Combined Wind Profiler/Polarimetric Radar Studies of the Vertical Motion and Microphysical Characteristics of Convection: Darwin and Oklahoma Observations

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Introduction

Wind profilers offer the unique ability to directly measure vertical motion profiles through precipitating and non-precipitating cloud systems. This ability has been exploited through a series of analyses of storms near Darwin, Northern Australia, which have focused on the statistical characteristics of the vertical motion within a large number of storms as well as case studies of squall lines and isolated convection. The statistical study of May and Rajopadhyaya (1999) looked at the intensity, size, and mass flux characteristics of a sample of twenty-nine, mostly continental storms (the monsoon was particularly weak for the year that continuous vertical motion data was available). These results were compared with aircraft studies. These showed that the intensity of the vertical motion was quite consistent with a number of tropical aircraft studies and much less than the continental convection sampled during the thunderstorm project. The size of the convective cores seen in Darwin during continental convection was somewhat larger than the oceanic cases and similar to the thunderstorm project indicating the importance of boundary-layer depth. Following these analyses, a request was made to obtain similar data from the Southern Great Plains (SGP) site to further investigate the differences in the two regimes. Observations were taken in 1999 and 2000. At present, there is insufficient data for statistical analysis, partly due to equipment reliability and partly because the probability of having storms directly over a small site, is less in Oklahoma than in Darwin. This paper will briefly describe some recent Darwin observations, discuss the Oklahoma data, and draw some conclusions on the utility of these types of analyses for Atmospheric Radiation Measurement (ARM) Program science goals.

Profiler Analysis Techniques

There are two wind profiler radars located at the sites of interest, one operating at 50 megahertz (MHz) and the other at 920 MHz. In Darwin, the 920-MHz system was operating in a fixed 2-minute cycle with a 45 s-long vertical sampling followed by a 15 s off vertical record, while the 50-MHz Radio Acoustic Sounding System (RASS) records were approximately 30 s long. At the Cloud and Radiation Testbed (CART) site continuous 60 s vertical beam measurements were undertaken with both radars. The 50-MHz clear air signals are used to measure the vertical motion. The 920-MHz profiler is used as a vertically pointing Doppler weather radar to measure the reflectivity-weighted fall speed spectrum.

The reflectivity-weighted fall speed spectrum is used to estimate hydrometeor size distributions. We use a similar technique that is described by Gossard (1988) to remove the effects of turbulence using the 50-MHz profiler data.

Darwin Observations

A series of ambitious experiment-combining polarimetric radar and multiple frequency wind profiler observations have been performed near Darwin, Northern Australia, during November and December 1997 and January and February 2000. The first experiment was designed to study, inter alia, quantitative precipitation measurement with polarimetric and conventional weather radar techniques using the Bureau of Meteorology Research Centre (BMRC) C-band (5-cm wavelength) dual polarization weather radar (C-Pol; Keenan et al. 1998). The scanning strategy for C-Pol included a sequence of a volume scan (for Tropical Rainfall Measuring Mission [TRMM] requirements) followed by a range height indicator (RHI) scan and a 2-minute fixed elevation, fixed azimuth scan directed over the wind profiler site, 23 km to the south. Results from the first experiment have been reported by May et al. (2001). In the early part of the experiment several short-lived storms that formed on sea breeze convergence lines passed over the profilers. Although these storms were relatively shallow, with echo tops below 7 km, they produced significant amounts of large ice (diameters ~1 to 2 cm) (Figure 1).

Melting ice signatures were seen in both the profiler and polarimetric radar data (May et al. 2001). The melting ice produces columns of enhanced differential reflectivity that have often been interpreted as the presence of giant raindrops. However, the profiler spectral data clearly showed the peaks at fall speeds in excess of even the largest drops showing conclusively that these were, in fact, hail signatures. These sea breeze storms are interesting and important in many respects. Although they are generally short-lived, they can be intense with updrafts faster than 10 ms^{-1} and local heavy rain associated with reflectivities in excess of 50 dBZ. They are widespread across the tropics and are the precursor convection that triggers deep island-based convection over much of the maritime continent. However, these observations lack any thermodynamic information. RASS observations have recently been attempted to remedy this.

SGP Results

Data from three events have been analyzed. The convection mode of profiler operation was applied with the approach of an organized line of severe convective storms in all three cases. Two examples are clearly associated with these main lines, while the third was from an isolated convective cell. All three cases are sufficiently different to discuss separately and each provides examples of data of significance for general ARM science goals.

Figure 2 shows time height cross sections of radar reflectivity measured with the 915-MHz profiler located next to the 50-MHz system along with the analyzed vertical motion through a fairly shallow isolated convective cell. This is an example where the strongest updrafts are limited to the region above the freezing level and the reflectivity field indicates that the rain is falling out and the cell decaying. The location of the updrafts is close to the reflectivity maxima, in contrast to the Darwin observations of developing cells where the strongest reflectivity was adjacent to tilted updrafts.

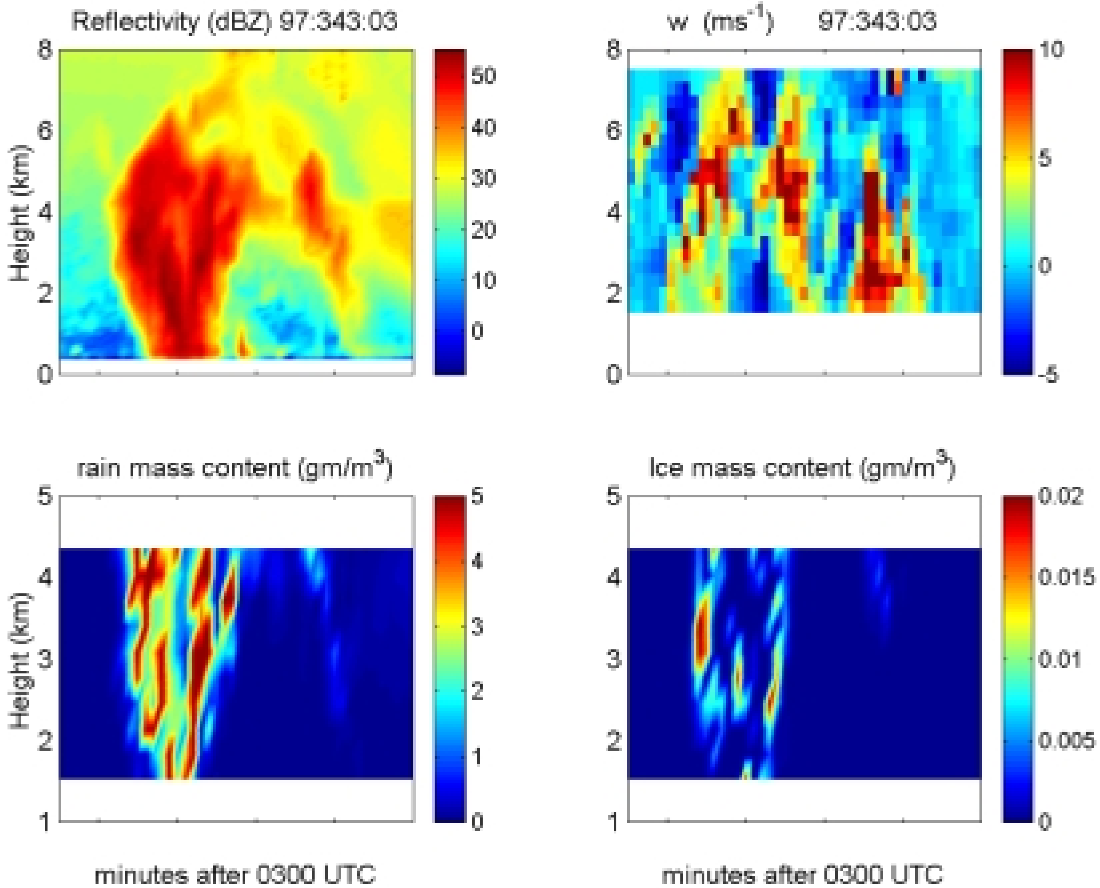

Figure 1. Time height cross sections of radar reflectivity, vertical motion, rain water content, and hail mass content measured using two wind profilers in Darwin, northern Australia, as a shallow thunder storm passed over the observing site. The rain is derived using the reflectivity-weighted fall speed spectrum. The hail is estimated using the spectral information at velocities in excess of the asymptotic limit for rain.

The second example (Figure 3) is during the passage of a squall line. The reflectivity field shows a series of maxima in reflectivity passed over the radars in the first 20 minutes of observations. The leading shallow maximum has an updraft on the leading edge of the reflectivity maximum. The updrafts associated with the next 2 maxima merge above 6 km. The largest intrusion of super-cooled water (inferred by the reflectivity maximum extending above the freezing level) is on the leading updraft of the couplet. The fallout of large ice crystals formed within the storm is seen by a series of descending bands, with successive ones being weaker. Each probably corresponds to separate updraft cores. The radar reflectivity is dominated by the large crystals at this time as the fall speeds are ~7 ms^{-1}. The vertical motion field behind the main convection has indications of wave activity with a series of bands of upward and downward motion with a slight vertical tilt.

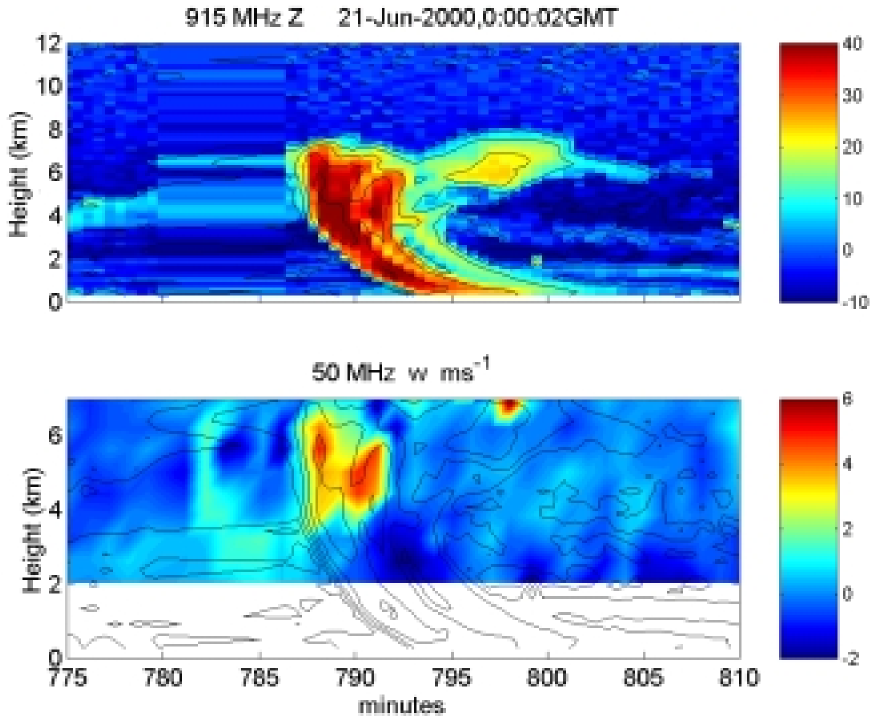

Figure 2. Time height cross sections are radar echo power and vertical motion of an isolated thunderstorm that passed over the CART site in Northern Oklahoma.

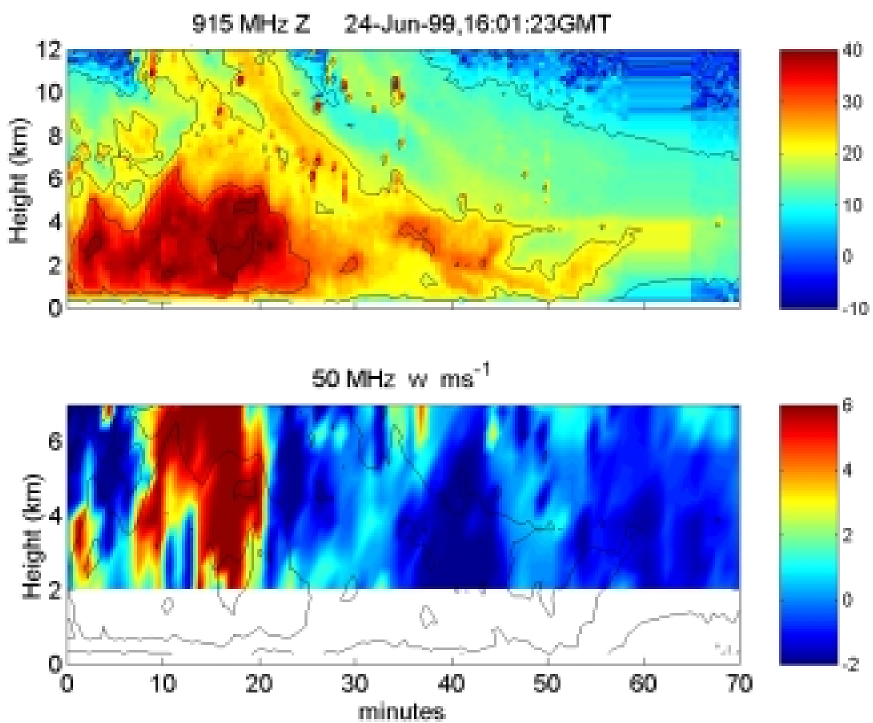

Figure 3. Same as Figure 2, but a squall line case.

The third example is also from a squall line passage, but in this case a leading anvil is clearly seen in the reflectivity data (Figure 4). The height of the anvil varies and this is correlated with the vertical motion measured at the anvil base. The high reflectivity zones associated with the leading convection all correlate with the updrafts measured with the 50-MHz system. The decaying cell at t ~110 to 115 minutes also has a weak updraft associated with it. This is in some contrast to Darwin examples where the most frequent signature of decaying convection is a transformation into an updraft/downdraft couplet similar to a typical trailing stratiform circulation.

This data set is not yet large enough to do a comprehensive statistical analysis such as May and Rajopadhyaya (1999), but the indications with the available data is that the results are quite similar to Darwin in the statistical characteristics. However, it should be noted that neither the Darwin data nor the available Oklahoma data have captured a major damaging convective cell.

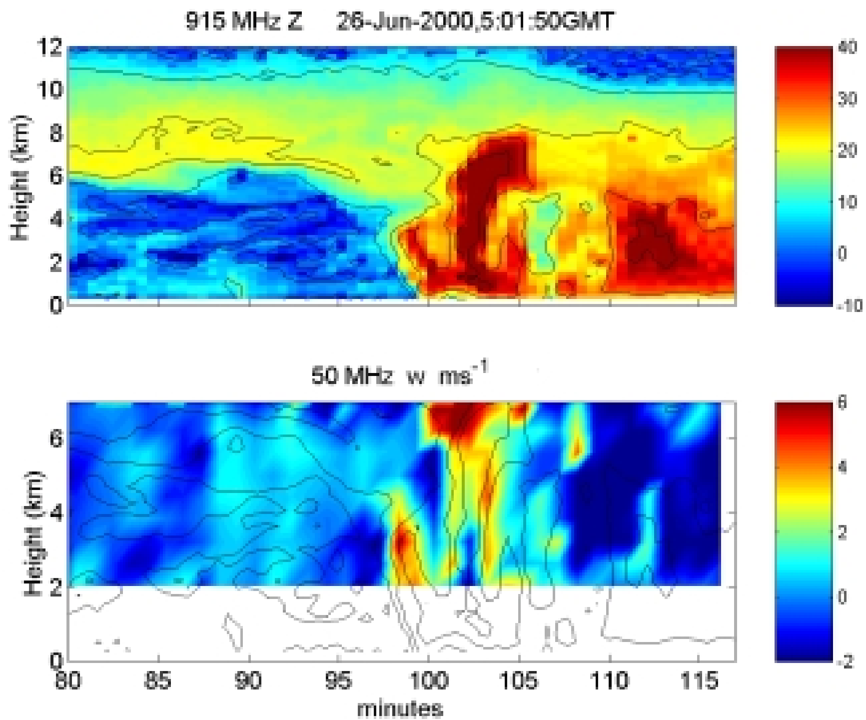

Figure 4. Same as Figure 3, except a leading anvil is seen here.

Conclusions

These data show some results from a systematic attempt to measure the vertical motion, thermal structure, and precipitation characteristics within convection. 50-MHz profilers remain the only systems that can probe vertical motions both in and out of precipitation. The results clearly indicate the power of this approach and the need for further experimentation. These types of analyses have significant implications for heating profiles, cumulus parameterisation on increasingly small scales, and defining the source and type of the cloud and precipitation. These data are not used in present parameterisations, but looking down the track, it is quite likely that the key scaling for cloud formation is going to be linked to vertical motion; or putting it another way, the vertical velocity may well be one of the best ways of getting at sub-grid scale scaling for paramaterisation. There is a need to sample more intense convection.

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