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Numerical simulation on the vertical motion in the tropical nimbostratus

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A tropical cloud cluster consists of three parts: a convective precipitation region, a stratiform precipitation region, and a cirriform cloud region. Continuous gentle rainfall, which characterizes the stratiform precipitation region, comes from nimbostratus. Several processes release latent heat in nimbostratus and they are: deposition growth of ice under ice-supersaturation conditions; old cells flowing out of cumulonimbus in vertical wind shear; new cells created by liming just above the 0C level; and forced upward motion in gravity waves excited in convective clouds. However, the complicated mechanisms of ice cloud physics have hindered complete understanding of rain production in nimbostratus.
VHF radar can directly observe vertical motion both in and out of clouds. Nishi et al. (2007, JAMC) controlled observation mode of the EAR (a VHF radar system in western Sumatra, Indonesia) to observe fine structure in nimbostratus and found an interesting pattern in vertical motion - very gentle upward motion (0-40 cm s^{-1}) continuing for 2-3 hours over a several-km-high range in three well-developed mesoscale cloud systems in November 2003. The variability in vertical motion is impressively small even at a very high resolution and accuracy: a vertical resolution of 150 m, time resolution of 3 minutes, and horizontal extent of the beam of about 400 m at the 10 km height level.
We conducted numerical experiments to examine the causes of this continuous gentle upward motion. Although many previous studies with numerical models showed the vertical wind distribution in a tropical cloud system, most of their results are horizontally and temporally averaged and are not appropriate for investigating the possible cause of variability in upward motion at a small time-scale. We attempted analysis with fine time/space resolution and minimum averaging. We used a community model WRF/ARW version 2.1. The domain size is 300 x 300 x 2 2.8 km; the horizontal resolution is 600 m, and the vertical grid number is 74. Since we considered deposition growth as the most likely mechanism, we added a routine to get the instantaneous phase change of water (not time averaged), together with the vertical motion in every 1 minute, to the original output routine.
We made several experiments with various vertical shear patterns of basic wind that have a large effect on the extent of nimbostratus in the stratiform precipitation region. However, we could hardly obtain gentle upward motion even when the nimbostratus had a very wide extent and continuous light rainfall was detected. In our experiment, large-amplitude gravity waves are the primary cause of time/space variability. In particular, gravity waves with very short periods (10-2 0 minutes) have large amplitudes and propagate in the nimbostratus region. In addition, the so-called old cells that come from the convective region, which have 1 m s^{-1}scale upward motion, are a secondary source of variability. If these kinds of variability were suppressed, gentle upward motion would be obtained widely in our experiments. We analyzed the distribution of the phase change of water and found that latent heat release is positive only in a limited region with upward motion corresponding to the upward motion phase of gravity waves. Mesoscale uniform upward motion, which has been considered the primary cause of uniform stratiform precipitation, was not well detected in our experiments.
Although our experiments could readily simulate continuous light rainfall and weak (10-40 cm s^{-1})

upward motion in the mean field within the nimbostratus, it was difficult to suppress strong gravity waves and old cells, and we could not obtain gentle upward motion as observed by EAR. These results suggest that it is important to correctly simulate gravity waves with a relatively short time scale and convective cells flowing from cumulonimbus region.

Keywords: tropics, vertical motion, cloud system, numerical experiment