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Three-dimensional nonhydrostatic simulations of summer thunderstorms in the humid subtropics versus High Plains

Hsin-mu Lin, Pao K. Wang*, Robert E. Schlesinger

Department of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison, 1225 W. Dayton Street, Madison, WI 53706, USA

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Abstract

This article presents a detailed comparison of cloud microphysical evolution among six warm-season thunderstorm simulations using a time-dependent three-dimensional model WISCDYMM. The six thunderstorms chosen for this study consist of three apiece from two contrasting climate zones, the US High Plains (one supercell and two multicells) and the humid subtropics (two in Florida, US and one in Taipei, Taiwan, all multicells). The primary goal of this study is to investigate the differences among thunderstorms in different climate regimes in terms of their microphysical structures and how differently these structures evolve in time. A subtropical case is used as an example to illustrate the general contents of a simulated storm, and two examples of the simulated storms, one humid subtropical and one northern High Plains case, are used to describe in detail the microphysical histories. The simulation results are compared with the available observational data, and the agreement between the two is shown to be at least fairly close overall.

The analysis, synthesis and implications of the simulation results are then presented. The microphysical histories of the six simulated storms in terms of the domain-integrated masses of all five hydrometeor classes (cloud water, cloud ice, rain, snow, graupel/hail), along with the individual sources (and sinks) of the three precipitating hydrometeor classes (rain, snow, graupel/hail) are analyzed in detail. These analyses encompass both the absolute magnitudes and their percentage contributions to the totals, for the condensate mass and their precipitation production (and depletion) rates, respectively.

* Corresponding author. Tel.: +1 608 263 6479; fax: +1 608 262 7482.
E-mail address: pao@windy.aos.wisc.edu (P.K. Wang).

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Comparisons between the hydrometeor mass partitionings for the High Plains versus subtropical thunderstorms show that, in a time-averaged sense, ice hydrometeors (cloud ice, snow, graupel/hail) account for ~70–80% of the total hydrometeor mass for the High Plains storms but only ~50% for the subtropical storms, after the systems have reached quasi-steady mature states. This demonstrates that ice processes are highly important even in thunderstorms occurring in warm climatic regimes.

The dominant rain sources are two of the graupel/hail sinks, shedding and melting, in both High Plains and subtropical storms, while the main rain sinks are accretion by hail and evaporation. The dominant graupel/hail sources are accretion of rain, snow and cloud water, while its main sinks are shedding and melting. The dominant snow sources are the Bergeron-Findeisen process and accretion of cloud water, while the main sinks are accretion by graupel/hail and sublimation. However, the rankings of the leading production and depletion mechanisms differ somewhat in different storm cases, especially for graupel/hail.

The model results indicate that the same hydrometeor types in the different climates have their favored microphysical sources and sinks. These findings not only prove that thunderstorm structure depends on local dynamic and thermodynamic atmospheric conditions that are generally climate-dependent, but also provide information about the partitioning of hydrometeors in the storms. Such information is potentially useful for convective parameterization in large-scale models.

Keywords: Thunderstorm simulations; Hydrometeor partitioning; Microphysical structure; Subtropical thunderstorms; High Plains thunderstorms; Nonhydrostatic cloud models

1. Introduction

Clouds and precipitation are paramount meteorological processes in the general public's concept of "weather". Deep precipitating convective cloud systems in the form of thunderstorms, in particular, have long posed especially acute concern to society because of their attendant risks of injuries, deaths and damage to property and crops from lightning, floods, hail, strong straight-line winds, tornadoes or a combination among these phenomena (e.g., Kessler and White, 1981). Over the last 10–15 years, the societal impacts of convective storms have become more urgent amid mounting circumstantial signs of climate change qualitatively consistent with decadal-scale climate predictions using general circulation models (GCMs), designed to gauge the effects of doubling the concentration of atmospheric carbon dioxide (Price and Rind, 1994; Gregory and Mitchell, 1995; Frei et al., 1998). These effects, projected to the end of the 21st century, globally and annually averaged, include the following: warming of several Celsius degrees from the earth's surface through the midtroposphere, increased atmospheric water vapor content roughly sufficient to maintain the relative humidity at most levels, more frequent exceptionally heavy 1-day rainfalls, and more frequent thunderstorms as inferred from higher parameterized counts of lightning flashes. While great care must be taken when attempting to link global warming and an upward trend in the atmospheric CO_2 concentration (Michaels and Stooksbury, 1992), data from Mauna Loa Observatory during 1958–2002 do show an increase of ~18% in the mean annual (deseasonalized) CO_2 concentration in a systematic and accelerating trend (Keeling and Whorf, 2003).