Identifying and comparing Antarctic continental shelf water masses in models and observations

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Abstract

A wealth of new climate model simulations have recently become available through the Coupled Model Intercomparison Project, Phase 6 (CMIP6). Evaluation of the representation of the Antarctic ocean across CMIP6 models is critical: projections of near-ice sheet temperature change will be used as input into sea level projections, and previous CMIP ensembles show substantial biases with a wide inter-model and inter-region spread. However, the ocean over the Antarctic continental shelf remains sparsely sampled, posing challenges for model-data comparison. Here, we assess a new clustering-based, grid-independent, methodology to identify and compare regional water masses, focusing on the Pacific sector of the Antarctic continental shelf. We find that temperature is insufficient to differentiate water masses, given the complexity and diversity of hydrographic profiles on the continental shelf. In contrast, clustering approaches applied to World Ocean Atlas 2018 temperature and salinity profiles identify "source" and "mixed" regimes that have a physically interpretable basis. For example, meltwater-freshened coastal currents in the Amundsen Sea, and High Salinity Shelf Water formation regions in the western Ross Sea, emerge naturally from the algorithm. We compare the location and properties of observed regimes to those found in the modern hydrographic state of the Community Earth System Model, version 2. Although CESM2 biases can be substantial, the locations of distinct regimes, and inter-cluster differences in water mass properties, are relatively consistent with observations. Differences in the locations and properties of hydrographic regimes are consistent with those expected from missing or poorly-represented physical processes (e.g. katabatic winds, ice shelf basal melting). We note other applications of this method, including the assessment of seasonal variability, and model-data comparison with different CMIP6 simulations and higher resolution regional ocean models.

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Introduction

The Antarctic Continental Shelf Seas (**ACSS**) are a critical, rapidly-changing, element of the Earth system. Global-scale general circulation model (**GCM**) simulations, including those available through the Coupled Model Intercomparison Project, Phase 6 (**CMIP6**), can help reveal the origins of observed changes and predict the future evolution of the ACSS. However, an evaluation of ACSS hydrography in GCMs is vital: previous CMIP ensembles exhibit substantial mean-state biases (reflecting, for example, misplaced water masses) with a wide inter-model and inter-region spread. Furthermore, the ACSS is sparsely sampled, posing challenges for model-data comparison.

Here, we apply K-means clustering to salinity and temperature fields from one GCM (the Community Earth System Model; **CESM**) and one observational product (the World Ocean Atlas; **WOA**), focusing on the Amundsen, Bellingshausen, and Ross Seas (Figure 1). The resulting objectively-defined "groups" facilitate comparison of **both** the spatial distribution and properties of ACSS hydrographic regimes.

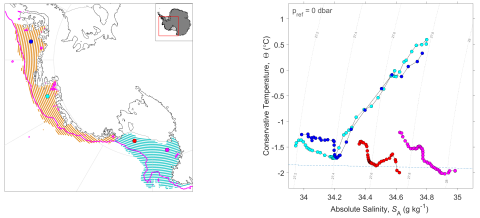


Figure 1 (left) The study domain. (right) T/S properties at four representative locations (corresponding to colored circles in map).

Methods

The K-means algorithm is applied to metrics calculated from decadal-mean (1995 to 2004) salinity and temperature fields from: 1) the 0.25-degree World Ocean Atlas (**WOA**) and 2) the Community Earth System Model (**CESM**) on its native grid. We find that physically interpretable groups can be identified by clustering using two simple metrics: 1) salinity at vertical temperature minimum and 2) salinity at vertical temperature maximum (shown for WOA in Figure 2).

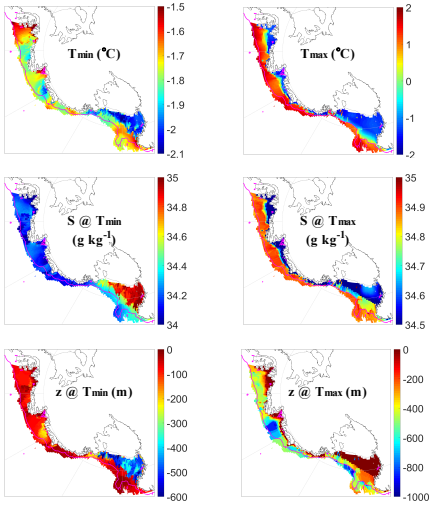


Figure 2 Minimum temperature at each WOA grid point (top left), and the salinity (middle left) and depth (bottom left) at the minimum temperature. Right, as left, but for quantities at the temperature maximum.

- **Temperature-coordinate salinity metrics are used to identify and compare hydrographic regimes in the World Ocean Atlas and the Community Earth System Model.**
- **High Salinity Shelf Water, coastal freshwater-enriched, and off-shelf hydrographic regimes are identified in observations and the model.**
- **CESM is generally fresher than WOA but lacks a clearly defined freshwater-enriched coastal current.**
- **The locations and properties of HSSW regimes at other locations on the Antarctic continental shelf are objectively identified, suggesting this technique could be used to evaluate CMIP6 models on a circum-Antarctic basis.**

Determination of the number of groups

Based on physical intuition, and statistical evaluation with Silhouette scores (not shown), which suggest between 3-6 groups, 5 groups are chosen for the CESM-WOA comparison.

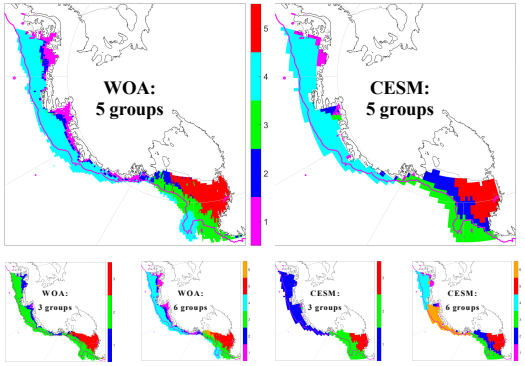


Figure 3 Locations of groups for WOA (left) and for CESM (right) corresponding to different (pre-defined) numbers of groups.

T/S regimes in WOA

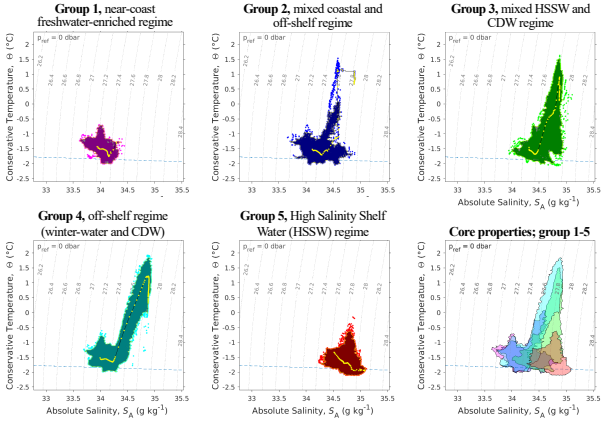


Figure 4 T/S properties for five WOA groups. Dark shaded areas are the "cores" of each group, defined using a data density-based algorithm. The core of each group is shown in at bottom right.

Comparison of T/S properties in WOA and CESM

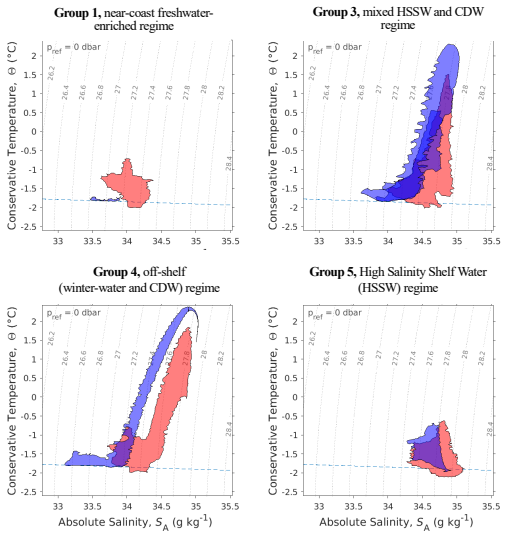
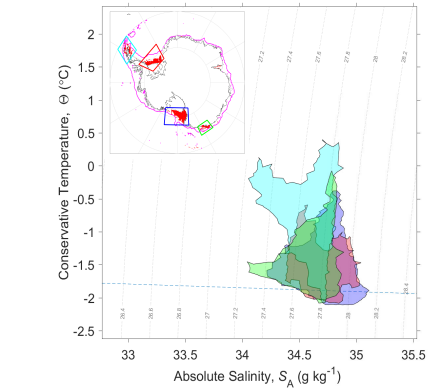


Figure 5 "Core" T/S properties in WOA (red) and CESM (blue).

Application to the circum-Antarctic Continental Shelf



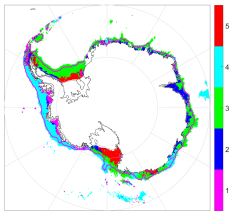


Figure 6 (Top) T/S properties of HSSW regions, with their geographic location and color code shown in the zoomed map. The locations of all 5 groups are shown in the lower panel.

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