"NON-REVIEWED"

BROKEN CUMULUS BASES AND MODELING

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INTRODUCTION

Convective cumuliform clouds are sustained by thermal upcurrents produced by solar heating of the ground. Under these conditions, the slice of atmosphere between the ground and the cumulus base is thoroughly mixed by the thermals, so that the water vapor content is the same at all levels in this slice, and the temperature lapse rate is constant, being almost the same as the dry adiabatic value. Thus, the level where condensation begins (i.e. the base of the cumulus cloud) can be predicted fairly accurately from ground-level measurements of air temperature and humidity, provided that the convective updraughts are strong and sustained. If this is so, then the cumulus base will be flat and at least as wide as the main body of the cloud. Special thermodynamic diagrams (tephigrams and others) can be used to estimate this cloud-base level by means of a quick and simple construction.

A number of cumulus cloud models have been developed to predict the top height of, and the rainwater produced by convective clouds of given sizes under specified atmospheric conditions (e.g. Simpson and Wiggert, 1971, Hirsch, 1971, and Wisner, Orville and Myers, 1972). The input to these models consists of the vertical profile of temperature and humidity prevailing in the atmosphere at the time, together with the expected height above ground of the cloud-base.

Some of the models are called "steady state" because they look only at the growing phase in the cloud life-cycle, making no attempt to calculate the changes taking place with the passage of time, which the more sophisticated "time-dependent" models do. One of the most advanced steady state cloud models to be used operationally in rainfall stimulation experiments was developed at the Experimental Meteorology Laboratory in Florida (Simpson and Wiggert, 1969 and 1971). A selection of data from the 1973/74 cloud seeding program in Zimbabwe (formerly Rhodesia) in southeast Africa (McNaughton, 1975) was run through this model, but the cumulus tops and rainfalls calculated by computer tended to disagree with those observed. A few comparisons are presented in Table I, where "lower base" refers to the cumulus base calculated from the tephigram, as indicated above.

OCCASIONAL ABSENCE OF UPDRAFTS NEAR CLOUD BASE

In Zimbabwe (Rhodesia), cumuliform clouds are often observed with ragged broken bases (see photographs in Figure 1). Occasionally the cloud tower even separates itself completely from its lowest portion, leaving only small puffs of cloud at the level which the tephigram construction indicated would be the cumulus base Sometimes a cloud of this sort begins with a firm, flat

FIGURE 1.

SOME CUMULUS CLOUDS WITH POOR BASES

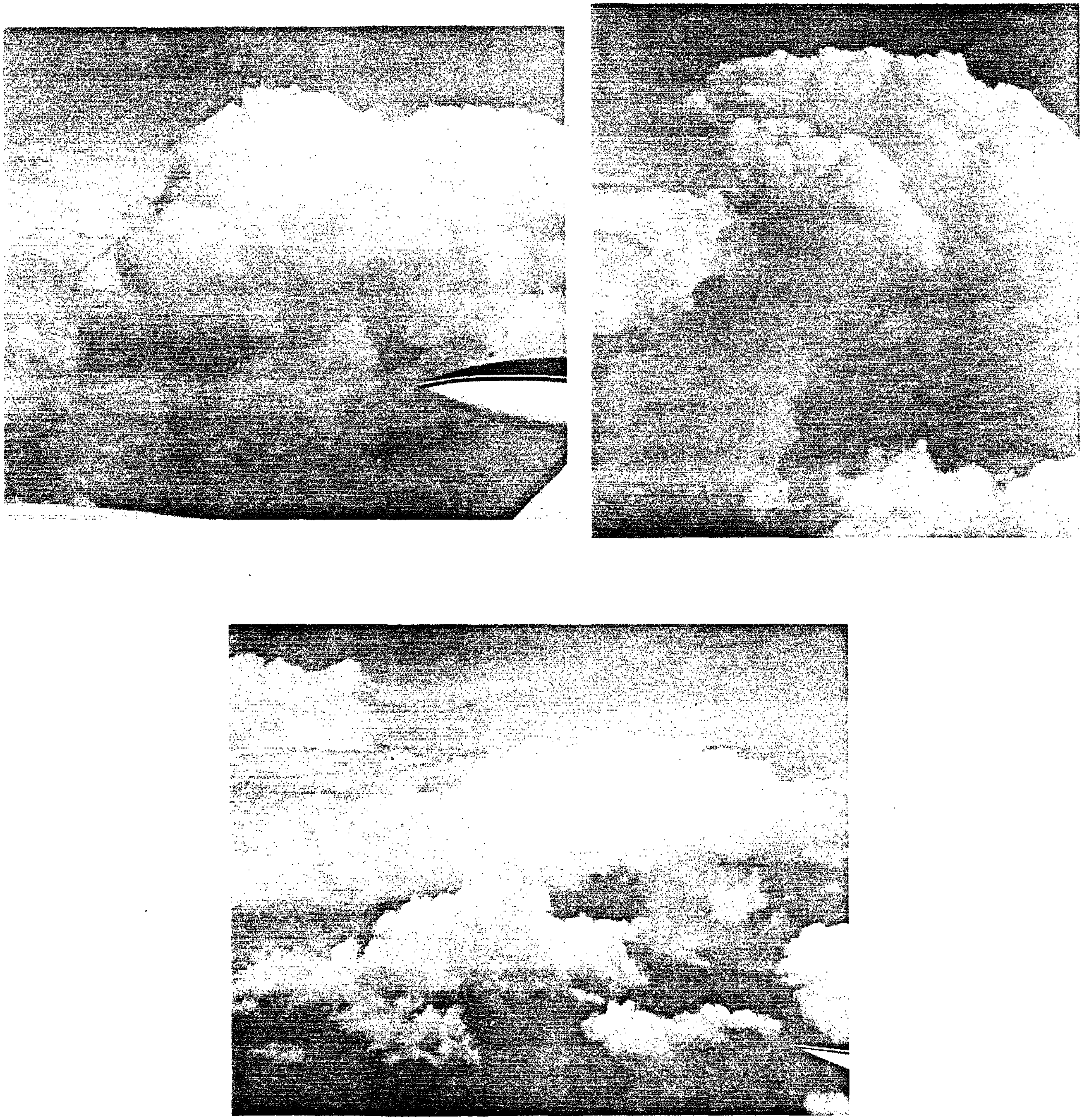
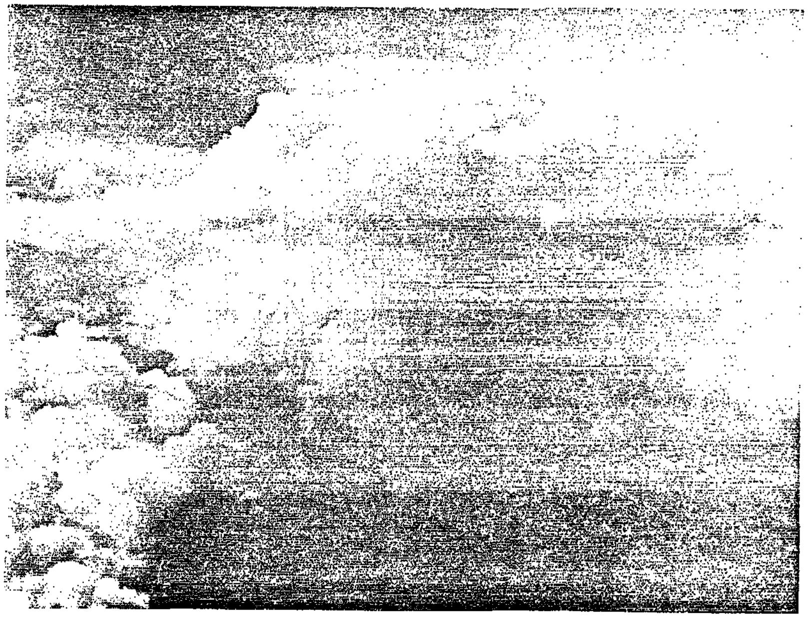
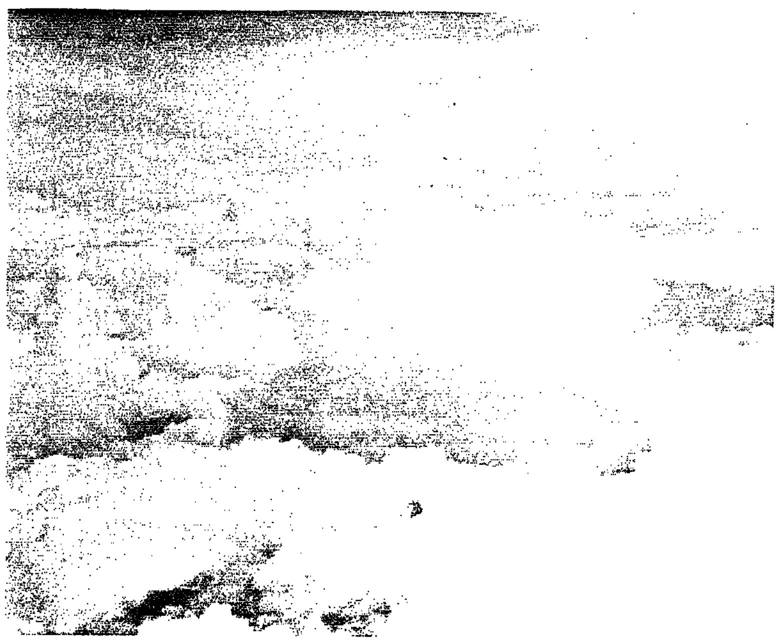
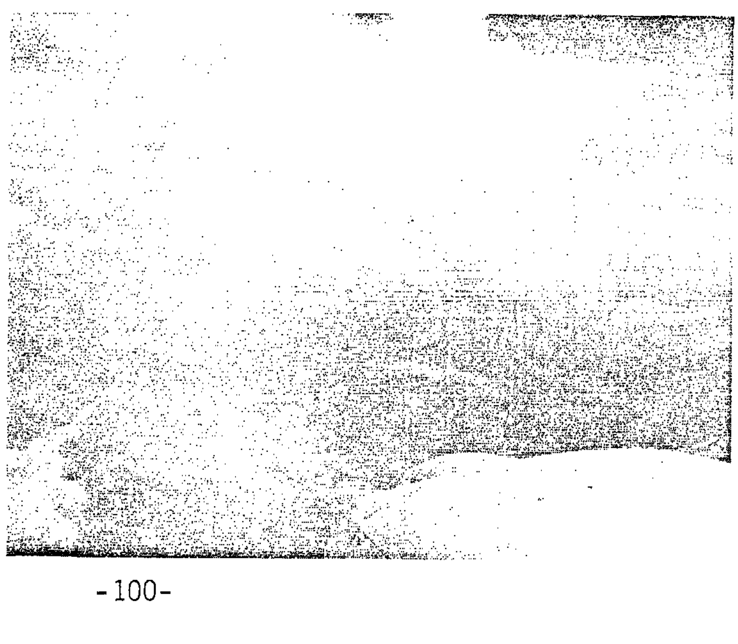


FIGURE 1 (Con't.)







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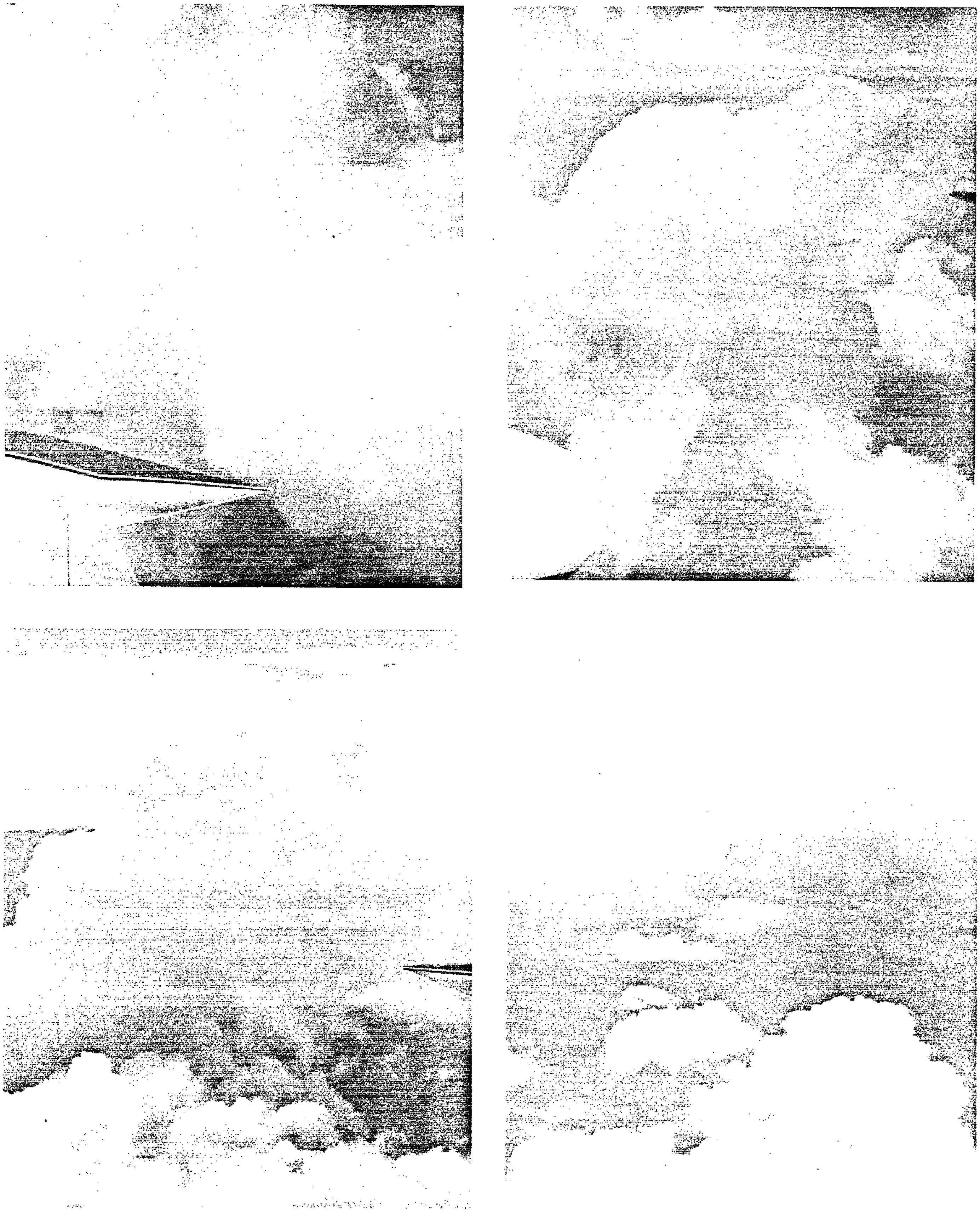

TABLE I. SIMPSON CLOUD MODEL OUTPUT USING "UPPER" AND "LOWER" BASE, COMPARED WITH ACTUAL CLOUD BEHAVIOUR

Cloud	ACTUAL		MODELLED (LOWER BASE)		MODELLED (UPPER BASE)	
	Top height attained (m)	Rain produced (10^3 m^3)	Top height attained (m)	Rain produced (10^3 m^3)	Top height attained (m)	Rain produced (10^3 m^3)
17/1/74 (First)	5 852	Trace	5 173	4.4	4 733	0.2
17/1/74 (Second)	5 233	13	6 695	45	6 478	27
29/1/74 (First)	5 220	6	7 840	237	6 000	0.4
29/1/74 (Second)	5 154	1	9 740	132	5 500	0.3

base, only to deteriorate later in its lifetime. Similar behaviour has been suspected in some Australian clouds (E.J. Smith, personal communication).

When the Simpson or Hirsch cloud model was run with these clouds, assuming the base to be the bottom of the ragged portion (i.e. the base as predicted by the ground-level air temperature and humidity), then the calculations indicated very strong updrafts in the region immediately above this base (just as they did in Florida; see Simpson and Wiggert, 1969). If these upcurrents really were present, then the lifted air would have cooled and produced large amounts of liquid cloud-water by condensation of its vapor. Thus, the fact that the lower part of the cloud was either patchy or had disappeared completely, indicated that there were no sustained updrafts there.

This was confirmed during the 1973/74/75 Rhodesian experiments, when penetrations were made by the research aircraft into the broken region of these clouds. No updrafts were encountered, showing that in these instances the steady state model calculations were unrealistic. On the other hand, upcurrents were often found in the solid cloud-mass above the ragged section.

ASSIGNING AN "UPPER" CLOUD-BASE TO USE WITH THE MODEL

It is worth considering whether it might be better to regard the top of the broken portion as the true cloud-base: this was often about one, occasionally two thousand meters above the conventional base. Unfortunately, this "upper" base was never flat and clearly defined (as in the ideal cumulus); instead there tended to be a gradual transition from broken cloud lower down to a solid mass higher up. Nevertheless, during the experiments a discretionary value was assigned to the base of the solid section, enabling the computer model to be re-run assuming this was the true cloud-base; see Table I. In all cases the rainfall produced by the model run with the higher base was lighter and closer to reality than was the rain from the model run with the original, lower cloud-base. Furthermore, in three out of the four cases examined in Table I, the predicted heights were better when the top of the broken section was treated as the true cloud-base. Even then, however, the agreement was far from perfect.

Many clouds which fail to respond to seeding do in fact have broken or abnormally high bases (McNaughton, 1977 and 1978). However, if they are to be modeled successfully, a way must be found of predicting the extent of these ragged bases; as has been mentioned above, the standard tephigram constructions estimate only the lowest level of the broken portion. Also, since many of these clouds commence their lives with flat, firm bases, only to deterioriate later on, it seems likely that steady state models will never be able to describe them adequately. It is possible, however, that time-dependent models will be more successful.

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