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Vertically resolved analysis of the Madden-Julian Oscillation highlights the role of convective transport of moist static energy

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We simulate the Madden-Julian oscillation (MJO) over an aquaplanet with uniform surface temperature using the multiscale modeling framework (MMF) configuration of the Energy Exascale Earth System Model (E3SM-MMF). The simulated MJOs have similar spatial structures and propagation behavior to observations. To explore the processes involved in the propagation and maintenance of the MJO, we perform a vertically resolved moist static energy (MSE) analysis for the MJO (Yao, Yang, and Tan 2022; Yao and Yang 2023). Unlike the column-integrated MSE analysis, our method quantifies how individual physical processes amplify and propagate the MJO's characteristic vertical structure. We find that radiation, convection, and boundary layer processes all contribute to maintaining the MJO, balanced by the large-scale MSE transport. Furthermore, large-scale dynamics, convection, and boundary layer processes all contribute to the eastward propagation of the MJO, while radiation slows the propagation. We further show that the MJO can still self-emerge when radiative heating rate is horizontally homogenized, highlighting that convective and boundary-layer MSE transports are sufficient to sustain the MJO. These transport processes might be overlooked in the column-integrated MSE analysis.