Numerical experiment on the spontaneous organization of cumulus convection: CISK or CIFK?

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[Up-Down asymmetry and large-scale structure of the earth's cloud convection]

One of the important processes in the cloud convection in the earth's atmosphere is the rapid removal of condensate produced in the upward motion branch. This results in an intrinsic asymmetry between upward and downward motions; there is effectively no 'negative condensation' in the downward motion branch. Due to this asymmetry, cloud convection is composed of the narrow upward motion branch destabilized by buoyancy generated by the conensation heating and the widespread stable downward motion branch where buoyancy perturbation acts as the restoring force. The wave-like nature of the downward motion branch acts as an inertia, which becomes a source of various types of large-scale space-time structures that appear in the statistical distribution of the upward motion area.

[Linear theories of the cloud organization: CIFK and CISK]

Such large-scale organization of cloud convection is often examined in the framework of linear theory where heating by the cloud activity is linked to large scale vertical motion in various ways, which are devided in two types.

First type is 'conditional instability of the first kind' (CIFK), where the heating is assumed to be proportional to the in-situ vertical velocity. The unstable mode that appears in CIFK theory has short wave length and large growth rate, so that it is unually identified to individual cumulus elements. It should be noted, however, long wavelength modes have small but posotive growth rates.

Second type is 'conditional instability of the second kind' (CISK), where the heating is assumed to be proportional to the vertical velocity at the lowermost levels of the atmosphere below the position considered irrespective of the in-situ vertical velocity. This assumption seems to be strange at first glance, but it has been accepted as a naive representation of the statistical relationship between the activity of cloud ensemble and large-scale vertical motion.

Nakajima (2004, joint meeting) reported that, in a very large domain cloud convection model, the simulated cloud activity spontaneously concentrates itself into a fixed region. In this presentation, we examine whether it originates from CIFK or CIFK.

[Idealized numerical experiment]

The model is two-dimensional cloud resolving model with the horizontal domain size of 32,768km. A fixed-rate body cooled is introduced to simulate the radiative process. Water vapor and heat fluxed are supplied from the lower boundary, both of which are calculated using fixed wind speed. This last assumption employed in order to avoid the growth of large-scale disturbances originating from so-called WISHE, wind-induced surface heat exchange. The body cooling is strong in the upper troposphere.

Within first several days, the cloud activity becomes organized into horizontally propagating structure which has a wavelength of about 3,000km and phase speed of 20m/s. In time averaged sense, activity of clouds is horizontally uniform. After that, however, stationary wavenumber one modulation gradually develops, and, eventually, almost all of the cloud activity becomes concentrated in a narrow fixed zone.

The growth of the stationary structure is not inconsitent with the prediction of CIFK, only if one accepts the development of modes with the growth rates smaller than the largest grooth rate. However, this type of stationary cloud concentration does not occur in another experiment with the body cooling that is stronger in the lower troposphere, where large-scale CIFK shold be equally permitted. This sensitivity to the vertical profile of body cooling implies that the stationary cloud organization should be interpreted as a kind of CISK.

This last hypothesis will be examined in more detail in the presentation combmining the correlation between the cloud and atmopheric vertial motion in the model and re-examination of linear wave-CISK theory.