# Evolving challenges and opportunities in ocean bottom sensing

## From autonomous deployments, cabled observatories, to SMART cables

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## Abstract

With over 26,000 stations in the International Registry of Seismograph Stations, Earthquake-prone regions around the globe are densely instrumented and monitored. The scientific community is increasingly looking to the ~71% of Earth's surface covered by oceans for a deeper understanding of the Earth's structure, tectonic processes, and potential hazards through Ocean-bottom seismic (OBS) data acquisition. However, the unique challenges of deep-sea environments require innovative engineering solutions and robust manufacturing techniques to safeguard data quality, data completeness and system reliability, without compromising ease of deployment. These challenges have largely restricted the scope of studies until the recent wider market availability of OBS platforms. Currently, a range of cabled and autonomous ocean bottom solutions represent the state-of-the-art deployments that support the global community's study of the oceans' environment, 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, as well as the technology and capability solutions that the Nanometrics team developed to address those challenges for differing configurations and use cases. With proven technologies such as integrated kinematic gimbals to level at all landing tilt-angles, and designs certified for deployment depths to 6000m, Nanometrics has enabled seamless multidisciplinary data collection across diverse marine environments, supported by a wide range of application-driven options for sensing instruments and data loggers.

## Ocean Bottom Sensing Ambitions

While **oceans cover 71% of Earth's surface**, most of our knowledge about earthquakes comes from land-based monitoring stations. This leaves huge gaps in our understanding of the Earth's structure and limits our ability to detect and warn about earthquakes that happen under the sea.

Expanding seismic monitoring to the oceans' floor would offer several benefits, including:

- ✓ **Improved understanding of Earth's interior:** By gathering data from the oceans, we can create a more complete and accurate picture of the Earth's structure.
- ✓ **Enhanced tsunami and earthquake warnings**: Ocean-based sensors would allow for quicker detection of undersea earthquakes, leading to faster warnings for coastal communities. This could save lives and reduce damage to infrastructure.
- ✓ **Better monitoring of marine ecosystems:** Seismic data from the ocean floor can also help us track changes in marine environments, particularly in the face of climate change.
- ✓ **Support for offshore energy projects**: Seismic monitoring is becoming increasingly important for the safety and efficiency of offshore wind farms and carbon capture and storage (CCUS) projects. It helps assess earthquake risk before construction and monitor for any seismic activity induced by these operations.

## OBS Challenges

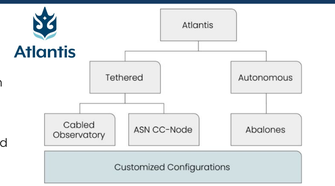
The ocean floor remains one of the most challenging frontiers for seismic monitoring. Deploying and maintaining sensitive instrumentation in this extreme environment presents a unique set of obstacles that push the boundaries of engineering and scientific ingenuity. The deep ocean demands specialized, pressure-resistant equipment and complex deployment procedures, resulting in significant financial investment. The harsh, inaccessible nature of the seafloor also makes all processes more technically challenging, from robust communications and power infrastructure, to equipment servicing and retrieval. This poster focuses on highlighting the challenges in three aspects of a typical ocean deployment of seismic instrumentation, and the various solutions Nanometrics has developed to meet those challenges:

1. **DEPLOYMENT:**
   Working at sea is **EXP€N$IVE.** While OBS instrumentation can be costly on its own, these costs are often eclipsed by the costs associated with the deployment and recovery efforts. It is thus critical that OBS systems are specifically tailored for the particular use case, are robust and can be deployed efficiently and with confidence.
2. **SUBSEA LANDING ANGLE & ORIENTATION:**
   The ocean floor has a dynamic and often uncharted terrain, especially with free-fall deployments of Ocean Bottom Seismometers (OBS). Despite this unpredictability, the performance of the OBS instrument must not be compromised or suffer reduced efficiency due to a poor landing angle on the seafloor. Additionally, reliable interpretation of the collected data requires a trusted azimuth orientation with a quantifiable level of accuracy.
3. **TIMING:**
   GPS/GNSS signals emitted by satellites cannot penetrate water, however, reliable time-stamping of OBS data recorded at depth is still required. The autonomous / free-fall systems thus rely on high-accuracy, low-drift, temperature-stable and power efficient timing solutions. Telemetry connected systems require timing synchronization to a time reference with ultra-low uncertainty.
4. **SENSING AGILITY:**
   With an array of wide-ranging submarine applications of different deployment depths, sensing requirements and operational mandates, OBS systems must be flexible to adapt to each specific use case. The agility to fine-tune the systems' "measuring capabilities", providing flexibility to incorporate additional instruments, is of high value.
5. **DATA QUALITY:**
   Similarly to land deployments, collecting geophysical data of the best-possible quality bares the highest return on investment. Uncompromised coupling to the seafloor, noise mitigation measures, and retention of full system-wide dynamic range potential independent of the platforms' landing angle require unique design and Engineering solutions.
5. **RECOVERY & DATA RETRIEVAL:**
   The autonomous OBS systems are deployed to the depths of the oceans, left undisturbed to record geophysical data for extended periods. At the end of the mission, all stakes rest on the ability to reliably locate and recover the systems, providing user-friendly, efficient, and timely retrieval of time-corrected data sets.

## Nanometrics ATLANTIS OBS Portfolio

Ocean bottom sensing solutions have been developed by Nanometrics in collaboration with researchers and industry to meet current and evolving science needs, including:

- Same high performing, low noise data quality and acquisition as terrestrial deployments, using Nanometrics instrumentation built for the ocean bottom
- Optimized processes for all phases of the deployment lifecycle, including streamlined configuration and data retrieval
- Customizable platforms that allow for integration of a broad range of ground motion and multidisciplinary sensors to meet application and project-specific requirements




**ABALONES** Autonomous OBS:

Free-fall broadband + (optionally) hydroacoustic sensing platform, providing maximum flexibility, down to **6,000 m** depth.

- **132 x 112 x 74 cm** @ 375 kg (205 kg w/o anchor)
- **< 400 mW** (total) power consumption (w. TC OBS)
- **≤ 20 months** fully-autonomous deployment
- BB seismometer directly coupled to the seafloor
- Wireless interface for efficient "on-deck" operation
- Supports range of broadband/very-broadband seismometers for best-fit sensing capability. Integration of 3rd party instruments supported.

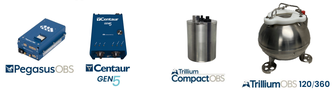
**Cabled** Ocean Bottom Seismic **Observatory** (COBSO):

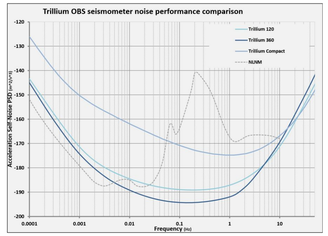
**Observatory-class**, telemetry-connected ocean bottom sensing platform for **mission-critical** applications, where provision of **real-time data** is essential.

- **33 x 42 cm @ 42 kg** (~14.5 kg in sea water)
- **~5W** (total) power consumption (BB/SM/Data Logger)
- **BB sensor** colocated with Class A (FBA) **accelerometer**
- **220 dB** system dynamic range with high clip level
- Continuous deploy. for **≤ ~25 years < 6,000 m** depth
- Real-time streaming of waveform and SOH data
- Remote access for system configuration and control

**OBS Instruments:**

Data Loggers — Broadband Seismometers




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

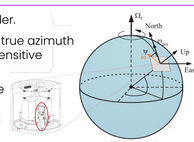
## ATLANTIS Solutions

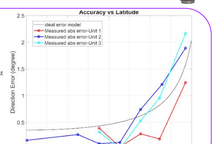
1. **DEPLOYMENT:**
   Rated for **100g / 20g shock protection** (TC OBS / T120360, resp.), with **no mass or gimbal lock** mechanism required, the Abalones and the Cabled OBS Observatory have been engineered for maximum resilience to rough conditions at sea, and reliable deployment, requiring little preparation time. The **S**ize **W**eight **A**nd **P**ower (SWAP) has been optimized (see above).
2. **SUBSEA LANDING ANGLE & ORIENTATION:**
   The seismometer in both OBS platforms is integrated with **noise-free auto-leveling kinematic gimbal**, supporting tilt-correction ≤ **360°** (Abalones w. TC OBS) / **±50°** (COBSO) retaining system's full dynamic range independent of the seafloor landing

NEW **SUBSEA ORIENTATION:** Introducing Nanometrics' North Finder.

The North Finder (patent pending) determines and reports true azimuth orientation on the seafloor using a fully integrated, highly sensitive rotational sensor to measure Earth's rotation.

It provides results more rapidly and accurately than can be achieved with alternative, less efficient methods, such as polarization analysis of known events and direct alignment using an ROV.

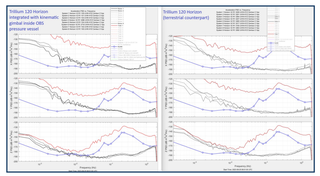



Measured results, following 8 hour operation at various latitudes for three prototype seismometers (shown on the right).

3. **TIMING:**
   Abalones employs high-precision VCXO clock, with certified drift rate of ~0.04 msec / day (< 15 msec / year), with support for automatic time-drift correction on retrieval of the data. COBSO, as a real-time streaming networked instrument, supports network timing using Precision Timing Protocol (PTPv2) or NTP, as well as an option to synchronize via 1PPS+NMEA.
4. **SENSING AGILITY:**
   Both OBS platforms support wide range of BB / VBB seismometers (see ATLANTIS Performance), as well as integration of 3rd party sensors, aligning the platform's sensing capabilities with the application, mission objectives, and deployment environment.


5. **DATA QUALITY:**
   The seismometer in both OBS platforms couples directly to the seafloor, greatly augmenting the data quality potential. The pressure vessel, housing the seismometer, provides additional noise-suppression (see figure on right)




6. **RECOVERY & DATA RETRIEVAL:**
   The Abalones will ascend to the surface at a rate of ~60 m/min following activation of the acoustic anchor release. An integrated beacon and high-visibility features simplify location of the platform.
   An integrated USB3.0 interface, with transfer rates > 100 Mbps, enables ultra-fast data retrieval, with support for automatic time-drift correction
   **(Download of 1 year of 4Ch @ 100 sps data in < 2 mins)**

## ATLANTIS Performance

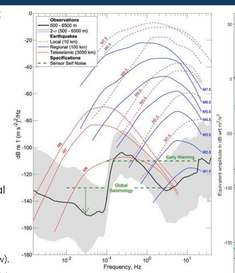
The oceans present a dynamic environment, with deployment conditions varying significantly based on depth (see figure on the right), seafloor characteristics and other factors. The ATLANTIS OBS portfolio has a range of seismometer performance and packaging options which allow optimization of solutions for specific monitoring objectives and conditions.

The Trillium Compact OBS is a robust, ultra low power seismometer with 360° gimbal that delivers broadband performance with pressure vessel options to support deployments up to 1800m or 6000m depths. It provides an optimal solution for many applications, including the ASN Climate Change Node (see below).

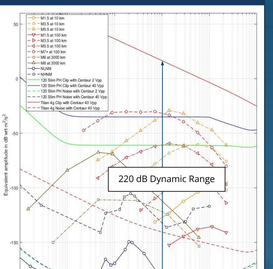
The Trillium 360 OBS, with its ultra low self-noise provides best-in-class performance that is especially suitable for global seismology research (see figure under OBS instruments).

COBSO combines a Trillium 120 (or 360) seismometer with a Class A Titan accelerometer to deliver system-wide dynamic range > 220 dB. It is an ideal solution for both early warning applications and weak / strong motion research (see COSZO below).

Whether your objectives relate to teleseismic research, seafloor geohazard monitoring, or industry-mandated monitoring & mitigation of induced seismicity risk, the ATLANTIS portfolio has a solution that is optimal for your unique requirements.




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




## Nanometrics' ATLANTIS helping solve real-world challenges

**ASN Announces Pioneering Collaboration with Nanometrics and RBR on SMART Cable**


- The world's first two SMART cable deployments, the TAMTAM (Vanuatu - New Caledonia) and the SMART Atlantic CAM (Continent (Portugal) - Azores - Madeira), are scheduled for deployment, beginning in 2026. These projects represent world's first instances of geophysical instrumentation being integrated into "standard" subsea telecommunications cabling and infrastructure
- Given the small diameter of the subsea telecom "repeater nodes" / "SMART nodes", re-engineering the seismic instrumentation to the required form-factor, without compromise to the instruments' performance or reliability, presented a notable Engineering challenge

What *"IS" SMART?*

The **S**cientific **M**onitoring **A**nd **R**eliable **T**elecommunications (SMART) Subsea Cables Initiative *"seeks to revolutionize deep ocean observing by equipping transoceanic telecommunications cables with sensors to provide novel and persistent insights into the state of the ocean to monitor climate change, including ocean heat content, circulation, and sea level rise, provide early warning for earthquakes and tsunamis, and monitor seismic activity for earth structure and related hazards."*

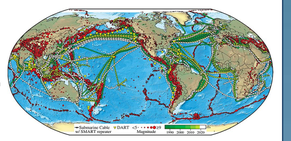
**SMART vision in the nutshell:**

- ✓ Opportunity to integrate (geophysical) sensors along new or scheduled for upgrade submarine telecommunication cable routes (~1.4M km of existing and operational subsea cabling os of today)
- ✓ Sensing instruments incorporated into the same form-factor housing as is used for subsea telecom repeater nodes, located every 70-100 km
- ✓ *"The most economical"* cabled OBS deployment, as standard cable laying vessels, rather than specialized ships, may be used to deploy SMART-enabled cables
- ✓ *"The low hanging fruit"* in achieving transcontinental ocean bottom sensing capability and provision of near real-time data
- ✓ Immense potential to augment existing monitoring capabilities of natural and man-made events, while growing our knowledge of submarine geology and the changing marine climate

Nanometrics worked closely with ASN to customize our advanced seismic monitoring technologies to meet ASN requirements and integrate our best-in-class instruments into the ASN "Climate Change" (CC)-node.

The instrumentation 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.




* 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)

**Nanometrics Selected to Provide Seismic Instrumentation Solution for the Cascadia Subduction Zone** (COSZO)

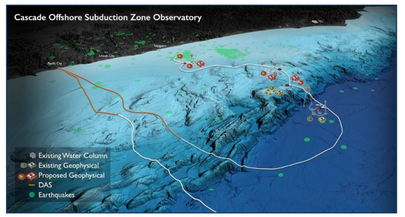
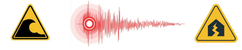



*Image courtesy of Cascadia Offshore Subduction Zone Observatory (COSZO).*



- ✓ **Enhancing Tsunami & Earthquake Early Warning**
- ✓ **Improve understanding of the Cascadia Subduction Zone**
  - The project will add science junction boxes and geophysical instruments to the OOI RCA, which has been providing seismic data to the public since 2014
  - Nanometrics Atlantis Cabled Observatory will be deployed in the Cascadia Subduction Zone at water depths of 80 – 1300 m, buried in the sediments within a caisson and back-filled with silica beads for further noise reduction
  - First set of instruments in the water by summer 2026