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Morphological Structure of Evolving Cumuli as Seen by a Radar and Stereographic Photographs

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Abstract

Evolving cumulonimbi was observed by a conventional weather radar and stereographic photographs. Although the radar echo was a single cluster and its movement was almost stationary, the clouds which organized the echo show intermittent development one after another. The reasons for stationary radar echo were considered that a new cumulonimbi developed at the rear of the cloud movement and the region of strong updraft shifted backward even in a individual cloud. The movement of cloud was more speedy than the radar echo movement.

The developing clouds were categorized into five stages ; Stage I (Tower), Stage II (Cone), Stage III (Cauliflower), Stage IV (Anvil) and Stage V (Dissipating). The cone-like shape stage (Stage II) showed a strong upward velocity. The stage was short-lived but important for the development of cumulonimbi in order to analyze its structure.

1. Introduction

Mechanisms of development and dissipation of cumulonimbi are one of major interests in the field of cloud physics and meso-scale meteorology. The studies on the detailed morphology of evolving cumuli are necessary to understand their mechanism ; such as the formation, maintenance and development of cumulonimbi. Dependence of radiation effects on cloud shapes is also a great concern in relation to problems of climate change.

One of the most prominent indications of cloud development is its visible image taken by photographs. The morphology of clouds reflects the distribution of cloud droplets in clouds. Their time variation indicates air flows in and around clouds. For example, updraft speeds in clouds are estimated by tracing the tops of evolving clouds. On the other hand, radar reflectivity represents the amount of precipitation droplets in clouds. Simultaneous observation of radar

reflectivity and stereographic photographs are considered to reveal detailed structures of developing clouds.

Malkus and Scorer (1955) observed the erosion of cumulus towers by time-lapse photographs. Examples of stereographic photographs observed on clouds are a series of studies by Magono et al. (1967a, b, c, 1969) and Hozumi and Magono (1984). Since their major concern was detecting the distribution of cloud sheets over a wide region, the detailed structure of cloud shape was not of concern. Battan and Theiss (1966) revealed the vertical motion in a thunderstorm by using a vertically pointing Doppler radar and cloud photographs. Wakimoto and Bringi (1988) recently compared photographs of clouds and multiparameter radar data. They were not using stereographic photographs, therefore the fine structure of the cloud morphology was not clear as yet.

For the detailed study of cloud morphology, stereographic photographs are required to be taken at a short intervals. Simultaneous observation of evolving clouds by a weather radar and stereographic photographs has been difficult to obtain, because the opportunity of suitable cloud distribution for both observation sites is very limited. It is worthwhile to carry out such simultaneous observations in order to reveal the detailed structure of developing and dissipating clouds. This article presents a case study of simultaneous observation of evolving cumulonimbi with a weather radar and stereographic photographs.

2. Methods

The observation of the morphological structure of developing cumuli was carried out with a weather radar and stereographic cameras from 26 August to 8 September in 1986.

A conventional weather radar was set up at the Chikyu-Misaki, Muroran, Hokkaido. The wavelength and beam width of the radar is 3.2 cm and 2.0°, respectively. PPI reflectivities of echoes in the range of 64 km from the radar site were recorded on magnetic tapes every 10 minutes (11 elevations in 1.1° intervals starting from 1.0°). CAPPI at several altitudes and RHI at selected direction were composed by these radar data.

Bronica cameras (6×6 size film, $f=50$ mm) were placed at two points. One is close to the radar site point (110 m above sea level) and the other point (146 m above sea level) is 1189 m away from the radar site. The base line of stereographic photograph extend 110° azimuth angle, that is, nearly the east to the west. Therefore the south side clouds to the site were available for stereographic photographs. Simultaneous photographs were taken every one minute

at the two points. Printed photographs were used for the analysis of distance, height and morphology of clouds by a trigonometric method.

High quality stereographic photographs of developing cumuli were taken in the afternoon on 7 September 1986 around Oshima peninsula, Hokkaido. This case was analyzed precisely by utilizing GMS satellite data.

3. Results

3.1 Time series of cloud evolution

We obtained time-series photographs of clouds and radar echoes of cumulonimbi at the same time. Isolated radar echoes had been observed from 11 JST over Oshima peninsula. We selected an echo to analyze that which developed severely around 1350 JST and lasted for about two hours.

PPI radar echoes (from 1400 JST at 20 minute intervals) at an elevation angle of 2.1° are shown in Fig. 1. In order to compare the photographs with the radar echo easily, PPI radar displays in this article are all reversed in contrast to ordinary maps; i.e., the south side is up and the north side is down. The radar echoes moved slowly until 1440 JST, then the echoes broke up and moved

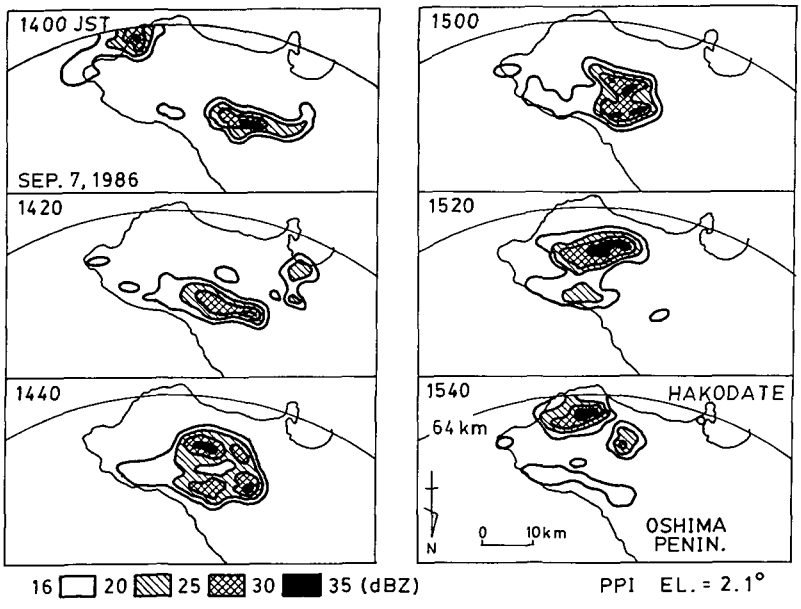

Fig. 1. Time series of PPI scans from 1400 to 1540 JST, 7 September 1986. The north is down and the south is up.

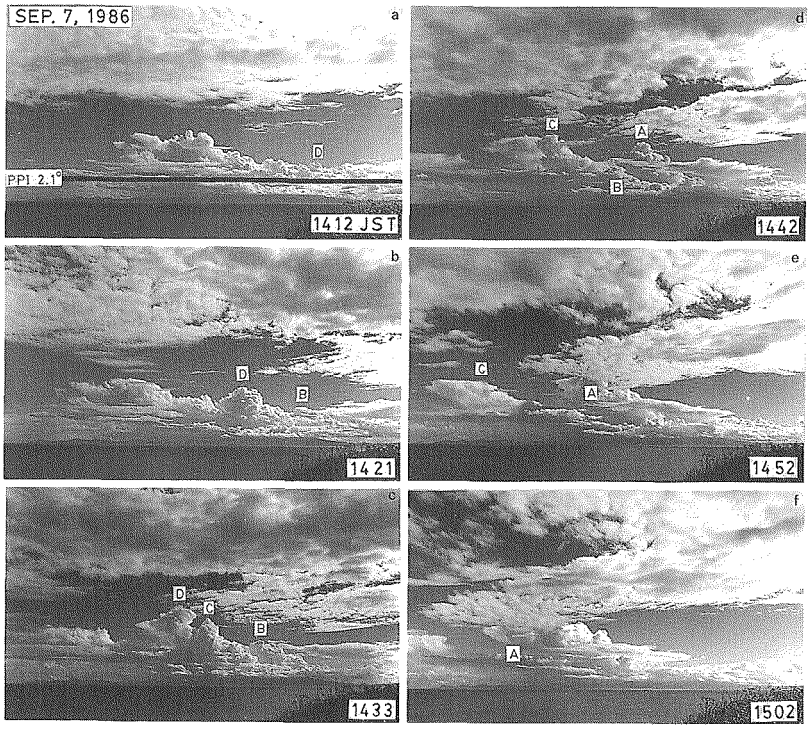

Fig. 2. Cloud photographs at about 10 minute intervals from the radar site to the south. The thick line in (a) corresponds to the height of PPI 2.1° beam.

at a speed of about 6 m/s from northwest to southeast.

Photographs (from 1412 JST about 10 minutes intervals) which correspond to the radar echoes are shown in Fig. 2. The photographs are the views from the radar site looking south. The clouds A, B, C and D were determined by the trace of one minute interval photographs. The thick line in Fig. 2(a) corresponds to the height of PPI 2.1° beam.

Though the radar echoes were almost steady, the clouds developed intermittently one after another and they moved from right side to left side (from east to west) at a relatively high speed. These photographs indicate that a new cumulonimbus continuously developes at the rear side of storm motion and a single cluster of radar echo contains several cumulonimbi in it. The cloud C developed rapidly around 1430 JST and it showed a cone-like shape (discussed in detail later) at 1433 JST. And then it maintained an anvil shape after entering a mature stage.

3.2. Developing stage

Radar echoes and photographs revealed the maximally developed stage of the cloud at around 1440 JST. Figure 3(a) is the radar echo at 1446 JST at the elevation angle of 2.1°. The echoes A, B and C correspond to that of the clouds in Fig. 2. The photographic angle of Fig. 2 is indicated by dashed lines in Fig. 3(a). A vertical cross section of the echo along the line X-Y on Fig. 3(a) is shown in Fig. 3(b). Photographs of clouds around the maximum developing stages are shown in Fig. 4.

The maximally developed echo A is very steep and its top reached the height of 9 km. The echo A of Fig. 3(b), which corresponds to the echo A of Fig. 3(a), developed rapidly from 1440 to 1446 JST. The cloud A of Fig. 4 also developed rapidly from 1436 JST to 1443 JST. The cloud shape of A showed a cone-like shape at 1440 JST when it developed rapidly. The cloud A shows cauliflower-like shape at 1443 JST in its mature stage. The cloud C maintained its anvil shape after the mature stage as shown at 1443 JST. On the other hand, the cloud B did not develop so much.

According to these photographic presence, we summarized features of the

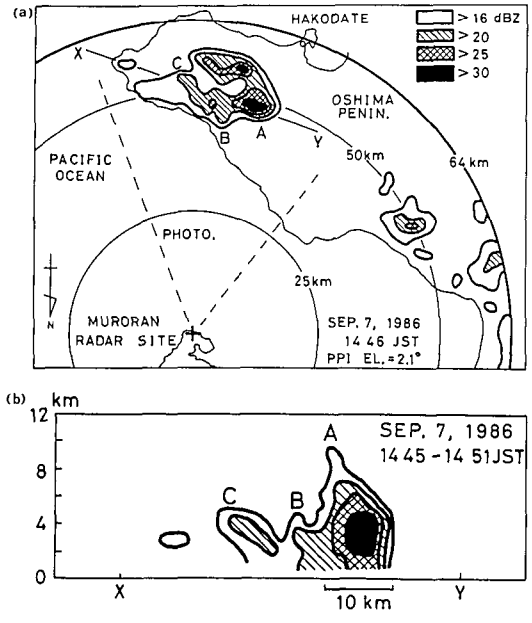

Fig. 3. (a) PPI radar reflectivity at 1446 JST. (b) A vertical cross section of the echo (RHI) along the line X-Y on (a).

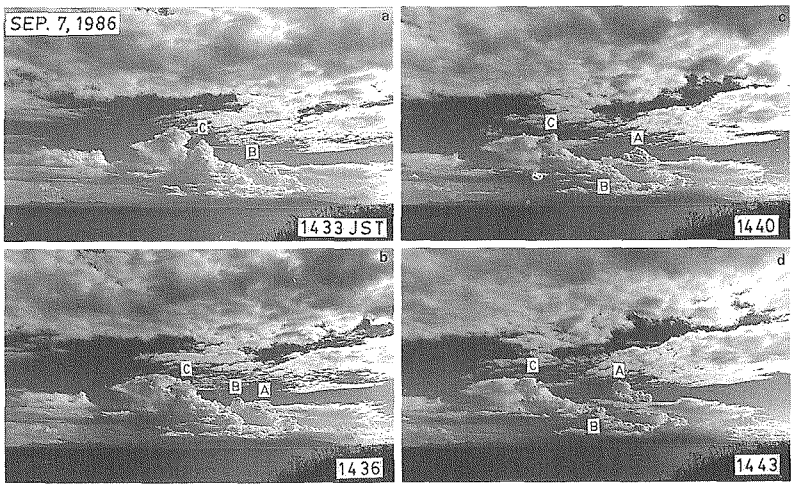

Fig. 4. Cloud photographs at about 3 minute intervals from the radar side.

observed clouds as five stages ; four developing stages and one dissipating stage. They are categorized as follows ;

Stage I : Tower, early developing stage.
Stage II : Cone, rapid upward growth stage.
Stage III : Cauliflower, mature developing stage.
Stage IV : Anvil, after developing stage.
Stage V : Dissipating, descending cloud top stage.

Their developing stages are illustrated in Fig. 5.

3.3 Cloud signatures

Time series of cloud top heights of A, B and C are plotted on Fig. 6. The cloud C has two different tops, that is, the cloud top C′ was displaced by C. Horizontal distance is measured from the standard point of the cloud top A at 1443 JST. The averaged horizontal speed of cloud top movement is also shown. The upward velocity of the cloud top A was estimated about 5 m/s in its developing stage. It was not an upward velocity of air-flow in the cloud, since the cloud top drifted to the leeward ; however, a strong updraft would be expected.

Steep rise of the cloud top A indicates rapid developments. In its developing stages, horizontal speed of cloud top movement is slower than other cloud tops. The cloud top C′ leaped to the cloud top C at 1436 to 1437 JST, since the cloud top reached its anvil stage. The heights of the cloud top C and C′ were

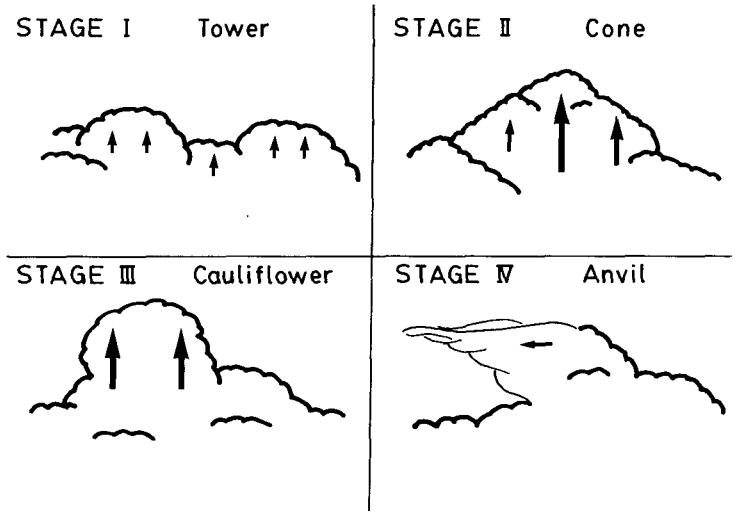

Fig. 5. Schematic illustrations of developing stage of cumuli.

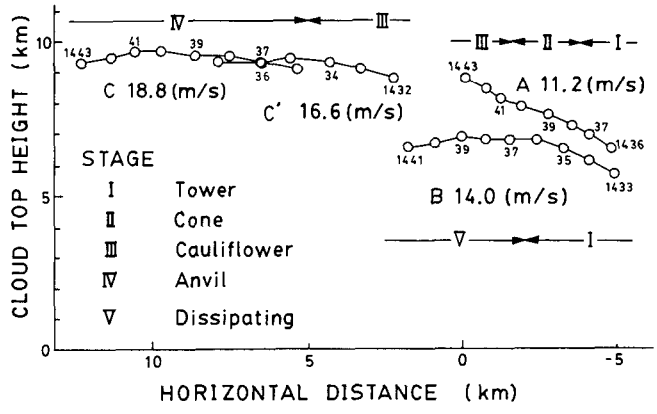

Fig. 6. Plots of cloud top heights and horizontal distance from the cloud top A at 1443 JST.

almost steady and their shapes were long lasting during their anvil stage. Their moving speed was faster than the cloud top A or B. The cloud top B dissipated without taking a stage of the cone and cauliflower. It has a speed of 14.0 m/s in cloud top movement, which is considered to be the representative velocity of clouds motion. It is faster than the moving speed of radar echoes (about 6 m/s).

Paying attention to the cloud A, which showed the most typical changes of

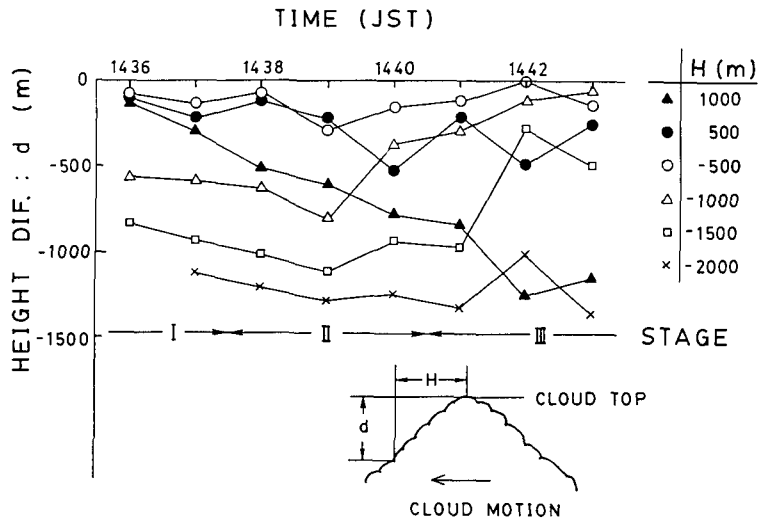

Fig. 7. Time series of height differences from the cloud top A.

its shapes, time variation of cloud feature was analyzed with definition parameters as shown in Fig. 7. Height difference d and horizontal distance H from cloud top are defined as in the illustration at the bottom of Fig. 7.

Locations of solid triangles (H = 1,000 m) and solid circles (H = 500 m) are ahead of the cloud top to the storm motion, and that of open circles (H = −500 m), open triangles (H = −1,000 m), open squares (H = −1,500 m) and crosses (H = −2,000 m) are behind the cloud top to the storm motion.

In order to clarify the moving velocity difference of cloud and radar echoes, we compare the height difference of the points of the same horizontal distances in 1,000 m ahead of and behind the cloud top. The depth of open triangle (H = −1,000 m) decreases from 750 m (at 1439 JST) to 0 m (at 1443 JST) in four minutes. On the other hand, the height difference of solid triangles (H = 1,000 m) increased from 200 m (at 1436 JST) to 1300 m (at 1442 JST) in six minutes. The height difference of the open squares (H = 1,500 m) show similar change as open triangles. The other points of horizontal distance did not show significant changes. These facts indicate that a region of strong updraft shifted backward in a individual cloud. It would be important to maintain a cumulonimbi evolution.

In the stage I, the height differences were shallow in the horizontal distance of −500 to 1,000 m. This indicates that the diameter of tower is about 1,500 m and the height differences around it are about 500 m. In the stage II, since the

height differences change symmetrically in 500 and 1,000 m, a cone-like shape is expected. In the stage III, the height difference of solid triangles (H = 1,000 m) and crosses (H = −2,000 m) are deep and that of the other symbols are shallow. This indicates that the diameter of cauliflower is about 2,000 m and the height differences (about 1,000 m) are larger than the tower-stage.

4. Discussion and conclusions

Observed convective clouds showed typical shape variation of their developing stage. We first consider the conditions when these clouds were formed. A visible image of GMS at 15 JST, as shown in Fig. 8, indicates that several isolated clouds exist over Hokkaido island. These clouds did not accompany fronts or synoptic low pressure systems. Developed clouds were observed around Oshima peninsula, near Hakodate. The target cloud was shown by a white arrow in Fig. 8. Our analyses on the relation between the location of radar echoes and orographs revealed that the developed clouds were considered to be triggered by orographic effects as seen in Fig. 1 and Fig. 2.

Next, we consider the importance of cloud morphology. The cone-like shape of evolving clouds A, C and D in Fig. 2 was extremely prominent at the beginning of Stage II. However it was not prominent in cloud B in Fig. 2 which dissipated without taking a mature stage. The stage II of cloud and tall and intense radar echo coincided well. It is confirmed that evolving clouds have Stage II of cone shape as shown in the analyses of Fig. 3 and Fig. 4, though this

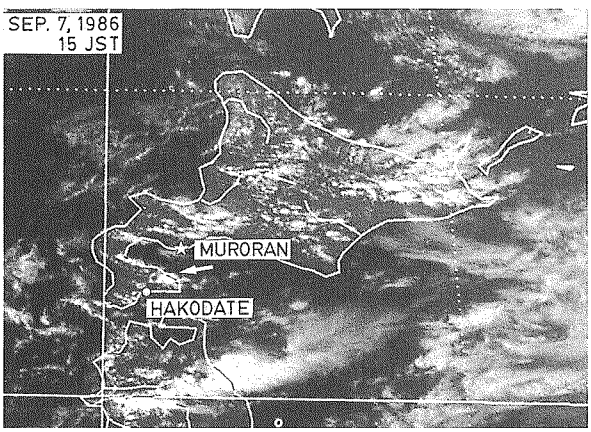

Fig. 8. GMS satellite visual image at 15 JST, 7 September 1986. A white arrow indicates the target cloud.

was only one case study.

The duration time of Stage II is very short compared to the other stages, however, it has a core of large updrafts which indicates the development in the next few minutes. Therefore, morphologlcal structure of Stage II required a more detailed study with Doppler radar observation and another equipment for short term forecast of heavy rainfalls and for the understanding cloud development. The morphological study of evolving clouds is also important to clarify the transport process of moisture and momentum from troposphere to stratosphere. The long lasting anvil stage affect the radiation by clouds. The method of analyses on cloud development proposed in this paper would give a key to reveal the structure and the role of convective clouds.

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References

Battan, L.J. and J.B. Theiss, 1966. Observations of vertical motions and particle sizes in a thunderstorm. J. Atmos. Sci., **23**, 78-87.

Hozumi, K. and C. Magono, 1984. The cloud structure of convergent cloud bands over the Japan Sea in winter monsoon period. J. Meteor. Soc. Japan., **62**, 522-533.

Magono, C., K. Kikuchi and T. Kasai, 1967a. Preliminary observation of cloud distribution using a 16 mm movie camera from an airplane — Clouds over the Pacific Ocean : Part I —. J. Meteor. Soc. Japan., **45**, 177-184.

Magono, C., K. Kikuchi and M. Kajikawa, 1967b. Distribution of low-level cloud rows and three dimensional analysis of cirrus clouds — Clouds over the Pacific Ocean : Part II —. J. Meteor. Soc. Japan., **45**, 467-477.

Magono, C., K. Kikuchi and T. Kasai, 1967c. Cloud Distribution across a cold front over the Middle Northern Pacific Ocean — Clouds over the Pacific Ocean : Part III —. J. Meteor. Soc. Japan., **45**, 478-489.

Magono, C., K. Kikuchi and T. Kasai, 1969. Comparison of aerial cloud pictures with satellite pictures — Clouds over the Pacific Ocean : Part IV —. J. Meteor. Soc. Japan., **47**, 227-234.

Malkus, J.S. and R.S. Scorer, 1955. The erosion of cumulus towers. J. Meteor., **12**, 43-57.

Wakimoto, R.M. and U.N. Bringi, 1988. Dual-polarizations of microbursts associated with intense convection : The 20 July storm during the MIST project. Mon. Wea. Rev., **116**, 1521-1539.