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Stochastic structural stability theory of the Antarctic Circumpolar Current

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The Antarctic Circumpolar Current (ACC) is the world's strongest ocean current. Despite its essential role in the climate system, the ACC remains poorly understood. The reason is that a comprehensive understanding of the dynamics governing the intricate balance between the small scale eddies and the mean current, on which the structure of the current sensitively depends, is currently lacking. In this work, we develop a theory of the ACC building on results from stochastic turbulence modeling, within a framework that is called Stochastic Structural Stability Theory (SSST). In the context of SSST, interaction between the eddies and the mean flow can be well approximated using a Stochastic Turbulence Model (STM) in which the eddies draw most of their energy from the mean flow while their sources are represented as stochastic forcing and effective eddy dissipation. In the case of the ACC, the stochastic forcing arises from both nonlinear scattering producing the turbulent cascade and from the variation of the surface wind stress due to wind gustiness. The STM provides an analytic method to obtain the quadratic statistics of the eddy field for a given mean flow structure. The average large scale flow is then forced by the momentum flux divergence, obtained from the STM, producing a closed set of eddy-mean flow equations. The equilibria of the SSST system are the steady large scale current and the stationary eddy statistics. A quasi-geostrophic, two layer baroclinic model with surface wind stress forcing was considered. First, the accuracy of the approximations inherent in the SSST was verified against results from previous numerical simulation studies. Then the equilibria of the SSST model were obtained and analyzed. Two regimes that depend on the ratio of the amplitude of the stochastic forcing over the amplitude of time mean stress were found. For moderate values of this ratio, we obtain an equivalent barotropic ACC structure in which the interfacial form stress from the eddies balances the momentum imparted by the wind stress. In this regime, the current transport increases linearly with the magnitude of the time mean stress for given stochastic forcing amplitude. For large values of this ratio, the eddy momentum fluxes are equally important to the interfacial form stress in balancing the momentum at the surface and the ACC transport is found to be weakly sensitive to the wind stress magnitude.