rf05 - Case of minimum drizzle. Part 2.

Gabor Vali - September 13, 2002 (tidied on Sept. 19)

New images are added here to those discussed in the last paragraph of Part 1, and two new analyses are presented. The new topics are: (i) statistics of the vertical velocities in the top and bottom layers of the cloud, and (ii) sizes of updraft and downdraft patches.

Velocity field:

The patchiness of those regions of vertical velocities which exceed 1 m s^{-1} in absolute value is clearly shown with the red color zones in Fig. 11 of Part 1. Here, that same image is repeated as Fig. 12 with a black and white palette. This figure is of the same format as the color image: successive rows show up and downward velocities for the same cloud segment.

There are two reasons for including this black and white image here: First, this rendering is even more effective than the color image in demonstrating the wide varieties of shapes an sizes of the up and downdraft regions. While there are upward and downward velocities with magnitudes of up to ±3 m s^{-1}, as shown in Figs. 5 and 6, this simplified representation highlights the shapes of the zones that could be considered important up and downdrafts. Second, there is a surprising set of small regions (single pixels) at both the upper and lower cloud boundary with velocities exceeding the ±1 m s- 1 threshold. These could not be clearly seen in the color images. It is difficult to be certain that these points are not influenced by some form of phase noise in the radar, there are some patterns in the locations of these points that give some assurance to the contrary. There are few such points above regions of downdrafts, very few at cloud top above or in the vicinity of major updraft patches, and there is a tendency to have alternate segments with these points either at the top or at the base of the cloud. Based on these patterns, I reversed my earlier decision to screen out these points and left them in Fig. 12 with the suggestion that perhaps these points represent regions of turbulence having sufficient intensity and large enough scale (order 10 m) to be detected by the radar.

Most of the points made with respect to vertical velocities, in either Part 1 or here, can be examined in more detail in Fig. 13 and Fig. 14. These figures contain segments of the data displayed earlier but at higher magnification. While there is no portion of the data that could be called 'typical', these segments were selected at least with that goal in mind.

Velocity statistics at cloud boundaries:

Statistics of observed vertical velocities were determined for 45-m layers at the top and at the bottom of the cloud (of the radar echo to be more precise). The 45-m value corresponds to 3 radar rangegates.

Because there are significant variations in the altitude of the echo, the question arose whether it is more significant to allow the top and bottom layers to vary up and down with the cloud (echo), or to take them at fixed geometric altitudes. It seems to me that the former is more representative of the cloud boundaries, but the latter may be more useful for model comparisons. Hence, both approaches were pursued.

Data for the undulating top and bottom layers was further restricted by including only contiguous cloud segments of at least 3 km in horizontal extent. The total path length retained was 158 km (85% of the total). Results for these layers are given in Table 1. The fixed-altitude layers bracketed the mean echo top (818.5 m) and the mean echo bottom (608.5 m) by ±22.5 m. A more compact summary of the results is given below:

Table 1 Summary

	TOP 45-m LAYER		**BOTTOM 45-m LAYER**	
	fixed altitude	**undulating**	**fixed altitude**	**undulating**
mean	0.027	-0.054	-0.164	-0.020
variance	0.196	0.236	0.680	0.756
skewness	-0.021	-0.096	0.290	0.051

The near-zero mean values for the velocities at the top and, specially, at the bottom confirm that there was little drizzle in this cloud to influence the results. Most notable is that the variance is much greater at the bottom than at the top of the cloud. There is also a fair indication in the values listed in Table 1 that the sign of the skewness changes from small negative values at the top to positive values at the base. The greater variance of velocities near cloud base is also clearly seen in the frequency distributions of velocities for the two regions; these distributions are shown in Fig. 15 and Fig. 16.

The difference between cloud top and cloud base regions is also well captured by the percentile values listed in the table below:

Table 2

	1%	**5%**	**10%**	**90%**	**95%**	**99%**
top 45 m	-1.55	-0.8	-0.57	0.43	0.6	1.31
bottom 45 m	-2.11	-1.44	-1.1	1.05	1.42	2.18
middle	-1.50	-1.00	-0.77	0.71	0.96	1.53

The 5, 10, 90 and 95% values are roughly twice as large at cloud base as at cloud top. The difference diminishes by the 1 and 99% values. At even greater extremes of probabilities (not shown in the table), the two distributions become closely alike: the outer 0.1% of values are ±2.8 m s^{-1} and the 0.01% values are ±3.4 m s^{-1} for both the cloud top and cloud base velocities. The velocity distribution at the bottom is fairly close to a Gaussian probability distribution, as also noted for the overall distribution shown in Fig.6; however the distribution in the top 45 m of the cloud is distinctly more peaked. For an added comparison, statistics are also shown in Table 2 for the middle portion of the cloud, which includes all points not in the top and bottom layers. This distribution has a spread inbetween the spreads seen in the top and bottom layers, and the extreme values are somewhat smaller: ±2.1 for the 0.1% values and ±2.8 for the 0.01% values. The variance for this middle layer is 0.37. All of this indicates a diminution of variability from the bottom layer toward the top, except that the extreme values return to the same values at the top as at the bottom.

The relationship between local reflectivity and velocity values was examined two different ways, in order to allow different possible connections to be explored. The average values of $\boldsymbol{V_r}$ for the top and bottom 45-m layers (in undulating form) were correlated with *VMZ* calculated either over the total depth of the cloud or only for the corresponding 45-m layers, VMZ_{45}. Some pattern in the relationship between velocities in the outer layers and the average reflectivity over the whole cloud depth, *VMZ*, might perhaps indicate that these velocities respond to how the droplet spectra evolved or how larger-scale circulations have an effect at various locations in the cloud. On the other hand, a relationship with VMZ_{45} could be viewed more as a reflection of "parcel" properties. The results for *VMZ* are given in Fig. 17 and Fig. 18 and for VMZ_{45} in Fig. 19 and Fig. 20. For the bottom layer there are practically no correlations in either form, even though some correlation could have been expected, for example, from entrainment regions having lower values of *VMZ* and stronger downward velocities at cloud base. Perhaps, this is offset by some regions where larger $\boldsymbol{V_r}$ -values are due to larger drop sizes and hence larger VMZ_{45}. Somewhat more of a pattern is seen in the cloud top data (Figs. 18 and 20): downward velocities are coupled to weaker reflectivities and maximum reflectivities correspond to intermediate positive velocities. This pattern is certainly unexpected and difficult to explain. One possible reason why the strongest updrafts are not accompanied by the largest *VMZ* or VMZ_{45}-values may be that these regions represent parcels of most recent entry into the cloud and that the drop spectra in these parcels have not yet undergone even the degree of limited coalescence growth found in older parcels. Since the evidence is for no drizzle development we are talking about a limited degree of spectral broadening here. These points will be examined further with the aid of the in situ data collected during the subsequent flight period.

Sizes of updraft and downdraft regions :

While the foregoing analyses narrow the range of speculations about how such clouds form and how they are maintained, and, while the statistical values can be used for comparisons with LES and other models, it is clear from the images of the velocity fields (cf. Figs 11 to 14) that one should go beyond frequency distributions of point values (in this case, each point represents about 570 m^3 of cloud volume) and look at the clustering of values into larger entities. A relatively simple step is included here, and it is doubtful that much more effort would be worthwhile due to the fact that this is all based on two-dimensional data (a vertical plane extending from the flight path) and there is no reliable way to overcome that inherent limitation. The manner of sampling has to be borne in mind when using these results; to a first approximation one could consider the flight path a random sample of the cloud, since it was based on a prescribed geometry, not adapted to the observed cloud structure. An additional limitation of the analysis is that it is based on sample elements of about 1:1.5 horizontal to vertical aspect ratio. The velocity patches are described, at this point, only in terms of areas, without identifying the contributions of the two dimensions. With all these caveats, Fig. 21 shows the size distributions of patches of updrafts exceeding 0.5 and 1 m s^{-1} in magnitude, in both up and down directions. These are cumulative distributions; the ordinate values represent the average distance between patches of indicated sizes or larger. This average distance increases with increasing patch sizes since small patches are the most numerous. Since the overall flight path was 186 km, an average distance of 18.6 km means that 10 patches of the corresponding size were observed. The abscissa is given in terms of patch areas. For three abscissa values the equivalent circular diameters are also indicated.

All of the distributions in Fig. 21 are reasonably close to exponential for sizes exceeding something between 100 and 200 m. The large numbers of small updraft and downdraft patches seen at the echo boundaries in Fig. 12 are responsible for the steepening of the distribution curves for small sizes. As was already seen in the overall frequency distributions of $\boldsymbol{V_r}$, the similarity between updraft and downdraft chracteristics also holds for patch sizes. From the images (Figs. 11 to 14) it is evident that the larger updraft patches extend upward from cloud base and that the larger downdraft patches are also found in the lower parts of the cloud. This differentiation between the lower and upper regions of clould be readily quantified but has not been done at this time.

Perhaps it is disappointing that the distributions do not reveal any scale preference for the more substantial updraft and downdraft regions. It is difficult to say to what extent this is due to the pattern of sample collection (a circle over a cellular (?) cloud field) and to what extent it is a reflection of the complex cloud structure and its temporal variability. The current data can't really address that issue. Once again, examinations of the in situ data may provide further clarifications. That will be the subject of coming installments of this report.