Department of Marine Sciences, University of Gothenburg

Project title : Global Trends of Mixed-Layer Properties
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Period : 5th Nov 2025 – 7th June 2026 (30 weeks)

Background

The ocean's surface mixed layer is the primary interface for climate regulation, governing the exchange of heat, momentum, and critical biogeochemical tracers between the atmosphere and the ocean interior. Properties of the Mixed Layer, including its temperature, salinity and depth, are impact weather patterns, marine ecosystem productivity, and the global carbon cycle (de Boyer Montégut *et al.*, 2004). Therefore, accurately quantifying their long-term trends is a fundamental challenge in climate science.

Global trends in temperature (Cheng *et al.*, 2024) have been reported, related to global warming. More difficult to estimate, a summertime trend in depth has also been reported (Sallée *et al.*, 2021) while the global trend in salinity remain uncertain due to large cancellations (Durack, Wijffels and Matear, 2012). The task of estimating these trends is complicated by the rapid evolution of the ocean observing system. The turn of the century has seen a transition from sparse, mostly ship-based measurements to a sampling dominated by autonomous profiling floats, provided much better spatial and temporal coverage. This abrupt change may generate systematic observational biases that need to be assessed.

A recent Master thesis work has identified the possibility of fictitious trends in mixed-layer depth related to the steep increase in profiling float data in the 2000s (Holmquist, 2024). This bias is particularly pronounced in regions of high mesoscale eddy activity and could therefore be related to over-sampling of certain eddies by the floats. Because autonomous floats drift with currents, they can be trapped within converging eddies, potentially leading to preferential sampling of certain MLD conditions (Dong *et al.*, 2008). On average, anticyclonic eddies are associated with deeper mixed layer (Gaube *et al.*, 2019). It is critical to better understand the origin of observationally based mixed layer trends and assess their robustness in relation to long-term climate change.

Purpose
During this project, the Master student will analyze the impact of observational sampling, both temporal and spatial, on estimated trends in mixed layer properties. A great emphasis will be put in assessing the effect of the introduction of profiling floats in the early 2000s, which deeply modified the observing system.

Method
In this study we will use the EN4 in-situ database of profiles as the reference. For each profile that is available, we will compute the MLT, MLS and MLD based on a density threshold method. We will then compute temporal trends for these properties, after removing a mean seasonal cycle.

To assess the impact of sampling, we will use the ECCO v4r4 reanalysis as a surrogate of the ocean state for the period 1992-2017. We will collocate ECCO at place and time of each profile available in EN4 and use these artificial data to reconstruct mixed-layer trends. They will be compared with the trends obtained using EN4 observations, blending the different data sources (CTD, Argo, MEOP) and computing the trends for each data source separately.

To analyze the impact of Argo data, we will also find pairs of Argo/CTD data and pairs of Argo/MEOP data obtained in similar location and time and analyze how they differ. The goal is to determine if there are systematic biases between different data sources.

To test the importance of mesoscale variability in producing potential biases, we cannot use ECCO because this product has a coarse, non-eddying resolution. Instead, we will use satellite altimetry (Aviso) to estimate the convergence/divergence nature of the local flow and analyze whether Argo profiling floats over-sample converging zones. Mesoscale eddies are classified as cyclonic (negative SSH anomaly) or anticyclonic (positive SSH anomaly). EN4 profiles will be grouped as cyclonic, anticyclonic, or neutral using the Okubo–Weiss criterion.

Preliminary dates
Written examination: May 27, 2026
Oral Examination: June 2, 2026

Feedback and contact with the supervisor will occur through mail, Zoom, telephone or in person. A meeting with the supervisor will be organized with a weekly nominal frequency.

Project schedule (30 weeks)

Weeks	Week numbers	Dates	Activity/work planned
1-5	45-49	5 weeks Nov 5 – Dec 9	Literature Review Download EN4/ECCO & Pre-processing (ML properties)
6-9	50 – 1	4 weeks Dec 10 – Jan 6	Analyze ML trends for EN4 and co-located ECCO and compare.
10- 16	2 – 8	7 weeks Jan 7 – Feb 24	Pair Argo profiles with CTD and MEOP and study statistics of the difference.
17 – 23	9 – 15	7 weeks Feb 25 – Apr 14	Compute Okubo-Weiss from altimetry. Classify all data points (cyclonic, anticyclonic, neutral).
24 – 29	16 – 21	6 weeks Apr 15 – May 26	Writing of report
30	22	1 week May 27 – June 2	Preparation of oral presentation

References

de Boyer Montégut, C. *et al.* (2004) "Mixed layer depth over the global ocean: An examination of profile data and a profile-based climatology," *Journal of Geophysical Research: Oceans*, 109(C12). Available at: https://doi.org/10.1029/2004JC002378.

Cheng, L. *et al.* (2024) "New Record Ocean Temperatures and Related Climate Indicators in 2023," *Advances in Atmospheric Sciences*, 41(6), pp. 1068–1082. Available at: https://doi.org/10.1007/s00376-024-3378-5.

Dong, S. *et al.* (2008) "Southern Ocean Mixed-Layer Depth from Argo Float Profiles," *Journal of Geophysical Research: Oceans*, 113(C6), p. C06013. Available at: https://doi.org/10.1029/2006JC004051.

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Gaube, P. *et al.* (2019) "Satellite Observations of Mesoscale Eddy-Induced Ekman Pumping," *Journal of Physical Oceanography*, 49(1), pp. 241–265. Available at: https://doi.org/10.1175/JPO-D-18-0126.1.

Holmquist, L.W. (2024) *Detectability of Global Trends in the Mixed-Layer Depth Since 1970*. Master's thesis. University of Gothenburg.

Sallée, J.-B. *et al.* (2021) "Summertime increases in upper-ocean stratification and mixed-layer depth," *Nature*, 591(7851), pp. 592–598. Available at: https://doi.org/10.1038/s41586-021-03303-x.