https://phys.org/news/2020-09-temperature-ocean.html)

Seismic sound waves crossing the deep ocean could be a new thermometer

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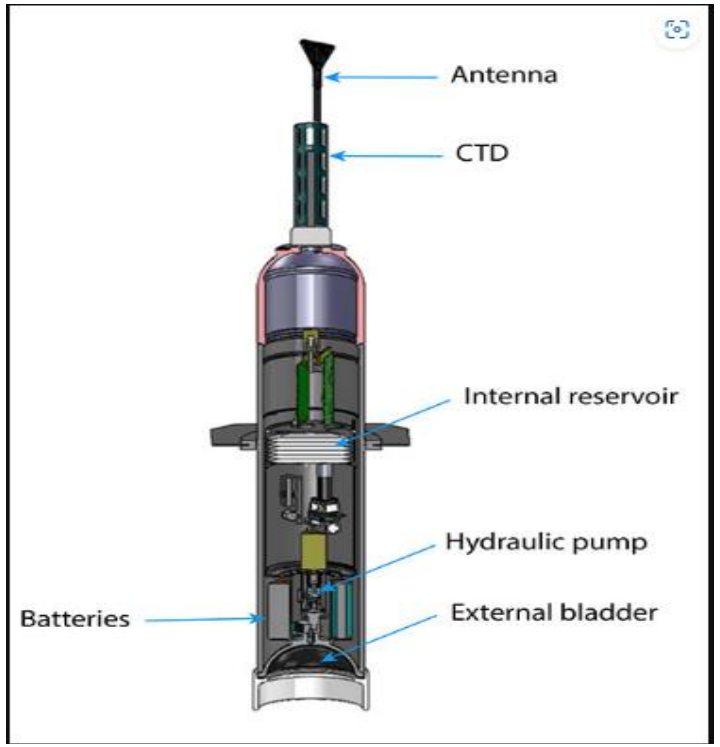
Introduction

- Global warming causes the planet to heat up, and scientists continue to study its effects. Among these areas of research are the **oceans**.
- According to some models, the oceans absorb about 90 % of the excess heat generated by greenhouse gases.
- As a result of the ocean's vastness and numerous variables, scientists do not know how much warmer the ocean has become.
- Making a long-term change in ocean warmth a major factor in how the world might respond to global warming
- A climate scientist needs accurate information on the ocean's warming. However, obtaining precise temperature measurements, at multiple depths and locations, is a huge challenge.
- To know the amount of temprature on the global and the oceans, scientists use Argo floats global system, man-made sound sources, and T-waves to find fluctuate climate change on the globe.

Argo

- Among the methods of measuring ocean temperatures and salinity is Argo.
- Argo is a network of thousands of robots that measure temperature, salinity, and other ocean conditions.
- Established in late 1990 and is a global system.
- Argo is a 2 m long, freely drifting robotic device
- Has antenna, CTD (conductivity, temperature, depth), interior reservoir, and exterior bladder.



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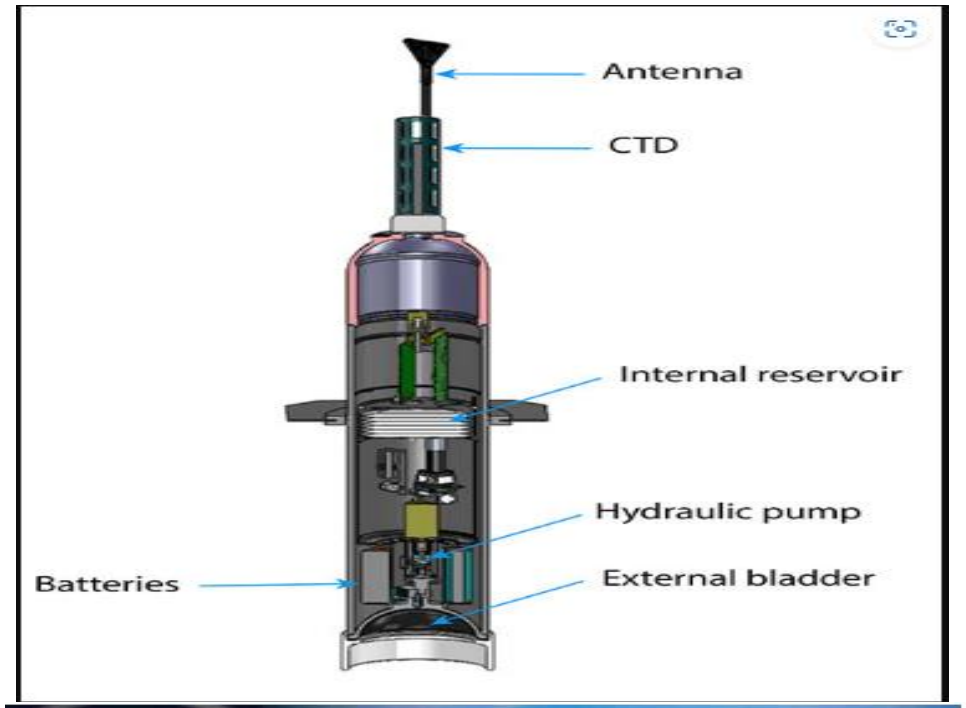
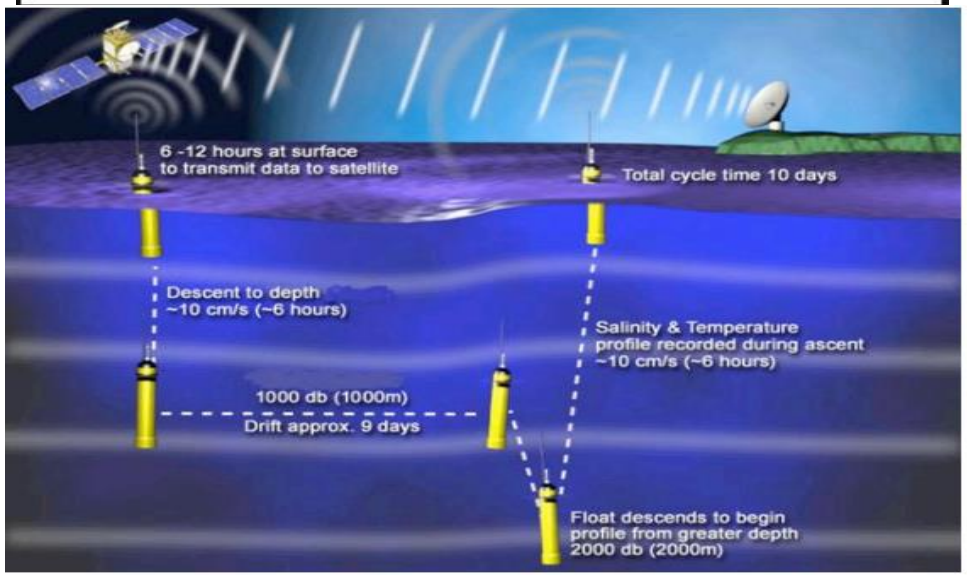
Argo (continue)

- 4, 000 autonomous floats drift the globe.
- 10-day cycle.
- Drafting along with the deep ocean.
- Float is on the surface, it receives its location, often through **GPS.**
- Communicate with a **satellite**.
- Has a **15-minute to one-hour** surface transit time.
- Once the float has sunk to **1000 meters** of drift depth, it sinks to **2000 meters** of profile depth before slowly rising to the surface.
- Measure conductivity, temperature, and pressure.
- Die after four to five years.





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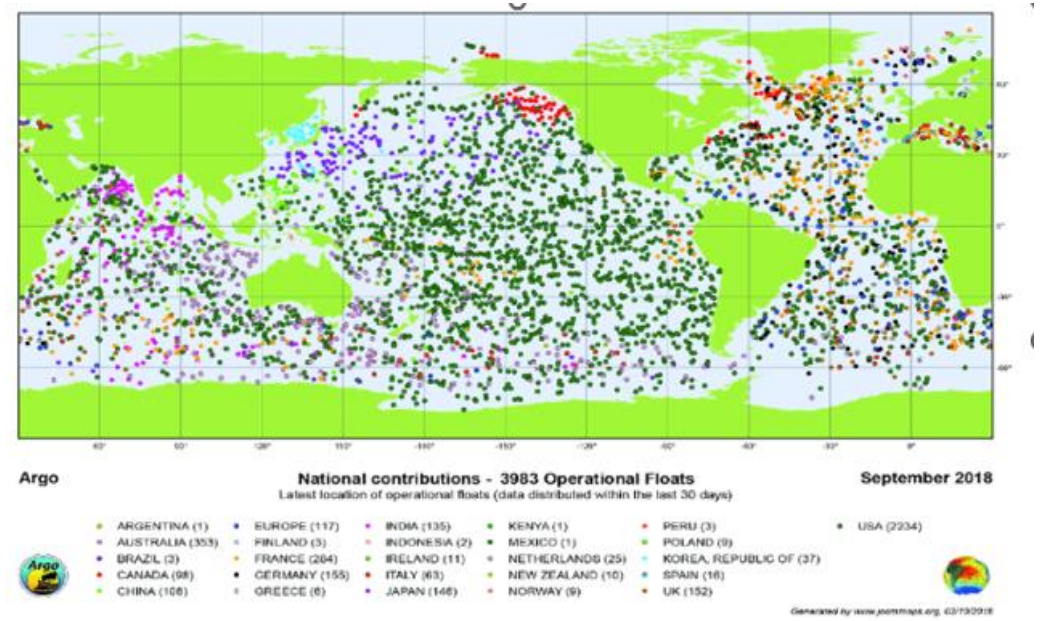
Argo (continue)

- Global ocean observing system
- over 30 nations across continents are part of the Argo program.
- 3,900 floats
- Where can you get the data and how much does it cost?
- Who uses the data?

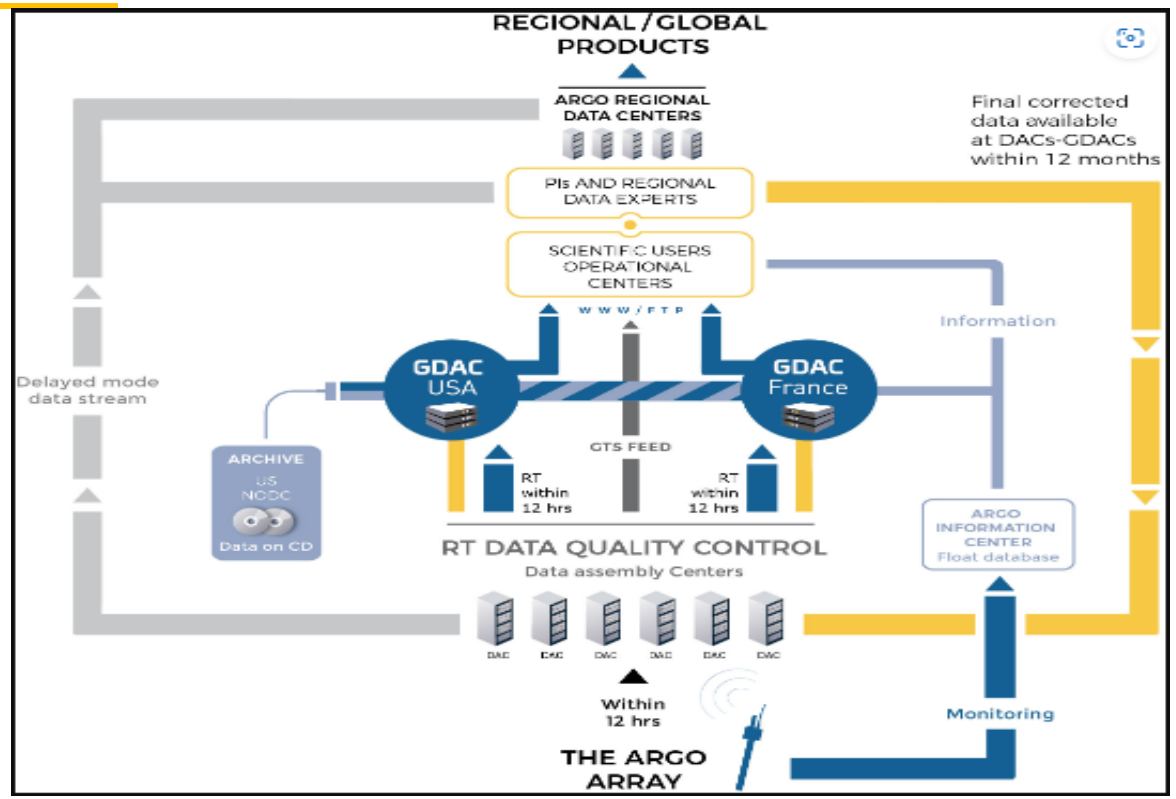


Global map of operational Core Argo floats, by nation, in September 2018 (Source: JCOMMOPS).

| Global map of operational Core Argo floats, by nation, in September... | Download Scientific Diagram (researchgate.net)

Argo (continue)

- Argo has Global Data Assembly Centers:
  - USA
  - France



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Argo (continue)

Limitation:

- Argo measurement stops at 2, 000 meters.
- Ship-based measurements involve collecting data from the sea surface and then shipping the data back to shore for analysis.
- very costly and time-consuming process and deploying sensors on ships or buoys can be expensive and require multiple trips to the exact location.
- Although Argo floats have greatly assisted in capturing temperature data, there are still many gaps in our understanding. Especially true in the case of waters deeper than 2,000 meters.

Ocean acoustic tomography

- Developed by **Walter Munk and Carl Wunsch in 1975**.
- A technique used to measure the **temperature**, **salinity,** and **current speeds.**
- Measures how long **sound signals** take to travel from an **acoustic source** to a **receiver.**
- Sound waves travel faster in warm water than in cold water.
- Experiment conducted in 1981.
- The ranges are separated by 100-5,000 km.
- A 1 °C (1.8 °F) is equivalent to 4 m/s or (13 ft/s).
- Measurements are providing a detailed picture of how the ocean is changing and how it affects the global climate
- The idea was ultimately scrapped in order to protect marine mammals from the potential negative impacts of sound waves.

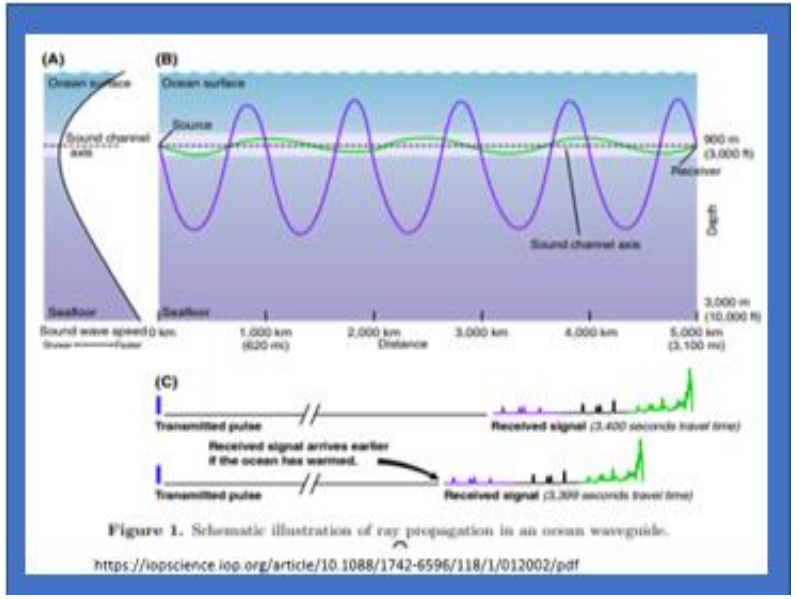
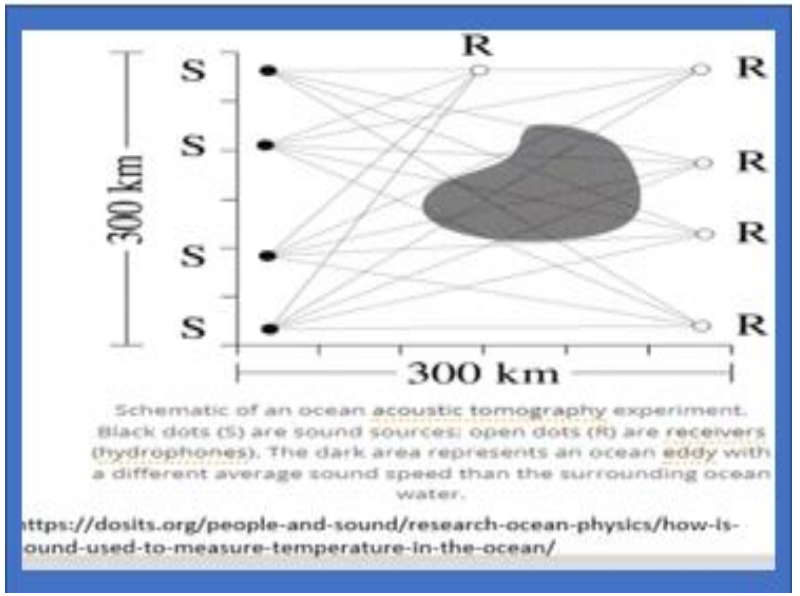


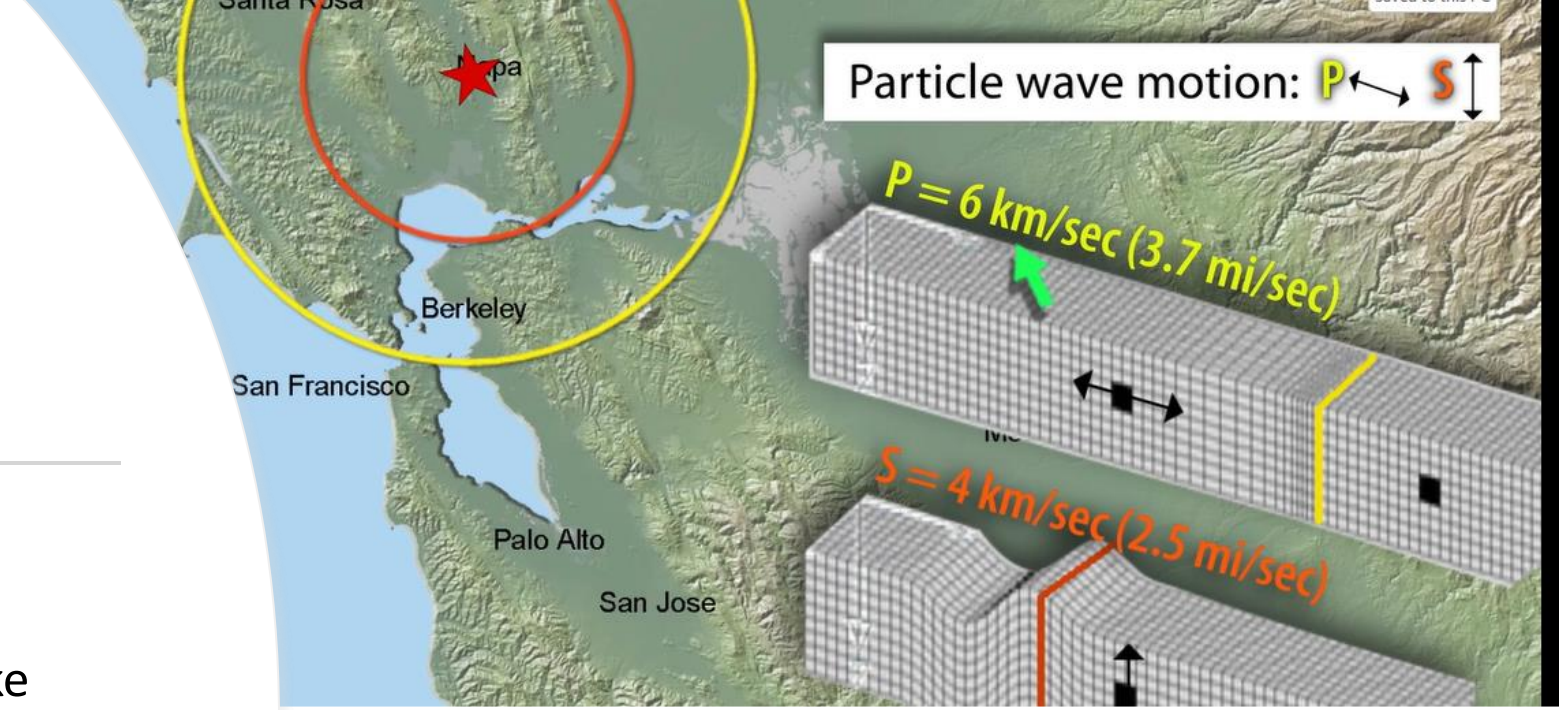
Figure 1. Schematic illustration of ray propagation in an ocean waveguide.
https://iopscience.iop.org/article/10.1088/1742-6596/118/1/012002/pdf

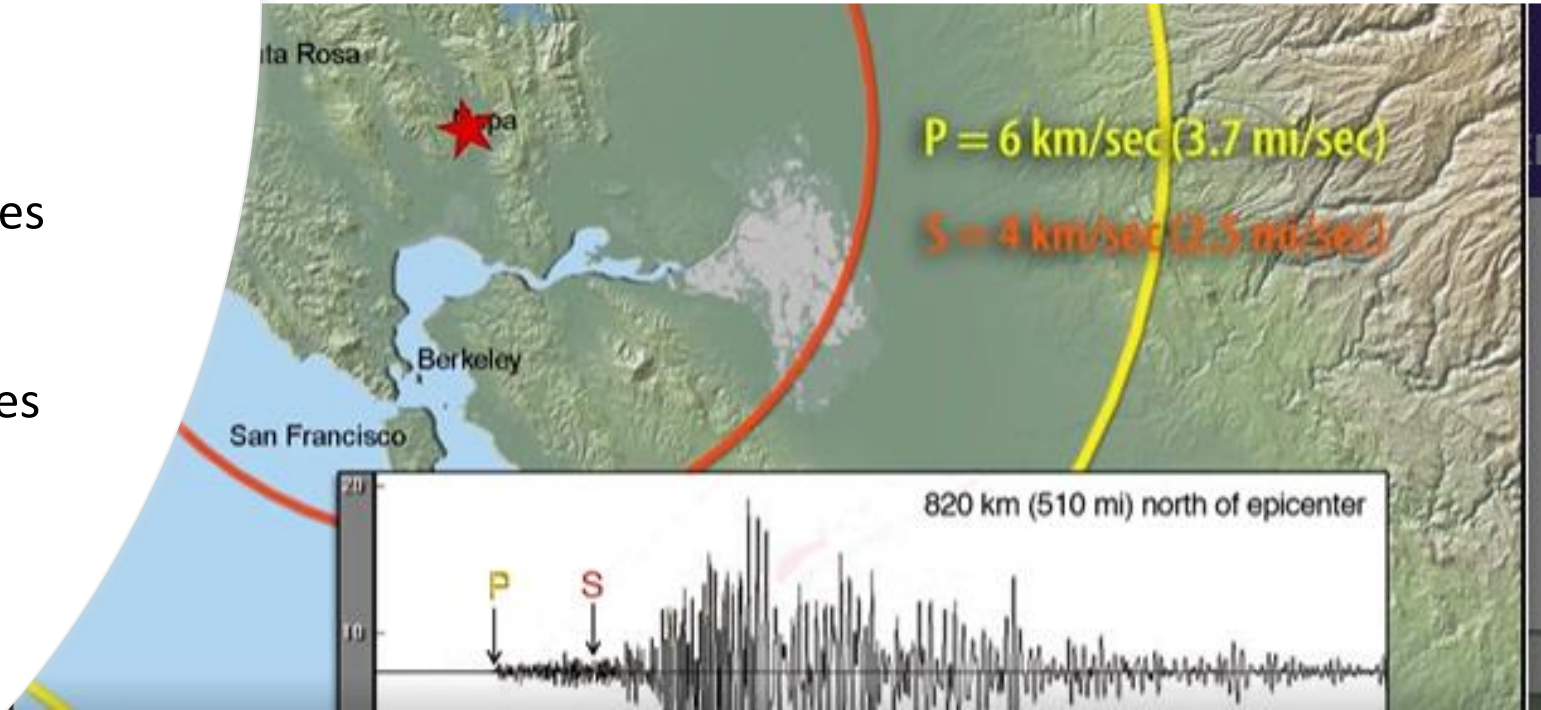


Schematic of an ocean acoustic tomography experiment. Black dots (S) are sound sources; open dots (R) are receivers (hydrophones). The dark area represents an ocean eddy with a different average sound speed than the surrounding ocean water.
https://dosits.org/people-and-sound/research-ocean-physics/how-is-sound-used-to-measure-temperature-in-the-ocean/

Seismic wave

- The new approach involves using the naturally produced sound waves that occur when an underwater earthquake strikes.
- As a result of an earthquake, seismic waves are created in the ocean.
- **Seismic waves** produced by earthquakes subtly change velocity or direction as they pass through different materials.
- There are several types of seismic waves released by earthquakes:

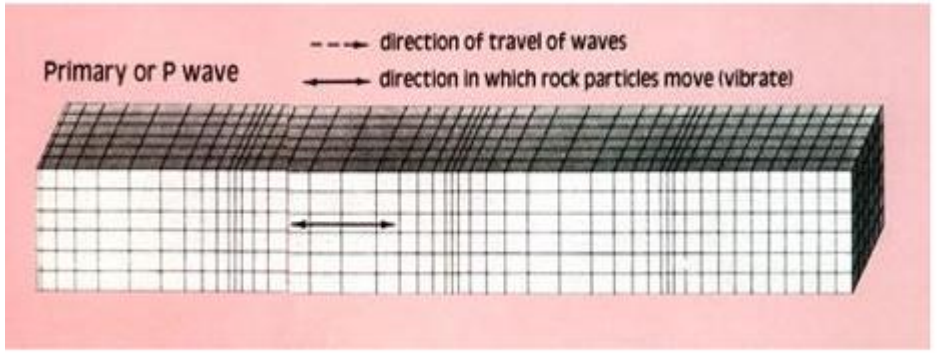




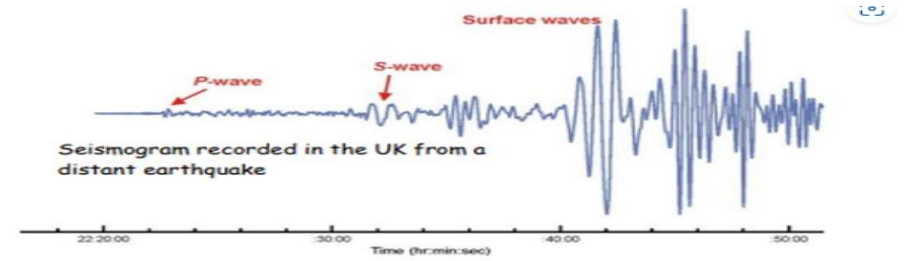
Seismic wave (continue)

- **Primary wave or P-wave**
- **Secondary wave or S-wave**
- **Tertiary wave or T-wave**

- **Primary wave or P-wave**
  - Is faster than any other seismic wave.
  - travel through solid, liquid, and gas.
  - has shorter wavelengths



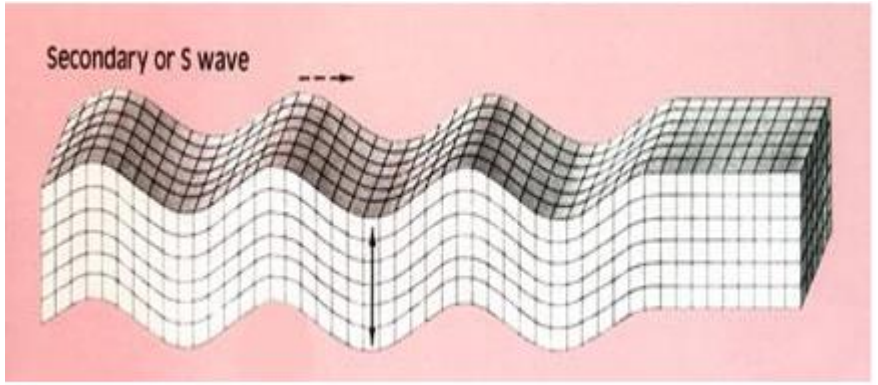
https://www.iris.edu/hq/inclass/animation/p_wave_vs_s_wave



Seismogram showing the arrival time sequence of P-, S- and surface waves from a distant earthquake. ©UKRI. All rights reserved.

Seismic Wave (continue)

- **Secondary wave**
  - Transverse Slower
  - Travels through solids only
  - has long wavelengths



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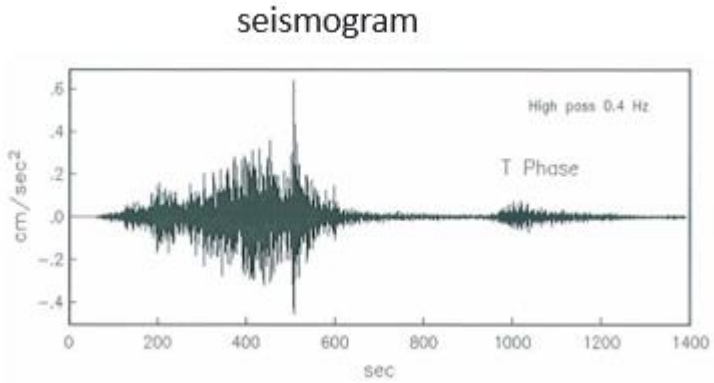
Seismic Wave

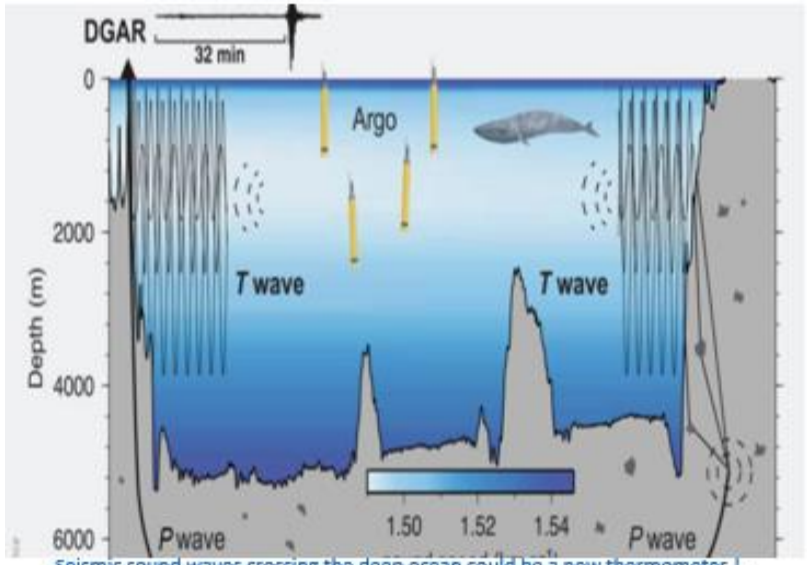


Tertiary or T-wave:

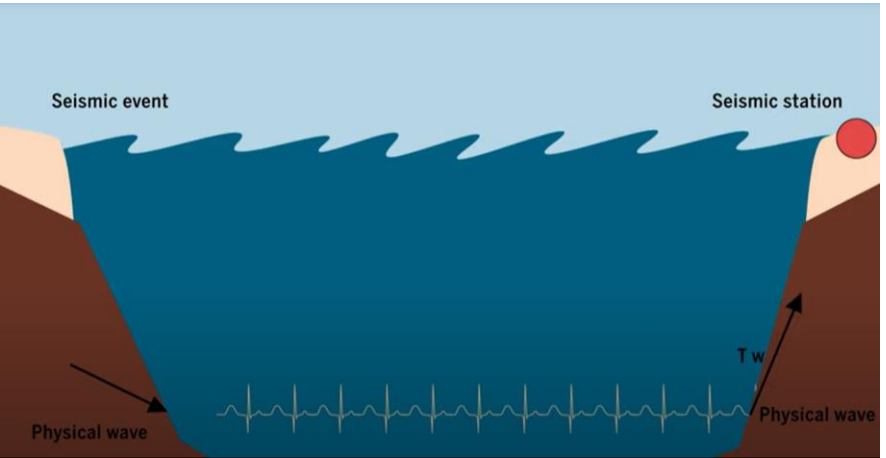
- T-waves are underwater acoustic waves generated by earthquakes
- Deliver valuable data about ocean temperature.
- T-wave speed is sensitive to water temperature. With warmer water slowing it down.

Seismometer:

- Used to detect very small differences in timing, so this is capable of measuring changes of much less than 1 degree Celsius



[1] [6] Seismic sound waves crossing the deep ocean could be a new thermometer | Ars Technica



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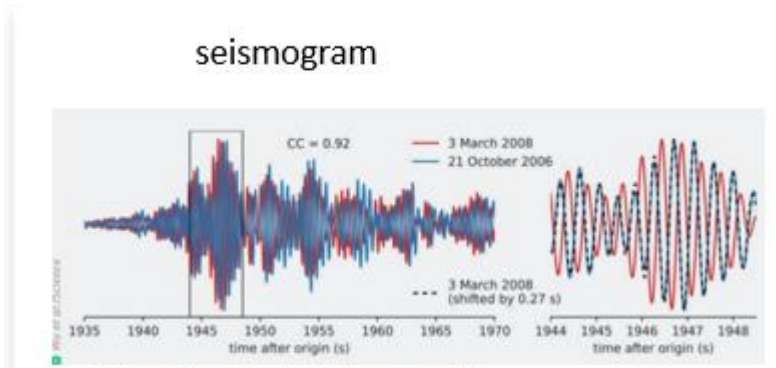
Seismic wave

- Sumatra region is one of the most seismically active zones on earth.
- Located at the boundary between the Indian and Eurasian mountain plates.
- Between 2004 and 2016, over 4,000 earthquakes of 3.0 or more occurred in Sumatra.
- Due to the active seismic plate boundary there, earthquakes often occur
- The researchers carefully processed all of these events to find “repeaters”, earthquakes with almost identical origins and power
- Researchers found over 2,000 such pairs based on 900 earthquakes.
- Measuring slow-moving signals taken to travel across the waters from **Sumatra** to a monitoring station on the island of **Diego Garcia.**
- researchers work out the changes in temperature for the whole of the ocean over the **10-year period.**

Seismic wave (con)

- Sound waves about half an hour to travel from **Sumatra to Diego Garcia**,“
- The temperature change between Sumatra and Diego Garcia affects the half-hour travel time by tenths of a second.
- With these measurements, researchers are able to detect changes in the deep ocean's average temperature by approximately one-tenth.
- Takes 5.4 seconds longer for earthquake T-waves to reach this **seismometer** at Diego Garcia
- Thus, it is clear the observed changes in seismic waves are indicative of changes in the Indian Ocean's temperature



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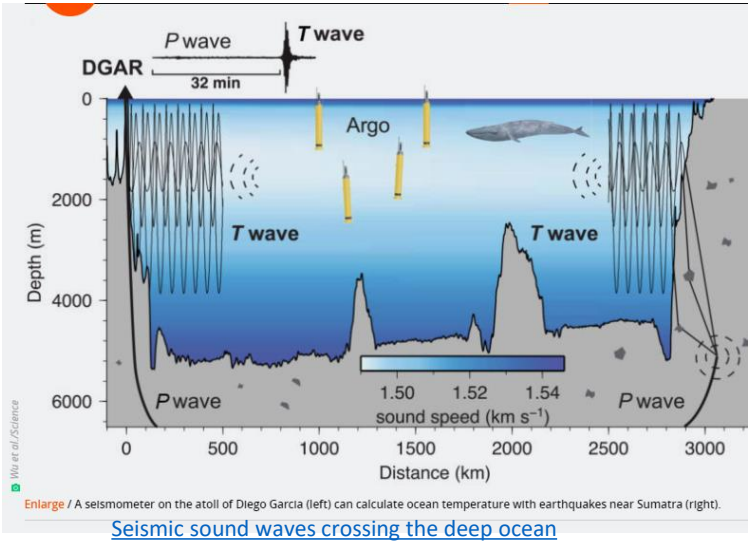

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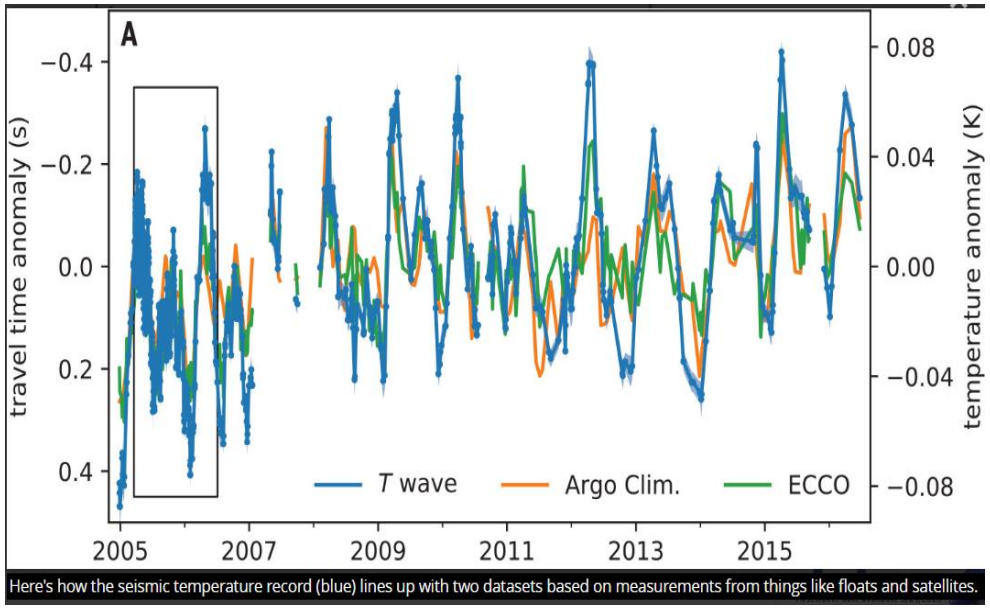
Seismic ocean thermometry

- The trend, however, is slightly larger according to seismic ocean thermometry.
- As compared to estimates from the automated Argo floating array dataset, the researchers believe their estimate is reasonable.
- Argo shows a warming trend of 0.026° C per decade over the same time period
- According to seismic estimates, temperatures are expected to rise by 0.044°C per decade



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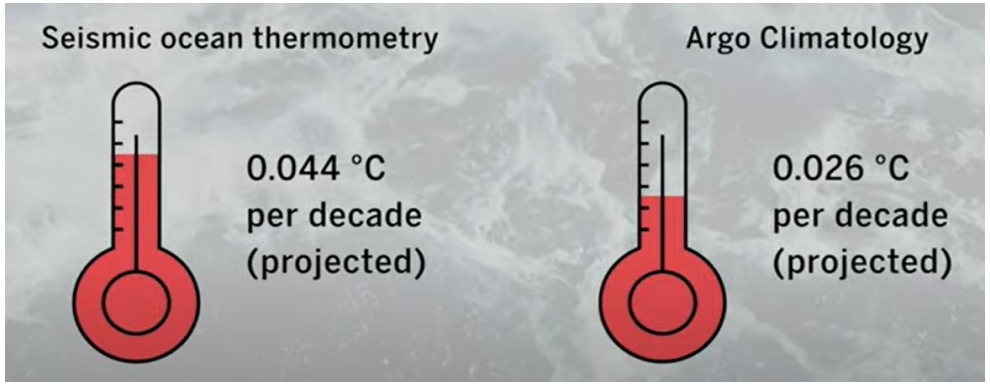

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Conclusion

- Based on data and mathematical models, they found a temperature change of approximately 0.044° per decade over the past 10 years. A trend larger than those predicted by Argo.
- Finding that seismic ocean thermometry is an effective method of measuring changes in ocean temperature.
- It is relatively inexpensive since it uses existing data and is temperature-sensitive, since it does not require deploying a large number of new instruments.

Thank you
Q and A

reference

[1] https://escweb.wr.usgs.gov/share/mooney/SriL.II2.pdf
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