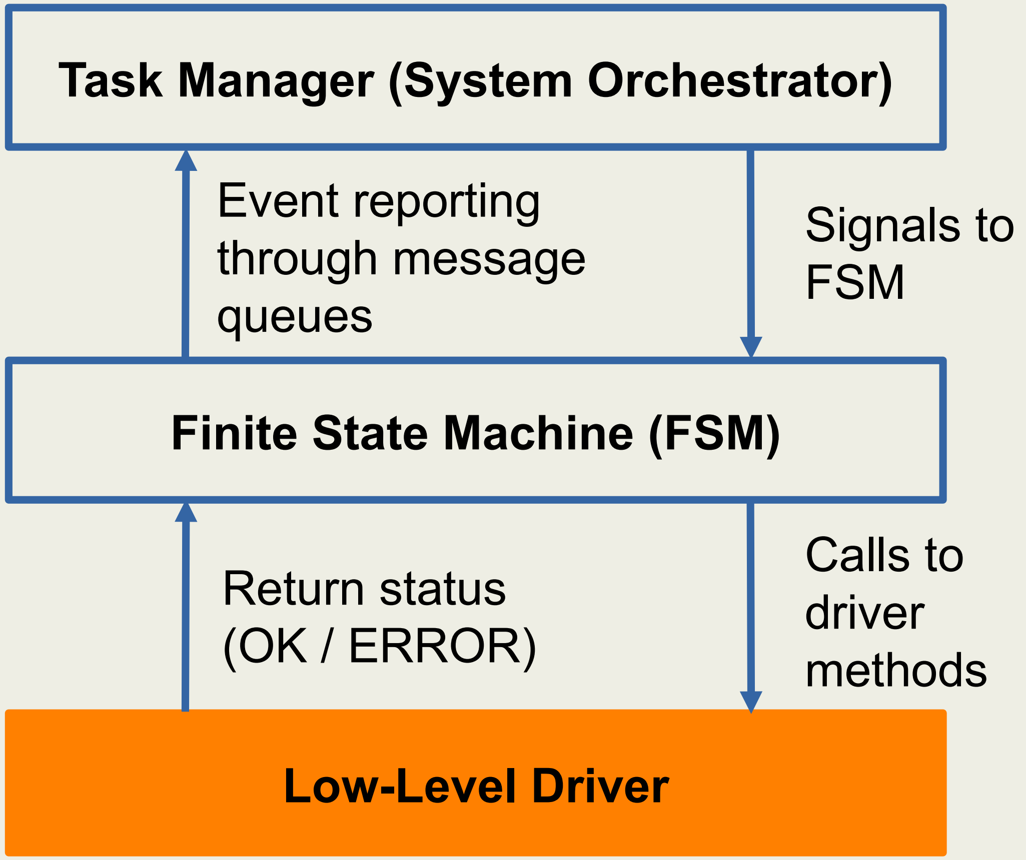

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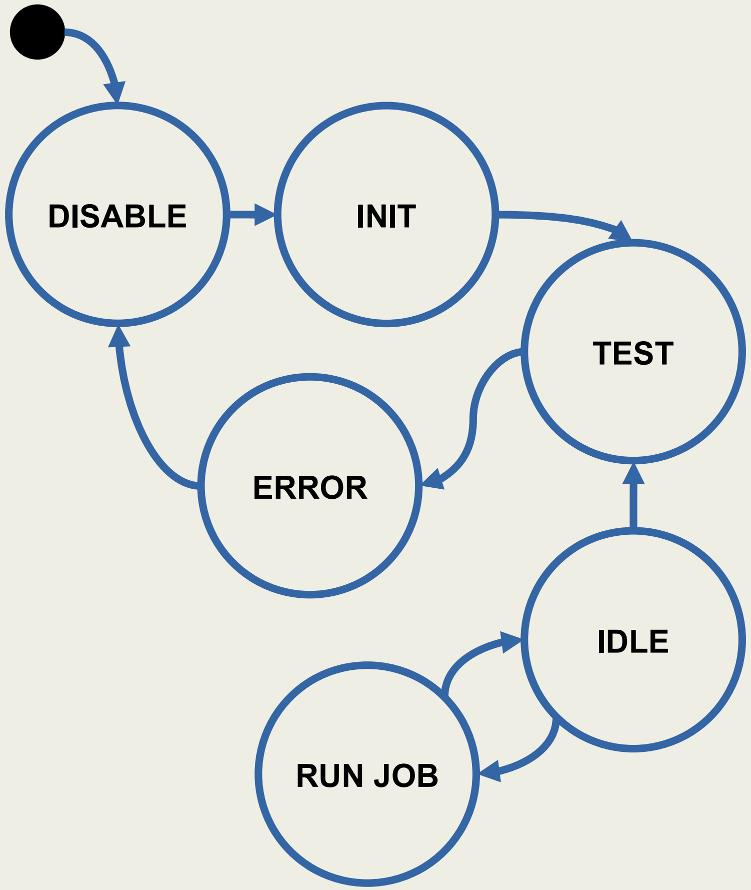
State Machine Design Pattern

This generic FSM pattern is used across multiple modules to manage their internal logic and execution flow.

- DISABLE: The module is inactive and resources are released.
- INIT: Initializes hardware and internal variables.
- TEST: Performs self-checks and verifies correct functionality.
- ERROR: Captures faults and attempts recovery or shutdown.
- IDLE: Waits for commands or events.
- RUN JOB: Executes the main task or acquisition.



Transitions are triggered by internal events or commands.

Each FSM has a scheduler, message_handler and update functions

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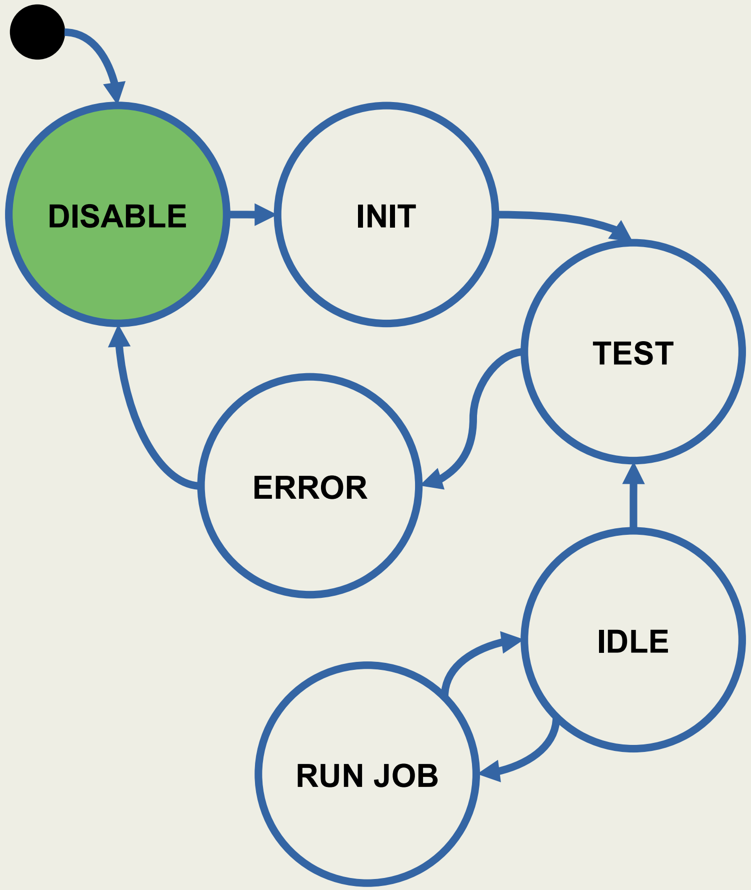
State Machine Design Pattern

This generic FSM pattern is used across multiple modules to manage their internal logic and execution flow.

- **DISABLE**: The module is inactive and resources are released.
- INIT: Initializes hardware and internal variables.
- TEST: Performs self-checks and verifies correct functionality.
- ERROR: Captures faults and attempts recovery or shutdown.
- IDLE: Waits for commands or events.
- RUN JOB: Executes the main task or acquisition.



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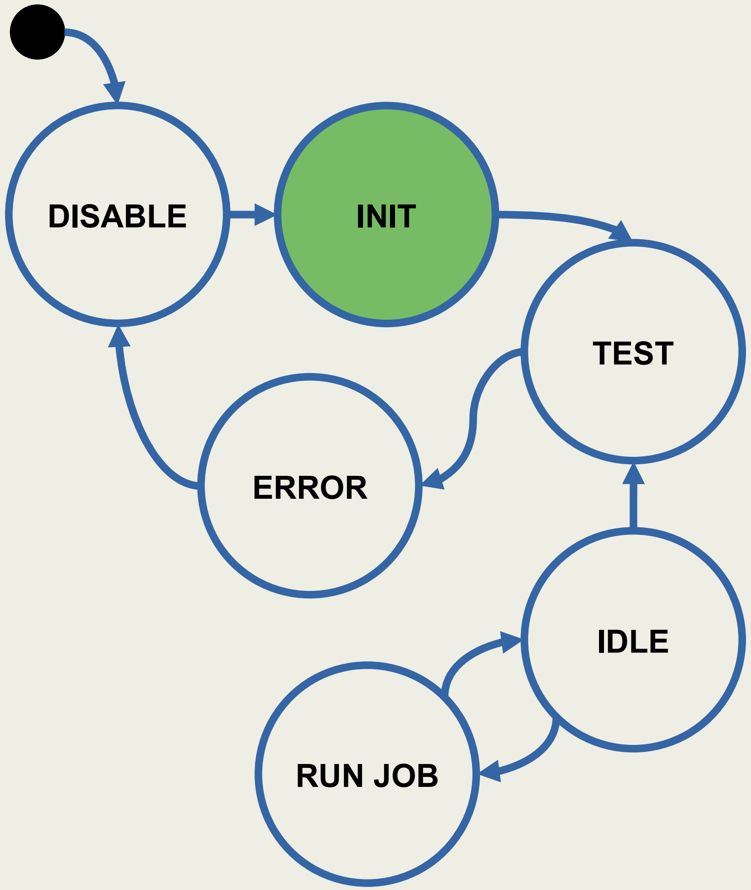

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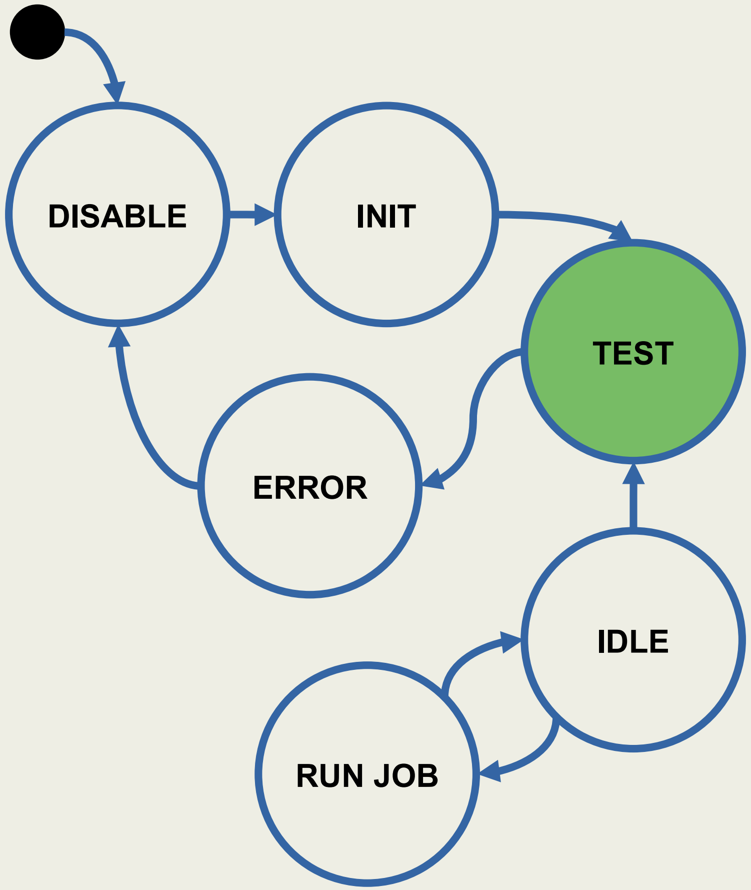

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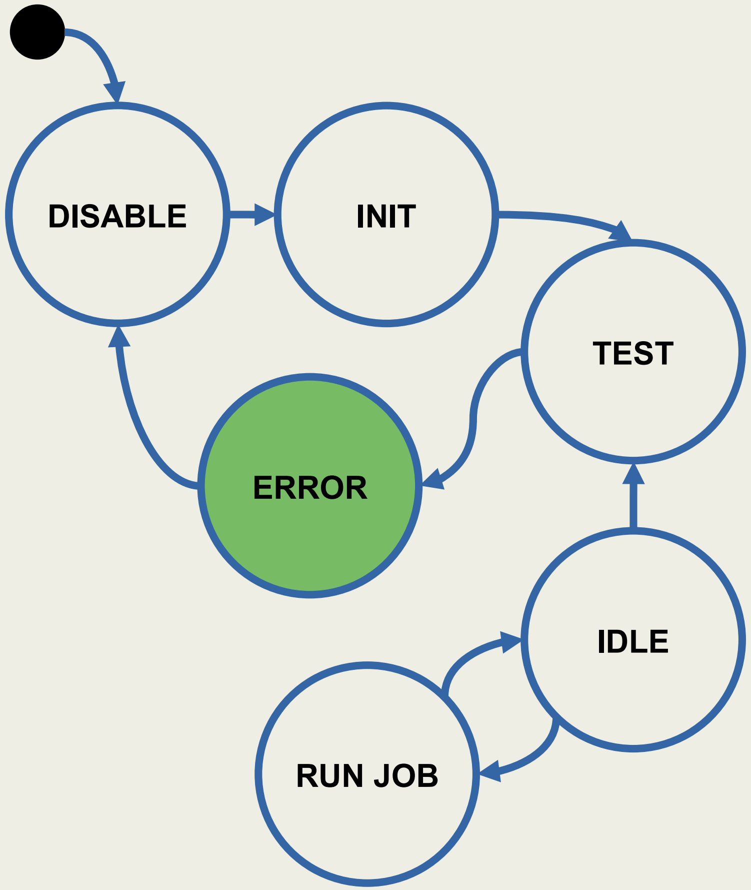

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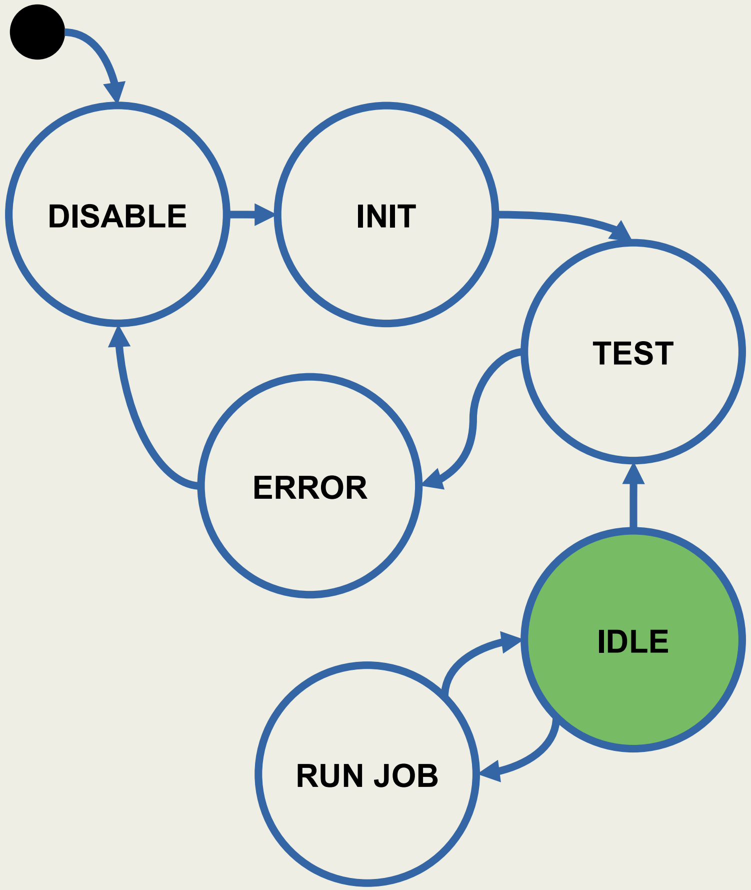

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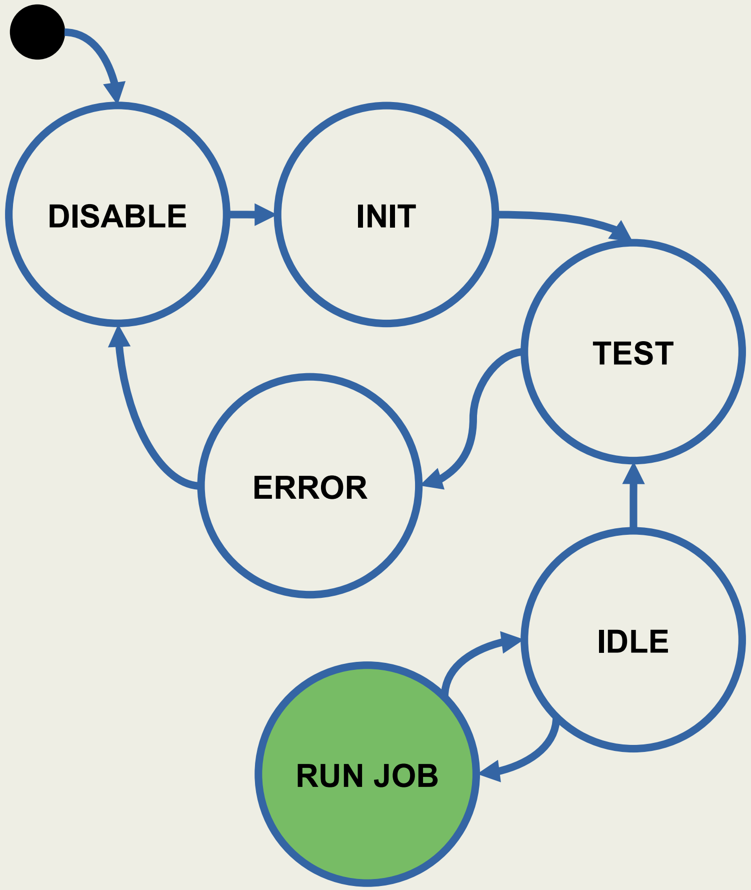

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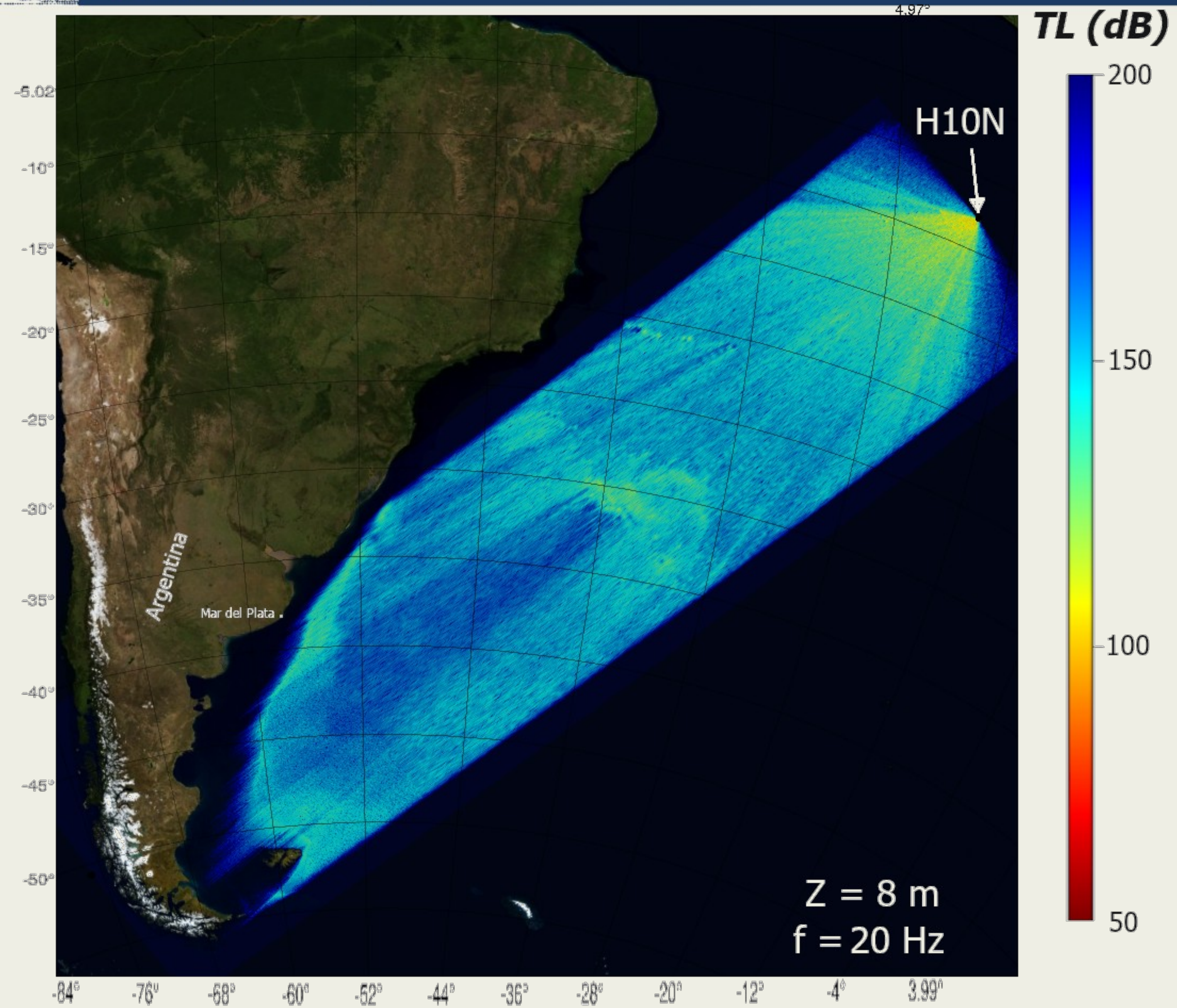
Conclusions

- A **new platform** for underwater noise measurement was developed for **shallow waters** on the Argentine continental shelf: application to **impulsive sound monitoring**
- Potential relevance for **basin-scale propagation analysis** using impulsive signals detected by the **IMS hydroacoustic network**.
- The **low-cost prototype buoy** for coastal **acoustic monitoring** is in its final integration stage, designed for robustness with a static mooring system.
- Proposed deployment sites (MDQ and CRD) were selected to **enhance detection** in previously **uncovered regions.**
- This platform paves the way for a **scalable coastal monitoring system** supporting baseline studies of shallow water **soundscapes** and long-range propagation analysis.
- **Coverage analysis improvement** through the **3D Split-Step Fourier Method** is currently under development; further details are available in **e-poster P1.3-766**.


TL (dB)
200
150
100
50
H10N
Argentina
Mar del Plata
Z = 8 m
f = 20 Hz
-5.02°
-10°
-15°
-20°
-25°
-30°
-35°
-40°
-45°
-50°
-84°
-76°
-68°
-60°
-52°
-44°
-36°
-28°
-20°
-12°
-4°
3.99°

Thank you!