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The Goddard Cumulus Ensemble model (GCE): Improvements and applications for studying precipitation processes

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ABSTRACT

Convection is the primary transport process in the Earth's atmosphere. About two-thirds of the Earth's rainfall and severe floods derive from convection. In addition, two-thirds of the global rain falls in the tropics, while the associated latent heat release accounts for three-fourths of the total heat energy for the Earth's atmosphere. Cloud-resolving models (CRMs) have been used to improve our understanding of cloud and precipitation processes and phenomena from micro-scale to cloud-scale and mesoscale as well as their interactions with radiation and surface processes. CRMs use sophisticated and realistic representations of cloud microphysical processes and can reasonably well resolve the time evolution, structure, and life cycles of clouds and cloud systems. CRMs also allow for explicit interaction between clouds, outgoing longwave (cooling) and incoming solar (heating) radiation, and ocean and land surface processes. Observations are required to initialize CRMs and to validate their results.

The Goddard Cumulus Ensemble model (GCE) has been developed and improved at NASA/Goddard Space Flight Center over the past three decades. It is a multi-dimensional non-hydrostatic CRM that can simulate clouds and cloud systems in different environments. Early improvements and testing were presented in Tao and Simpson (1993) and Tao et al. (2003a). A review on the application of the GCE to the understanding of precipitation processes can be found in Simpson and Tao (1993) and Tao (2003). In this paper, recent model improvements (microphysics, radiation and land surface processes) are described along with their impact and performance on cloud and precipitation events in different geographic locations via comparisons with observations. In addition, recent advanced applications of the GCE are presented that include understanding the physical processes responsible for diurnal variation, examining the impact of aerosols (cloud condensation nuclei or CCN and ice nuclei or IN) on precipitation processes, utilizing a satellite simulator to improve the

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microphysics, providing better simulations for satellite-derived latent heating retrieval, and coupling with a general circulation model to improve the representation of precipitation processes. Future research is also discussed.

Contents

1. Introduction

Cloud-resolving models (CRMs) have been developed over the past four decades. They have been used to improve our understanding of cloud and precipitation processes over a range of scales from micro- to cloud- to meso- as well as their interaction with radiation, aerosol and surface processes. The basic characteristic of CRMs is that their governing equations are non-hydrostatic since the vertical and horizontal scales of atmospheric convection are similar. CRMs use sophisticated and physically realistic cloud microphysical processes at very fine spatial and temporal resolution. However, these cloud-microphysical processes (nucleation, diffusion growth and collision among cloud and precipitation particles) must be parameterized in CRMs as does atmospheric turbulence, turbulent processes at oceanic or terrestrial boundaries (latent and sensible heat fluxes into the atmosphere), and radiative transfer processes, which can be complex in the presence of clouds. These processes have to be allowed to interact explicitly with the cloud dynamics (i.e., convective draft/circulation, pressure gradient force, convectively-generated gravity waves, and cool pool). Observations are crucial for verifying model results and improving the initial and boundary conditions as well as the aforementioned physics processes.

Some of the major advantages of using CRMs include their ability to quantify the effects of each physical process upon convective events by means of sensitivity tests (e.g., by eliminating a specific process such as evaporative cooling, melting of precipitating ice particles) and their detailed dynamic and thermodynamic budget calculations. Fig. 1 shows a schematic of the main characteristics of typical CRMs. Reviews of CRMs including their history and applications can be found in Tao (2003, 2007) and Tao and Moncrieff (2009).

The Goddard Cumulus Ensemble model (GCE) is a CRM that has been developed and improved at NASA Goddard Space Flight Center (GSFC) over the past three decades. Its development and main features were published in Tao and Simpson