Unsupervised classification identifies coherent thermohaline structures in the Weddell Gyre

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Abstract

The Weddell Gyre is a dominant feature of the Southern Ocean and an important component of the climate system; it regulates air-sea exchanges, controls the formation of deep and bottom water, and hosts upwelling of relatively warm subsurface waters. It is characterized by extremely low sea surface temperatures, active sea ice formation, and widespread salt stratification that stabilizes the water column. Studying the Weddell Gyre is difficult, as it is extremely remote and largely covered with sea ice; at present, it is one of the most poorly-sampled regions of the global ocean, highlighting the need to extract as much value as possible from existing observations. Thanks to recent efforts of the EU SO-CHIC project, much of the existing Weddell Gyre data, including ship-based CTD, seal tag, and Argo float profiles, has been assembled into a coherent framework, enabling new comprehensive studies. Here, we apply unsupervised classification techniques (e.g. Gaussian Mixture Modeling) to the new comprehensive Weddell Gyre dataset to look for coherent regimes in temperature and salinity. We find that, despite not being given any latitude or longitude information, unsupervised classification algorithms identify spatially coherent thermohaline domains. The highlighted features include the Antarctic Circumpolar Current, the central Weddell Gyre, and the Antarctic Slope current; we also find potential signatures of the inflow of Weddell Deep Water and export pathways of Antarctic Bottom Water. We show how varying the statistical, machine learning derived representations of the data can reveal different physical structures and circulation pathways that are relevant to the delivery of relatively warm waters to the higher-latitude seas and their associated ice shelves.

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SO-WISE
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1) Introduction

The Weddell Gyre region is important for water mass formation and heat transport (e.g. to the undersides of ice shelves). Here we examine the climatological structure of the Weddell Gyre (approximate location shown by black oval) as revealed by a newly-curated dataset (credit EU SO-CHIC project).

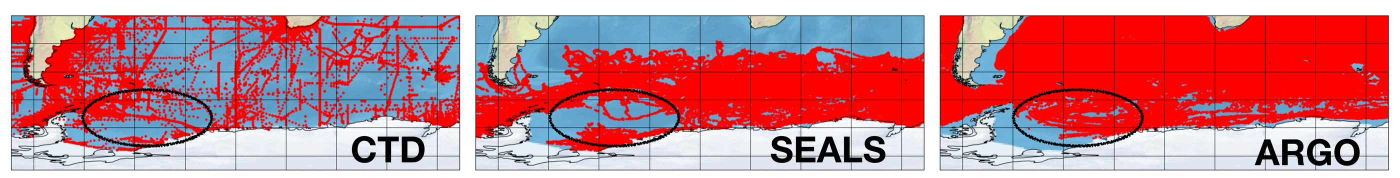

Fig. 1. Profile locations in the new SO-CHIC merged dataset.

2) Method: unsupervised classification

We use unsupervised classification to identify possible "profile types" and define regions in a robust, data-driven fashion

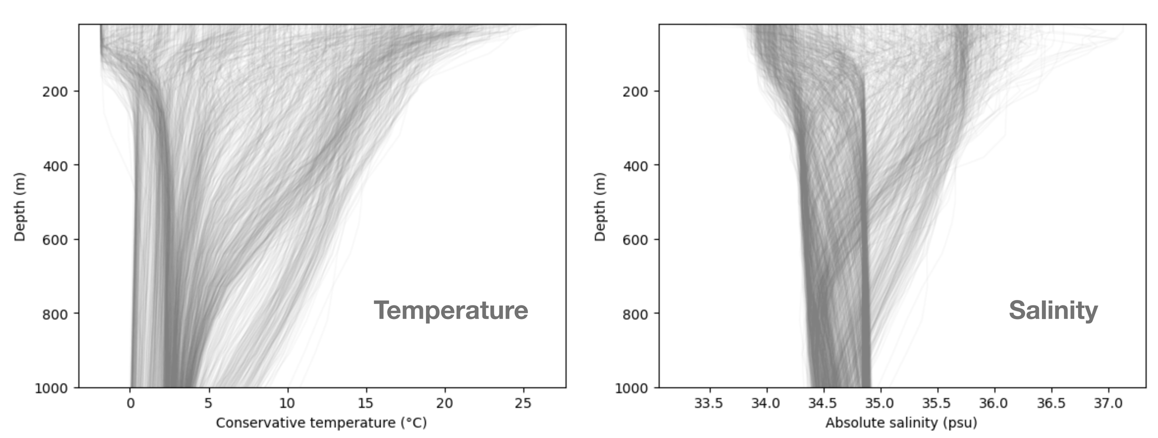

Fig. 2. Selection of conservative temperature (left) and absolute salinity (right) profiles. We use Gaussian mixture modeling (GMM) to identify profile types (e.g. Maze et al. 2017, Jones et al. 2019, Rosso et al. 2020, Boehme and Rosso, 2021).

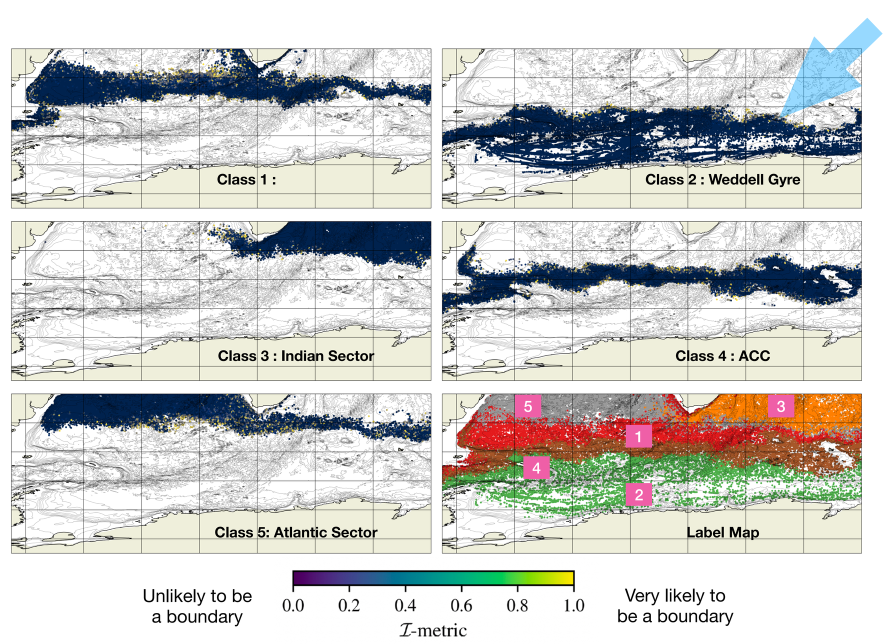

Fig.3. When applied to the top 1000 m of the entire SO-CHIC dataset, we can identify a near-Antarctic class (class 2, see blue arrow). It is the only class that is salt stratified in the near-surface layers.

Shading is the *I*-metric, indicating the probability that a profile is at a class boundary (Thomas et al. 2021). The class label map is shown in the bottom right.

3) Subdividing the Weddell Gyre class (top 1000 m)

Different classification models may be suitable for different regions and depth ranges. The results of GMM depend on the dataset that it is trained on. Here we examine the Weddell gyre class substructure by sub-classifying class 2 from the previous section.

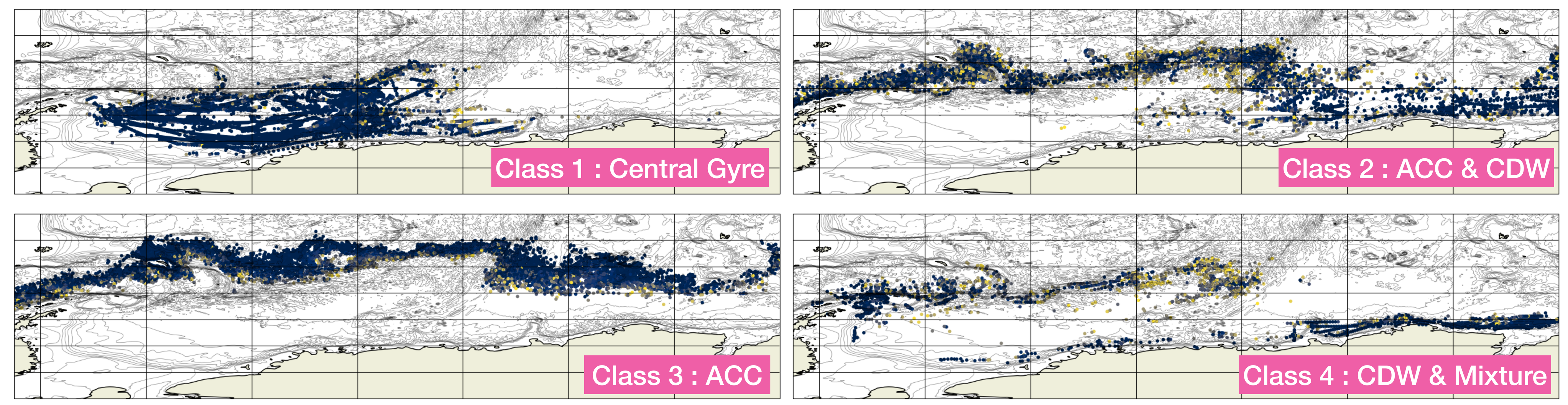

Fig.4. The Weddell Gyre class from part (2) can be sub-divided further into the above four profile types. Shown are the *I*-metric values for each of the four classes.

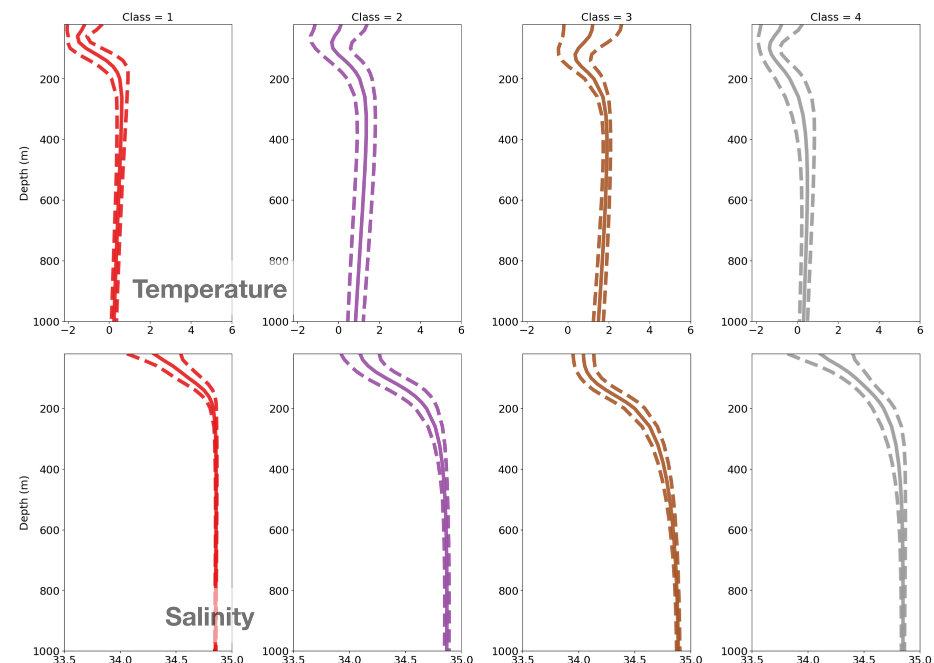

Fig.5. The temperature and salinity properties of the profiles. Solid lines indicate the class means, and dashed lines indicate +/- one standard deviation. The classes can be described as follows:

Class 1: Central Gyre. Especially cold and fresh at the surface, relatively uniform T/S over the subsurface. Located in the "core" of the Weddell Gyre.

Class 2: Antarctic Circumpolar Current (ACC) and Circumpolar Deep water (CDW). Consistent with the circulation of ACC and the entry of CDW into the Weddell Gyre along its eastern boundary.

Class 3: ACC. The northernmost edge of the salt stratified class, contained largely in the ACC. Relatively warm throughout the water column.

Class 4: CDW and mixture. Contains near-costal profiles and those along the boundary of ACC and gyre waters.

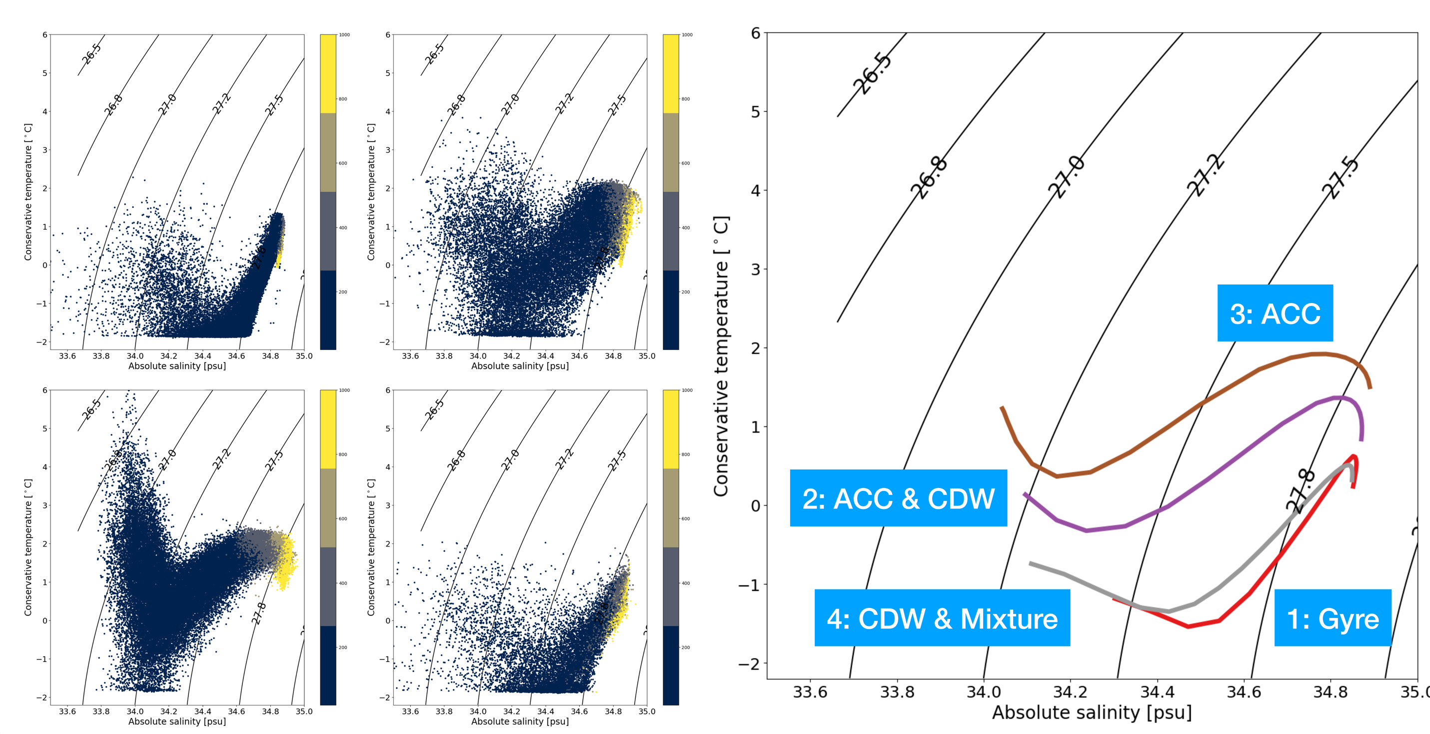

Fig.6. The classes as shown in temperature/salinity space. In the left four panels, each T/S value is shaded by depth. A single profile contributes a number of points to this plot. In the right-most panel, we plot the mean class values for each of the four classes.

4) Exploring the shelf (10-300m)

If we instead classify the top 10-300m, we arrive at a slightly different structure, with a somewhat clearer separation beteen gyre, ACC, and shelf profiles

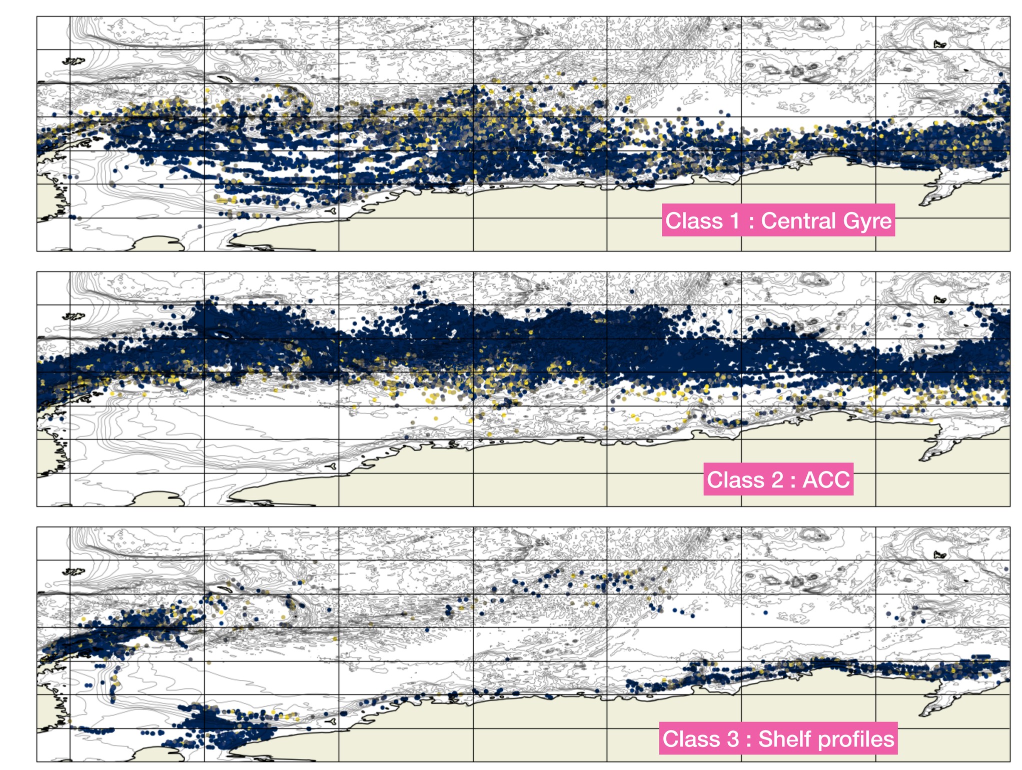

Fig. 7. *I*-metric values for the three classes derived from the 10-300m depth range.

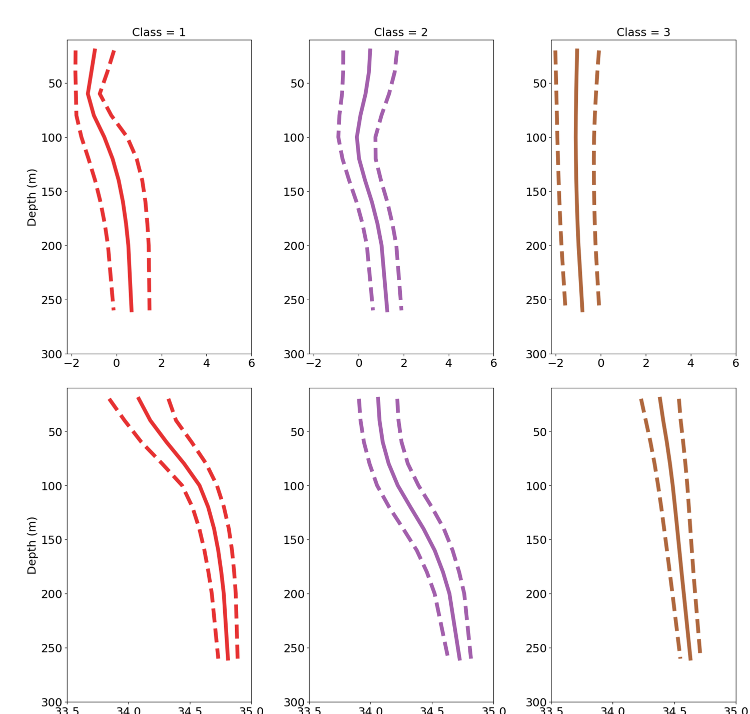

Fig. 8. Mean (solid line) and +/- one standard deviation (dashed lines) of the three classes derived from the 10-300 m depth range classification model. The gyre profiles (class 1) feature increasing temperature and salinity with depth. The mean ACC profile (class 2) features a subsurface temperature minimum. The mean shelf profile (class 3) is cold and relatively uniform, with relatively high salt values near the surface.

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