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

Prario, I. Bos, P. Marques Rojo, R. Cinquini,M. Blanc, S.

Argentinian Navy Research Office & UNIDEF (CONICET)

Presentation Date: 11 September 2025

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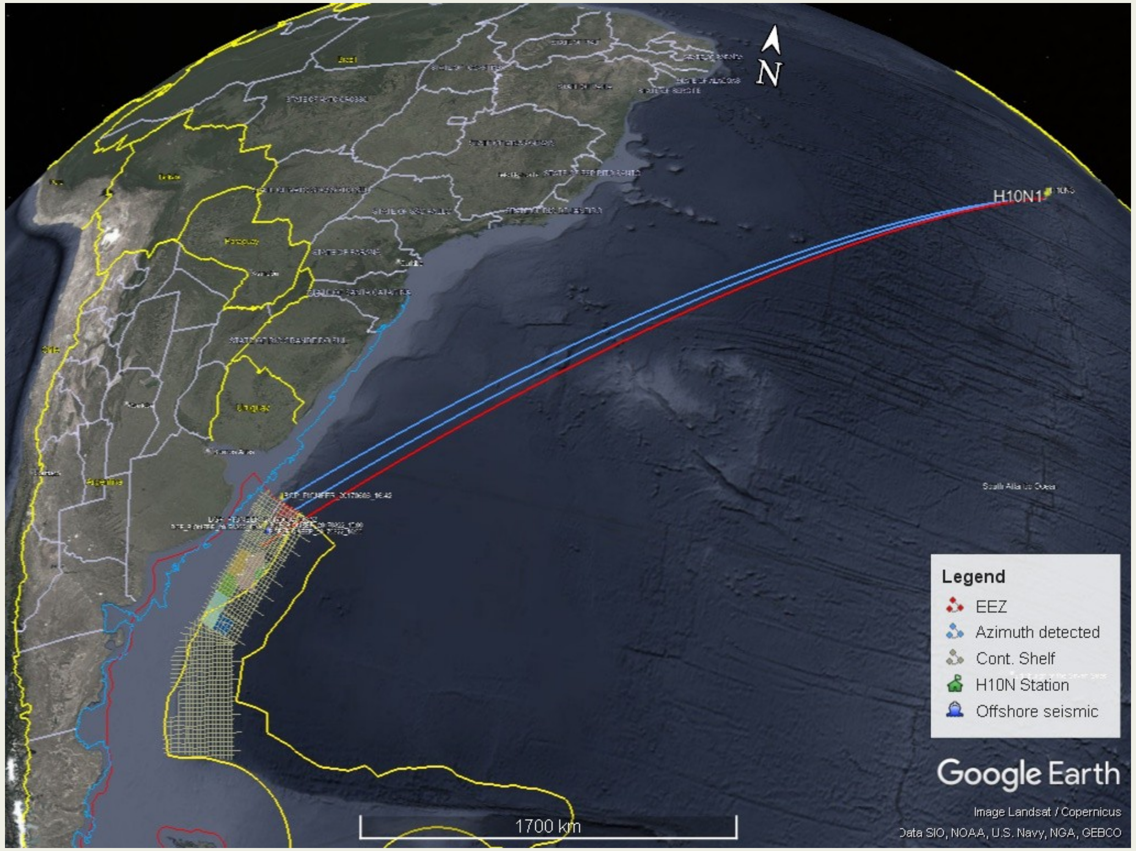
# Background

- Airgun array used in seismic surveys generate sound pulses (5–60 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.




[(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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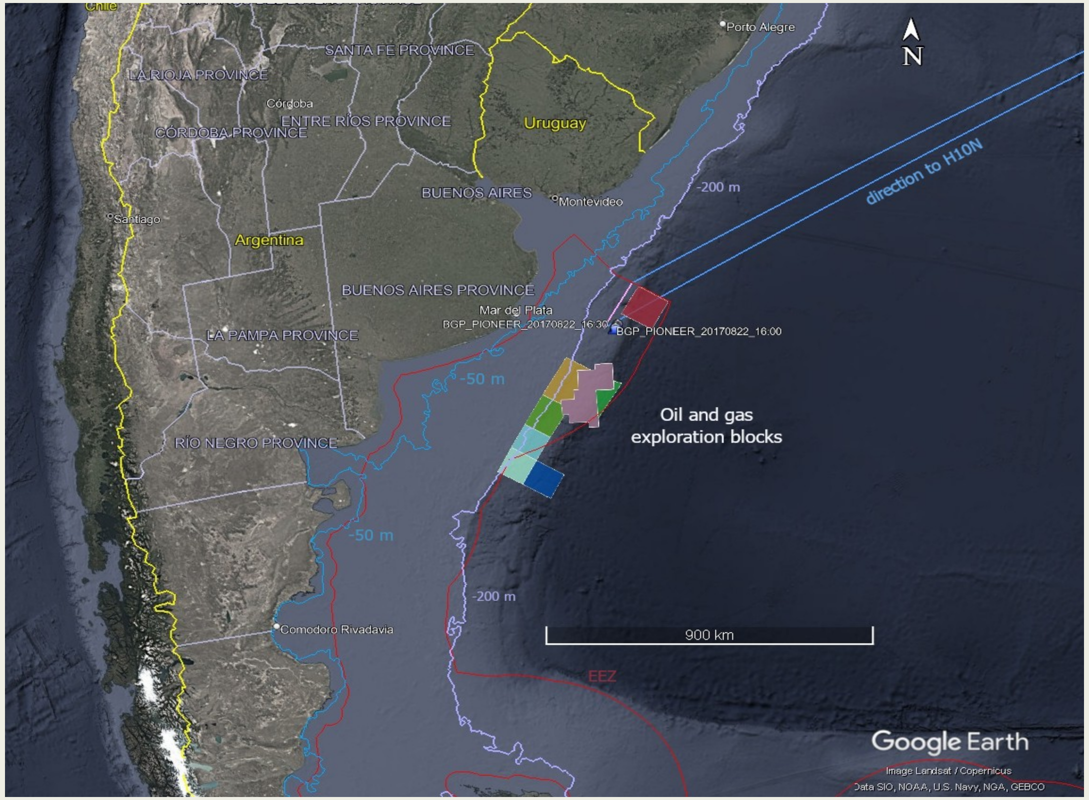
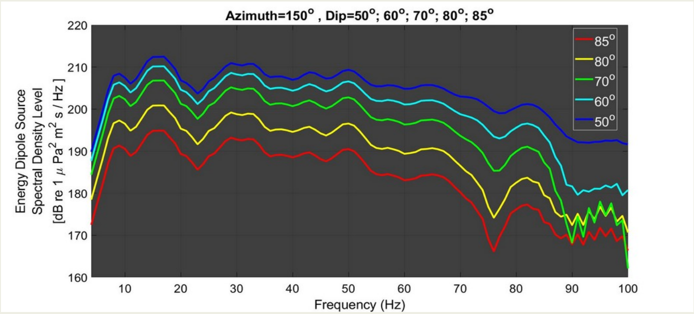
# Motivation




- Offshore Argentina: seismic surveys are conducted in oil & gas exploration blocks.
- Large dataset of high-amplitude impulsive signals → basin-scale range propagation analysis.
- Airgun array source levels simulated with an open-source airgun modelling software(2); source energy concentrated in 5–70 Hz band (HA10 direction); SL~ 210-190 dB re 1uPa$^2$m$^2$s.
- Need for local measurement sites on the Continental Shelf (airgun shots signals & other underwater noise sources).

(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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# Acoustic coverage in Argentinian Continental Shelf

- **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: 2–100 Hz.
  - Transmission Loss (TL) computed along Nx2D radial transects from H10N.
  - Source depth = 8 m (typical for airgun array).
- **Coverage criterion:** TL < 200 dB; NL ~ 80 dB re 1uPa$^2$ .
- **Goal:** identify candidate shallow-water sites (<200 m depth) for improved local monitoring.

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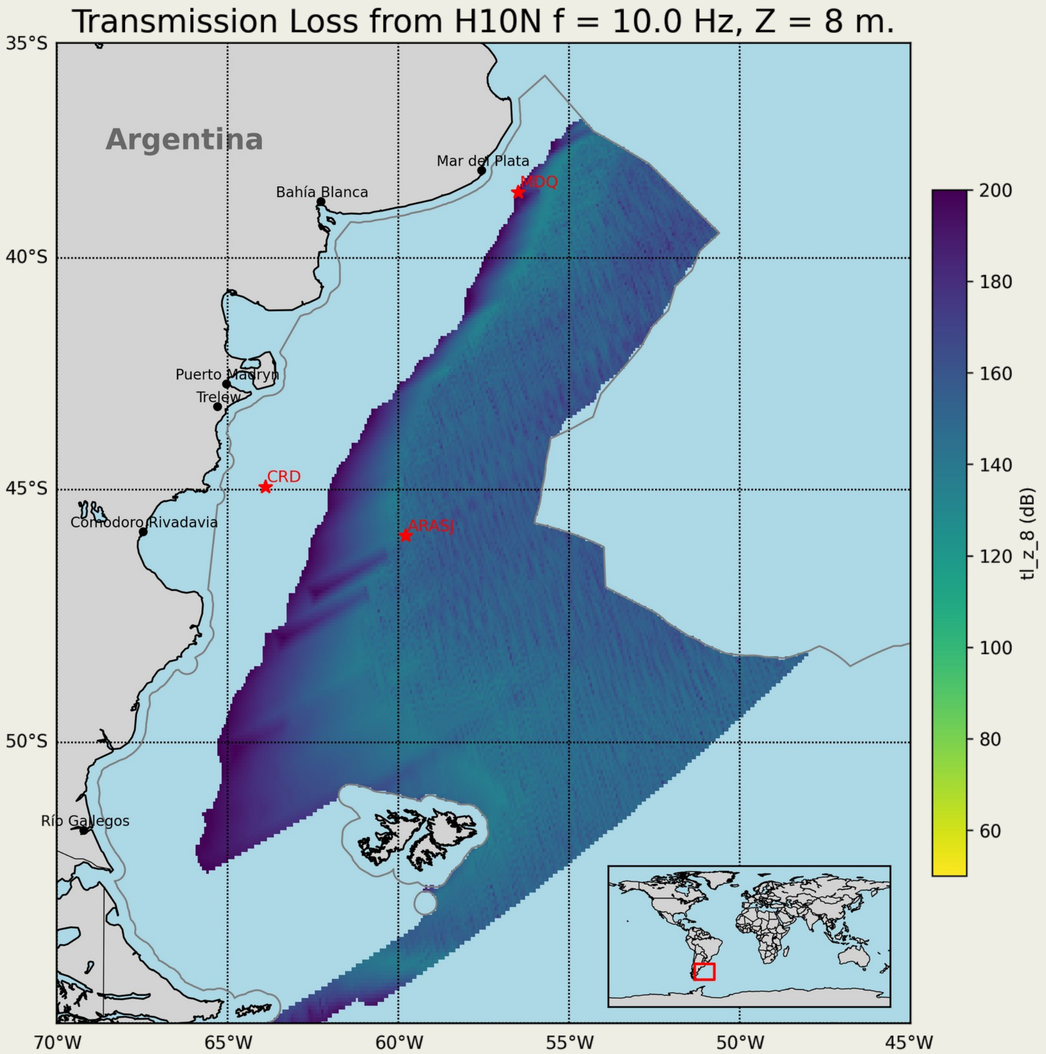
# Offshore Argentina coverage of Ascention station H10N




- Strong frequency dependence:
  - Low frequencies (<10 Hz): coastal shadow zones, TL > 200 dB.
  - Higher frequencies (10–80 Hz): partial coverage, but limited in shallow waters.
- Argentine 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[3])
- Offshore candidate sites identified: 1-MDQ, 2-CRD

[3] 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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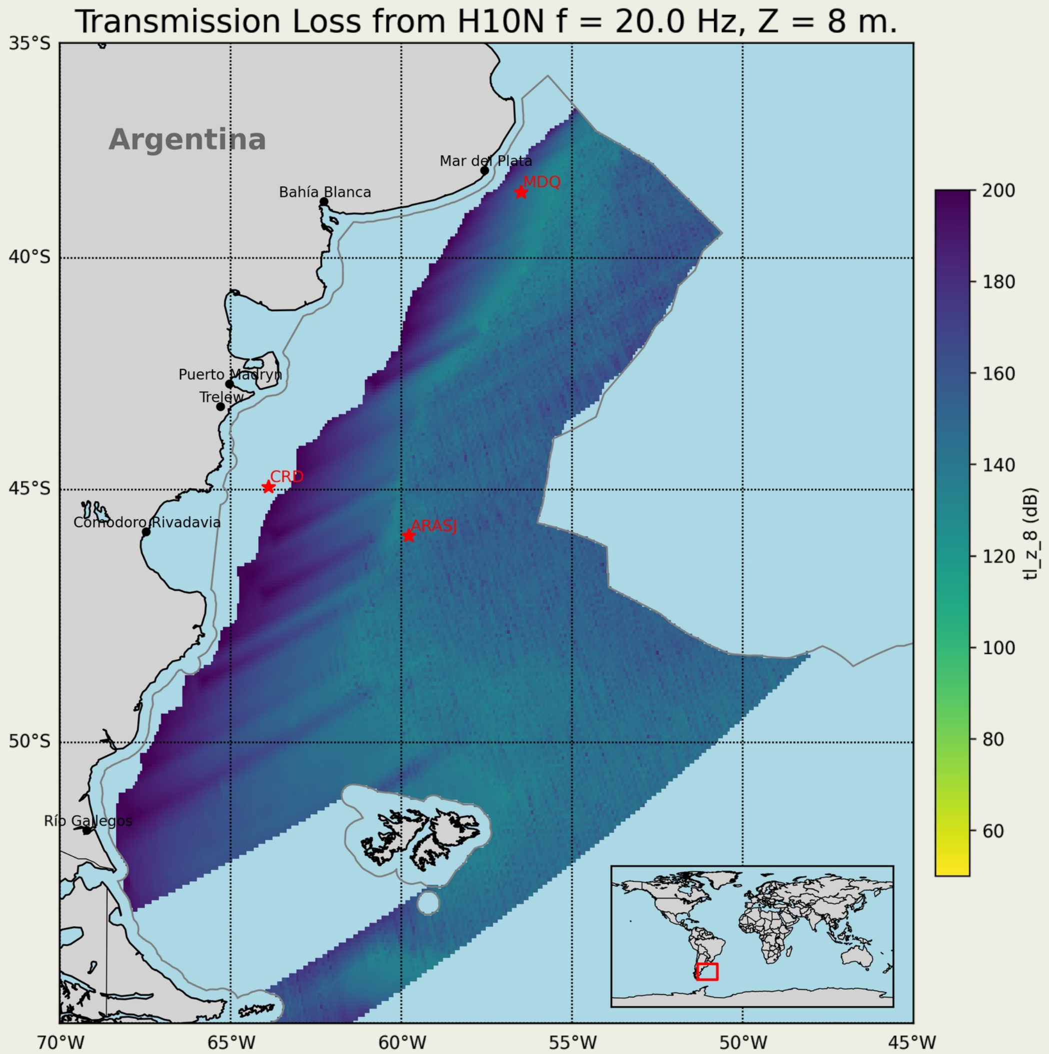


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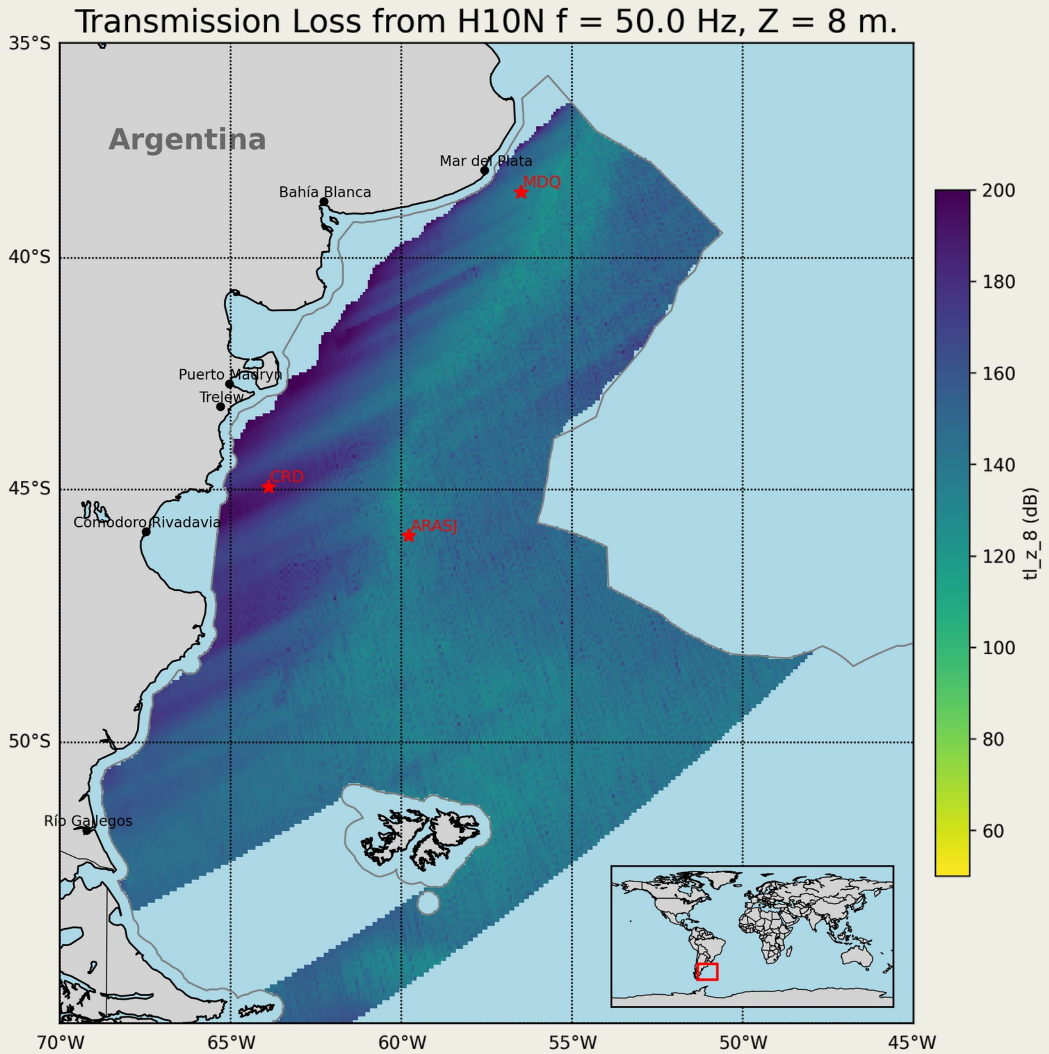


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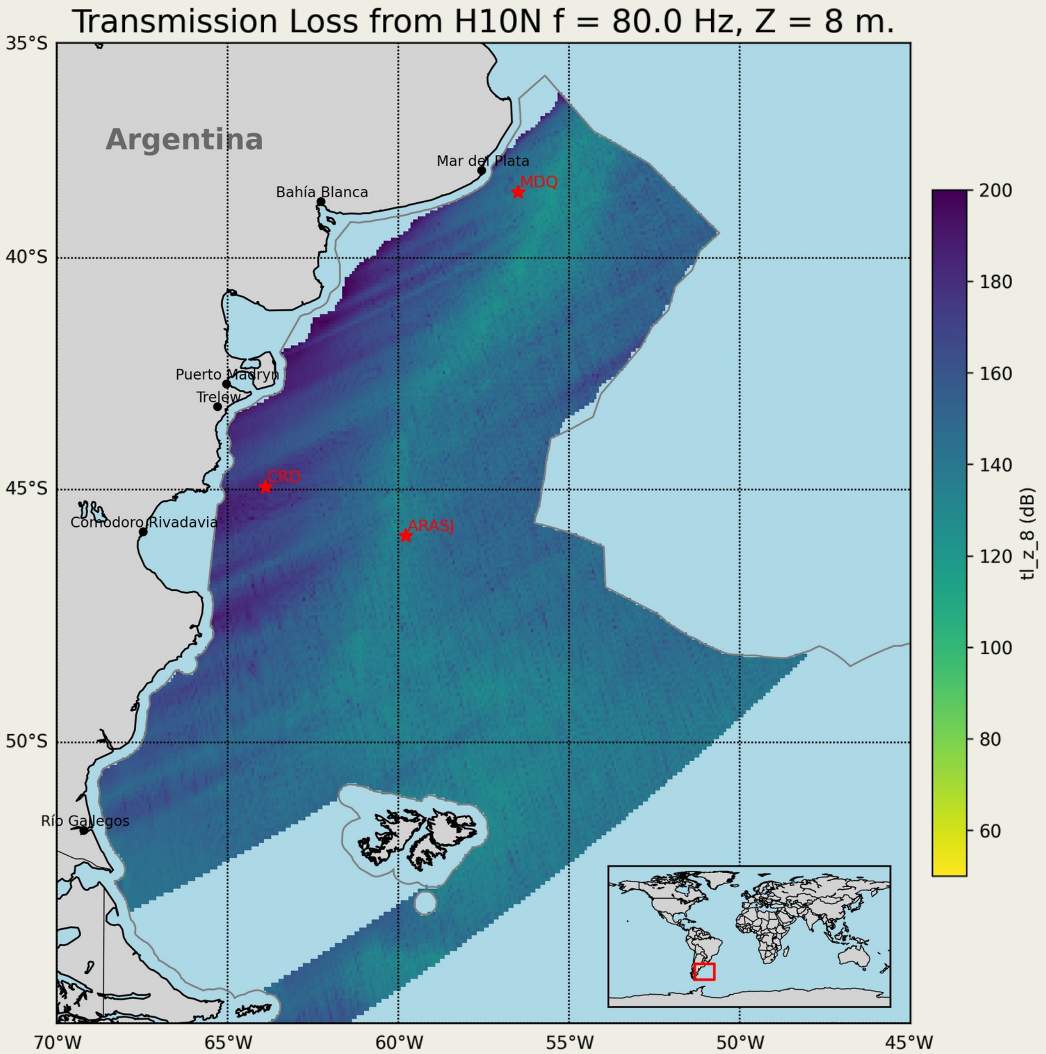


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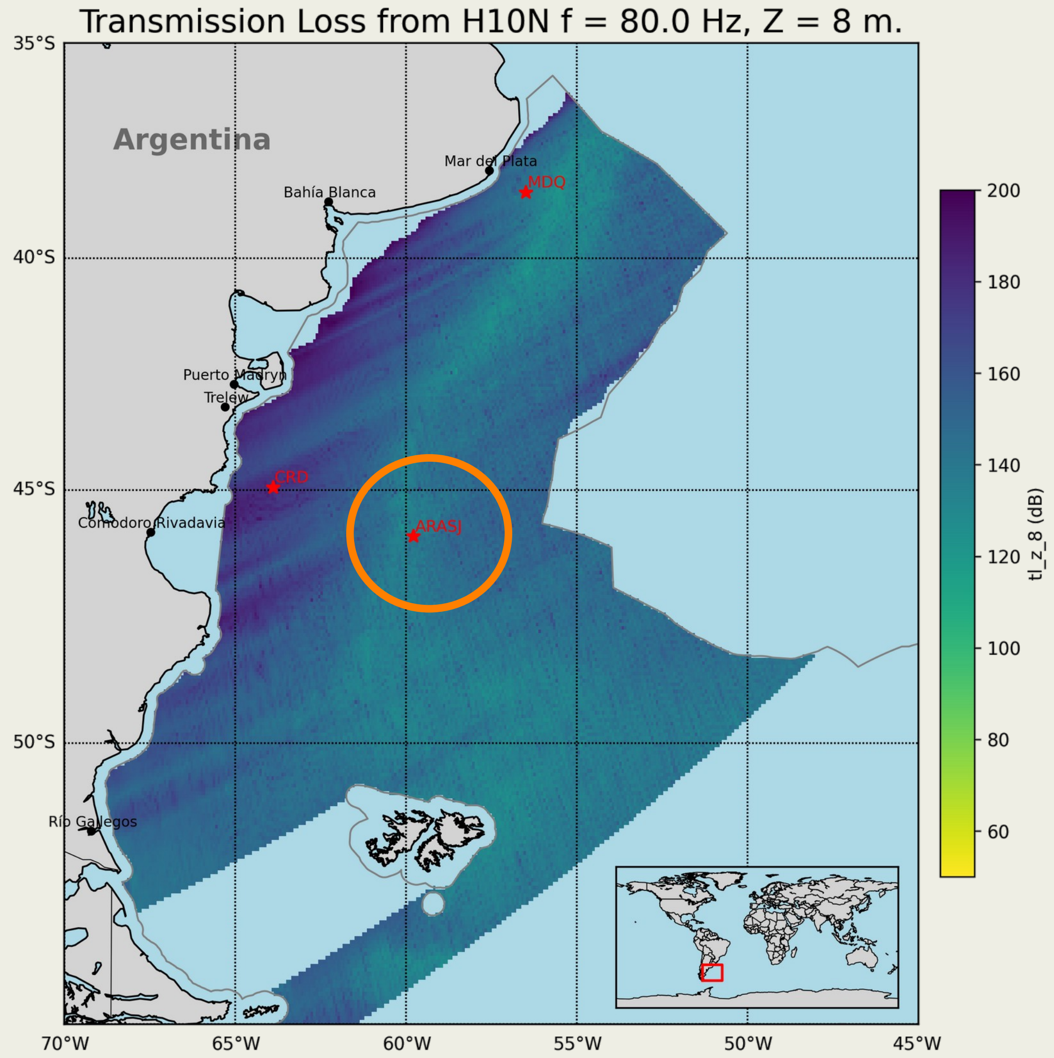


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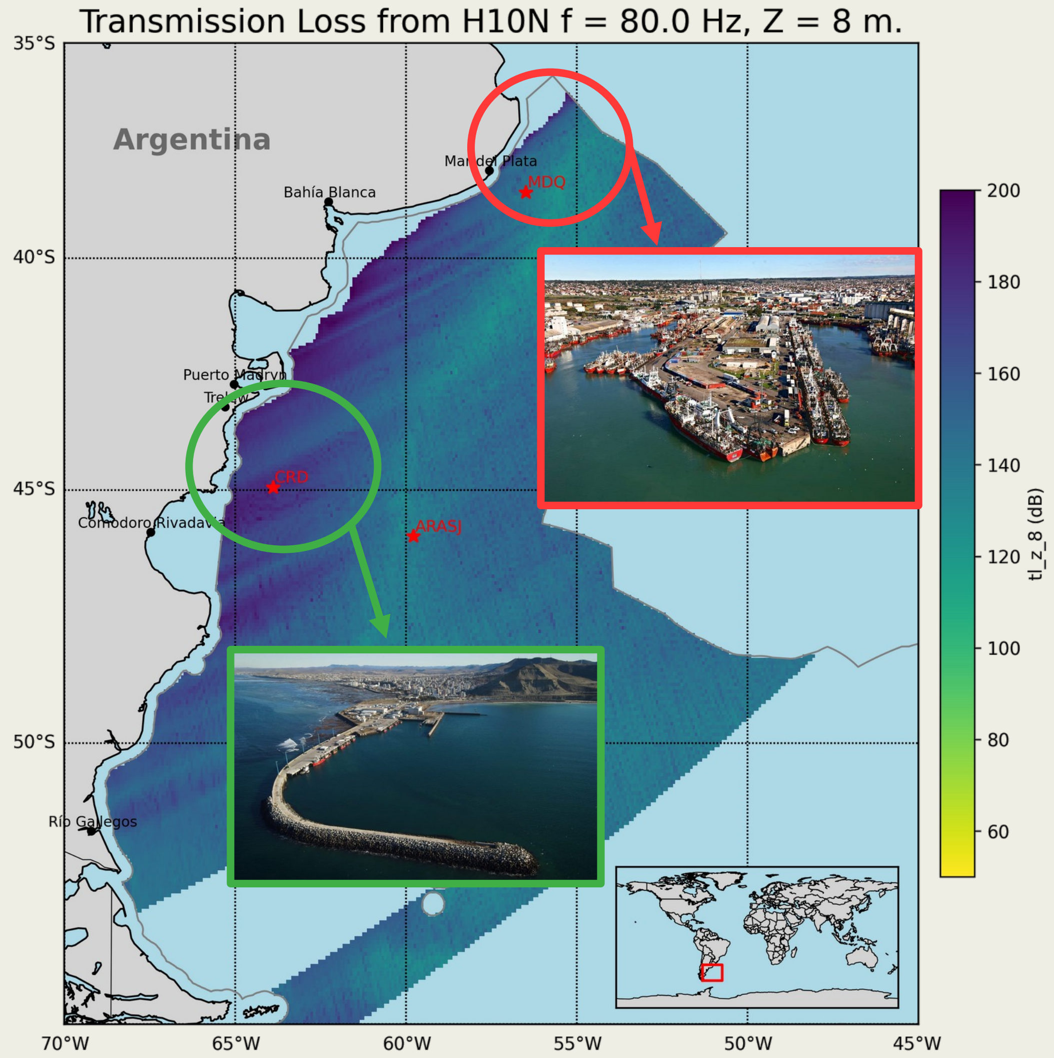


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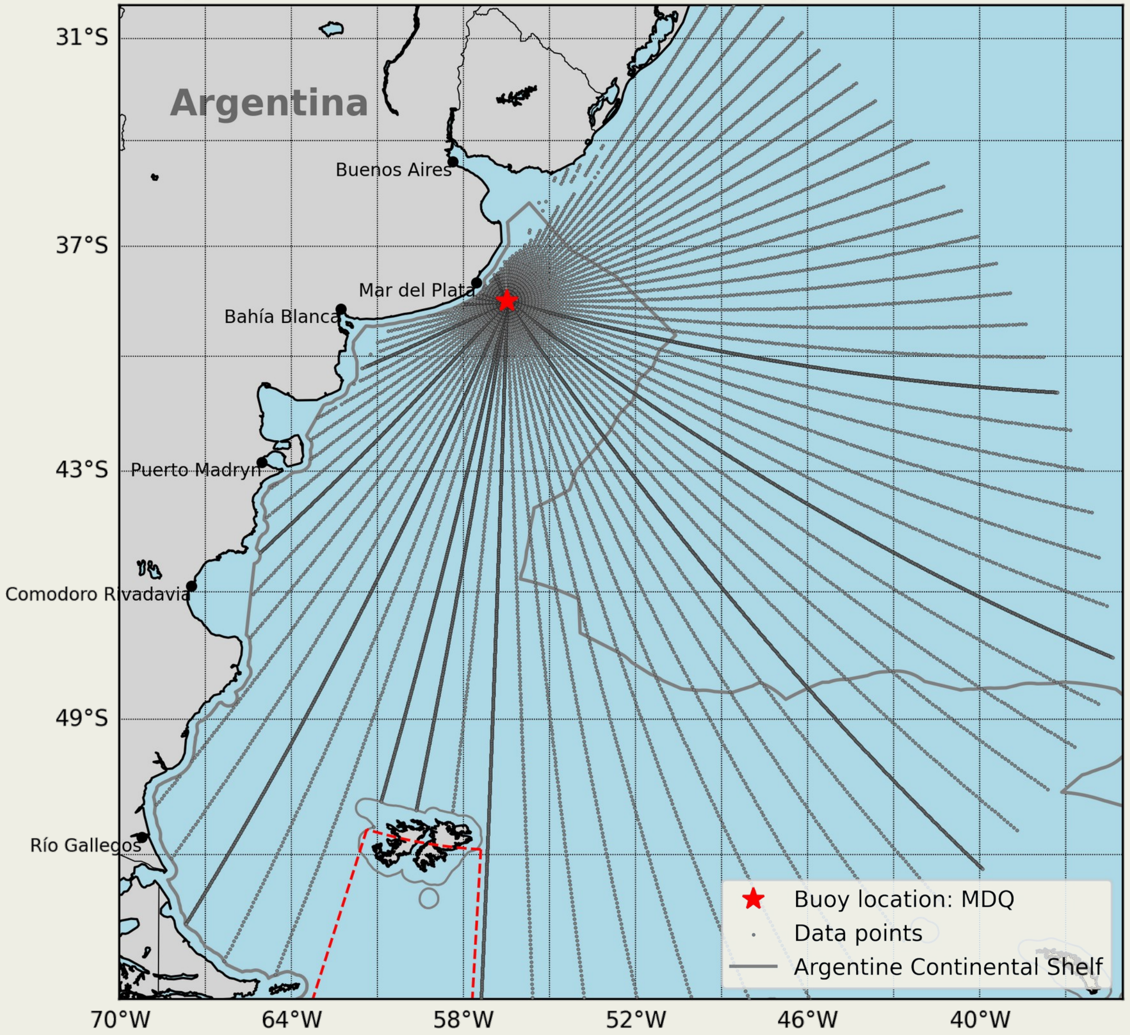
# Coverage of candidate 1 station (offshore Mar del Plata - MDQ)

- **Acoustic scenario:**
  - Frequency range: 2–100 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.
  - Seabead: sand? Width?
  - NL~80-85 dB re 1uPa$^2$
- **Simulation:**
  - 2D PE with RAM.jl.
  - Transmission Loss (TL) along Nx2D radial transects from the candidate hydrophone deployment station.
- **Objective:**
  - Assess acoustic coverage over the continental shelf and adjacent waters.

N geodesic radial lines from the buoy for TL modeling



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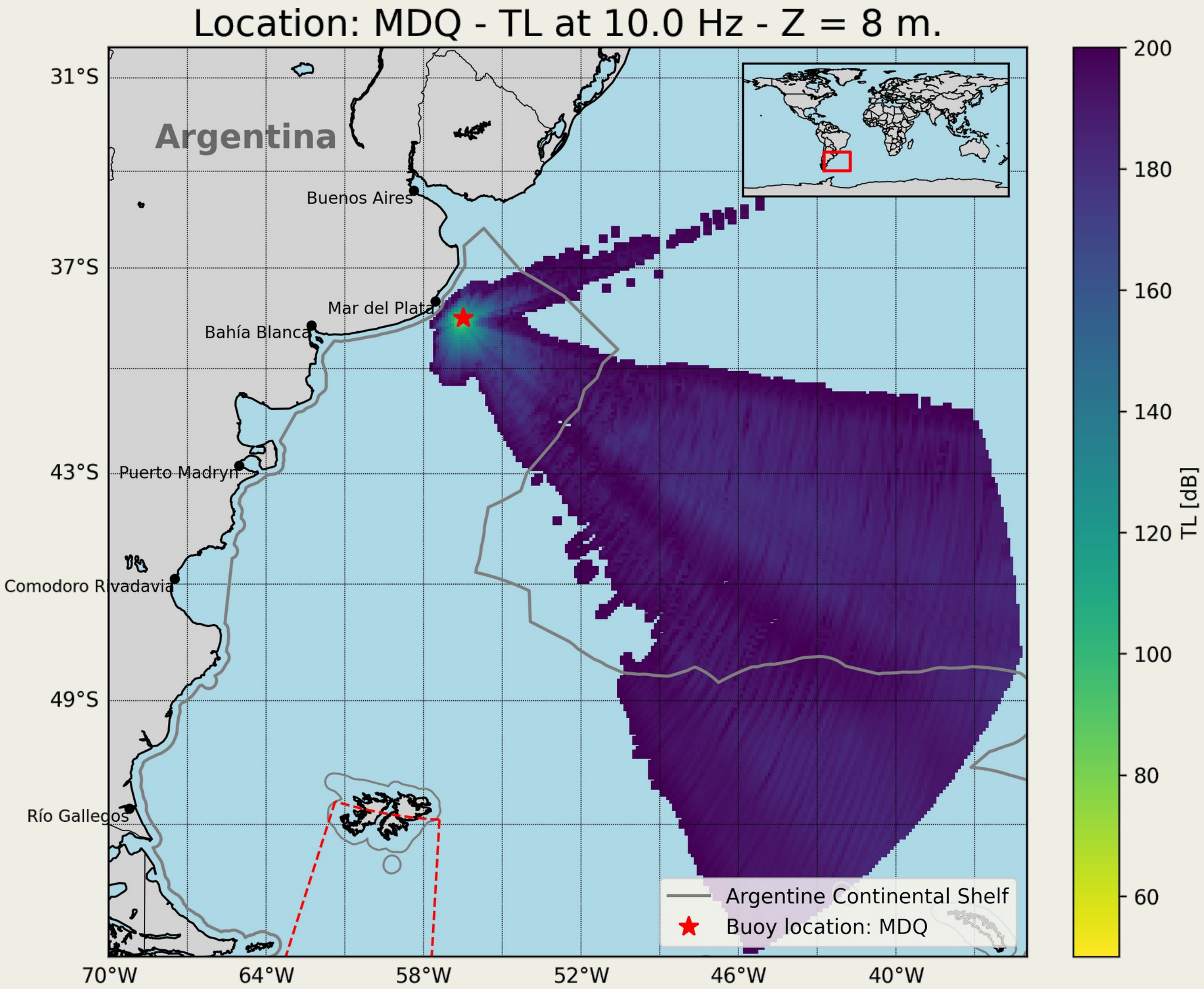


- Strong frequency dependence: lower frequencies (10 Hz) show larger shadow zones.
- Shelf filtering effect: continental slope reduces transmission at low frequencies (<20 Hz).
- Improved coverage at mid–high frequencies (50–80 Hz) across shelf and slope.
- Shallow-water gap: limited detectability close to the coast (<200 m depth).
- Implication: buoy at MDQ enhances monitoring in northern shelf region.

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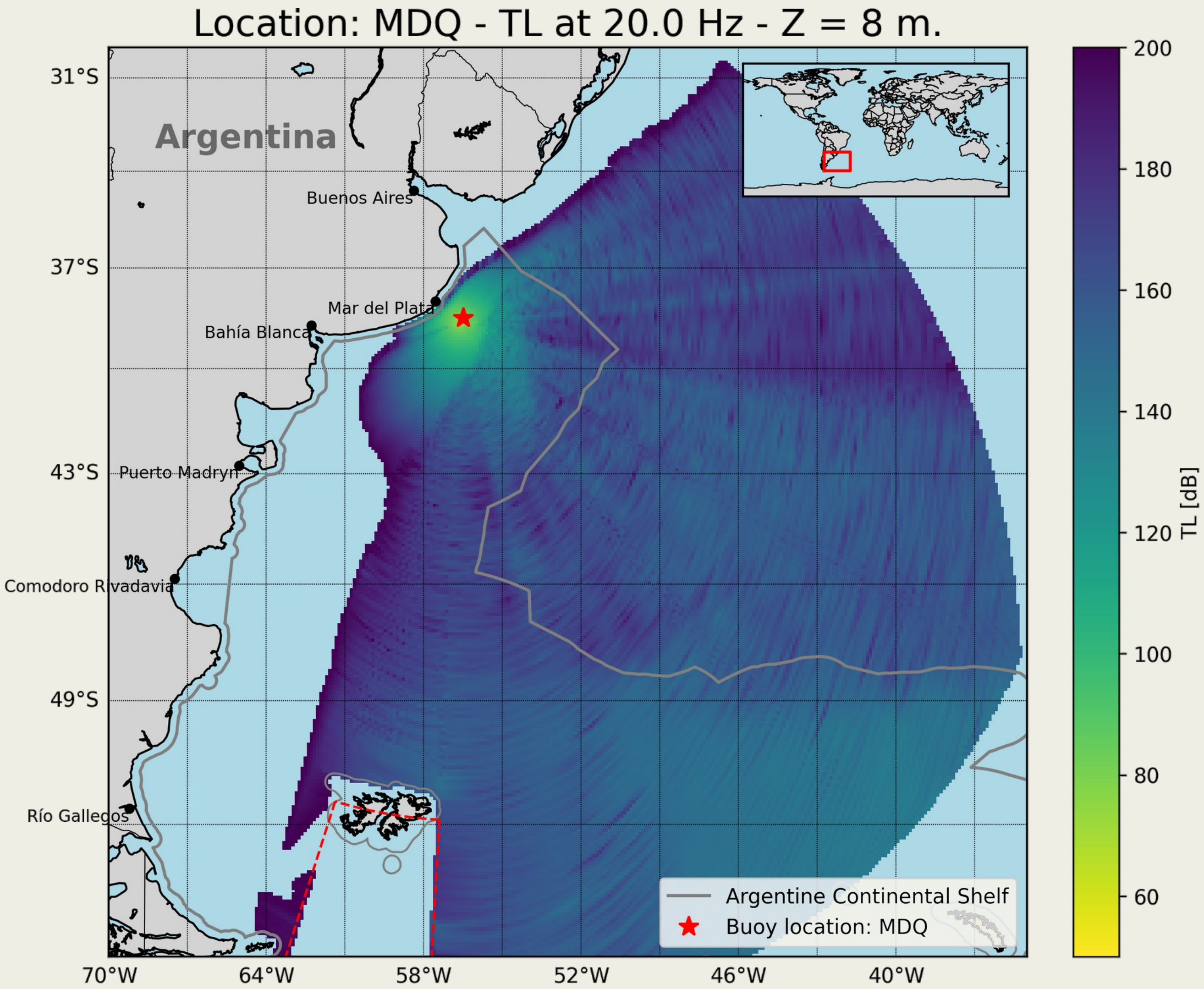


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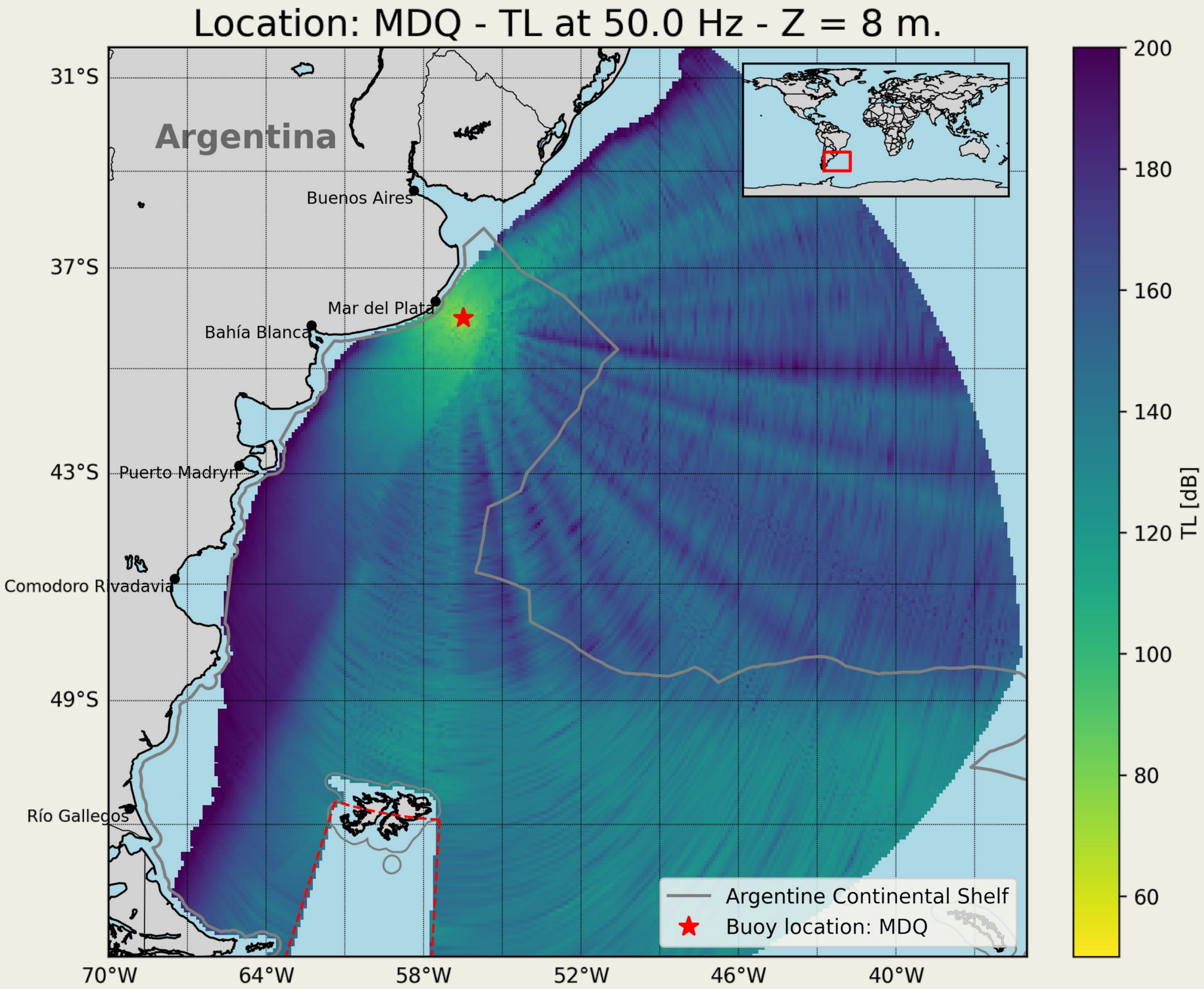


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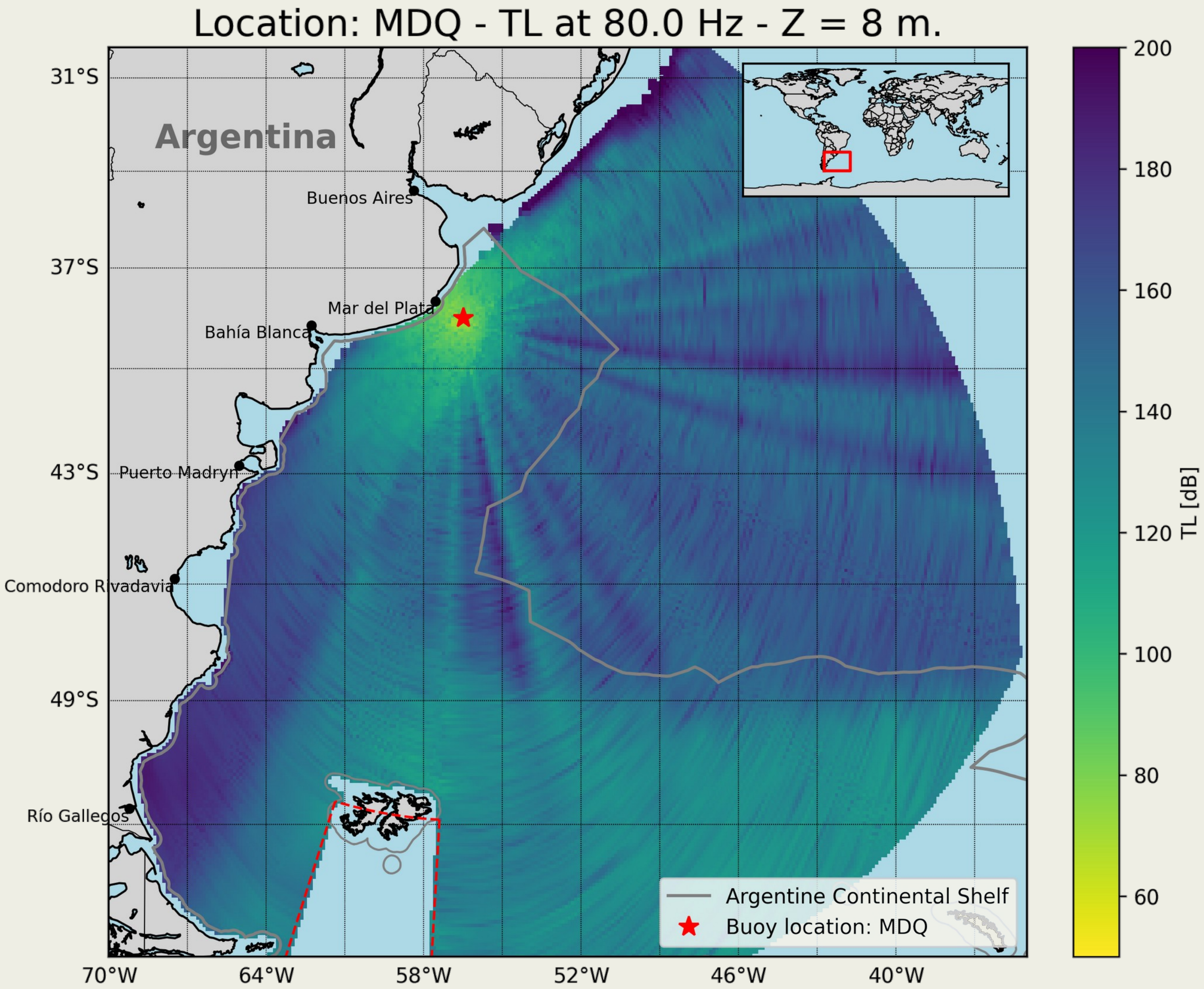


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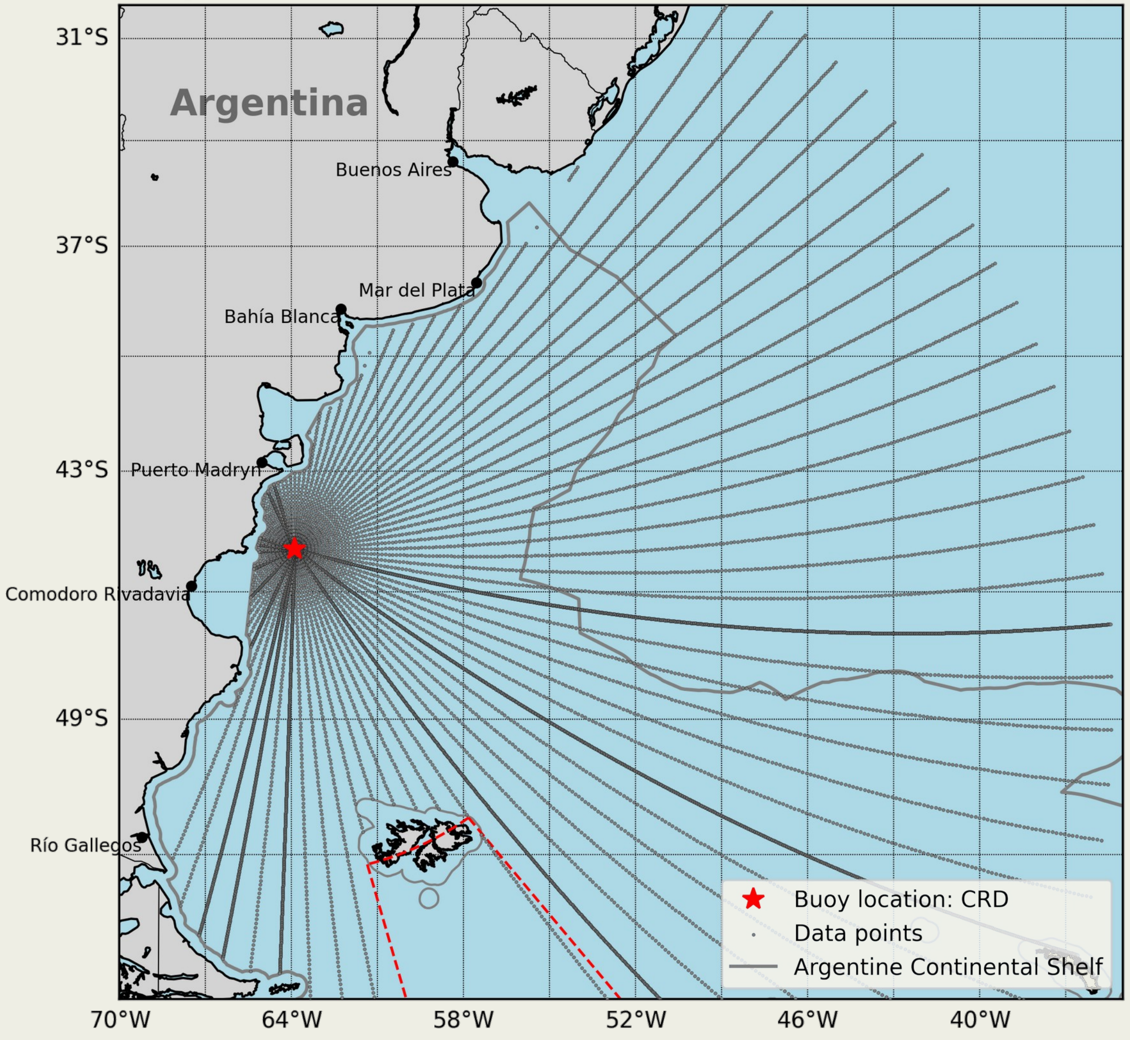
# Coverage of candidate 2 station (offshore Comodoro Rivadavia - CRD)

- **Model setup:**
  - Frequency range: 2–100 Hz (results shown at 10, 20, 50, 80 Hz).
  - Source depth = 8 m (typical airgun tow depth).
  - Receiver depth (hydrophone) = 40 m.
- **Environmental inputs:**
  - Oceanographic profiles from Copernicus.
  - Bathymetry from GEBCO database.
- **Simulation method:**
  - 2D RAM.
  - Transmission Loss (TL) along radial transects from the candidate buoy site in all directions.
- **Objective:**
  - Assess acoustic coverage over the continental shelf and adjacent waters.

N geodesic radial lines from the buoy for TL modeling



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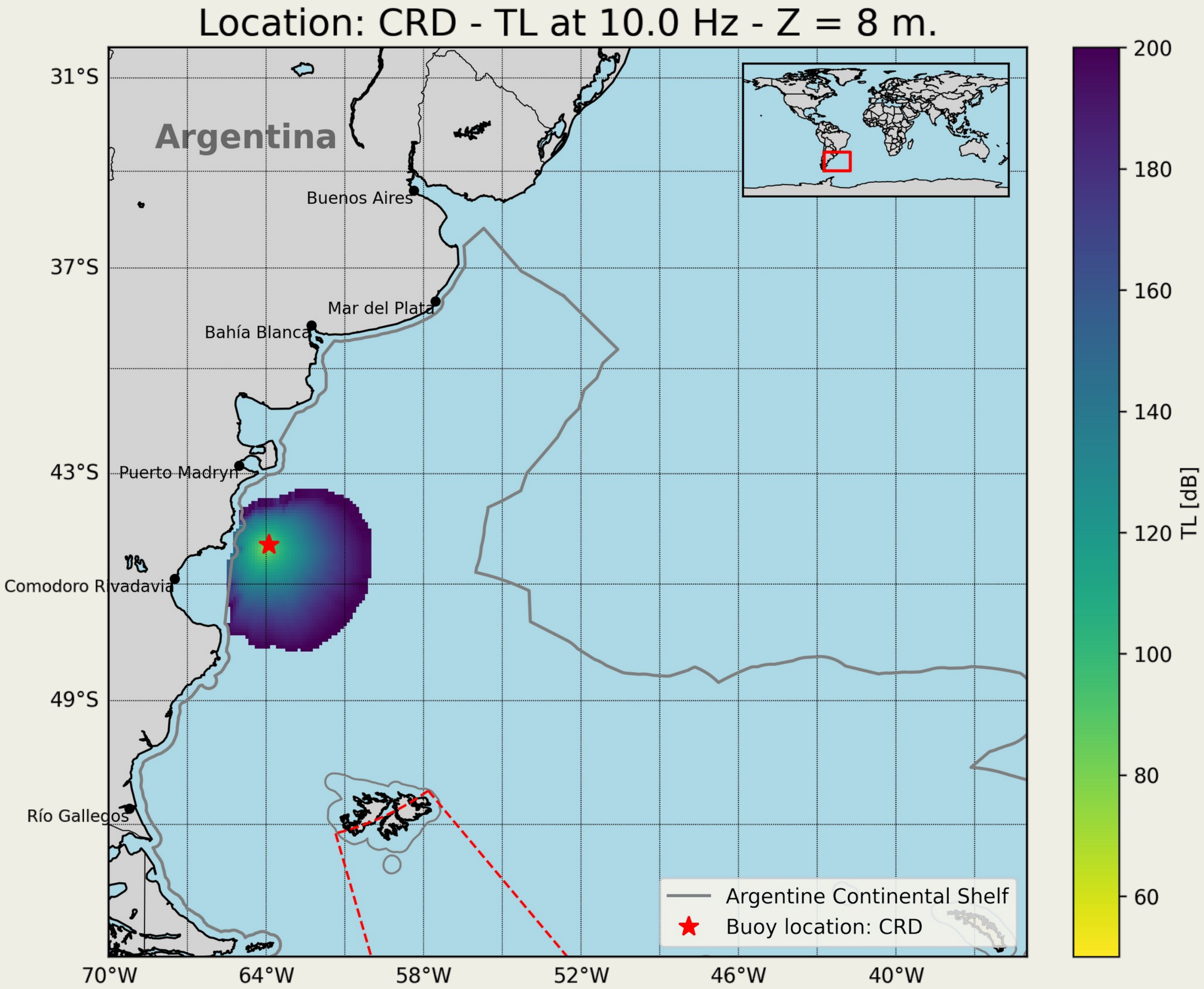


- Marked frequency variation: stronger attenuation at 10–20 Hz, better propagation at 50–80 Hz.
- Continental shelf slope creates coastal shadow zones at low frequencies.
- Broader mid-frequency coverage compared to MDQ, extending farther offshore.
- Shallow-water limitations remain near coastlines.
- Implication: buoy at CRD improves coverage in southern shelf and complements MDQ site.

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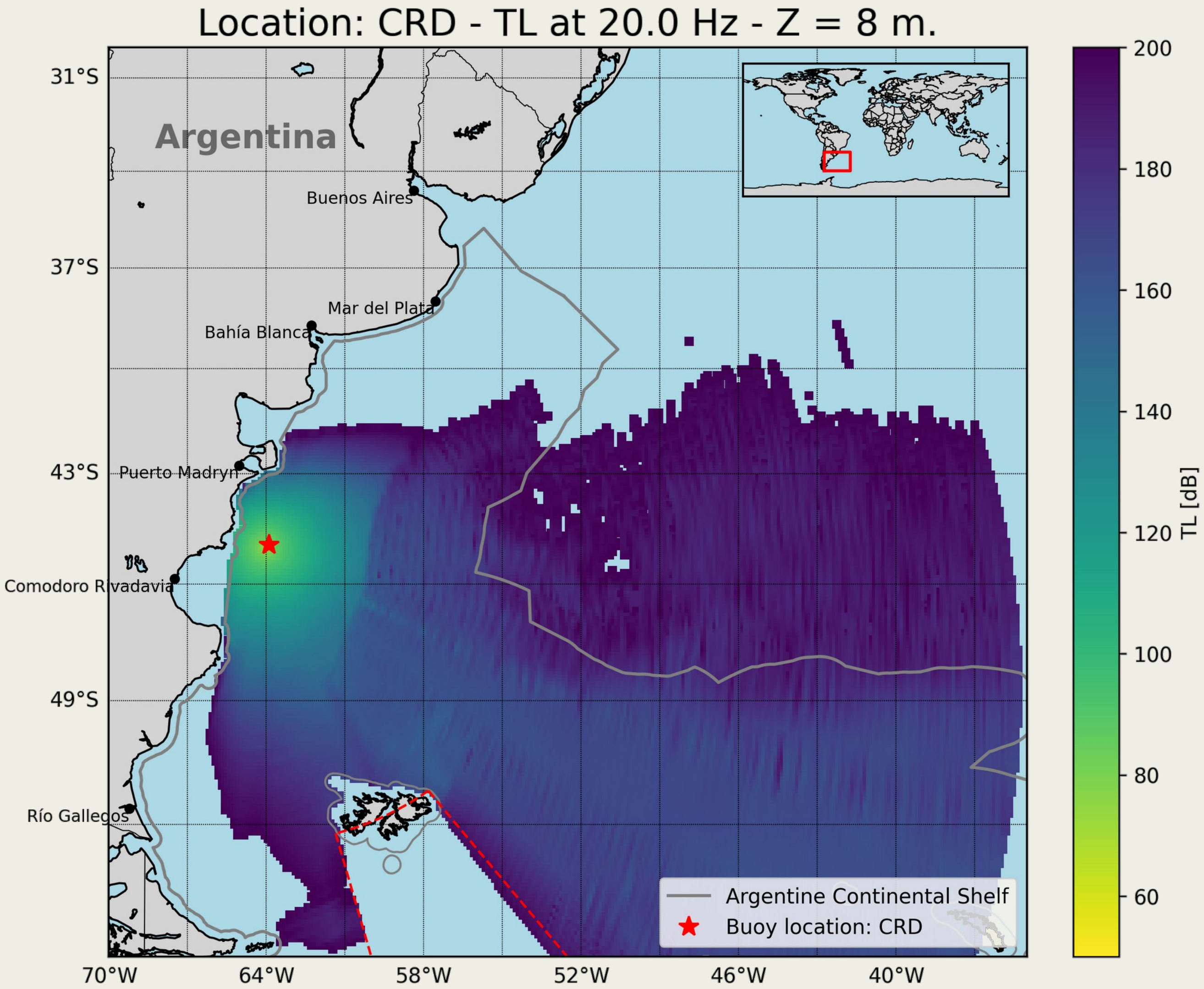


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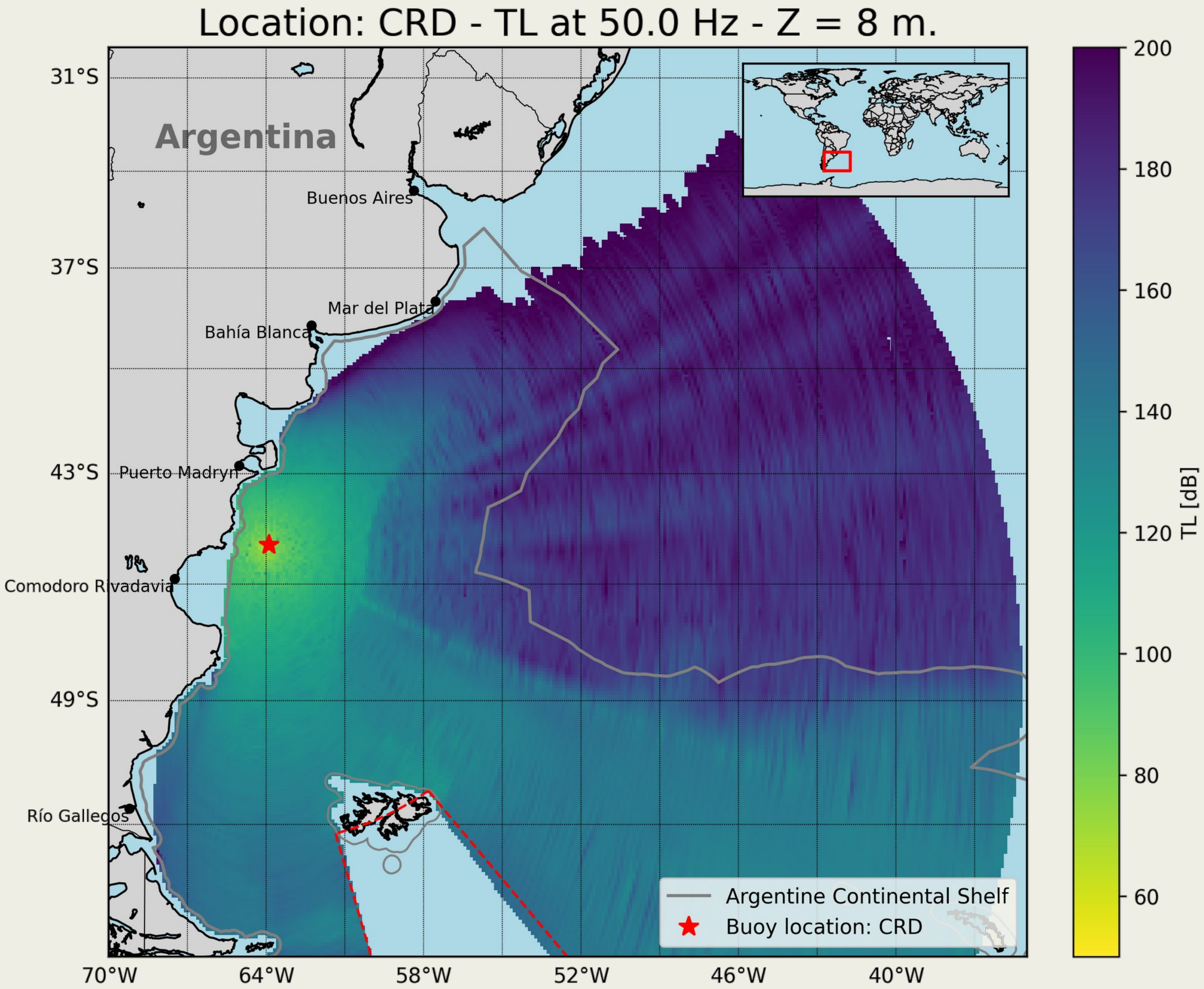


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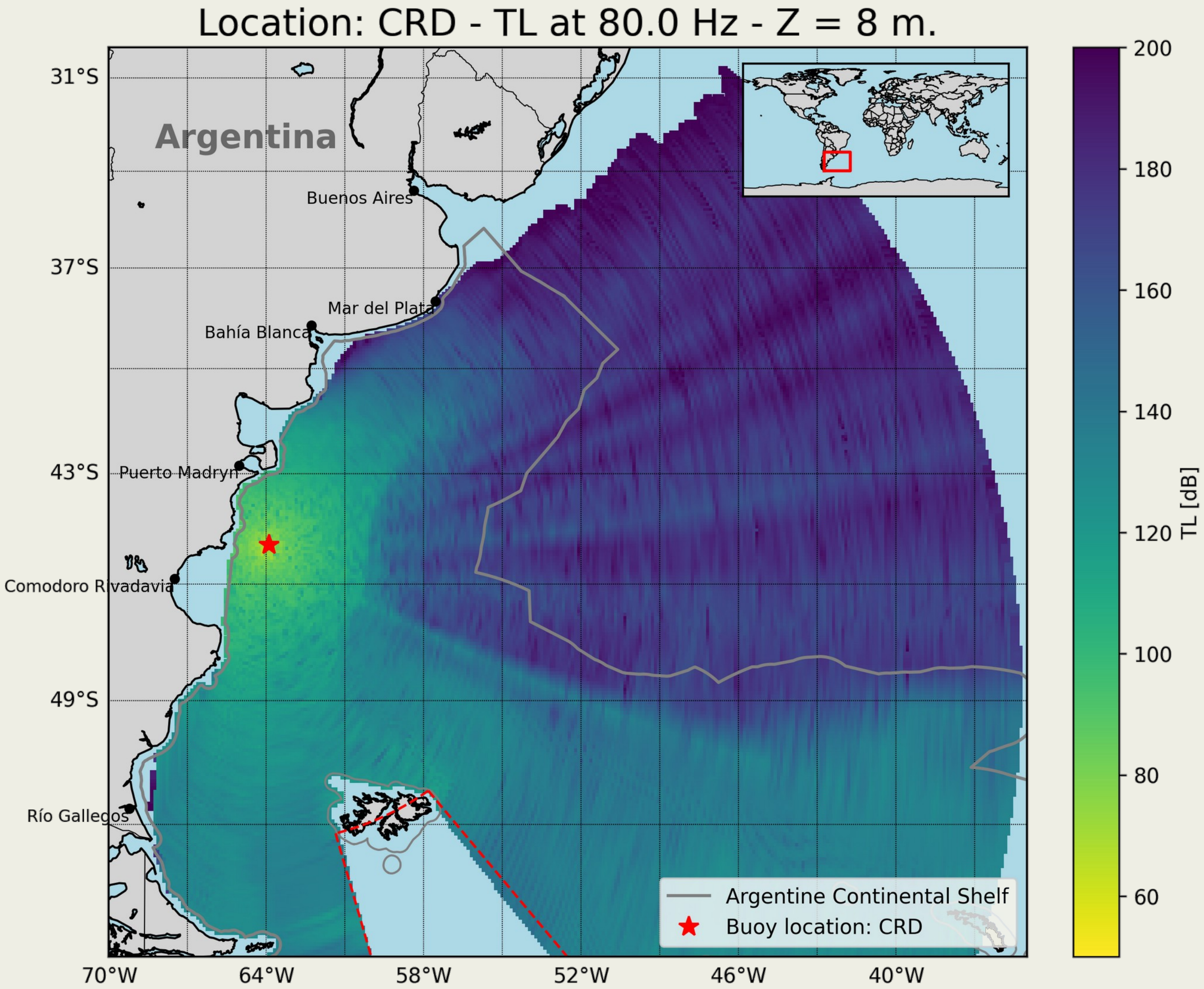


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# Experimental Buoy Platform for hydrophones deployment


This custom-designed buoy is a prototype platform developed for the deployment of hydroacoustic instrumentation in a coastal environment.

It features:

- A GRP (Glass-Reinforced Plastic) hull for corrosion resistance and lightweight performance.
- A solar power system to support autonomous operations.
- A sealed electronics compartment and a central mast for sensors, antennas, satellite transmission and GPS.
- Designed to withstand harsh marine conditions, including strong currents and waves up to 4 meters.

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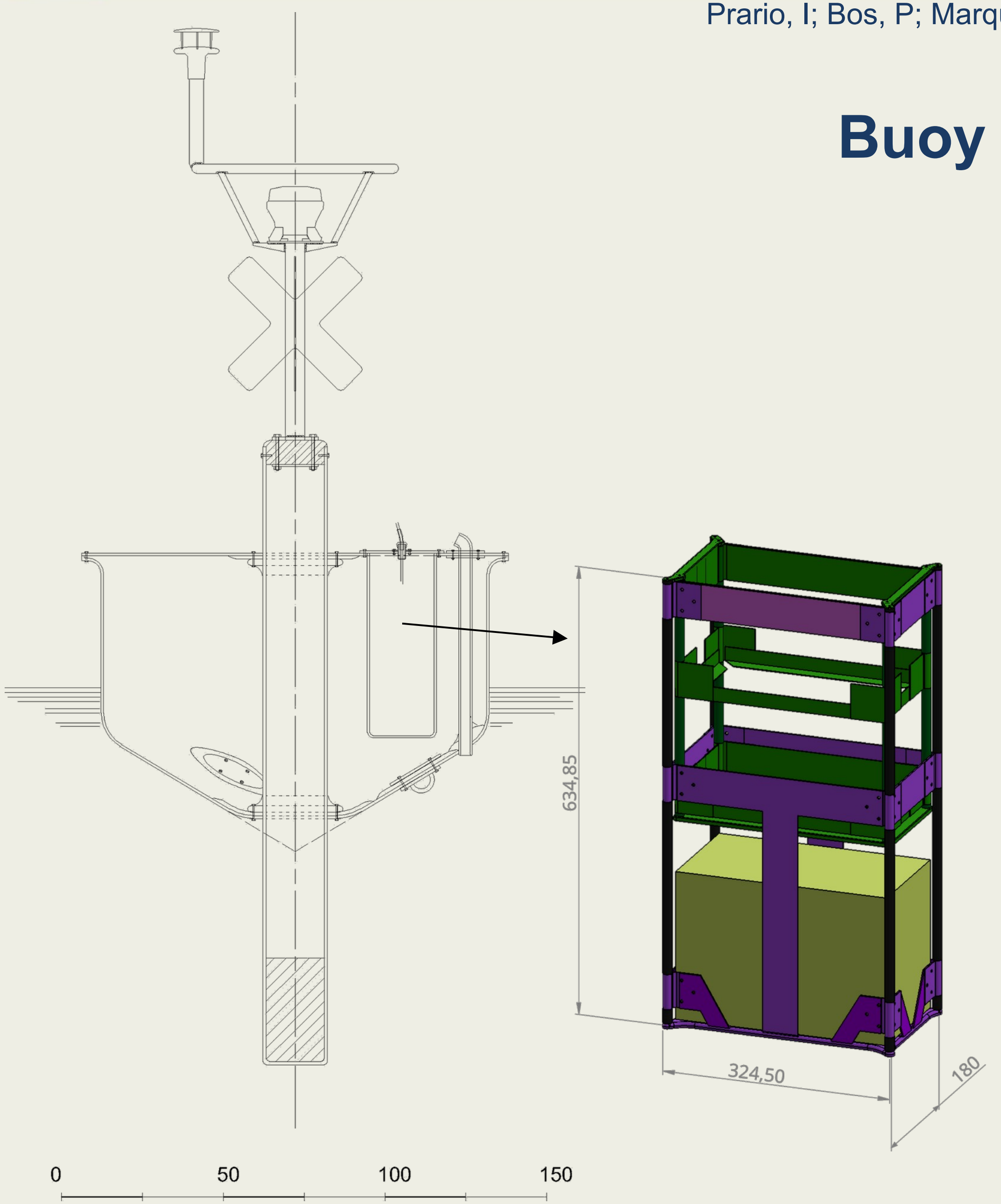
# Buoy Electronics Rack




Removable, lift-out aluminum rack houses:

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

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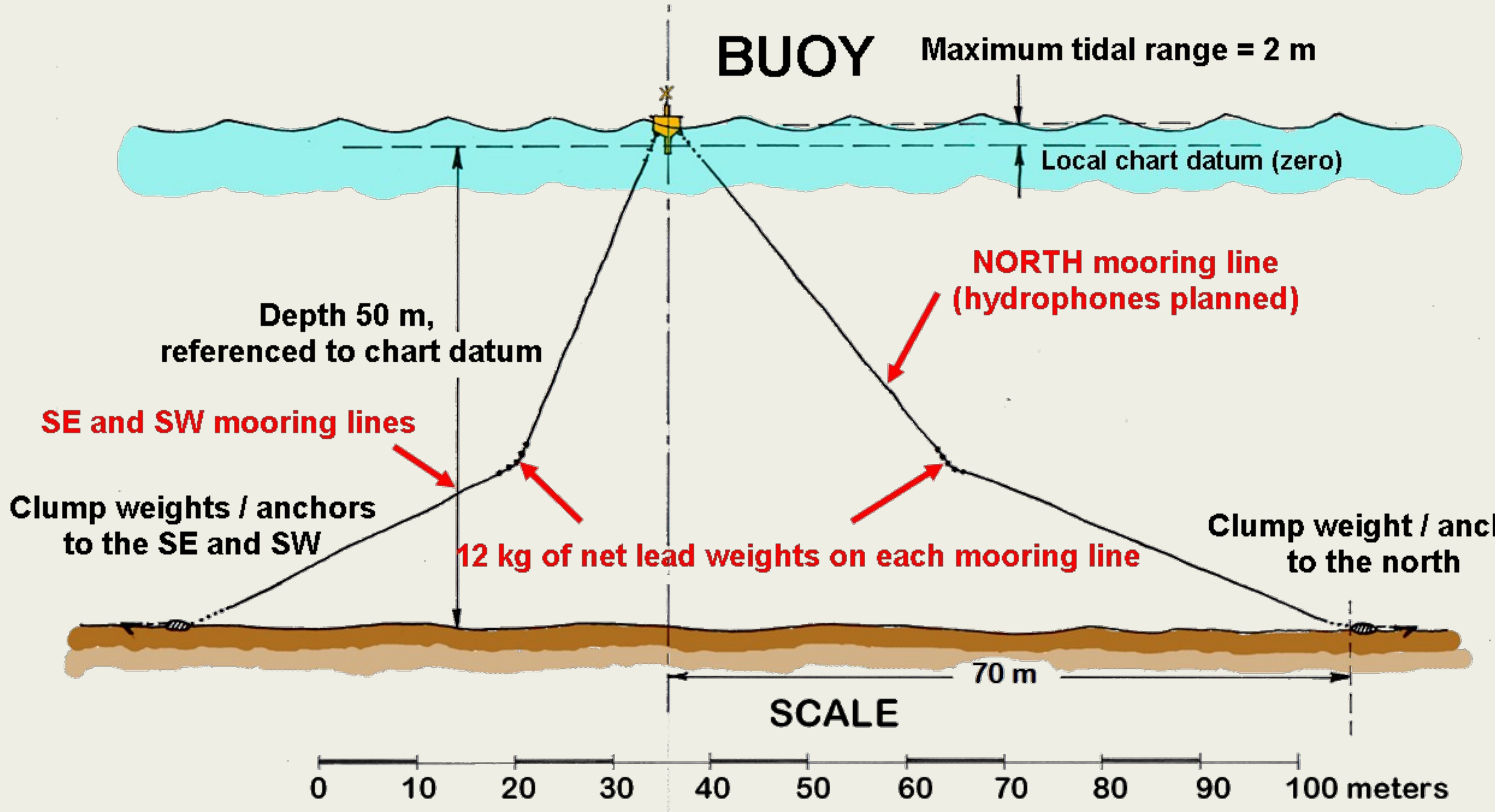
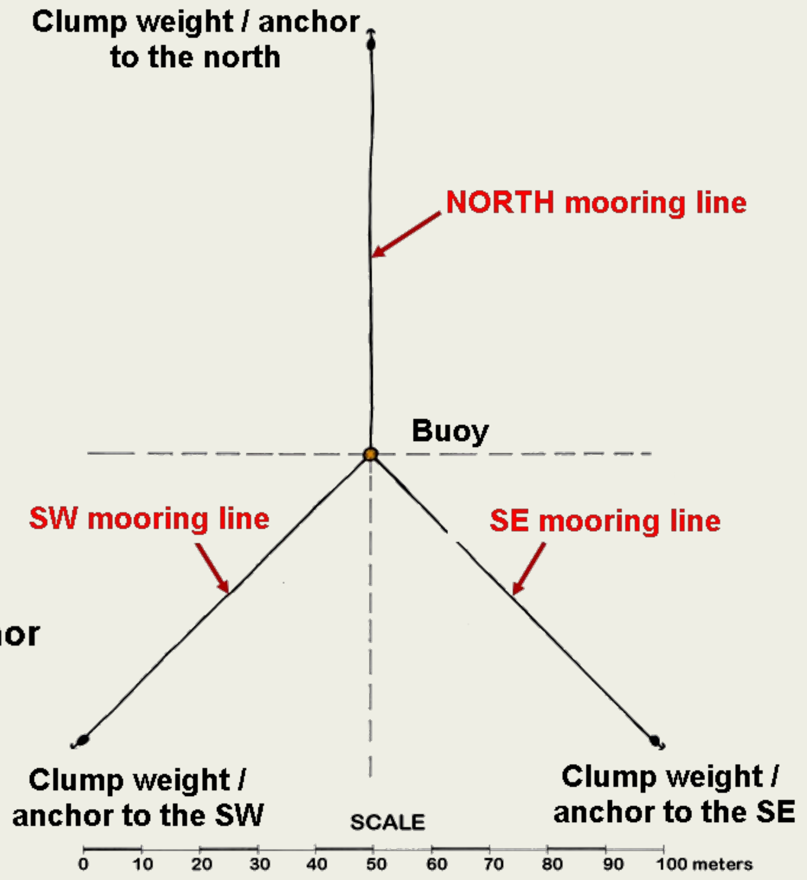
# SCHEMATIC OF THE BUOY MOORING SYSTEM WITH HYDROPHONES



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# Layered Architecture of the Embedded System

## 🔝 Orchestrator Layer

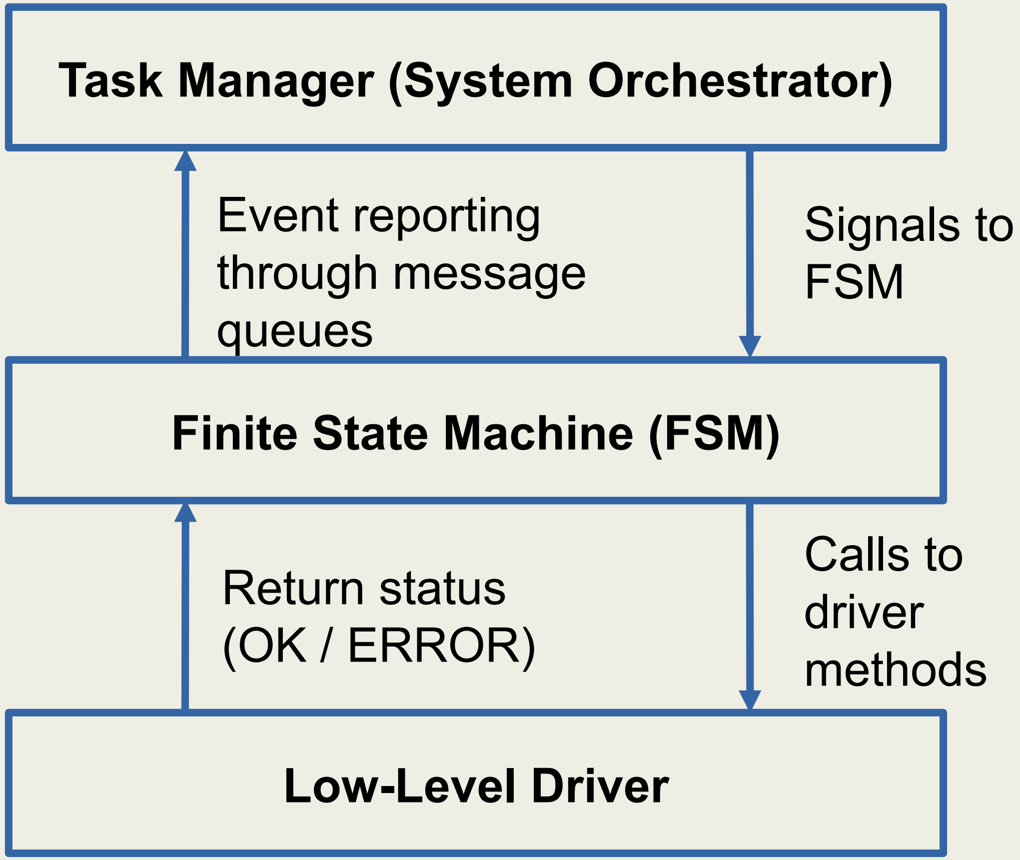
- Coordinates overall system flow.
- Decides which FSM to activate and when.
- Handles high-level internal and external events.

## 🔁 State Machine Layer (FSM)

- Manages module behaviour based on current state.
- Responds 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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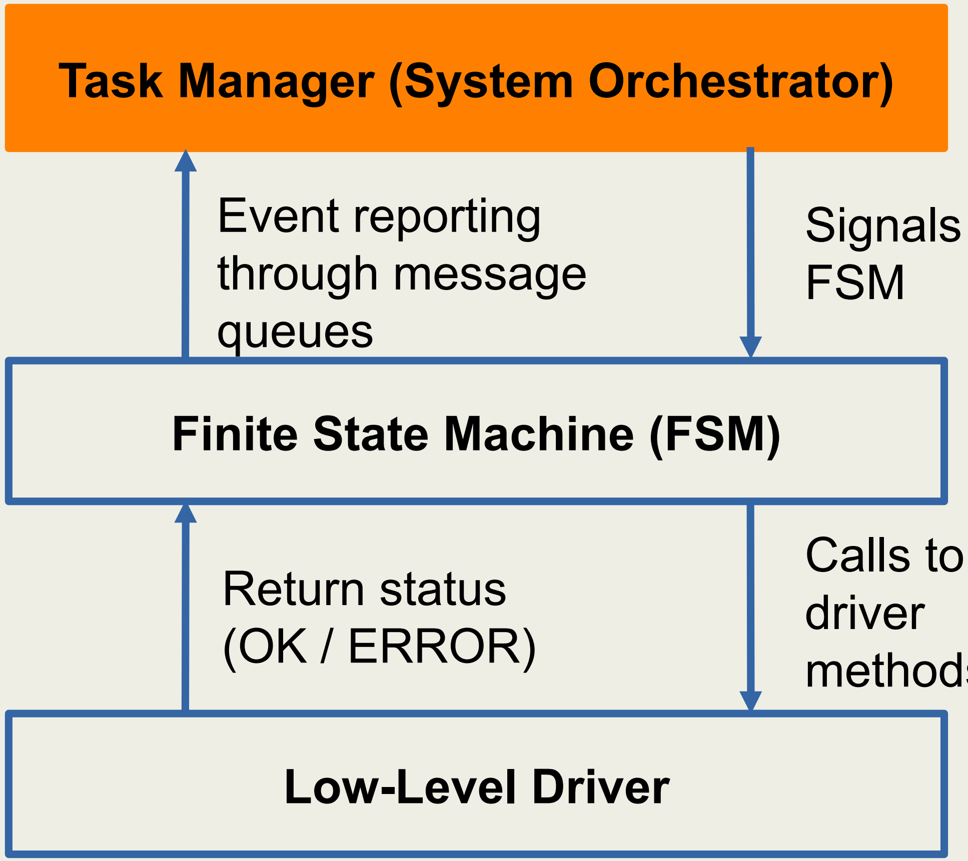

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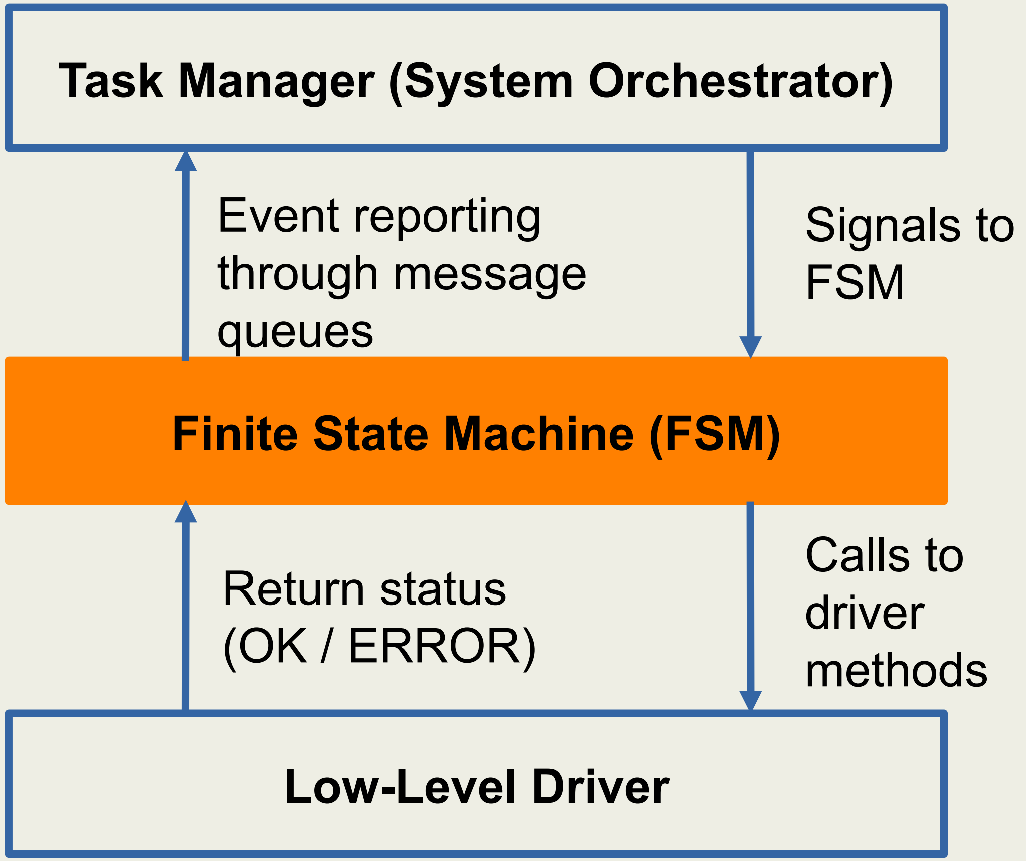

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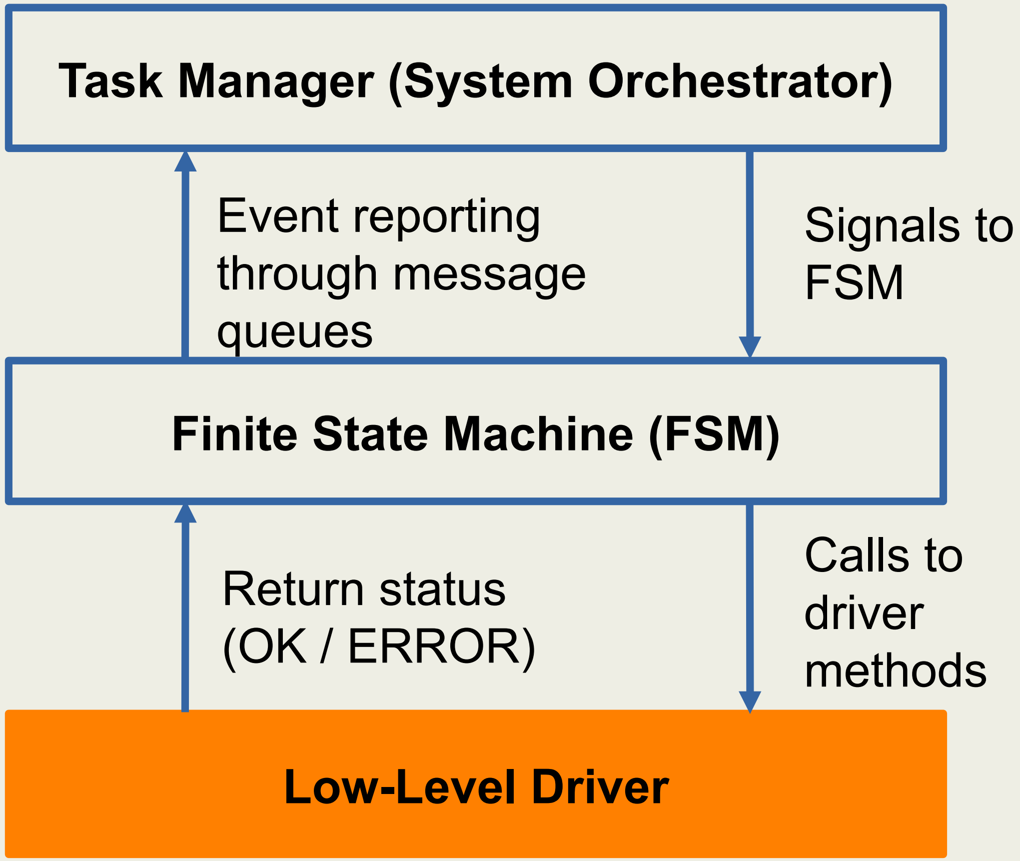

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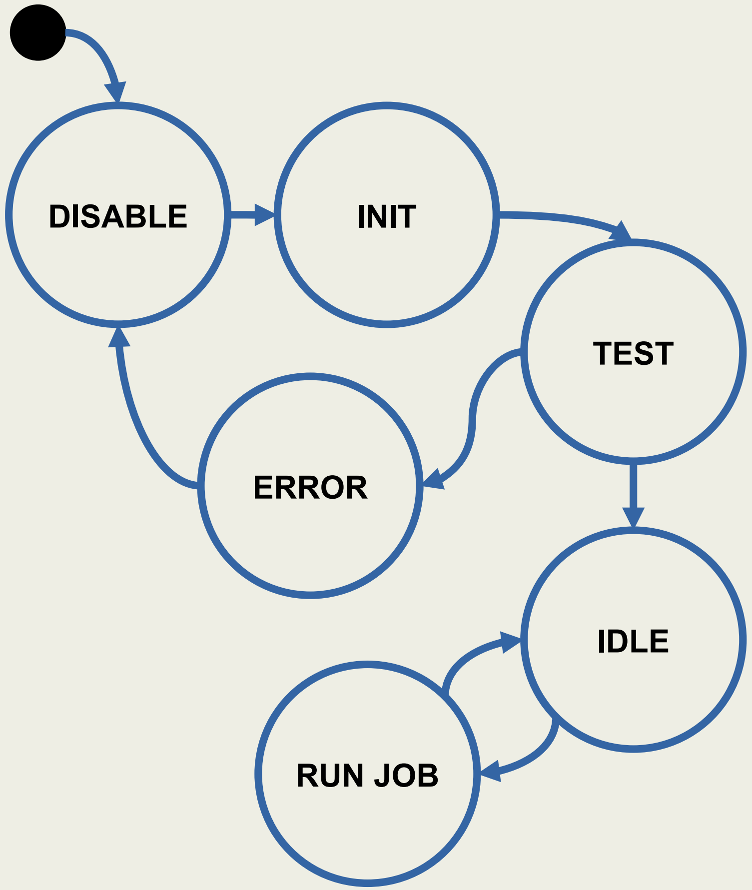
# State Machine Design Pattern

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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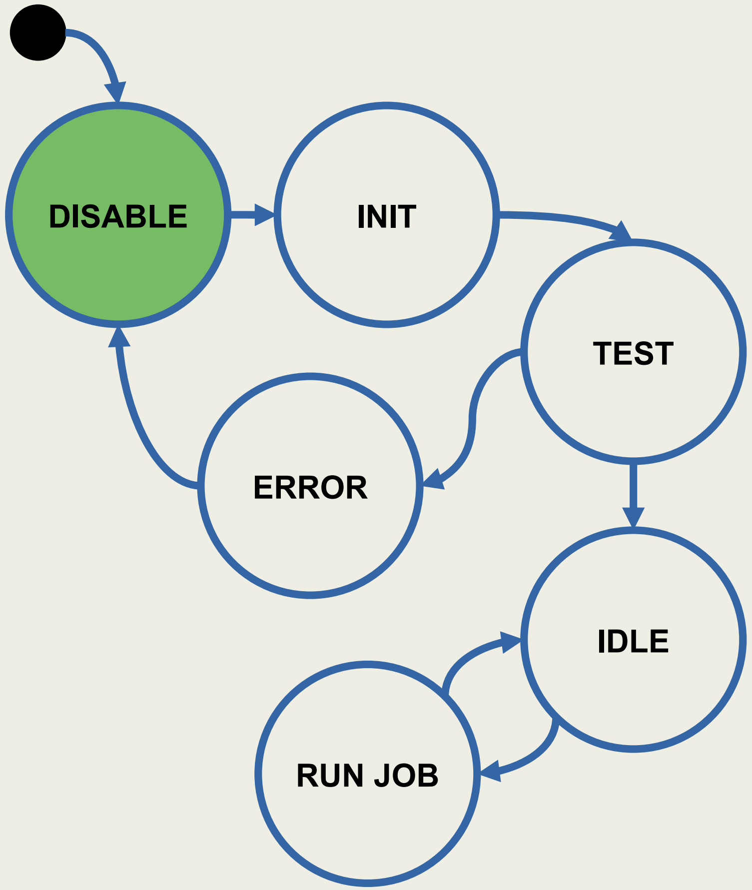
# State Machine Design Pattern

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.




Transitions are triggered by internal events or commands.

Each FSM has a scheduler, message_handler and update functions

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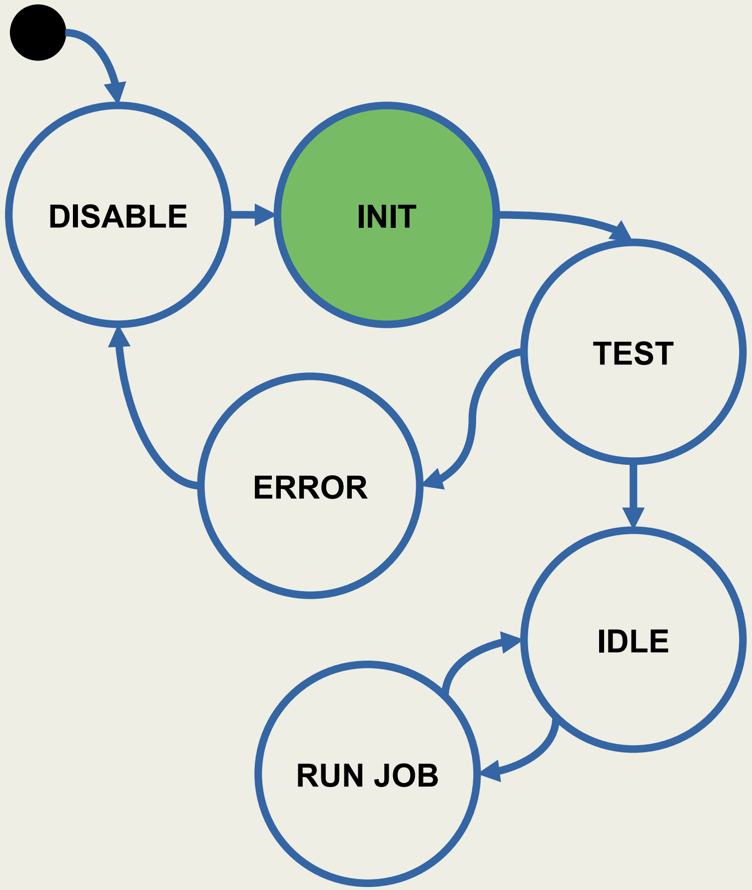


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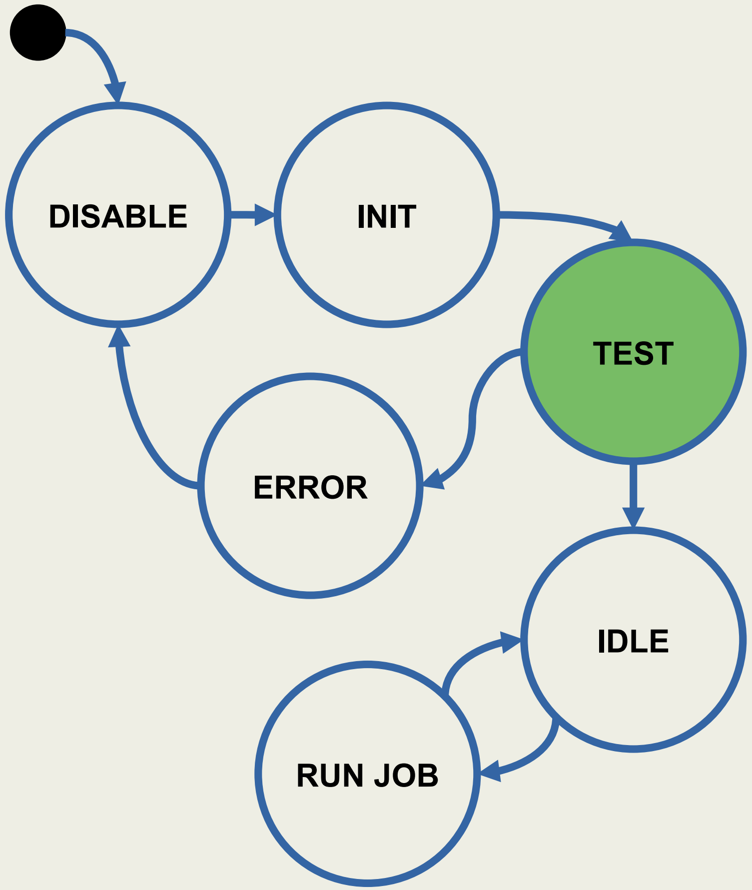


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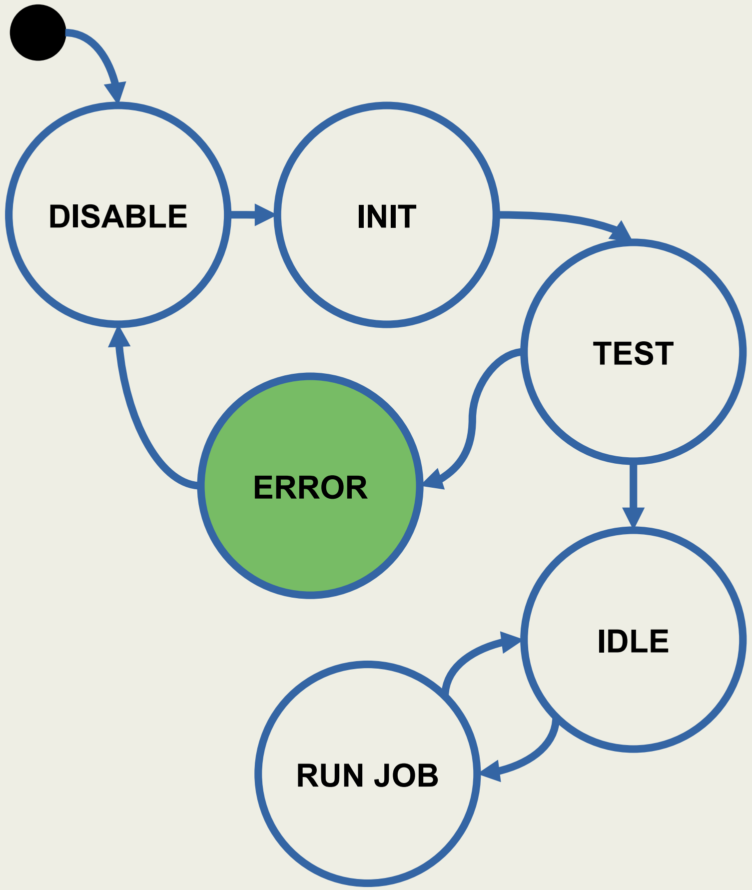


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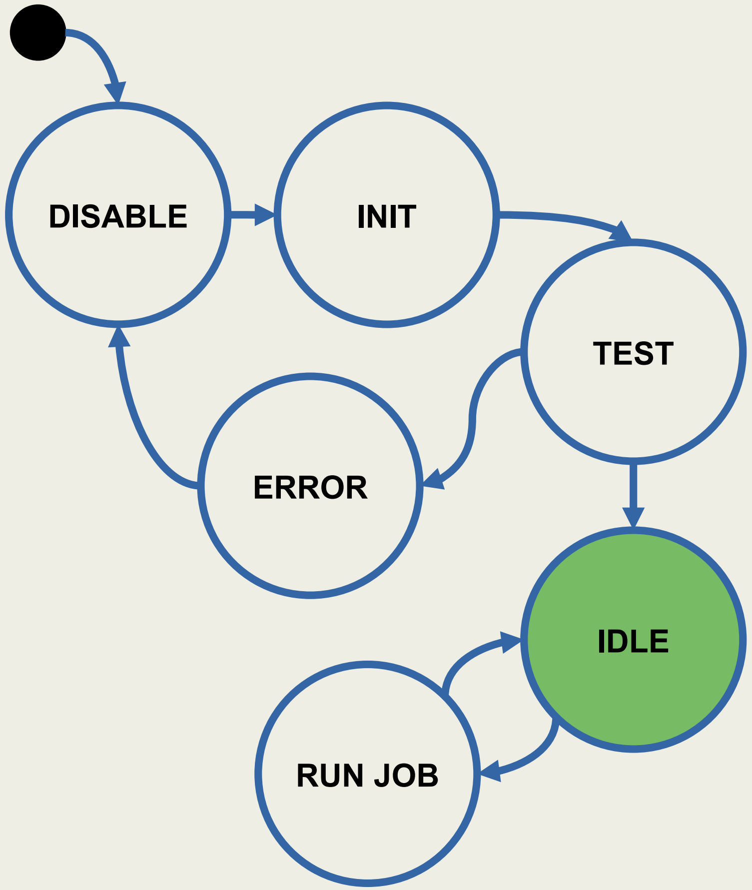


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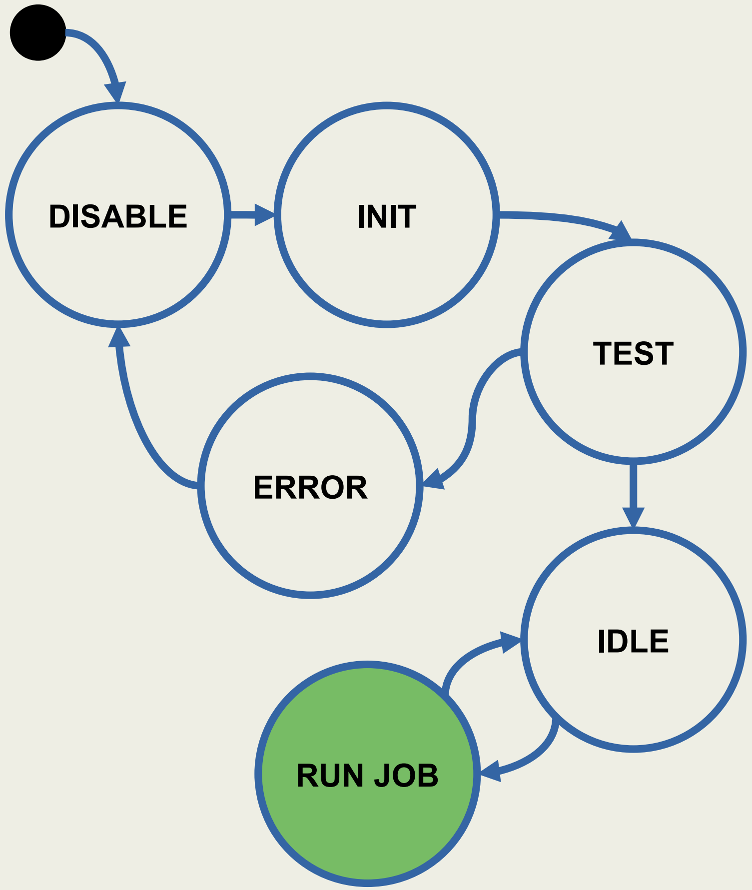


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# Conclusions

- A low-cost prototype buoy for coastal acoustic monitoring is under integration, designed for robustness and autonomous operation.
- The system complements IMS hydroacoustic stations by addressing shallow-water coverage gaps on the Argentine continental shelf.
- Proposed deployment sites (MDQ and CRD) optimise detection in previously uncovered regions.
- This platform paves the way for a scalable coastal monitoring system supporting baseline studies of ambient underwater noise and long-range propagation analysis.