Modeling Mesoscale Convective Systems in a Highly Simplified Environment

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INTRODUCTION

The classic theory of atmospheric convection predicts that conditional instability favors the smallest possible scale of cumulus clouds (Bjerknes 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 WSHF 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 schemes are 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

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Gridpoints</th>
<th>Modeling Days</th>
<th>Cloud Microphysics</th>
<th>Wind Shear</th>
<th>Cloud Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCE1</td>
<td>256x256x41</td>
<td>40 Warm</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>RCE2</td>
<td>256x256x41</td>
<td>20 Cold</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>RCE3</td>
<td>256x256x41</td>
<td>20 Warm</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>RCE4</td>
<td>256x256x41</td>
<td>60 Cold</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>RCE2B</td>
<td>512x512x41</td>
<td>20 Cold</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>RCE2B</td>
<td>128x128x41</td>
<td>20 Cold</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

SENSITIVITY TO CLOUD MICROPHYSICS

All CRM simulations start from the sounding of KWAIJEX and run until the radiative-convective equilibrium (RCE) arrives. This study analyzes the cloud organization at RCE. Experiment RCE chooses 256x256x41 gridpoints, the microphysical 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.

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.

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

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REFERENCES