An improvement of a 1D thermal evolution calculation scheme based on mixing length theory

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Solid-state thermal convection plays a major role in the thermal evolution of solid planetary bodies. Solving the equation system for thermal evolution considering convection requires a 2-D or 3-D modeling, resulting in large calculation costs. A 1-D calculation scheme based on mixing length theory (MLT) requires a much lower calculation cost and is suitable for parameter studies. A major concern for the MLT scheme is its accuracy because of a lack of detailed comparisons with higher dimensional schemes. In this study, I quantify its accuracy by comparing steady-state thermal profiles obtained by 1-D MLT and 3-D numerical schemes for different curvatures, different Rayleigh numbers, and different viscosity contrasts. For isoviscous cases, I find that relative errors for the mean temperature and Nusselt number can be up to >100% and ~50%. In order to improve the accuracy, I propose a new definition of the mixing length, which is a parameter controlling the efficiency of heat transportation due to convection. I find that the use of a smaller peak depth and a larger peak value of the mixing lengths decreases errors. I provide empirical quadratic functions for the peak depth and the peak value leading accurate results. Similar analyses were done for temperature-dependent viscosity cases. I find that the use of the new definition of the mixing length also improves results for time-dependent calculations, indicating that this approach is useful for thermal evolution studies.

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