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A nonlinear perspective on the dynamics of the MJO: idealized large-eddy simulations

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The 30-60 day intraseasonal atmospheric oscillation in the equatorial atmosphere, the Madden-Julian oscillation (MJO), is most visible in its signature of outgoing longwave radiation and associated convective centers. Diabatic processes related to tropical convection and two-way atmosphere-ocean interaction are hence generally believed to be crucial in explaining the origin of the MJO phenomenon. However, reliable deterministic forecasting of the MJO in global circulation models and understanding its mechanism remains unsatisfactory. Here a different approach is taken, where the hypothesis is tested that eastward propagating MJO-like structures originate fundamentally as a result of nonlinear (dry) Rossby wave dynamics. A laboratory-scale numerical model is constructed, where the generation of solitary structures is excited and maintained via zonally propagating meanders of the meridional boundaries of a zonally-periodic beta-plane. The large-eddy simulations capture details of the formation of solitary structures and of their impact on the convective organization. The horizontal structure and the propagation of anomalous streamfunction patterns, a diagnostic typically used in tracing the equatorial MJO, are similar to archetype solutions of the Korteweg-deVries equation, which extends the linear shallow water theory — commonly used to explain equatorial wave motions — to a weakly nonlinear regime for small Rossby numbers. Furthermore, the characteristics of the three-dimensional laboratory-scale numerical results compare well with observed features of the equatorial MJO and thus the study provides indirect evidence of the basic principles underlying the wave-driven eastward propagation of the MJO.