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Ocean-Bottom Seismology: Next-Generation Technology Solutions for Marine Monitoring

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nanometrics

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Abstract

Researchers continue to intensify their focus on the seafloor to gain a deeper understanding of the Earth's structure, tectonic processes, and potential hazards through the acquisition of **ocean-bottom seismic (OBS) data**. However, the unique challenges of deep-sea environments require **innovative, purpose-built engineering solutions** and **robust manufacturing techniques** to safeguard **data quality, data completeness** and **system reliability**, while meeting scientific objectives and optimizing ease of deployment. A range of cabled and autonomous ocean bottom sensing solutions are now available, supporting the global community's study of underwater ground motion, its dynamic properties, and natural or triggered events on the seafloor.

This poster presentation provides a comprehensive overview of the engineering challenges in the domain of OBS platforms, highlighting the advancements in technology and capability solutions that the Nanometrics team has developed to address those challenges for various configurations and use cases. With proven technologies such as **integrated kinematic gimbals** for levelling at all landing tilt angles, an **integrated MEMS gyrocompass** for precise orientation, and designs **certified for deployment depths of up to 6000m**, this poster will demonstrate that seamless multidisciplinary data collection across diverse marine environments is now more accessible than ever before. Recent technological advances include customer deliveries of both **SMART cable seismic instrumentation** and an **integrated Cabled OBS observatory**, expanding options to support a wide range of application-driven sensing instruments and dataloggers. This continuous innovation aims to facilitate further understanding of the dynamic properties in these challenging deep ocean environments.

The Deep-Sea Blind Spot: Why OBS Sensing Matters

Despite oceans covering most of the Earth's surface, our seismic knowledge relies almost entirely on **land-based stations**. This leaves enormous gaps in our understanding of Earth's structure, particularly the oceanic crust and mantle, and severely limits our ability to detect and warn about **undersea earthquakes** and **tsunamis**.

Core Benefits of Ocean Bottom Seismology (OBS)

Expanding seismic monitoring to the seafloor is a game-changer, promising breakthroughs across science, safety, and industry:

- **Earth's Interior Structure:** OBS provides the critical data needed to generate a **complete, accurate 3D model** of our planet, especially the unique **oceanic crust and mantle**.
- **Enhanced Hazard Warnings**: Sensors placed closer to seismic sources (like subduction zones) allow for **quicker detection** of undersea earthquakes and the immediate tracking of **tsunamis**, issuing faster, life-saving warnings to coastal populations.
- **Supporting the Blue Economy:** OBS is essential for the safety and longevity of key offshore energy projects:
  - **Offshore Wind Farms:** Assessing and monitoring earthquake risk for turbine foundation stability.
  - **Carbon Capture & Storage (CCUS):** Continuously monitoring the integrity of subsurface CO_2 reservoirs to ensure safe, permanent sequestration.
- **Marine Ecosystem Tracking**: Continuous seismic data allows **environmental seismology** research to monitor subtle changes in the ocean floor environment. This data can be directly linked to **marine habitat health** and tracking the impacts of **climate change** on sub-seafloor processes.

Facing the Abyss: The Engineering Challenges of OBS

The ocean floor is Earth's **final, harshest frontier** for seismic monitoring. Deploying and maintaining sensitive instruments in this extreme, inaccessible environment demands sophisticated engineering and significant investment. Our focus is to address these technical obstacles head-on:

Challenge	Impact on Mission	Engineering Solution Focus
💰 Deployment Costs	High equipment cost and complex logistics increase financial risk.	**Tailored, robust, and efficient OBS systems** to ensure high confidence and rapid deployment/recovery, maximizing mission success.
📐 Subsea Landing & Orientation	Free-fall landing on unpredictable terrain can compromise data quality; unknown azimuth hinders data interpretation.	**Robust, low-noise, self-leveling mechanisms** to ensure perfect seafloor coupling regardless of landing angle. **Trusted, accurate orientation sensors** for reliable data processing.
🕒 Reliable Timing (Synchronization)	GPS signals cannot penetrate water, yet accurate time-stamping of data is critical for analysis.	Integration of **high-accuracy, ultra-low-drift, temperature-stable clocks** and synchronization protocols to maintain microsecond timing precision autonomously.
🎛️ Sensing Agility	Wide variety of mission depths, scientific requirements, and operational mandates require flexible hardware.	**Modular system designs** capable of fine-tuning measuring capabilities and easily incorporating supplementary scientific instruments (e.g. pressure sensors).
🔊 Data Quality	Poor seafloor coupling and system noise can degrade the value of collected geophysical data.	Unique designs for **uncompromised ground coupling**, effective **noise mitigation**, and ensuring full system-wide **dynamic range** potential is maintained.
🚢 Recovery & Retrieval	Mission success depends entirely on reliably locating, surfacing, and offloading data from autonomous systems at the end of the mission	**Robust acoustic transponders** for reliable location. User-friendly, efficient workflows for **timely retrieval** of **ready-to-use time-corrected data sets**.

Nanometrics' Goal: To transform these deep-sea obstacles into manageable engineering problems, enabling reliable, **high-quality data acquisition** for **scientific study, hazard monitoring and industrial applications**.

Nanometrics ATLANTIS OBS Portfolio

The ATLANTIS portfolio offers innovative seismic sensing solutions that help address the engineering challenges of ocean bottom deployments, with solutions engineered with the benefit of decades of experience and collaboration:

- **Data Quality, Without Compromise:** Expect the same high-performance, low-noise data acquisition on the seafloor as obtained with terrestrial deployments
- **Innovative Technology:** Purpose-built innovations that address the complexities of deploying on the ocean bottom
- **Customizable Solutions:** Each OBS deployment is unique. Our team works closely with researchers and industry to tailor solutions to meet the goals and operational constraints of each project.

Atlantis

ABALONES Autonomous OBS

Free-fall broadband seismic system where the seismometer **couples directly to the seafloor** while mechanically decoupling from the frame..

- Supports a range of Nanometrics **broadband / very-broadband seismometers** for best-fit capability
- Uses Scripps Institution of Oceanography's versatile OBS deployment technology: a very stable, **trawl-resistant design** that shields the seismometer from **unwanted environmental noise**.
- Seismometer interfaced with **noise-free auto-leveling kinematic gimbal**, that always retains the system's **full dynamic range.**
- **Optimized on-deck workflow** with the integrated Pegasus OBS, to facilitate rapid system configuration, deployment, retrieval, and data recovery.
- Supports **integration of multidisciplinary sensors** (e.g. hydrophone, differential pressure gauge, etc.) that enable further customization.

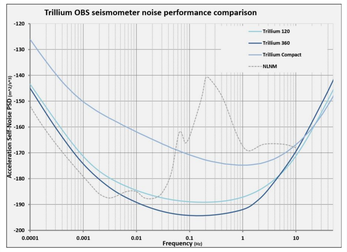
Cabled Ocean Bottom Seismic Observatory (COBSO)

Observatory-class, telemetry-connected ocean bottom sensing platform for **high-fidelity research** and **low-latency early-warning systems**.

- **High-Performance Seismic Monitoring:** Uses very-broadband Trillium 120 or 360 OBS seismometer and the Class A Titan accelerometer for best-in-class seismic measurement.
- **Industry-Leading Dynamic Range:** Up to 220dB of dynamic range for the entire system.
- **Designed for the Ocean Bottom:** Purpose-built titanium pressure vessel for depths to 6000m. Expansion capabilities for additional serial and analog sensors to allow tailoring to specific applications.

OBS Instruments

Data Loggers | Broadband Seismometers



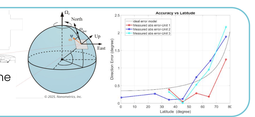
All OBS instruments are available for integration into 3rd party OBS platforms and pressure vessels

ATLANTIS Solutions

1. **Optimized Robustness & Efficiency**
   100g (Compact OBS) / **20g** (T120/360 OBS) **shock protection** that requires no mass or gimbal lock. Optimized SWAP (Size, Weight, and Power) and minimal preparation time ensures **fast, confident, and cost-efficient deployment** even in rough seas.
2. **Reliable Leveling and Orientation**
   Integrated, noise-free kinematic gimbal supports **full dynamic range** and **tilt correction** up to 360° (Compact OBS) or ±50° (T120/360 OBS, COBSO). This guarantees uncompromised performance regardless of the seafloor landing angle.

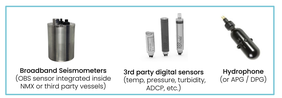
NEW

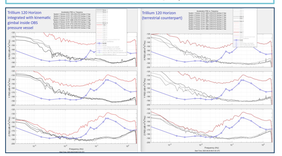
***SUBSEA ORIENTATION*: Introducing Nanometrics' North Finder.**
The **North Finder** (patent pending) technology guarantees high-accuracy orientation for OBS instruments by measuring **Earth's rotation** using a fully integrated, highly sensitive rotational sensor.
- **Unmatched Accuracy:** Achieves azimuth orientation to within **0.5°** (latitude dependent).
- **Versatile & Efficient:** Determines **true north** without external tools or reliance on GPS. Immune to local **magnetic disturbances** and integrates seamlessly without increasing sensor size.



Measured results, following 8 hour operation at various latitudes for three prototype seismometers (shown on the right).

3. **Precision Time Synchronization**
   Abalones: Uses a high-precision **VCXO clock** (~ 0.04 msec/day drift) with built-in support for **automatic time-drift correction** upon data retrieval. **COBSO:** Supports network timing using **PTPv2** or **NTP**. Also supports timing from a IPPS/NMEA source.
4. **Modular Sensor Integration**
   Supports a **wide range of Broadband / Very-Broadband seismometers**, and the integration of **third-party sensors**. This flexibility allows the platform's capabilities to be precisely **tailored to specific mission objectives** and environments.
5. **Superior Seafloor Coupling & Noise Mitigation**
   In both the **Abalones** and **COBSO** platforms, data quality is maximized with the **seismometer coupling directly to the seafloor**. For autonomous deployments, the Abalones housing provides the added benefit of acting as a **shield against environmental noise**, enhancing measurement fidelity.
6. **Fast, Reliable System Recovery**
   Abalones ascends rapidly (~ 60 m/min) after acoustic release. Integrated features like a **beacon** and **high-visibility design** simplify location and recovery. Data retrieval is ultra-fast via a **USB 3.0 interface** (>100 Mbps) with **automated time correction**. (Download of 1 year of 4Ch @ 100 sps data in < 2 mins)

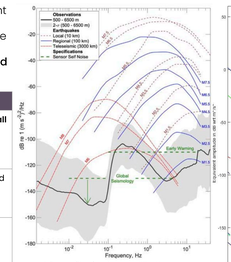


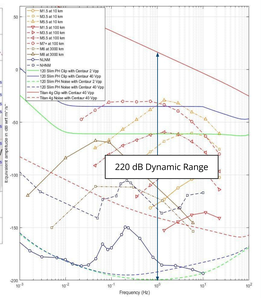


Tailored Performance: Aligning ATLANTIS with Mission Goals

The ocean environment is highly dynamic, with deployment conditions varying widely by depth, seafloor type, and mission objective. The ATLANTIS OBS portfolio offers a range of high-performance instrumentation and packaging options, ensuring the chosen **solution is perfectly optimized** for your specific requirements.

Instrument	Key Feature	Optimal Application
Trillium Compact OBS	Robust, **ultra-low power** broadband seismometer with 360° gimbal. Rated for **6000m** depths.	**Autonomous Deployments, Small Form Factor Integrations** (e.g. ASN Climate Change Node (see below)
Trillium 360 OBS	**Very low self-noise** design provides **best-in-class performance**.	**Global Seismology Research** and missions requiring the highest fidelity data to study distant, subtle teleseismic events.
COBSO	Combines a **Trillium 120/360 Seismometer** with a **Class A Titan Accelerometer**. Delivers a massive system-wide **dynamic range of >220 dB**	**Early Warning Systems** and comprehensive **Weak/Strong Motion Research**, ideal for seafloor geohazard monitoring and high-strain events.





* Ocean (floor) noise quantification estimates for depths between 500 - 6000 meters. (Janiszewski et al., 2020)

Whether your goal is teleseismic research, mitigating induced seismicity risk, or studying geohazards, the ATLANTIS portfolio ensures that your **instrumentation choice fully aligns with experimental conditions** to maximize data return.

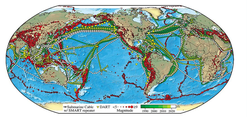
Nanometrics' ATLANTIS helping solve real-world challenges

Real-World Impact: Pioneering the SMART Cable Revolution

The instrumentation package integrated into the CC-node includes:
- **Titan Accelerometer:** High performing strong motion sensor with industry leading dynamic range and high clip level to record intense local shaking
- **Trillium Compact OBS Seismometer:** Ultra-low power broadband seismometer with exceptional dynamic range and low noise floor to detect small distant events
- **Pegasus OBS Data Logger:** Ultra-low power data logger, customized to support ASN real-time streaming protocol.

ATLANTIS solutions are at the heart of the world's first **SMART (Scientific Monitoring and Reliable Telecommunications) Cable** projects, a pioneering collaboration with **Alcatel Submarine Networks (ASN)** and **RBR**. This partnership integrates high-precision ATLANTIS seismic instrumentation into standard subsea telecom infrastructure.

- **Pioneering Projects:** The **TAMTAM** (Vanuatu - New Caledonia) and **SMART Atlantic CAM** (Portugal - Azores - Madeira) systems, scheduled for deployment beginning in 2026, represent the first instances of geophysical sensing being seamlessly integrated into commercial telecom cables.
- **Engineering Challenge Met:** Integrating seismic instruments into the small-diameter subsea repeater notes (or 'SMART nodes') required significant re-engineering. ATLANTIS successfully **reduced the instrument form-factor** without compromising **performance or reliability**.
- **Critical Outcomes:** These networks will provide **real-time seismic, tsunami, and environmental monitoring** data from previously unexplored regions of the ocean floor. This critical, immediate data delivery will **enhance disaster preparedness**, helping to save lives and reduce damage from natural hazards.



* SMART Subsea Cables for Observing the Earth and Ocean, Mitigating Environmental Hazards, and Supporting the Blue Economy, by Howe BM et al., 07 February 2022.

Also shown are the historical earthquakes (red), and existing DART (Deep-ocean Assessment and Reporting of Tsunamis) tsunami buoys (yellow triangles)

Seismic Solutions at the Megathrust: The Cascadia Subduction Zone

Nanometrics was selected to provide the seismic instrumentation for the Cascadia Offshore Subduction Zone Observatory (COSZO), expanding the existing OOI Cabled Array. This critical project targets the Cascadia Subduction Zone, a major fault capable of producing Magnitude 9 earthquakes and destructive tsunamis.

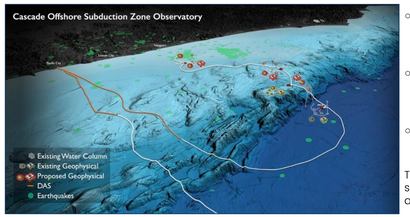


Image courtesy of Cascadia Offshore Subduction Zone Observatory (COSZO)

- COSZO Mission: The project's goal is to significantly improve the understanding of strain accumulation and release in the poorly understood central Oregon region, directly contributing to enhanced tsunami and earthquake early warning systems.
- The ATLANTIS Solution: Nanometrics is providing the COBSO in depths of 80m to 1300m. The COBSO is designed for long-term reliability, providing the low-latency data necessary for real-time hazard detection.
- To achieve ultra-low noise performance, the instruments will be buried within a caisson and backfilled with silica beads. The first instruments are scheduled for deployment in Summer 2026.

This collaboration provides a world-class scientific network enhanced seismic monitoring capabilities to transform hazard preparedness along the Pacific Northwest coast.