Gravity wave response to convective heating and its importance to understanding the weak temperature gradient approximation and its limitation

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Convection is a key process in tropical weather and climate. Its buoyant energy generation and turbulent mixing directly change the temperature and moisture distribution in the small area around clouds, while the secondary compensative circulations driven by its strong latent heating indirectly modulate the environment outside convective regions. Internal gravity waves generated by convection are considered as the key mechanism that communicates the imposed localized perturbation to the surrounding atmosphere. As these gravity waves propagating outward from heating centers, compensating subsidence is induced to balance the strong upward mass fluxes within clouds. The resulting adiabatic warming spreads the localized latent heating over a much wider domain that didn’t experience convection. Through its propagation, convective-generated gravity wave quickly homogenizes the buoyancy perturbation, leading to the weak temperature gradient (WTG) feature widely observed in the tropic.

The analytical solutions of the gravity wave response to an isolated heat source were first derived in a two-dimensional hydrostatic Boussinesq fluid by Bretherton and Smolarkiewicz (1989). Their solution suggests that the adjustment time scale and range of gravity wave on temperature field depend on its propagation speed, which is simply controlled by background stratification and vertical structure of imposed heating. Dissipation, rotation, stratosphere, and cylindrically symmetry was further added into this highly idealized model. The modified solutions showed that both the extension to full dimensions and the inclusion of the stratosphere damped the wave signals in the troposphere as they propagated away from the heating source, trapping the response within a confined distance like dissipation and rotation. The combination of these damping scales could help identify the suitable time and space scales for the WTG approximation.

A regional model named SCALE-RM (Scalable Computing for Advanced Library and Environment) is utilized to justify the behavior of gravity wave response predicted by theoretical solutions and to further identify the damping scales in our cloud-resolving model. Several idealized experiments were carried out in a high-resolution configuration that is capable to resolve convective-generated gravity waves. The features in the numerical simulation are generally consistent with that in theory; however, for real convection, the situation becomes much more complicated as the strength and heating structure change along with the cloud’s life cycle. Non-linear interaction might be another reason that deviates simulation from the linearized solution.

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