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Discovering Dominant Controls on Southern Ocean Dynamics Under Climate Change: New Knowledge Through Physics-Guided Machine Learning

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The Southern Ocean closes the global overturning circulation and is key to the regulation of carbon, heat, biological production, and sea level. However, the dynamics of the general circulation and its leading order controls remain poorly understood, in part because of the challenge of characterizing and tracking changes in ocean physics in complex models. This gap in understanding is especially problematic in the face of climate change. Here, we wish to understand changes in the dynamics of the Southern Ocean under climate change, specifically how bathymetric controls on the general circulation could impact the location of major currents and impact upwelling. We use a suite of CMIP models for our analysis. A physics-informed equation discovery framework guided by machine learning is used to partition and interpret dynamics is used to understand spatial structures, and a supervised learning framework that quantifies its uncertainty and provides explanations of its predictions is leveraged to track change. The method, called Tracking global Heating with Ocean Regimes (THOR). A region undergoing a profound shift is where the Antarctic Circumpolar Current intersects with bathymetry, for example, the Pacific-Antarctic Ridge. We see major changes in areas associated with upwelling between the CMIP models, suggesting the changes in wind stress allow the control bathymetry has in the historical scenario to change. For example, we find that as the Antarctic Circumpolar Current shifts north under intensifying wind stress, when meeting the Pacific-Antarctic Ridge. We note associated change in the regions where gyre circulation favors upwelling, with spatial distributions varying between models. Our efforts go towards a better understanding of what dynamics are driving changes, and could allow reduction of bias between models and decrease uncertainties in future projections.