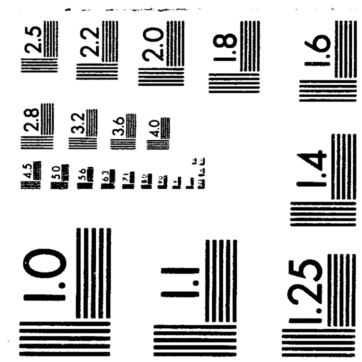
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Factors Influencing the Parameterization of Tropical Anvils within GCMs

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Factors Influencing the Parameterization of Tropical Anvils within GCMs

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Introduction

The overall goal of this project is to improve the representation of anvil clouds and their effects in general circulation models (GCMs). We have concentrated on an important portion of the overall goal; the evolution of cumulus-generated anvil clouds and their effects on the large-scale environment. Because of the large range of spatial and temporal scales involved, we have been using a multi-scale approach. For the early-time generation and development of the cirrus anvil we are using a cloud-scale model with a horizontal resolution of 1-2 kilometers, while for the transport of anvils by the large-scale flow we are using a mesoscale model with a horizontal resolution of 10-40 kilometers. The eventual goal is to use the information obtained from these simulations, together with available observations to develop an improved cloud parameterization for use in GCMs. The cloud-scale simulation of a midlatitude squall line case and the mesoscale study of a tropical anvil using an anvil generator were presented at the last ARM science team meeting. This paper concentrates on the cloud-scale study of a tropical squall line. Results are compared with its midlatitude counterparts to further our understanding of the formation mechanism of anvil clouds and the sensitivity of radiation to their optical properties.

Model description and initialization

A two-dimensional non-hydrostatic, compressible cloud model (Chin, 1993) is used to simulate a tropical oceanic squall line. Model physics modules include: turbulence, a planetary boundary layer, a two-category liquid water scheme (i.e., cloud droplets and rain), a three-category ice phase scheme (i.e., ice crystals, snowflakes and hail) and long- (LW) and shortwave (SW) radiative transfer. In this study, Fu and Liou's (1993) radiative transfer scheme (referred to as scheme A) is used together with the one described by Chin (1993, referred to as scheme B), where the phase impact of condensates on bulk cloud optical properties is considered, but precipitating condensates are assumed to have the same effect as non-precipitating particles on cloud optical properties; this assumption imposes some uncertainty, which is estimated in this study. In scheme A, ice crystals are assumed to be randomly oriented and to have the hexagonal structure that is responsible for the observed optical phenomena associated with cirrus, such as halos and arcs. The impacts of both the hydrometeor phase and type (precipitating or non-precipitating) on cloud optical properties are represented in this scheme.

The GATE[1] September 4 1974 squall line is chosen for this study due to the availability of observations for validation. The initial conditions are based on the pre-storm sounding from

[1] The GARP (Global Atmospheric Research Program) Atlantic Tropical Experiment.

Poryv at 0600 GMT. The base state wind (normal to the squall line) has a strong easterly jet with a maximum speed of 16 m s^{-1} near the 600 mb level. The model is initialized with a horizontally homogeneous sounding, a warm, moist bubble and large-scale ascent.

Results

1. Dynamic and microphysical structure

Sensitivity tests indicate that the modeled tropical squall line system cannot develop without large-scale ascent. The simulation without radiation (control run) evolves into a quasi-steady (mature) stage after the surface cold pool (due to evaporation of rain water) reaches its maximum intensity. In its mature stage, this storm is characterized by its upshear titling structure and organized in a multi-cellular mode. The dynamic structure of the modeled tropical squall line is very similar to its midlatitude counterpart, except for the upper-level outflow, which is much weaker in the leading segment and stronger in the trailing segment (Fig. 1). Our sensitivity test also indicates that this difference is primarily caused by the environmental wind, which has a mid-level easterly jet. The intensified trailing outflow results in a large separation between the bright melting band and the active convection in the model-derived radar reflectivity (Fig. 2), which bears good resemblance to the observations at its mature stage (see Fig. 25 of Houze, 1977). This result is in contrast to the earlier midlatitude squall line simulations (Chin, 1993), in which the transition zone of low radar reflectivity between the active convection and melting band cannot develop without LW radiation.

2. Diagnosed cloud optical properties

The cloud, temperature and moisture structures at the end of the control run (10 hours), as well as the distributions of other greenhouse gases (from climatology data), are used to study the impact of radiation on cloud optical properties. In this simulation, there are two types of stratiform clouds (low-level marine stratus-MS and upper-level anvil stratus-AS) formed in the model domain. The radiation calculation indicates that cloud optical properties are primarily determined by non-precipitating condensates. The calculations using different radiation schemes also show that the differences for LW and SW fluxes and heating rates between scheme A and B are small over the cloudy regions (1 ~ 2% and < 10%, respectively), except for the SW properties over the anvil stratiform region, where the maximum differences of SW cloud forcing (= $F^{\uparrow}_{clear}$-$F^{\uparrow}_{cloudy}$; $F^{\uparrow}$ is the upward flux at the top of model atmosphere) and heating rates at zero zenith angle are 7% and 50%, respectively. The differences of LW and SW fluxes and heating rates caused by treating precipitating ice-phase condensates as non-precipitating particles are, in general, negligible; the maximum difference of SW cloud forcing at zero zenith angle over the anvil stratus is 4%, which is certainly much smaller than the impact of condensate phase on cloud optical properties shown by Chin (1993).

The SW cloud forcing also shows that the modeled tropical anvil stratus more effectively cools the local earth-atmosphere system than the marine stratus. The SW cloud forcing (averaged over a diurnal cycle) is stronger than its LW counterpart, and results in a negative net cloud forcing for both marine and anvil stratus (-67 and -106 W/m^2, respectively; Table 1). The comparison with the midlatitude anvil also suggests that the tropical oceanic anvil plays a more important role in mitigating the greenhouse warming. The smaller SW cloud forcing of the midlatitude anvil is mainly attributable to its larger surface albedo and ice crystal size.

3. Water budget

The mid-level easterly jet impacts not only the dynamic structure of the tropical squall line system (Fig. 1), but also the water budget of the anvil stratus (Fig. 3). Unlike its counterpart in the midlatitude squall line case (66%), the contribution of deep convection to the water budget of the tropical anvil is a secondary source (40%). The larger contribution of net microphysical production (M) to the water budget of the tropical anvil is a consequence of the stronger and wider rear inflow, which results in more intense mesoscale ascent in the anvil stratus. The contribution of microphysical production without large-scale ascent (in the parenthesis of Fig. 3) indicates that large-scale ascent only makes a trivial contribution to the convective region and anvil stratus. However, it plays a significant role in maintaining the marine stratus.

Summary

The results presented here suggest that the tilting structure of mesoscale convective systems makes a substantial contribution to the water budget of anvil clouds, particularly in tropical anvils due to their strong SW cooling effect on the local earth-atmosphere system. However, this structure cannot be resolved by GCM grids. How to parameterize this sub-grid process is a crucially important issue that must be addressed in order to improve the cloud-radiation feedback to large-scale climate. We will continue our research on this problem as part of our ongoing ARM project. Work performed under the auspices of the US Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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Fu, Q., and K.-N. Liou, 1993: Parameterization of the radiative properties of cirrus clouds. *J. Atmos. Sci.*, **50**, 2008-2025.

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Table 1. Cloud forcing (W/m^2) for varied stratiform clouds.

Radiation / Cloud type	LW	$\overline{SW}$ *	Net CF
Tropical AS	+ 200	- 306	- 106
Tropical MS	+ 200	- 267	- 67
Mid-lat. AS	+ 190	- 210	- 20

* Overbar represents the mean over a diurnal cycle.

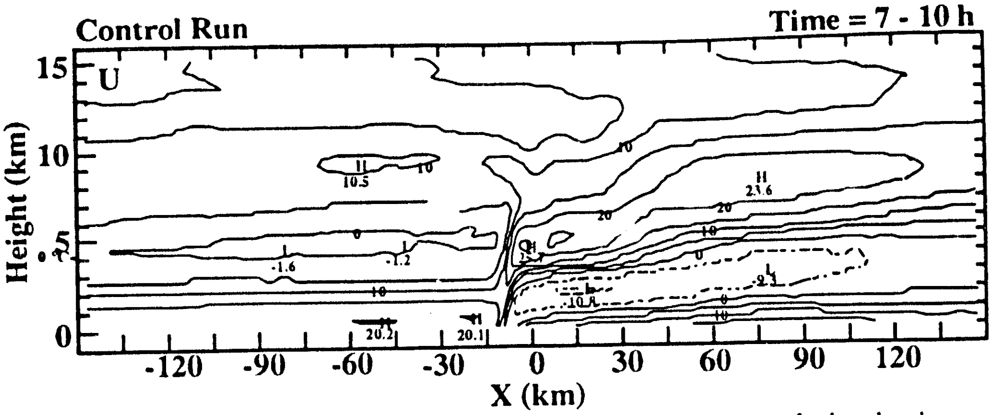

Fig. 1. Temporally averaged cross-section of system-relative horizonta velocity with a contour interval of 5 m s^{-1}.

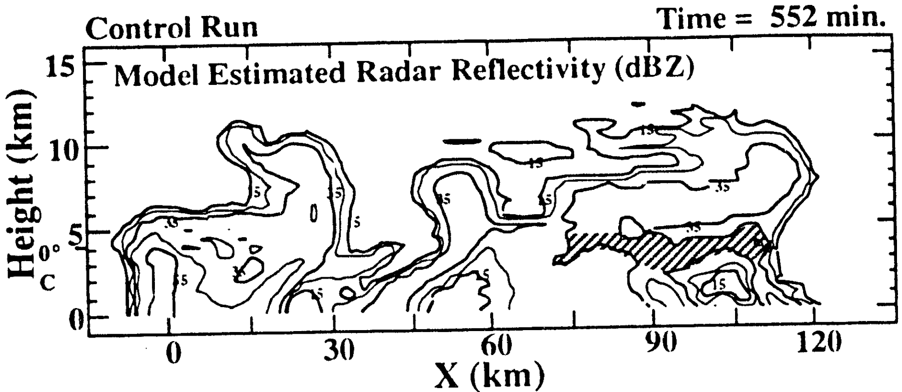

Fig. 2. Model estimated (instantaneous) radar reflectivity (dBZ) plotted at 10 dBZ intervals. Shading area represents the bright melting band.

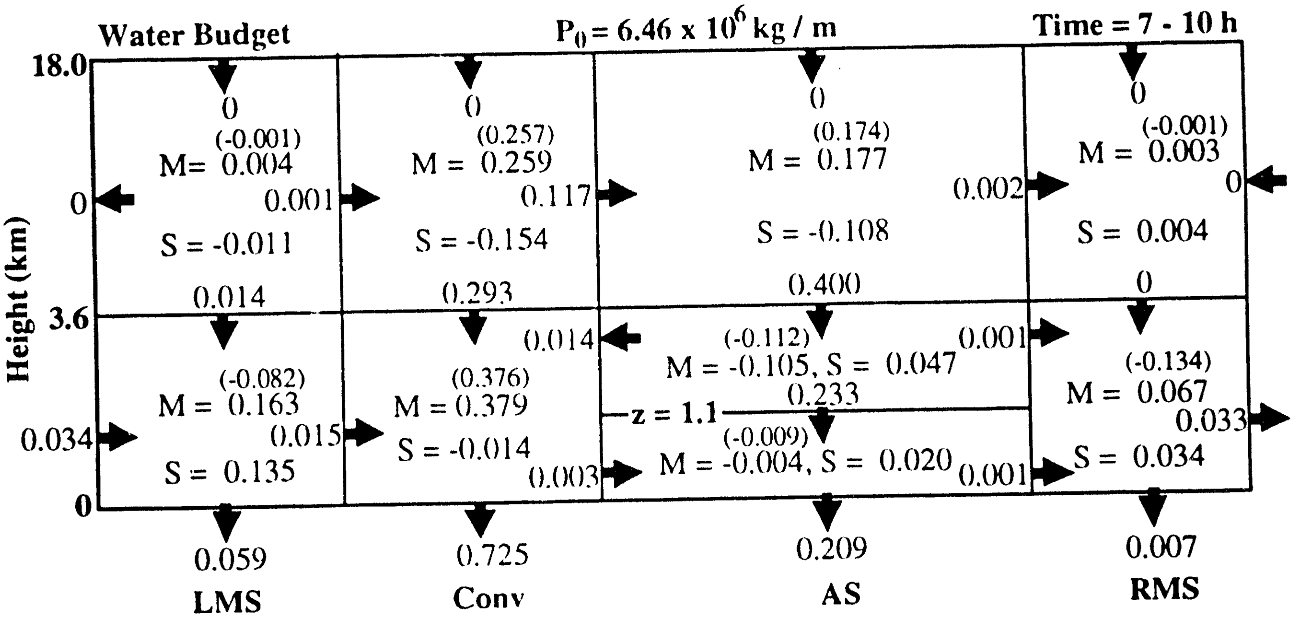

Fig. 3. The water budget of the control run over the whole domain at the mature stage. All quantities are normalized by the total surface precipitation (P_0). M represents the net microphysical production; S, the storage term, arrows, the horizontal and vertical transport; LMS and RMS, leading and rear marine stratus; Conv, convective; and AS, anvil stratus.

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