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Semiannual Status Report

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"Analysis of Three-Dimensional Thunderstorm Model Output in Terms of Geosynchronous Satellite Observations"

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a. Research Objectives

This project is using a three-dimensional numerical cloud model, residing on NCAR's CDC 7600 computer, to address two main areas relating to geostationary satellite observations of severe storms: (1) whether significant differences exist, in cloud top topography and outflow characteristics, between storms with and without significant rotation, and (2) the relationship between cloud top rise rate and vertical air velocity in developing storms.

b. Significant Accomplishments

The main accomplishments during March through August 1982 have been on two fronts, as summarized more fully in subsequent paragraphs: (1) backward trajectory analysis of storm dynamics for a previously executed strong-shear modeling experiment, and (2) testing of a less diffusive candidate for replacing the strongly damped "modified upstream" flux-conservative finite-difference scheme thus far carried along in the model for advecting heat and moisture, with an eye toward desired future improvements in model numerics and physics.

(1) PARCEL TRAJECTORY COMPUTATIONS

Selected backward trajectories have been calculated for two time stages, one during rapid storm growth (18 min) and the other during the mature phase with anvil development well along (48 min) in Case B, from a previously executed set of four 60-min comparative experiments A-D with moderate to strong low-level shear in A-C and weak shear in D. These comparative modeling experiments, and the salient results including those that have motivated the trajectory calculations, are described more fully in the accompanying copy of the paper "Mature Thunderstorm Cloud Top Structure: Numerical Simulation versus Satellite Observations," to be presented at the American Meteorological Society's upcoming Cloud Physics Conference, November 15-18, 1982 at Chicago.

The parcel trajectories have been calculated in order to trace back the source regions of parcels passing through an upshear cold region and a downshear warm region on the mature cloud top surface (a thermal couplet bearing considerable resemblance to geostationary infrared satellite observations), through the cloud summit at both time stages, and through various interior draft core locations at both stages. The main findings of the trajectory analyses have been: (i) air intercepting both the warm and cold cloud-top regions originates from upshear within the stratosphere, and mixes strongly with surrounding air as cloud top is approached, (ii) air intercepting the cloud summit in the rapid growth stage originates from upshear at only slightly lower levels, accelerated upward by a strong perturbation pressure gradient force and then overtaken by the cloud summit, (iii) the cloudy updraft core is fed from the downshear front flank by potentially warm low-level air, as expected, and (iv) the mature rear downdraft, more surprisingly, is also fed by potentially-warm low-level air that ascends partway into the updraft but then is accelerated downward by liquid water drag and mixes strongly with potentially colder air.

(2) ADVECTION SCHEME TESTING

An existing but relatively little-known flux-conservative finite-difference advection scheme, "flux-corrected transport" (FCT), has been tested with checkout experiments in steady non-uniform two-dimensional flows, advecting an initial "cone" of unit height in an otherwise zero initial scalar field. The two principal test flow patterns have been solid rotation and a simple slab-symmetric convective circulation. FCT entails a non-linear combination of "modified upstream" and a user-specified higher-order flux-conservative scheme, weighting the two schemes so as to provide just barely enough numerical diffusion to prevent any new extrema from occurring. Pure "modified upstream" supplies considerably more than enough.

Encouraging test results have been obtained with the choice of the non-split second-order Crowley scheme plus a third-order uncentered space correction for phase error, for the higher-order scheme. FCT is "monotonic," i.e., produces no new extrema, like the pure "modified upstream" scheme, but FCT also preserves the top of the cone far better, nearly as well as the pure higher-order scheme does, and without generating the small yet appreciable non-physical negative minima produced by the modified Crowley scheme alone. This appears to bode well for advecting moisture fields (vapor and liquid), which are intrinsically non-negative, with FCT in future experiments with the 3D cloud model.

c. Current Research

The 3D model results described above raise the question of whether the air intercepting observed thunderstorm tops, especially during rapid storm growth, really does originate at high levels, as occurs in Case B, instead of ascending through the cloud from the lowest layers, in view of a suspected excess of explicit (and quite possibly implicit) mixing in the model as thus far formulated. This question has motivated very recent additional backward parcel trajectory computations for Case B, as a sensitivity study, tracing back equally-spaced vertically stacked parcels only a few hundred meters apart: one stack of 12 parcels at the growing stage, from 1.35 km above to 3.6 km below the cloud summit, and two stacks of 6 parcels at the mature stage, from the cold and warm cloud-top spots to 2.7 km below them. Analysis of these new results is just underway -- but with the already striking finding that the first parcel below the cold spot and the second parcel below the warm spot have both come all the way up through the updraft core from only about 1 km above ground!

d. Conference Proceedings

Schlesinger, R. E., 1982: Mature thunderstorm cloud top structure: Three-dimensional numerical simulation versus satellite observations. To appear in Preprints, Conference on Cloud Physics, November 1982, American Meteorological Society.