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Statistical Determination of the Characteristic Time for Precipitation Development in Cumulus Clouds using Radar

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1. INTRODUCTION

A long-standing problem in cloud physics is to determine the physics governing the production and evolution of rain in warm clouds. The evolution of rain in and below clouds is determined to a large extent by the initial cloud condensation nuclei spectra, condensation or evaporation, the relative fall velocity of drops, collision between drops resulting in coalescence or breakup, and air motions. One of the major unresolved scientific issues in cloud physics is the explanation of the observed short time between initial cloud formation and the onset of precipitation in warm clouds. The growth process must account for growth from condensation nuclei to raindrops in about 15 to 20 minutes. Although diffusional growth theory can adequately explain the early stages of cloud droplet development with narrow size spectra, it cannot account for the observed broadening with time of the drop size distribution.

Recent evidence from field and modelling studies support the hypothesis that the onset of precipitation in warm cumulus clouds results from the early accretion of cloud water by deliquesced giant and ultragiant nuclei ingested into clouds through cloud base. Although giant and ultra-giant nuclei have the potential to produce large raindrops in observed times of 15 to 20 minutes, it is uncertain to date whether the concentration of these particles is sufficient to account for the onset of rain in warm maritime and continental clouds and the observed radar signatures of these clouds.

The purpose of this analysis is to determine whether significant differences exist in radar reflectivity evolution between the maritime and continental cloud populations. If precipitation development is dominated by accretional growth on giant and ultragiant aerosol then there is likely to be little difference in the early evolution of the radar signatures. On the other hand, if growth of precipitation is dependent on the spectral broadening associated with other processes, then the evolution of the radar reflectivity in these two cloud populations should be distinct since the continental clouds, with their narrow initial droplet spectra, require greater time for spectral broadening.

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2. THE SCMS FIELD PROJECT

The Small Cumulus Microphysics Study (SCMS) was conducted in 1995 near Cape Canaveral, Florida. The objective of this field project was to study warm cumuli in their earliest stages with the goal to understand 1. the onset of precipitation, 2. the evolution of droplet and raindrop size distributions, and 3. the process of entrainment and mixing. Clouds measured during SCMS were small cumuli growing in similar thermodynamic environments. The thermodynamic structure of the ambient environment in the vicinity of the clouds was well documented, and cloud base temperature and altitude, and therefore the vertical profile of the adiabatic liquid water content could be determined.

The CP2 radar of the National Center for Atmospheric Research provided information on the evolution of the radar reflectivity at two wavelengths (3 and 10 cm). The antennas of the X- and S-band radars were collocated on the same pedestal and adjusted to the same pointing angle. Clouds were scanned in the elevation angle direction (RHIs) at a series of azimuth angles spaced about 1° - 1.5° apart. The series of azimuths were usually repeated every 2 - 3 minutes. Measurements were taken every 100 m in range and about every 0.3° - 0.7° in elevation. Each measurement came from a pulse volume with both azimuth and elevation beamwidths of 1° and length of 150 m.

3. DATA ANALYSIS

The radar observations were partitioned into days where the clouds had either continental or maritime characteristics, and then the time evolution of the radar reflectivity in each cloud, for which sufficient data were available, was analyzed. The partitioning was based on 1. CCN concentrations published by Hudson and Yum (2001), 2. cloud droplet concentrations measured by the aircraft, and 3. observed on-shore or off-shore winds. Time-height cross-sections of radar reflectivity were developed for all clouds that feature sufficient radar histories, to determine a characteristic time for precipitation development and a characteristic adiabatic liquid water content.

Figure 1 shows an example of subsequent RHI scans representing a typical temporal evolution in X-band radar reflectivity of a cloud. Maximum and minimum heights of each 5 dB contour were taken from these

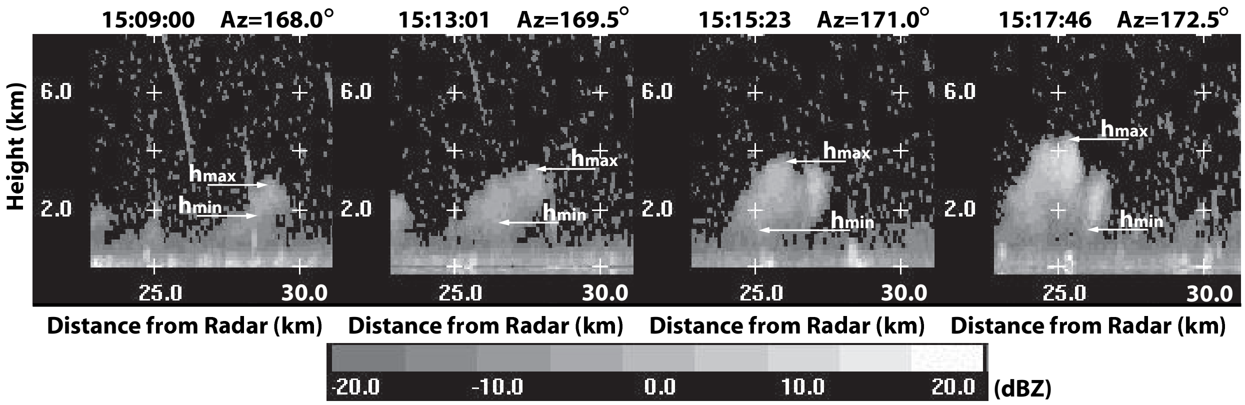

Figure 1: *Example of subsequent RHI scans representing the time evolution in X-band radar reflectivity of a cloud. Maximum and minimum heights of the -5 dBZ contour are indicated.*

RHI scans, starting at -15 dBZ. The resulting time-height cross-section of this particular cloud is depicted in Fig. 2. From this type of cross-sections, the characteristic time for the precipitation process was defined as the length of time between the first occurrences of X-band radar echoes ranging from -5 dBZ to 15 dBZ. The characteristic time for the cloud depicted in Fig. 1 and Fig. 2 was 13 min 35 s.

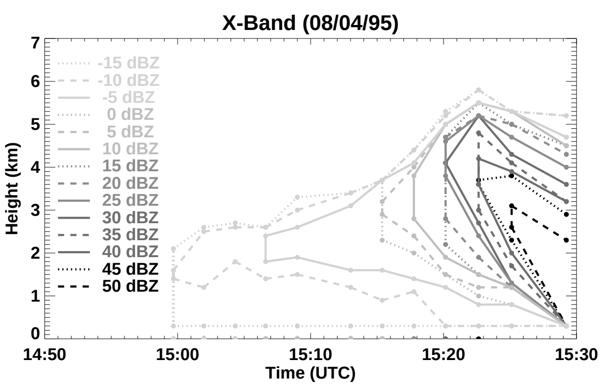

Figure 2: *Time-height cross-section of X-band radar reflectivity of the cloud depicted in Fig. 1.*

The liquid water content used to characterize the precipitation formation process is the adiabatic liquid water content determined at the altitude of the first occurrence of 15 dBZ. The characteristic adiabatic liquid water content was calculated based on aircraft measurements of the cloud base altitude and temperature according to a method used by Laird et al. (2000). It is only a function of height above cloud base, given knowledge of cloud base pressure and temperature. Since the time between the occurrence of two Rayleigh reflectivities and a characteristic adiabatic liquid water content are considered, this analysis includes implicitly the updraft speed, which is difficult to measure. Finally, each cloud analyzed has an associated characteristic time and liquid water content.

4. DISCUSSION AND OUTLOOK

The SCMS data set span 37 days of operations. On average, 2.5 clouds per day feature radar histories suitable for this analysis. The radar scanning strategy used in SCMS was not optimized for this type of analysis. The radar was located on the barrier island north of Cape Canaveral and scanned southwards, along the coast in order to obtain high resolution radar data on the small clouds developing on the Florida sea breeze. Radar echoes moved toward the west and often exited the scanning sector before enough data for this type of analysis were obtained. Nevertheless, data from 25% of all clouds suitable for this analysis showed the entire cloud development from very early radar echoes through the entire growth process and subsequent decay as depicted in Fig. 2.

The values from all analyzed clouds will be compared, to determine if there are significant differences between clouds characterized as maritime or continental. Statistical tests will be performed on subsets of the data set (e.g. intra-day, inter-day, more extreme continental vs. more extreme maritime cases) with the caveat that in some cases there may not be a large enough sample to achieve a high statistical significance.

ACKNOWLEDGMENT

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