Atmospheric model surface heat flux errors responsible for long-standing Southern Ocean climate model biases

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The Southern Ocean is a critically important region for global climate. However, it is poorly represented in most climate models with significant biases in near-surface temperature and wind fields that hinder their use to reliably address key climate questions. We use Atmospheric and Coupled Model Inter-comparison Project (AMIP5, CMIP5) output and observations to show, for the first time, that these biases are principally due to systematic errors in the representation of the atmospheric processes which control ocean-atmosphere exchanges. For the region 40-60^{o}S variations in simulated net surface heat flux across the AMIP5 models explain ~70% of the variance in sea surface temperature (SST) for the corresponding coupled models. AMIP5 net fluxes also explain ~52% of the variance across coupled models in the latitude of the Southern Ocean westerly wind jet, through associated SST-atmosphere feedbacks. The atmospheric heat flux errors, and associated wind feedbacks, influence ocean thermal structure to at least ~1500m depth. Models with low net heat flux biases generally achieve this because of compensating errors in individual flux components. We show that targeted model developments can improve the simulation of air-sea fluxes, providing a route to better represent the Southern Ocean and hence provide more accurate climate projections.