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Recent Southern Ocean surface cooling induced by sea-ice freshwater flux changes

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Despite global warming, large areas of the Southern Ocean surface waters between the sea-ice edge and the Subantarctic Front have been cooling over recent decades. Yet, most global climate models simulate a warming of this region over this period. Here, we investigate the potential sources of the surface cooling by forcing a newly developed regional configuration of the Regional Ocean Modeling System (ROMS) for the Southern Ocean with atmospheric reanalysis data and with recent observation-based estimates of surface fluxes from sea ice and land ice for the period 1982 to 2008. We perform factorial sensitivity experiments in which we perturb either the surface freshwater fluxes or the surface wind stress according to the observed changes. We find that most of the surface cooling could be explained by increased northward freshwater transport by sea ice that freshens the open-ocean around the sea-ice edge in the model. The freshening increases the surface density stratification between the sea-ice edge and the Subantarctic Front that reduces mixing of warmer deep waters into the surface layer in winter. As a result, the surface ocean cools and the subsurface ocean warms significantly, especially in the Pacific sector where the largest sea-ice changes occurred. The spatial pattern of these simulated temperature changes agrees well with the satellite-observed trends and trends derived from ocean in-situ data, suggesting that the observed surface cooling occurs primarily due to an increased sea-ice freshwater flux. In contrast, the surface temperature weakly increases in response to the increased surface wind stress over this period. Overall, we find opposing tendencies induced by the surface wind stress changes and freshwater flux changes in the ocean hydrography. We conclude that the upwelling of deep waters in the Southern Ocean is highly sensitive to the freshwater transport to the sea-ice edge and that this process is a major driver of the observed recent cooling in the Southern Ocean surface waters south of the Subantarctic Front.