Step-Change or Slow-Change?

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1. Introduction

In order for me to describe what the above title means, I need to start with an explanation. First, of all the major ocean currents are connected, so that if one undergoes a major-change, they all are affected to some degree. In order to get a correct explanation of these, I started with a term that I am already familiar with: The Meridional Overturning Circulation, and asked Microsoft Bing for an explanation of this, and the following was the result:

The Meridional Overturning Circulation is a global ocean conveyor belt that moves warm surface water northward and cold deep water southward, redistributing heat, salt, carbon, and nutrients, and playing a critical role in regulating Earth's climate.[1]

1.1. Overview of the MOC

The Meridional Overturning Circulation (MOC) is a system of ocean currents that primarily moves water in a north-south direction across the globe. In the Atlantic Ocean, this system is known as the Atlantic Meridional Overturning Circulation (AMOC). Warm, salty surface water flows northward from the tropics toward the North Atlantic, where it cools, becomes denser, and sinks to form deep water, such as the North Atlantic Deep Water (NADW). This deep water then flows southward toward the Southern Ocean and eventually circulates into the Indian and Pacific Oceans, completing a global loop.

1.2. Mechanisms Driving the MOC

The MOC is driven by thermohaline circulation, which depends on differences in water temperature and salinity. Warm, saline water is less dense and remains near the surface, while cooling and evaporation in high-latitude regions (located near the poles) increase water density, causing it to sink. This sinking motion pulls more warm water northward, sustaining the circulation. Surface currents, such as the Gulf Stream and North Atlantic Current, transport heat northward, while deep-ocean currents carry cold water southward.

1.3. Role in Climate and Ecosystems

The MOC is crucial for regulating global and regional climate. By transporting heat from the tropics to higher latitudes, it keeps northwestern Europe warmer than it would otherwise be and influences rainfall patterns, monsoons, and hurricane activity. The circulation also moves nutrients and carbon throughout the oceans, supporting marine ecosystems and acting as a carbon sink.

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[1] Query of Microsoft Bing to describe the "meridional overturning circulation". Bing retuned multiple sub-descriptions, but this link was primary: https://en.wikipedia.org/wiki/Atlantic_meridional_overturning_circulation

1.4. Observed Weakening and Potential Impacts

Recent studies indicate that the AMOC has been gradually weakening over the past decades, with observational data showing a decline of about 15% since the mid-20th century, likely due to freshwater input from melting Greenland ice and climate variability.

A Weaker MOC Could Lead to:

- *Colder winters in Europe and altered rainfall patterns in Africa and South Asia*
- *Accelerated sea-level rise along the U.S. East Coast*
- *Changes in hurricane intensity and tropical storm patterns*
- *Reduced nutrient transport, affecting marine ecosystems and fisheries*

While some models predict a potential collapse of the AMOC by the end of the century under extreme scenarios, current evidence suggests a gradual weakening is more likely, though the system remains a critical climate regulator.

Monitoring and Research

Scientists monitor the MOC using oceanographic arrays, satellite data, Argo floats, and seafloor instruments to measure temperature, salinity, and currents across multiple latitudes. Long-term observations are essential for understanding variability, validating climate models, and predicting regional climate impacts.

Conclusion

The Meridional Overturning Circulation is a vital component of Earth's climate system, acting as a planetary conveyor belt for heat, salt, carbon, and nutrients. Its ongoing weakening has significant implications for global climate, sea levels, and ecosystems, making continuous monitoring and climate action essential to mitigate potential impacts.

2. Argo Floats

Given the explanation in section 1 above, I wanted to study how our oceanographers are investigating this. I already knew about the system named the same as this section title. These are explained below.

Argo is an international program that collects information from inside the ocean using a fleet of robotic instruments that drift with the ocean currents and move up and down between the surface and a mid-water level. Each instrument (float) spends almost all its life below the surface. The name Argo was chosen because the array of floats works in partnership with the Jason earth observing satellites that measure the shape of the ocean surface. (In Greek mythology, Jason sailed on his ship Argo in search of the golden fleece).[2]

[2] https://argo.ucsd.edu/

2.1. What are this Fleet's Goals?

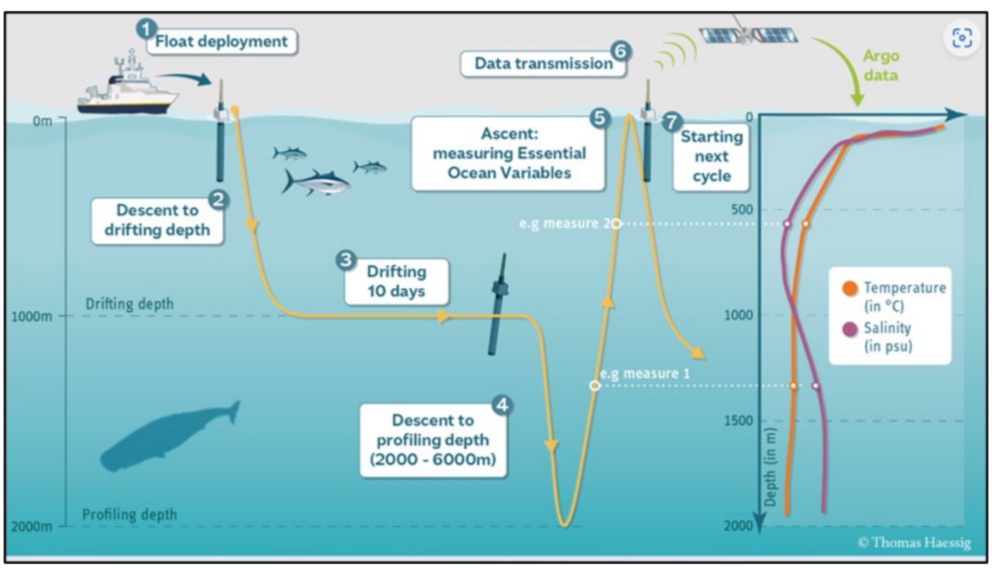
The data that Argo collects describes the temperature and salinity of the water and some of the floats measure other properties that describe the biology/chemistry of the ocean. The main reason for collecting these data is to help us understand the oceans' role in earth's climate and so be able to make improved estimates of how it will change in the future.

For example, the changes in sea level (once the tides are averaged out) depend partly on the melting of icecaps and partly on the amount of heat stored in the oceans. Argo's temperature measurements allow us to calculate how much heat is stored and to monitor from year to year how the distribution of heat changes with depth and from area to area. As ocean heat content increases, sea level rises, just like the mercury in a thermometer. Comparison of Argo's measurements with the Jason observations continue to give us new insights into how the oceans "work" that can be used to improve climate models.

At present (2024) Argo is collecting 13,000 data profiles each month (400+ a day). This greatly exceeds the amount of data that can be collected from below the ocean surface by any other method. Argo plans to continue its data collection for as long as those data remain a vital tool for a wide range of ocean applications of which understanding and predicting climate change is but one.

2.2. How does it work?

Each Argo float (costing between $25,000 and $185,000 depending on the individual float's technical specification) is launched from a ship. The float's weight is carefully adjusted so that, as it sinks, it eventually stabilizes at a pre-set level, usually 1 km. Ten days later, an internal battery-driven pump transfers oil between a reservoir inside the float and an external bladder. This makes the float first descend to 2km and then return to the surface measuring ocean properties as it rises. The data and the float position are relayed to satellites and then on to receiving stations on shore. The float then sinks again to repeat the 10-day cycle until its batteries are exhausted (see image below).



2.3. Data Delivery

The float measurements are sent to regional data centers where they are given rigorous quality checks and then passed to two global data centers from where they can be accessed by anyone wishing to use them. Some users have applications that require rapid access and so Argo aims for most "real-time" data to be available within 12 hrs. Other applications need a higher-quality version that replaces the real-time data after lengthy comparisons between nearby floats and between float data and information from research ships. A central rule for Argo is that all data are freely and openly available.

2.4. Data Visualizations

Argo data are stored in data files that first must be decoded before being readable. To address this difficulty for non-experts, several websites and web applications have been developed to showcase and interact with Argo data and metadata without having to understand how to decode it.

Author's comment: Note that the Reference 2 link has much more data on Argo, including links to data visualization and other tools and information.

2.5. Power Supply

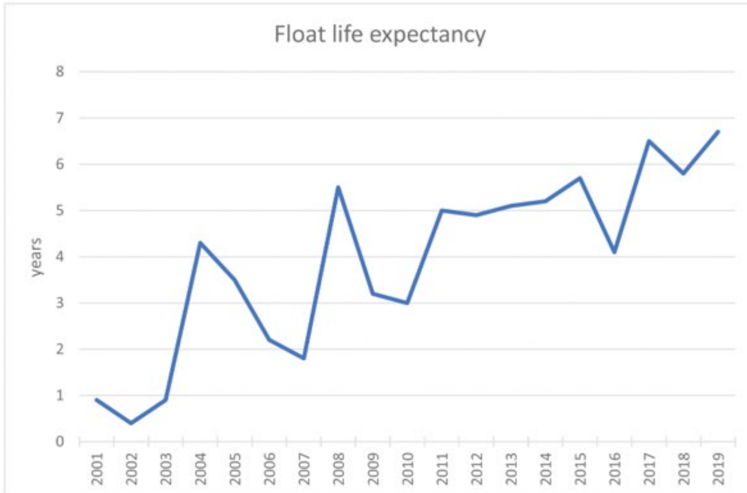
As I was approaching the posting date for this paper (like the day before), I was reading it one last time, and became curious about its power supply. From the text I was reading it sounded like it used a non-rechargeable battery, which I found curious. With a rechargeable battery there are many ways to recharge it, some of which would work in an under-water environment (see footnote 3 and go through the link therein).

I also drilled down through one of the earlier links and found some references for Argo power supply descriptions and excerpts from these are below.

If floats live for a long time, more profiles can be delivered and fewer floats need to be deployed each year. This helps keep the cost of the Argo Program from growing exponentially each year and reduces the pollution associated with float deployment. One of the most basic ways of extending float lifetimes is making sure that there is enough battery life inside the floats to power them for years. When Argo began in the early 2000's, all floats used alkaline batteries and had a goal float lifetime between 3- and 5-years. After monitoring technical data sent by floats, it became clear that after about three years, the alkaline batteries ran out of energy. A few alternatives were tested to improve the battery performance and now most Argo floats are powered by lithium or hybrid batteries. These batteries can cope better with colder conditions and also handle large current demands, like those needed to start the float ascent or descent. In addition, more battery packs were added to some float types that use lots of energy, like BGC (biogeochemical) floats that have 4 to 6 additional sensors. The figure on the next page shows the way that float life expectancy has increased over the years since Argo started.[4]

[3] Alternative Battery Energy Storage Chemistries, March 2026, https://www.energycentral.com/renewables/post/alternative-battery-energy-storage-chemistries-z05TocuvDakgGnN

[4] Argo, Technological innovations, Improving float lifetimes, https://argo.ucsd.edu/how-do-floats-work/technological-innovations/



2.6. International collaboration

There is no central funding for Argo. Each of the 30 countries that operate floats obtains their own national funding to buy floats, prepare and launch them and to process and distribute the data. The Argo Program is managed by teams of scientists and data experts who ensure that the program is run as efficiently and effectively as possible and that standards are maintained at the highest possible level. Argo is part of the Global Ocean and Global Climate Observing Systems. The total annual cost of Argo is estimated at least $40 million each year.