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A simple dynamical model linking radiative-convective instability, convective aggregation and large-scale dynamics

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A simple model is used to analyse the relation between the phenomenon of convective aggregation at small scales and larger scale variability, including MJO-like behaviour, that results from coupling between dynamics and moisture in the tropical atmosphere. The model is based on the single-layer dynamical equations coupled to a moisture equation to represent the dynamical effects of latent heating and radiative heating. The moisture variable q evolves through the effect of horizontal convergence, nonlinear horizontal advection and diffusion. Following previous work, the coupling between moisture and dynamics is included in such a way that a horizontally homogenous state may be unstable to inhomogeneous disturbances and, as a result, localised regions evolve towards either dry or moist states, with respectively divergence or convergence in the horizontal flow. The behaviour of the model system is investigated using a combination of theory and numerical simulation. The spatial organisation of the moist and dry regions demonstrates a spatial coarsening that, if moist regions and dry regions are interpreted respectively as convecting and non-convecting, represents a form of convective aggregation. When the weak temperature gradient (WTG) approximation (i.e. a local balance between heating and convergence) applies and horizontal advection is neglected the system reduces to a nonlinear reaction-diffusion equation for q and the coarsening is a well-know aspect of such systems. When nonlinear advection of moisture is included the large-scale flow that arises from the spatial pattern of divergence and convergence leads to a distinctly different coarsening process. When thermal and frictional damping and f-plane rotation are included in the dynamics, there is dynamical length scale Ldyn that sets an upper limit for the spatial coarsening of the moist and dry regions. The f-plane results provide a basis for interpreting the behaviour of the system on an equatorial β-plane, where the dynamics implies a displacement in the zonal direction of the divergence relative to q and hence to coherent equatorially confined zonally propagating disturbances, comprising separate moist and dry regions. In many cases the propagation speed and direction depend on the equatorial wave response to the moist heating, with the relative strength of the Rossby wave response to the Kelvin wave response determining whether the propagation is eastward or westward. The key overall properties of the propagating disturbances, the spatial scale and the phase speed, depend on nonlinearity in the coupling between moisture and dynamics and any linear theory for such disturbances therefore has limited usefulness. The model described here, in which the moisture and dynamical fields vary in two spatial dimensions and important aspects of nonlinearity are captured, provides an intermediate model between

theoretical models based on linearisation and one spatial dimension and three-dimensional GCMs or convection-resolving models.