Modeling Mesoscale Convective Systems in a Highly Simplified Environment

Xiping Zeng[1,2], Wei-Kuo Tao[2], Robert A. Houze Jr.[3]

[1]GEST/UMBC, Greenbelt, MD [2]NASA/GSFC, Greenbelt, MD [3]University of Washington, Seattle, Washington

INTRODUCTION

The classic theory of atmospheric convection predicts that conditional instability favors the smallest possible scale of cumulus clouds (Bjerkes 1938). However, satellite and field observations reveal that mesoscale convective systems (MCSs) are common in the Tropics (e. g., Houze 2004). Thus, it is interesting to bridge the gap between the current theory and observations on tropical convection. In this study, three-dimensional (3D) cloud-resolving model (CRM) simulations in a highly simplified environment are carried out to address the origin of MCSs in the Tropics.

MODEL SETUP

The 3D Goddard Cumulus Ensemble model (Tao et al. 2003), a CRM, is used to simulate clouds for weeks in a highly simplified environment. Its microphysical scheme and model setup are similar to previous ones (e. g., Zeng et al. 2009) except for no large-scale forcing. All the simulations resemble those of Bretherton et al. (2005) except for the following details. A constant surface wind is used to compute the sea surface fluxes, which excludes the WISHE mode. The radiative cooling rate is fixed, which introduces no cloud-radiation interaction. The vertical wind shear is fixed or no shear is introduced so that there is no momentum-cloud interaction. Microphysical scheme is chosen for warm or cold clouds. Domain size varies from 128 to 512 km, while maintaining the horizontal resolution of 1 km. Table 1 summarizes the simulations with parameters.

Table 1 Experiments with Various Parameters

Experi-ment	Gridpoints	*Modeling Days*	*Cloud Micro-physics*	*Wind Shear*	*Cloud Organi-zation*
RCE1	256x256x41	40	Warm	No	No
RCE2	256x256x41	20	Cold	No	Yes
RCE3	256x256x41	20	Warm	Yes	Yes
RCE4	256x256x41	60	Cold	Yes	Yes
RCE2B	512x512x41	20	Cold	No	Yes
RCE2S	128x128x41	20	Cold	No	Yes

SENSITIVITY TO CLOUD MICROPHYSICS

All CRM simulations start from the sounding of KWAJEX and run until the radiative-convective equilibrium (RCE) arrives. This study analyzes the cloud organization at RCE. Experiment RCE2 chooses 256x256x41 gridpoints, the microphysics scheme for cold clouds, and no vertical wind shear. Figure 1 displays the horizontal distribution of clouds at hour 315. Obviously, the model domain splits into two regions: clear and cloudy, although their boundary is not clear. Most clouds are enveloped. Their envelope aligns the *y*-axis and spans ~ 100 km wide.

In contrast to RCE2, RCE1 chooses the microphysical scheme for warm clouds (i.e., no ice in the simulation). Figure 2 displays the horizontal distribution of clouds at hour 326. Obviously, there is no clear cloud envelope.

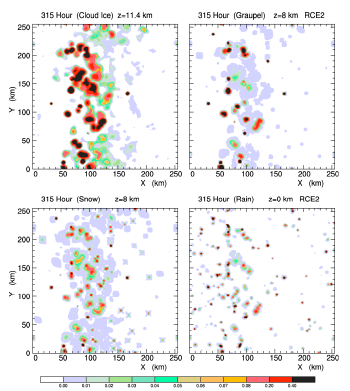

Fig. 1 Horizontal distributions of water species at hour 315: the mixing ratio of cloud ice at z = 11.4 km (top left), graupel at z = 8 km (top right), snow at z = 8 km (bottom left) and rainwater at z = 0 km (bottom right). The unit for color bar is g kg^{-1}.

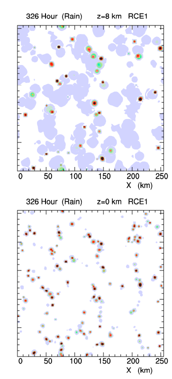

Fig. 2 Horizontal distribution of rainwater at z = 0 (bottom) and 8 km (top) at hour 326 from RCE1. The mixing ratio of rainwater is scaled with the same color bar as that in Fig. 1.

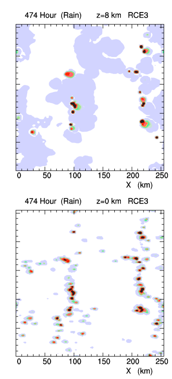

Fig. 5 Same as in Fig. 2 except from RCE3 and at hour 474.

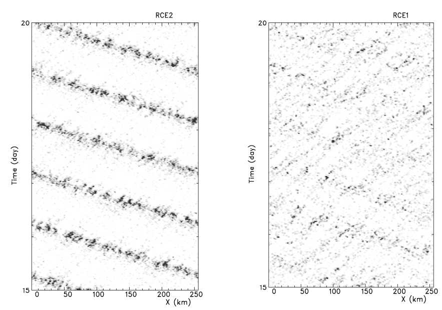

Fig. 3 Hovmöller (x-t) diagram for the surface rainfall rate, averaged in y-direction, from experiment RCE2 (left) and RCE 1 (right). Precipitation intensity is directly proportional to shading density.

The cloud envelope in RCE2 propagates to the left. Its propagation speed is quantified based on Fig. 3 or the Hovmöller (x-t) diagram for the surface rainfall rate from RCE2, where the surface rainfall rate is averaged in the *y*-direction. The envelope, as shown in the figure, propagates to the left at 3.1 m s^{-1} and brings about a precipitation oscillation with a period of 0.95 day. This figure also displays the Hovmöller diagram of the surface rainfall rate from RCE1 for comparison. Since RCE2 includes the effect of ice physics but RCE1 not, the contrast between the two diagrams indicates that ice physics dominate cloud envelope formation.

SENSITIVTY TO DOMAIN SIZE

To study the effect of domain size on cloud envelope, numerous simulations are carried out that use different domain sizes. RCE2B and RCE2S use the same processes as RCE2 except for 512x512x41 and 128x128x41 gridpoints, respectively. Figure 4 displays their Hovmöller diagrams for the surface rainfall rates averaged in the *y*-direction. Although RCE2B doubles the domain size of RCE2. It accommodates only one cloud envelope just as RCE2. Its envelope is as wide as that in RCE2. In contrast, RCE2S chooses half the domain size of RCE2. It gets no clear cloud envelope. In brief, cloud envelope propagates faster over a broader domain, and cloud envelope cannot be simulated well if the domain size is less than 128 km, which makes sense because cloud envelope is ~ 100 km wide.

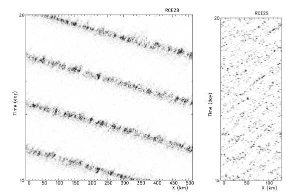

Fig. 4 Same as in Fig. 3, but for RCE2B (left) and RCE2S (right).

CONCLUSIONS

- The present modeling results support the conclusion of Bretherton et al. (2005) that clouds can self-aggregate, especially over a big domain.
- Clouds usually become enveloped with a width of ~100 km, where ice physics plays dominantly.
- Vertical wind shear brings about convective lines with a width of ~ 10 km (see Fig. 5).
- Convective lines are usually embedded in cloud envelopes, which resembles MCS and explains why MCSs are so common in the Tropics.

Acknowledgements: This work was supported by the DOE ARM Programs.

REFERENCES

1. Bjerknes, J., 1938: Saturated-adiabatic ascent of air through dry-adiabatically descending environment. *Quart. J. Roy. Meteor. Soc.* **64**, 325–330.
2. Houze, R. A., Jr., 2004: Mesoscale convective systems. *Rev. Geophys.*, **42**, 10.1029/2004RG000150, 43 pp.
3. Tao, W.-K., J. Simpson, D. Baker, S. Braun, M.-D. Chou, B. Ferrier, D. Johnson, A. Khain, S. Lang, B. Lynn, C.-L. Shie, D. Starr, C.-H. Sui, Y. Wang and P. Wetzel, 2003: Microphysics, radiation and surface processes in the Goddard Cumulus Ensemble (GCE) model. *Meteor. Atmos. Phys.*, **82**, 97-137.
4. Zeng, X., W.-K. Tao, M. Zhang, A. Y. Hou, S. Xie, S. Lang, X. Li, D. Starr, X. Li, and J. Simpson, 2009: An indirect effect of ice nuclei on atmospheric radiation. *J. Atmos. Sci.*, **66**, 41-61.
5. Bretherton, C. S., P. N. Blossey, and M. Khairoutdinov, 2005: An energy-balance analysis of deep convective self-aggregation above uniform SST. *J. Atmos. Sci.*, **62**, 4273-4292.