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Floating Seismographs (MERMAIDS)

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Definition

MERMAIDS are Lagrangian floats, drifting passively with the deep ocean current, detecting seismic waves, and recording seismograms (and possibly other data) which they transmit by satellite after coming to the surface. The name is an acronym for Mobile Earthquake Recording in Marine Areas by Independent Divers (Simons et al. 2009).

History

The need to observe the abyssal current in the oceans led John Swallow in the UK and Henry Stommel in the USA to develop submarine floats in the mid-1950s (see Riser et al. 2018, for a review). Though the early floats were equipped with a hydrophone, this was only used to track the float position by recording intermittently fired explosives from a surface vessel.

The first seismological application was by Bradner et al. (1970), who equipped a spherical aluminum float (Fig. 1) with a 3-component seismometer to record microseismic noise between 0.02 and 5 Hz at a depth of 1200 m. D'Spain and Hodgkiss (1991) used 17-inch diameter Benthos glass shell as a float to measure the background noise level in the 1–20 Hz frequency band. Nolet (1991) analyzed data from this instrument and discovered a weak signal of an earthquake of magnitude 6.8 at a depth of 26 km in the Andreanoff Islands (distance 47°) showing that floating seismographs could in principle be used to record teleseisms.

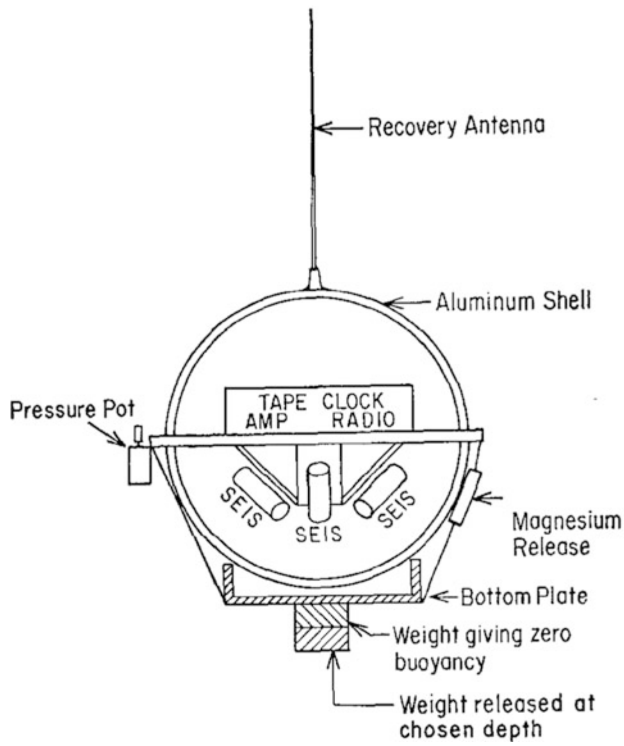
At the time, the technology was not yet advanced enough to have floats operate independently in mid-ocean. This changed with the development of autonomous sensors for oceanography such as RAFOS and SOLO floats (Riser et al. 2018 – SOLO stands for Sounding Oceanographic Lagrangian Observer, the acronym RAFOS is 'SOFAR', for SOund Fixing And Ranging, spelled backwards.), which can transmit a small volume of data by satellite (Argos) and be located by GPS when surfacing, thus obviating the need for tracking by a surface vessel. A modern float has a bladder that allows it to vary its volume and seek the depth where it is neutrally buoyant, since the density of seawater increases slowly with depth. A nominal cruising depth of 1500 m is a good compromise to get a good signal to noise ratio during monitoring and time needed to rise to surface in order to reduce the power consumption. Simons et al. (2009) successfully tested a hydrophone attached to a SOLO float to record a number of earthquake signals.

Adapting a RAFOS float, Hello et al. (2011) subsequently developed the first MERMAID capable of autonomously detecting earthquakes and transmitting these by satellite. The current version of the MERMAID uses a 17-inch glass sphere and was developed by OSEAN-SAS and the University of the Côte d'Azur, both located in the south France.

Technical Description

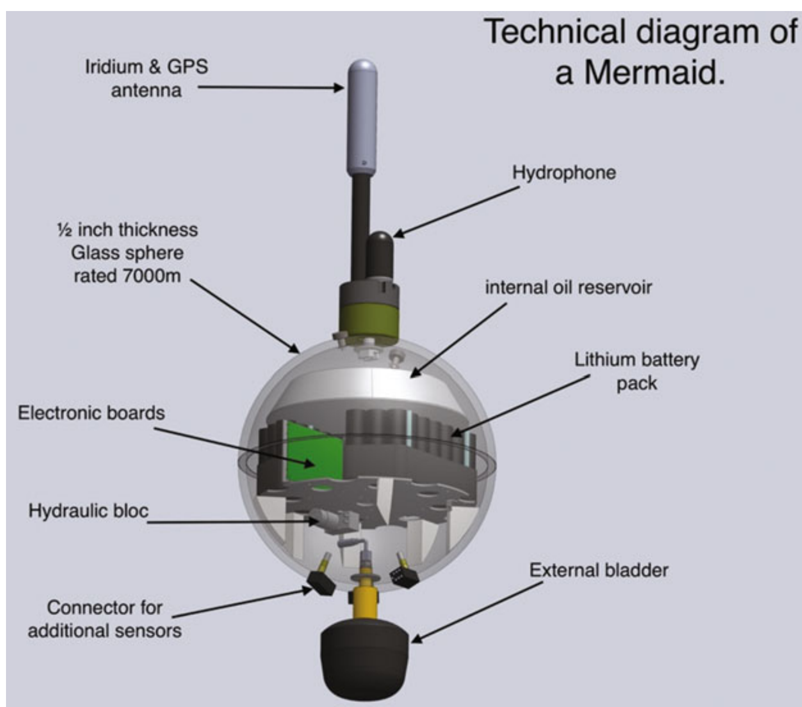
In the MERMAID, all hydraulic and electronic components are encapsulated in the glass sphere except for a bladder which adapts the float volume and controls its buoyancy in the water column (Fig. 2). Oil is pumped from an inner reservoir to the bladder outside. The piston can pump oil against a pressure up to 550 bar, equivalent to a depth of 5500 m, which forces the float to ascent to the surface from a 4000 m maximum cruising depth. To descend, the oil transfer from the bladder to the inside is controlled by valve or bypass. The float measures the pressure during its descent. It

H. K. Gupta (ed.), *Encyclopedia of Solid Earth Geophysics*, Encyclopedia of Earth Sciences Series,
https://doi.org/10.1007/978-3-030-10475-7_248-1



Floating Seismographs (MERMAIDS), Fig. 1 The spherical float used by Bradner et al. (1970) to record microseismic noise

Floating Seismographs (MERMAIDS), Fig. 2 The spherical glass float used by OSEAN-SAS and the University of the Côte d'Azur in France to detect, record and transmit earthquakes by satellite communication. (Credit: OSEAN-SAS)



calculates its speed and activates the pump or opens the valve to maintain a speed that varies according to the distance to the desired depth. For the ascent, the float will leave its cruising depth by gradually increasing its vertical speed to a maximum to reach the surface.

The MERMAID contains two circuit boards. A very low power (3,3 V/7,6 mA), acquisition board interacts with a pilot board that operates the pump. Both are powered up by lithium disposable batteries, like the rest of the system (motor, pump, Iridium modem, GPS receiver). For a battery with capacity 5 KWh, the MERMAID has an expected life time of 6 years of continuous monitoring the hydrophone signal at a depth of 1500 m, if a selection of 150 Kbytes of triggered seismogram data is transmitted every week.

Signal Discrimination

After the float descends to its drift depth, it oscillates around the level of natural buoyancy, typically 1 cycle/hour, but the pressure variations introduced by this are too little and too slow to affect seismic signals. To record acoustic signals, the MERMAID is equipped with a hydrophone that monitors the pressure in the acoustic frequency band (0.1–10 Hz). This is a useful passband for seismic P waves. The MERMAID float depth is too close to the surface to record low frequency waves (surface waves, normal modes) for which the pressure perturbation increases only slowly with depth from zero at the surface. The pressure signal is continuously analyzed by comparing energy averages over a short time window with that over a long-time window. When the STA/LTA or signal-to-noise (SNR) ratio triggers an alert, a wavelet decomposition is computed. Seismic P waves are efficiently converted to acoustic waves at the sea bottom and have a distinctive signature characterized by the power in different wavelet scales, but converted S waves have only been observed at intermediate distance ($<20°$). A measure of wavelet power, combined with the SNR, may trigger a return to the surface for transmission of the seismogram per satellite (Iridium). For specific details of the algorithm, see Sukhovich et al. (2011). If the detected signal is characterized as a P wave but rated too weak, it is recorded in a buffer to be transmitted later by Iridium. On surfacing, the major events are always transmitted first.

This signal discrimination is necessary to optimize the cost of data transmission and limit power consumption. However, continuous sampled data are stored in a circular buffer with a capacity of 6 Gbytes. Any signals missed by the algorithm can be retrieved using two-way communication by satellite, and continuous signals can be read from the buffer when the float is recovered.

A Typical Mission

A typical recording cycle comprises several stages. The first stage is the descent. The acoustic detection algorithm is activated during the second stage when it drifts at the assigned depth for a specified duration. This second stage may be cut short if the acquisition board detects a seismic signal of significant amplitude. The hydrophone data acquisition is stopped before the ascent, to avoid interference of pump noise with earthquake detection algorithm. Once at the surface, the float fully fills its oil bladder to gain maximum buoyancy for optimal satellite communication even in high seas.

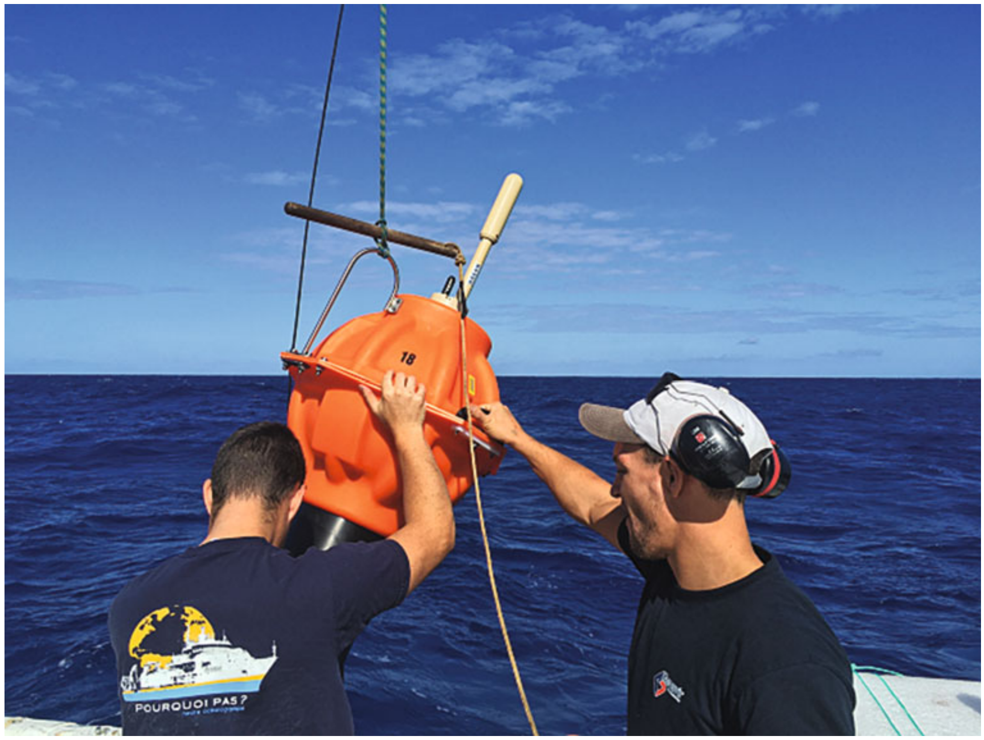
The float uses the GPS signal to get its geographical coordinates and to calculate the internal clock drift prior to synchronizing the clock on the MERMAID acquisition card against GPS time. GPS and Iridium communication system use the same helical special antenna to receive and transmit. Two-way communication allows for a command file containing float parameters such as depth and trigger level for the next dive to be downloaded. Seismograms are transferred to the SD card of the pilot board which performs the Iridium data upload. The float drift at depth is typically 4 km/day and rarely exceeds 10 km/day, whereas drift at the surface is usually between 1 and 2 km/hr; drift measurements by repeated GPS localizations allow for an accurate extrapolation of the float position during recording at depth (Nolet et al. 2019). Voltage level, internal vacuum, and external pressure are measured and a last GPS fix for MERMAID's clock synchronization is obtained before diving again.

If a major earthquake occurs in an area covered by one or more MERMAIDs, the floats have the option to revert to "lander" mode. This means that they can be commanded go down to the ocean bottom and stay anchored, much as an ocean bottom hydrophone (OBH). They can transmit recorded aftershock data by surfacing at programmed intervals until commanded to revert to their original mission at the end of the swarm. Similarly, landers can be rapidly deployed for this purpose as an OBH network to monitor aftershocks of a large earthquake. Continuous recordings may be recovered at the end of a rapid response campaign while transmitting identified events in quasi-real time at every surfacing.

Deploying Mermaid can be done by simply pushing it overboard from a small vessel, or using a crane or U-Frame from a research vessel (see Fig. 3). To recover a Mermaid, it can be commanded to stay at the surface and send its geographical coordinates. It can be lifted aboard by hand from a small vessel or with a snap-hook and a crane on a larger vessel.

Other Sensors

The MERMAID is a very recent addition to seismic instrumentation, but in its current version integrates functionality for oceanography, notably the option to accommodate a Seabird SBE 41 Conductivity Temperature Depth (CTD) sensor to measure salinity and temperature down to 4000 m depth. These data are compatible with the Argo program to monitor temperature, salinity, and abyssal currents in the oceans (Riser et al. 2018). The next development is a fully multidisciplinary Multi-MERMAID hosting multiple sensors.



Floating Seismographs (MERMAIDS), Fig. 3 A Mermaid being deployed from a research vessel

Multi-MERMAID

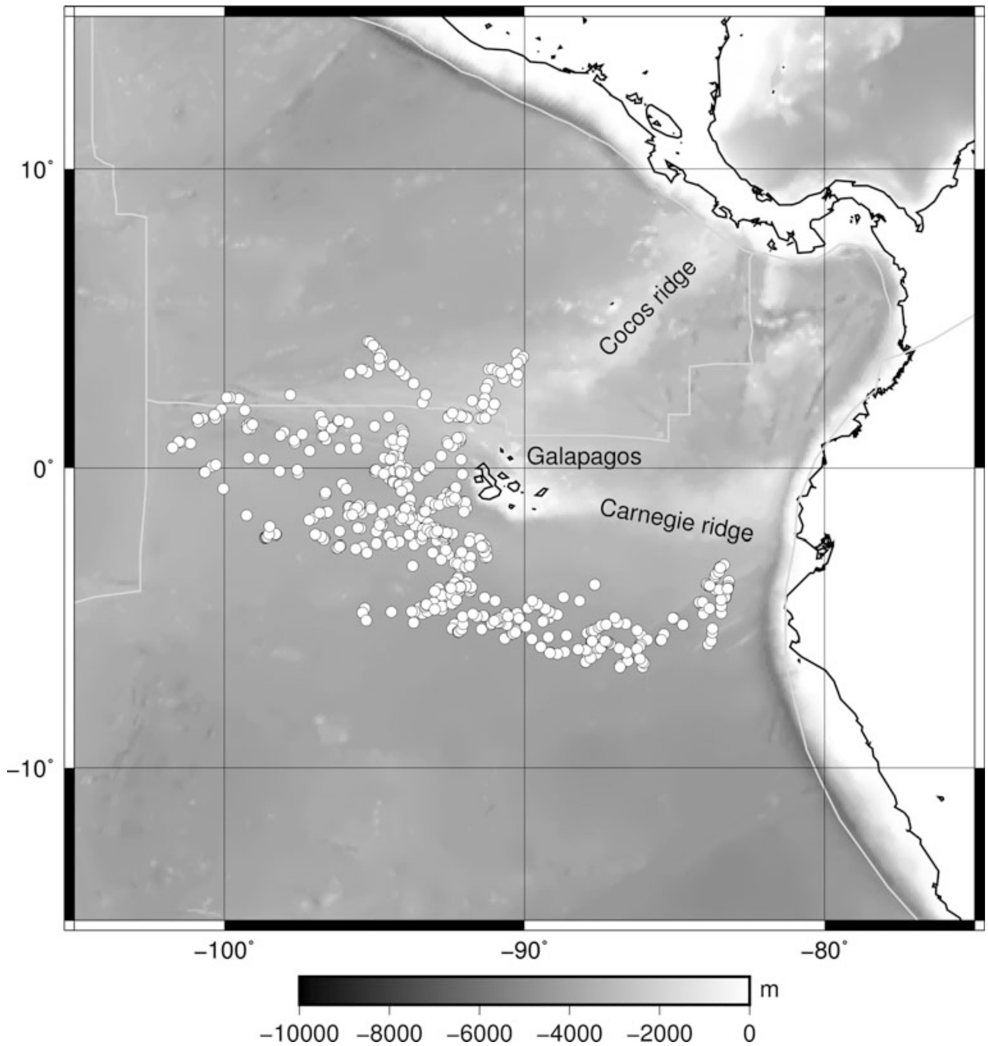
The MERMAID board is equipped with eight channels for external sensors. For example, a high frequency hydrophone allows for the monitoring of rainfall and storms over the oceans; cracking and sliding of ice sheets and icebergs; tracking of whales and ecological stressors (ship and airgun noise). Sensors for bathymetric, magnetic, optical, geochemical, or biological measurements can also be added. Flexibility is obtained by allowing the data management by the MERMAID board to be programmed by the scientists. A Domain Specific Language is scheduled to be operational in 2020. The software can be updated using two-way communication by satellite.

Recent Results

Sukhovich et al. (2015) showed that a large fraction of earthquakes with magnitude >6.5 are detected by MERMAIDs (35–63%, depending on the signal to noise ratio being higher than the programmed threshold, typically 2–3). Although they are a very recent addition to seismic instrumentation, Mermaids have already contributed scientific results of significance. Sukhovich et al. (2015) recorded more than 200 events of an earthquake swarm near the Indian Ocean triple junction that were not observed by land stations. His analysis showed the ability of Mermaids to detect nearby earthquakes with Richter scale magnitudes below 3. Nolet et al. (2019) used an array of 9 first generation MERMAIDs in the Pacific to image the plume under the Galapagos islands. This study resulted in a significant increase in image resolution in the upper mantle, due to the fact that the sensors change their position continuously, thus avoiding redundant ray paths (Fig. 4). Analysis of the images showed that the Galapagos plume carries a heat flux that is a factor of 6–7 higher than was assumed earlier on the basis of the bathymetry. Since 2019, a large network of 49 Mermaids is operating in the South Pacific in an effort to image the "superplume" beneath Tahiti (Simon 2020).

Summary

Floating seismographs have been made possible by recent advances in satellite communication, GPS miniaturization, low power high performance electronic components, and increased battery capacities. Though limited to the recording of acoustic (P) waves in the water columns, they can cover large areas and offer a low-cost complement to OBS deployments. They bring detailed resolution to seismic tomography and the option of a fast response to monitor aftershocks or seismic swarms.



Floating Seismographs (MERMAIDS), Fig. 4 The locations of 9 MERMAIDS at the time of recording of 580 P waves for which an arrival time could be measured, between May 2014 and October 2016. (Modified after Nolet et al. 2019)

Cross-References

- ▶ Earth Structure, Global
- ▶ Earthquake, Magnitude
- ▶ Ocean Bottom Seismometers
- ▶ Seismic Instrumentation
- ▶ Seismic Noise
- ▶ Seismic Tomography
- ▶ Seismicity, Intraplate
- ▶ Seismicity, Subduction Zones
- ▶ Seismogram Interpretation
- ▶ Seismological Networks

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