Numerical Study of Double-Cell-Type Solar Meridional Circulation Based on a Mean-Field Hydrodynamic Model

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Large-scale flow structures of the Sun, differential rotation and meridional circulation, play crucial roles in generating and sustaining the solar magnetic fields through the dynamo mechanism. In the framework of flux-transport dynamo model, most of the previous kinematic simulations have assumed a single-cell meridional circulation so that equator-ward migration of sunspot groups could be attributed to the equator-ward transport of toroidal magnetic fluxes by the meridional flow at the base of the convection zone. However, recent helioseismic observational results suggest the possibility of a double-cell structure for the meridional circulation with the pole-ward flow at the base, demanding some modifications for the conventional flux transport dynamo model. Therefore, the theoretical investigations on the maintenance mechanism of this double-cell meridional circulation is regarded as of a great importance.
By conducting mean-field hydrodynamic simulations where the effect of the angular momentum transport by the Reynolds stress is parameterized, we calculate the structures of differential rotation and meridional circulation self-consistently and investigate whether or not double-cell meridional circulation could be achieved along with the solar-like differential rotation. As a result, we find out that the double-cell meridional circulation can be achieved when the Reynolds stress transports angular momentum upward in the lower convection zone and downward in the upper layer. We confirm that, in the steady state, the accumulated angular momentum via the Reynolds stress in the middle layer is advected to both the upper and lower part of the convection zone by each of the upper and lower meridional circulation cells, respectively.

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