Three-dimensional simulation of glaciogenic seeding of clouds over Bethlehem

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Abstract

A time-dependent three-dimensional cloud model with bulk water parameterisations was applied to simulate heavy silver iodide seeding in an isolated cumulus congestus cloud. The ambient conditions were prescribed using observed sounding data from a case study of the Bethlehem Precipitation Research Project. In the simulations, the total mass of ice crystals formed in the seeded cloud was two orders of magnitude larger than that in natural clouds. Furthermore, precipitation developed slightly faster and more efficiently in the seeded case. However, the cloud updraft was only marginally stronger in the seeded case with almost no lasting effect on the cloud dynamics or cloud size. Seeding effects were also hardly evident in the amount of rainfall at the ground, with the accumulation value increased by only about 1%.

Introduction

The objective of the Bethlehem Precipitation Research Project (BPRP) is to examine summer-time precipitation processes in the interior plateau of Southern Africa and to determine the likelihood of rainfall enhancement through glaciogenic cloud seeding. The Weather Bureau and the Water Research Commission of South Africa have jointly sponsored the project for the last 17 years, from 1975 to the present. In 1990, the project name has been changed to to the National Precipitation Research Project (NPRP). Intensive field observation work is conducted around the town of Bethlehem (28°S, 28°E) in South Africa. Three instrumented aircraft are used for seeding and microphysical measurements, often making simultaneous cloud penetration at different altitudes. A C-band weather radar operating in volume scan, samples the three-dimensional precipitation structure. The field activity and research findings were reviewed by Krauss et al. (1987) and Hudak and List (1988).

In addition to field experimentation, BPRP also contains a modelling component using both simple and complex numerical models to assist in making operational decisions as well as in evaluating seeding cases. Hudak and List (1988) applied Nelson's (1979) one-dimensional model, which computes explicitly the evolution of size spectra of liquid drops and ice particles, to identify case study days that stimulate the rainfall following cloud seeding. One case study, 5 February 1981, was singled out to provide an excellent opportunity for both microphysical and dynamic seeding. Radar observations indicated that one cloud grew rapidly following seeding. However, rapid cloud growth was rather common in the convectively unstable environment existing on 5 February 1981, and therefore it was impossible to provide an unambigious causal relationship between cumulus development and seeding based on observations alone.

A one-dimensional model, in which temperature, updraft and cloud water mixing ratio can vary only in the vertical, has great limitations in simulating the complex cloud circulation. The seedability of the 5 February 1981 sounding conditions should thus be reanalysed using a three-dimensional (3D) model that can more realistically simulate the cloud dynamics. While two-dimensional (slab-symmetric) cloud models have been used extensively in weather modification studies (e.g. Hsie et al., 1980; Orville and Chen, 1982; Orville et al., 1984; 1987; Farley, 1987) fully three-dimensional cloud seeding simulations have been reported only by Cotton et al. (1980) and Levy and Cotton (1984). Three-dimensional cloud models require extensive computing time and core storage and "sacrifices" are thus needed in modelling the cloud microphysics. Usually both warm and cold rain processes have to be parameterised using a bulk water scheme.

The purpose of this study was to use a three-dimensional cloud model with bulk water microphysics to examine the potential for dynamic seeding to stimulate the rainfall of the 5 February case of BPRP. The results would then be compared to those of other studies.

Cloud model

The original numerical code was developed by Steiner (1973) to study moist convection in a three-dimensional sheared environment. Yau (1980) extended the model code to allow for deep convection and warm rain processes. The turbulence closure scheme was amended to include the effect of local buoyancy (Yau and Michaud, 1982) and later an ice-phase parameterisation was added by Yau and MacPherson (1984). The model was applied to tropical rain showers (Turpeinen and Yau 1981), a multi-cell storm (Yau and Michaud 1982) and an Alberta hailstorm (Yau and MacPherson 1984). Reuter (1988) used the model to investigate the water and kinetic energy budget of isolated convection. One of the cases presented, was initialised with the sounding of the 5 February BPRP case study.

The model was based on the deep anelastic system of equations with a diagnostic equation for the pressure perturbation. The sub-grid scale processes were modelled using a first-order closure scheme with the eddy exchange coefficient depending on deformation shear and local buoyancy. The Coriolis effect was neglected which is reasonable for short-lived convection. The lateral model boundary conditions were assumed to be periodic, i.e., any outflow through a lateral boundary was compensated by the same inflow through the opposite boundary. The bottom and top boundaries were assumed to be rigid, flat and free-slip and there was no outflow of heat and moisture, except for fall-out of precipitation at the ground.

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