積雨雲之研究(三)

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On The Life Cycle of Cumulus Rain Clouds

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4. Conclusion

According to the general appearance of the figures presented in this paper, it seems that we have achieved our goal of the simulation of the life cycle of a convective rain cloud cell; showing three stage of development. In addition, we have also found that in some conditions, only steady, thin, cold plume clouds can exist, while in some others, the produced plume clouds are "periodic". Viewing at these results of only six cases, we see that the variety of the clouds is very great. Besides the microphysical aspects of the hydrometeors, the factors involved in the formation and the development of clouds are too many. Conditions unfavorable for this kind of convective clouds may be favorable for a different kind. Therefore, the great variety of our results does not surprise us. In fact, if we look at the sky, we very often see clouds of many many different forms do co-exist.

In Table 3, the durations of the various stages of each cloud and other informations have been listed. Here, we should point out that the terminology abont the stages is different from that used in the Thunderstorm Report in which the durations are not well defined. In our way, cumulus stage begins at the formation of cloud and ends either when rain reaches the source or when the cloud is dissipated without rain, while rain stage begins when rain stops. All the numbers in Table 3, that are our results, are reasonable and are within the observed range.

In the present work, we have introduced only two changes to the original model persented in Paper A: one is the addition of a precipitation mechanism and the other, the change of a constant source to a variable one.

As we have stated before, our interest is not on the micsophysics of the dydrometors. Therefore, the precipitation mechanism adopted is a very simple one, as represented by (2.1) and (2.2). Nevertheless, (2.1) and (2.2) imply unique, but unknown assumptions on the various microphysical properties of the condensation nuclei and liquid water droplets. These unknown assumptions do not vary from case to case in our experiments. Cousequently, we can make comparison among our own results, for example, to compare the total rainfall of one cloud from that of another. It is not proper, however, to compare our results in a critical way with that of the other investigator's works which have different precipitation mechanism. Furthermore, our environmental and source conditions are arbitrarily assigned, and the also somewhat subjective. All these together do prevent us to compare our results to any spevific set of data. But, we believe that the major features of our model clouds will not be much different from those works using dif-

Table 3. Characteristics of model clouds

Case	Cloud Number	Cumulus stage (min)	Rain stage (min)	Life Span (min)	RRp (mm/hour)	Rt (mm)	Zr (km)	Zmax (km)	LWCmax (g/kg)	Wmax (+) (m/sec)	Wmax (−) (m/sec)	τ (min)	ΔTmax (+) (°C)	ΔTmin (−) (°C)	ΔTmax (−) (°C)
1	1								1.0	5.0					
2	2-1	73.3		73.3				4.1	3.04	6.15	-5.45		.52	-1.06	
	2-2	30.1		30.1				4.7	3.3	6.48	-6.29		.65	-1.5	
	2-3	32.1		32.1				4.9	3.26	6.39	-6.49		.52	-1.47	
3	3-1	38.0		38.0				6.4	4.13	9.8	-13.0	11.0	1.1	-3.3	2.2
	3-2	21.8	5.5	37.0	55.0	2.3	6.83	7.06	4.68	11.4	-14.8	11.0	1.4	-3.8	2.3
4	4-1	31.0		31.0				4.3	3.24	5.99			.38		
	4-2	23.0		23.0				3.6	3.76	7.43	- 5.0		.9		
	4-3	26.0	9.0	35.0	80.0	5.7	5.6	6.0	4.26	8.99	-10.9	10.5	1.05	-2.7	1.9
5	5	20.0	13.0	33.0	85.0	8.9	4.74	6.14	4.37	10.6	-12.8	11.0	1.3	-2.9	2.6
6	6		9.1		100.0	8.1	6.07	6.13	7.16	9.84	-12.0		1.16	-3.5	2.1

Cumulus stage, length of cumulus stage; Rain stage; length of rain stage; RR_p, peak rainfall rate; R_t, total rainfall; Z_r, Cloud height reach when rain reaches the source level; Z_{max}, maximum cloud height; LWC_{max}, maximum liquid water content in core; W_{max} (+), maximum updraft; W_{max} (−), maximum downdraft; τ, period of gravity oscillation in core; ΔT_{max} (+), maximum temperature excess in updraft; ΔT_{min}(−), maximum negative Temperature excess in downdraft; ΔT_{max} (−), maximum positive temperature excess in downdraft due to dry-adiabatic compression.

ferent precipitation mechanism, or from the general observations. For example, we sometimes feel uncomfortable hot right after a shower is over. As indicated by the last column of Table 3, this is due to the dry-adiabatically compressed, warm and high humidity downdraft which continues to come down to hit us at the expense of their kinetic energy.

In so far as the variable boundary conditions at the source is concerned, we have seen at least one phenomenon in our results, which may be taken as an indication of the existence of defect. The phenomenon is that whenever the rain is over, the cloud activity ceases; resulted from that once the vertical velocity at the source becomes negative, it could come back at most arround zero and never again attain its original, positive, upper limit value W_{so}, or even close to it. The reason is that in our variable boundary conditions, there is no explicit provision for restoring the original vertical velocity at the source. This is a logical consequence of the fact that we have ignored the mechanism below the source level, which produces the strong updraft through the source. Some sort of provision is necessary if we expect the sequence of events to repeat, since the upward notion of the gravity oscillation in the core region alone is not strong enough to generate an updraft as strog as that having W_{so} at the source. Because of this ignorance, we have no physical basis to "set" W_s back to equal to W_{so} arbitarily. Even we intend to do so, there is, however, no observation, at least to this author, about the time variation of the strength of an updraft produced by a high level heated mountain peak, to guide us to assign proper values to W_s in a proper manner. It seems to us, therefore, this difficulty is hard to overcome, and the only alternative seems to be simply to remove the source from our model. This will be our next task.

Another assumption, that is necessary and has great influence on our results, but not close to, in fact, very far from the reality, is the one which we have already made in Paper A, namely, no liquid water droplets, or rain drops, can exist in an unsaturated environment. The rain drops, no matter how large it may be, can not penetrate through an unsaturated sub-cloud region to reach the source. If a cloud is wet enough so that it is going to rain at all, this will delay the time of the starting of the rain at the source, and thus makes the front part of the rainfall rate curves steep, since the rain have to evaporate in order to saturate the sub-cloud region first. If the cloud is not wet enough, there will be no rain drops able to penetrate the unsaturated sub-cloud region and to reach the source at all. Of course, this is not true as we always see large rain drops falling to the ground when the surface relative humidity is still below 100%. Unless we can calculate the evaporation of rain drops in some way in an unsaturated sub-cloud region, it seems there is no simple way to alter this assumption. Finally, we should notics that the ignorance of the glaciation and the microphysics of the rain drops perhaps promotes the cessation of rain at the source.

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Legends

Fig 1. Case 1. The cloud is a thin, steady and cold plume cloud. The source conditions are: vertical velocity, 2 m sec^{-1}; temperature excess, 2C; radius, 1000 m; relative humidity, 75%; mixing ratio, 8.72 g kg^{-1}. The environmental conditions are: temperature lapse rate, 0.006C m^{-1}; relative humidity decreases from 50% at 0 m to zero at 9400 m. This is a quite dry environment. Note the depression of the cloud top at t=54 min, due to the suppression effect of the of the gravity oscillations above the cloud, as indicated by the -2 m sec^{-1} cloud contour.

Fig 2. Case 2. The clouds produced are a series of periodic plume clouds without rain. The source conditions are the same as case 1. The environmental conditions are: temperature lapse rate, 0.0065C m^{-1}, a standard atmosphere, only 0.0005C m^{-1} greater than case 1; Relative humidity decreases from 50% at 0 m to zero at 9400 m. Comparing this figure with fig 1, we see the cloud growth is very sensative to the environmental stability.

Fig 3. The profiles of various properties of Case 2 at t=78.5 min. At this time, the first cloud is dissipated and the second is about to develop. The residue is a thin and cold plume cloud supported by the source. The vertical velocity in the core region (upper lift), Wc in m sec^{-1}, shows downward velocity above and a strong gradient just on top of the cloud. The upper middle profile shown very strong dynamic detrainment, in percent, just on top of the cloud, which makes the radius of the IE region (middle right), RI in km. to increase; resulting in a thick, protective near environment good for the formation of a successive cloud. The upper right profile shows downward velocity, Wz in m sec^{-1}, in the IE region and out side of the cloud. The middle left profile, temperature excess in core rigion, Tc in C, shows that the cloud is cold, but warm above and below. The center profile, liquid water content in core, q_{Lc} in g kg^{-1}, shows that the cloud base is about 1.5 km and the top, 1.8 km. Maximum q_{Lc} is a little less than 1 g kg^{-1}. The lower left profile shows that the virtual temperature excess in core, T_{vc} in C, is nearly zero. This shows also the buoyancy force of the cloud is nearly zero. The lower middle profile, shows that the relative humidity in core, RH_c in %, is 100% in cloud, and above the cloud, the air is moister than environment up to Z=4.0 km. The The slant line on the left represents the relative humidity of the environment. The lower right profile shows the mixing ratio in core. Note that above the cloud, the air contains more water vapor than that of the environment, which is represented by the smooth curve on the left. The most important five profiles are those of T_c, T_{vc}, RI, RH_c and Q . They show that the first cloud has paved the way for the latter clouds by moisten and warm up the core and the IE rigion.

（以上圖說請參閱氣象預報與分析第59期 p.7. Fig 1; p.8. Fig 2 p.9. Fig 3 各圖。）

Fig. 4 Case 3. Two deep cumulus clouds: first has no rain, second has. The source conditions are the same as case 1 and 2. The environmental conditions are: temperature lapse rate, 0.008C m^{-1}; relative humidity decreases from 50% at 0 m to zero at 9400 m. The environment of this case is more unstable than case 1 and 2, so that the clouds produced are much deeper from those in the other two cases; however, it still needs the first cloud to pave the the way for the second. The temperature excess (bottom row) in the clouds is generally small except that associated with the downdraft which, in the first cloud, can not reach the source even it has -12 m sec^{-1}. The downdraft of the second cloud attains its maximum strength of greater than -14 m sec^{-1} at the the source a little after rain stops, so also the maximum negative temperature excess. The peak rainfall rate and the total rainfall are, respectively, 55 mm hr^{-1} and 2.3 mm. Note also the gravity oscillations in the core region after the downdraft has passed through the source, as shown clearly in the temperature and velocity fields. And note further, after the lower part of the second cloud is washed out by rain, a long-lasting, also-cumulus cloud is floating in the middle atmosphere.

Fig 5. Case 4. Three clouds are produced, the first two only pave the way for the third. The environmental conditions are: Standard stmosphere; relative humidity decreases from 50% at 0 m to zero at 9400 m. The source conditions are: relative humidity, 80% (5% increase than cases 1,2,3,) ; mixing ratio, 9.3 g kg^{-1}; others are the same as case 1,2 and 3. After the cessation of rain, the altocumulus is short lived. The reason is unclear. The variations of the downdraft and temperature excess after the stop of rain are similar to that of case, 3, and note further, in addition to that in the lower level, the gravity occillations also appears in the upper level when the altocumulus is dissipated.

Fig 6. Case 5. One deep rain cloud with low base is produced, because the relative humidity of the source air is increased to 90%, and the environmental relative humidity is increased to 80% at 0 m, decreasing to zero at 9400 m. But, the temperaturs excess, is decreased to 1C. Otherwise the same as case 4. This case is wetter than all the other cases, so it needs no predecessor. The peak rainfall rate and the total rainfall are 76 mm hr^{-1} and 8.9 mm, respectively.

Fig 7. Case 6. Same as case 4, except that the cloud is first assumed non-precipitation until it has reached a steady state. Then the precipitation mechamism is introduced and rain is produced, with peak rainfall rate, 100 mm hr^{-1}, total rainfall, 8.1 mm. The process of deleting the precipitation meachanism first may be taken to imply that all the condensation nuclei, water droplets,

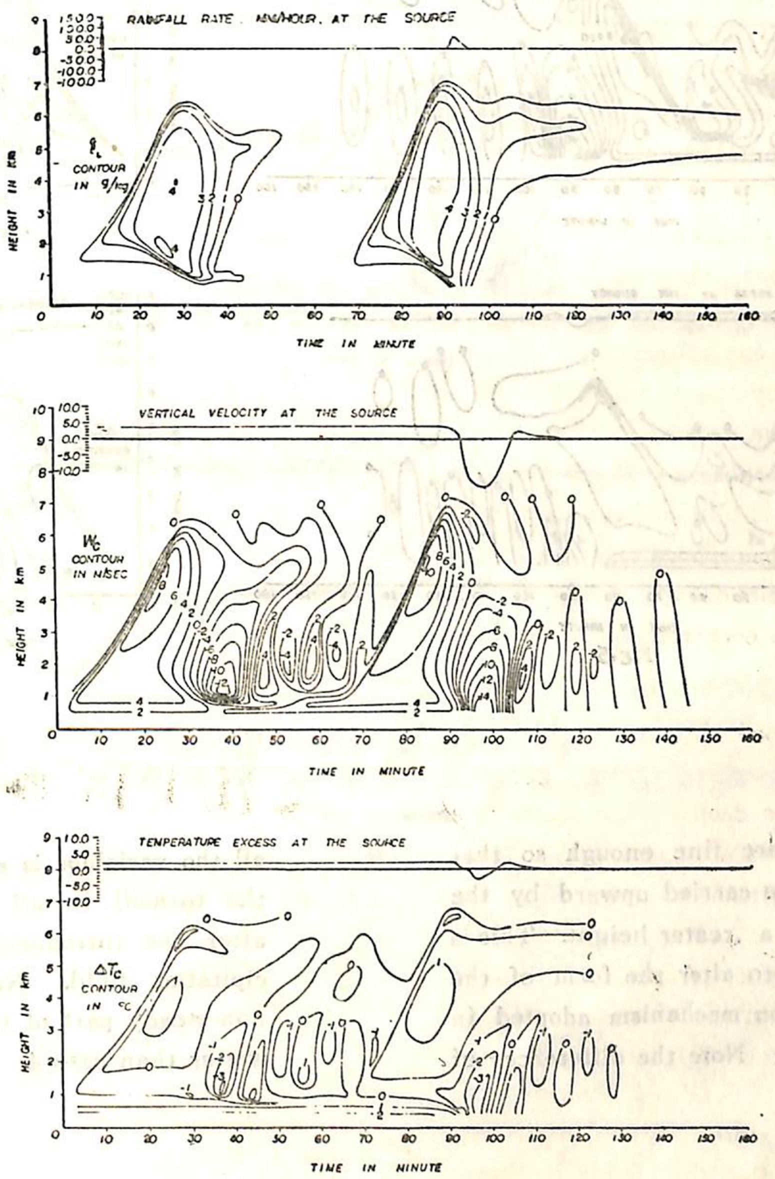


Fig.4

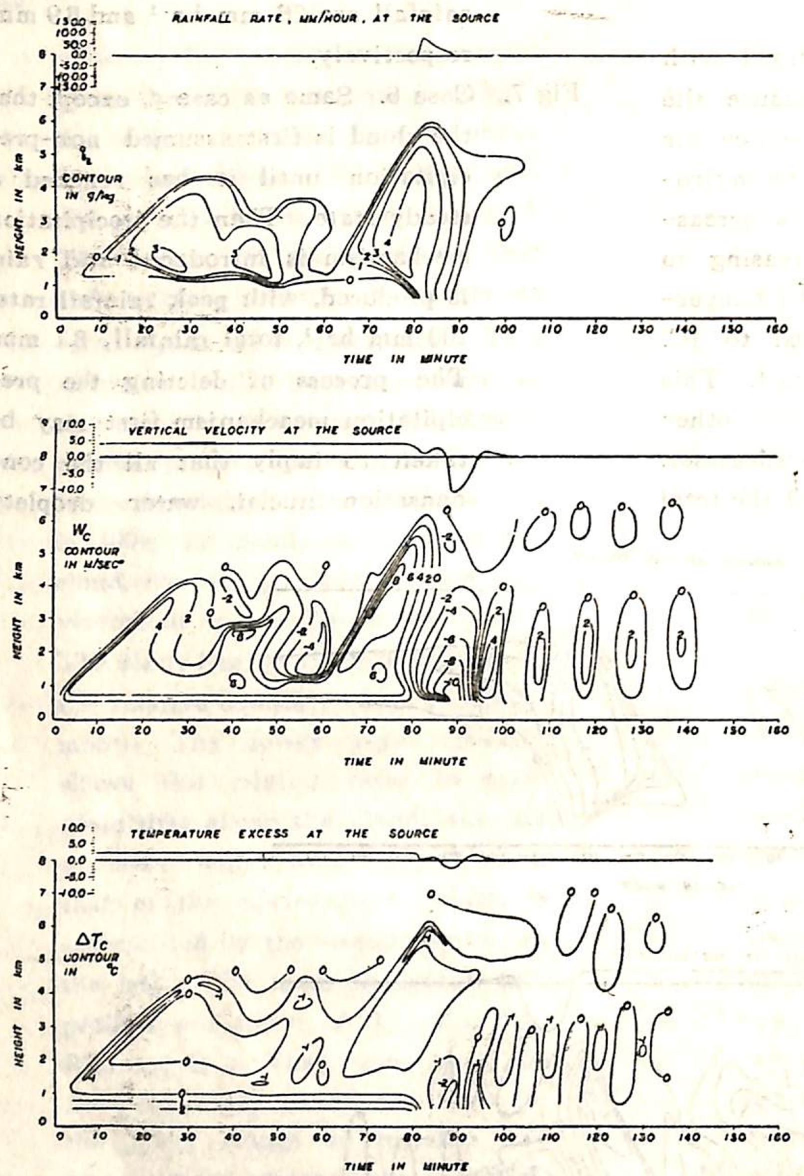


Fig.5

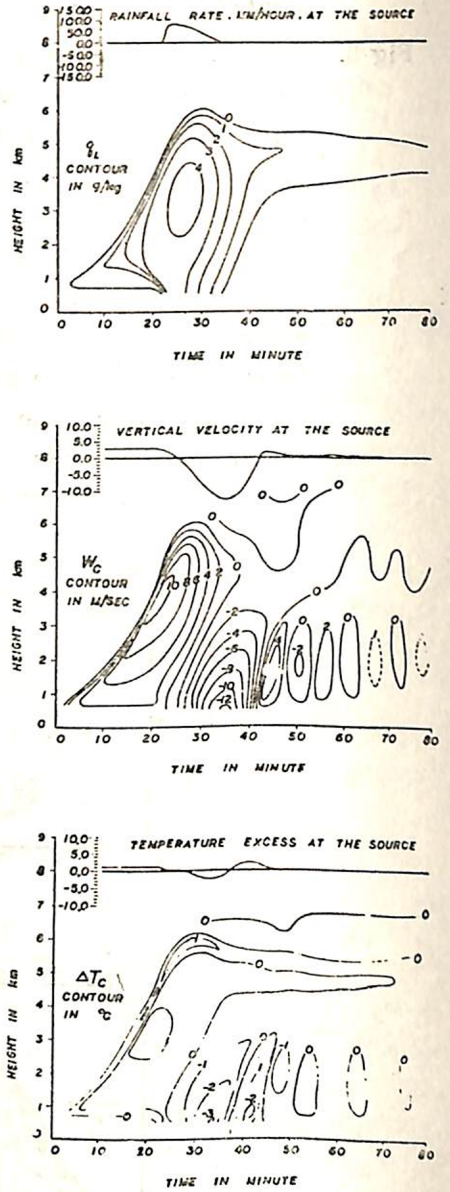
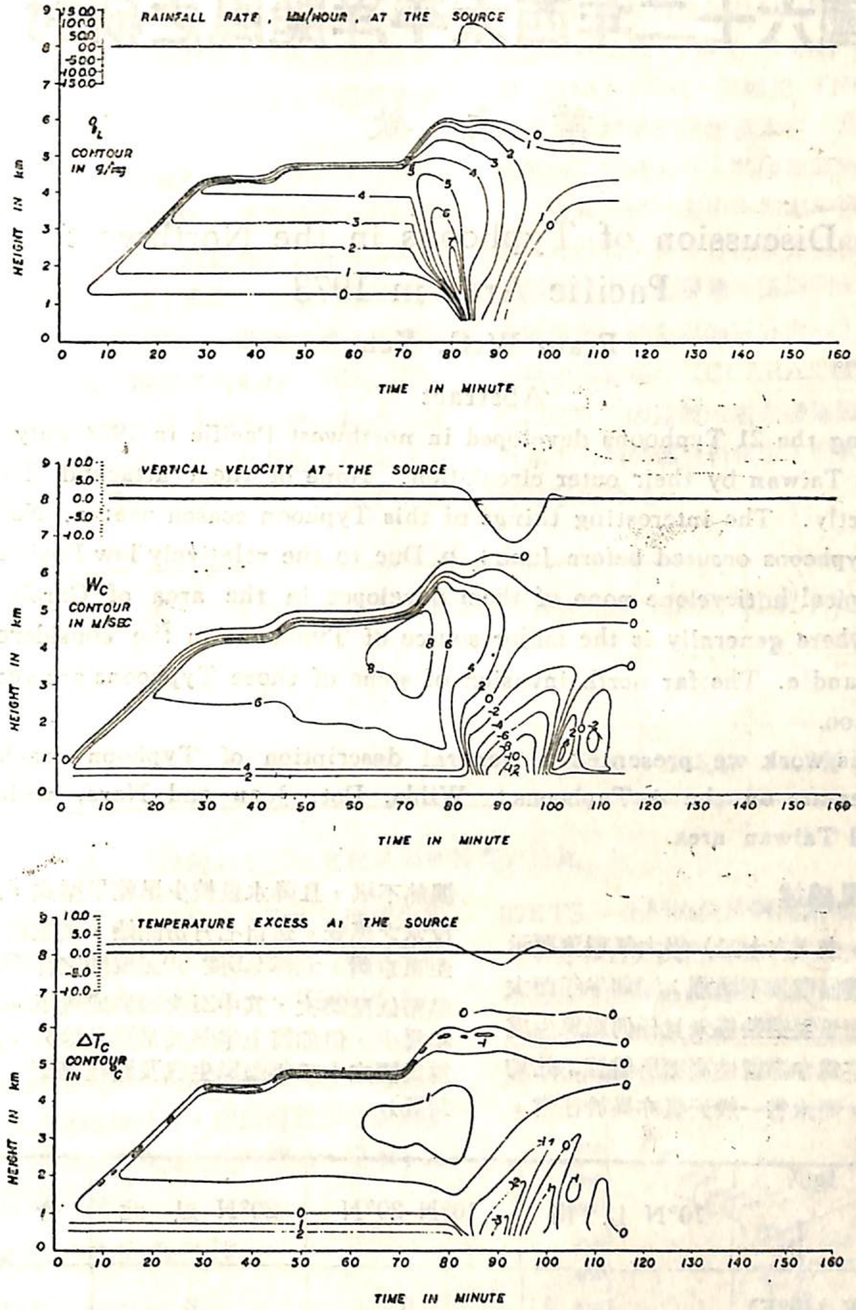


Fig.6

and thus are fine enough so that they can be carried upward by the updraft to a greater height. This is equivalent to alter the form of the precipitation mechanism adopted in this paper. Note the differences of all the variables is steady state and the turmoil in all fields occurred after the introduction of the precipitation field. Note further the non-steady part of this case is much wetter than case 4.



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