An Analysis of Stationary Rainbands as Observed by Radar (I)

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(Received September 15, 1961)

Abstract

An analysis is made of the formation and the feature of stationary rainbands observed in western and eastern Kanto District. It is shown that the generation of a small elementary cell depends on the atmospheric condition and the topography of the peninsulas, and that the principal factors governing the formation of a stationary rainband are the vertical wind profile and the depth of the moist layer. Furthermore, in order to examine the effect of trigger action due to topography, the distribution of updraft by topographies is calculated.

1. Introduction

Stationary rainbands were observed by the radar set up at the Meteorological Research Institute, Tokyo, Japan. The radar is of 3.2 cm wavelength and its indicator consists of PPI, RHI and A-Scope.

The most striking feature of these stationary rainbands was that their echoes had originated from small elementary cells generated in a certain area. The author describes the feature and the formation of such stationary rainbands associated with the tropical storm and the uniform air mass.

MALKUS, BUNKER and McCASLAND (1951) have demonstrated that, in the region of Cape Cod and the adjacent islands, an unusual and striking cumulus-cloud formed at altitudes of 3,000 feet or lower. Large numbers of dark, tenuous, pileus-like veils are related to the heating of the land surface relative to the surrounding waters.

LEOFOLD (1949) has shown that the local sea-breeze and land-wind regimes in Hawaii meet and interact with the prevailing trade wind giving rise to cloud lines of a distinctive character, and that these cloud systems are the source of rain and sufficiently frequent to exert important influences in local microclimates.

In this study, when the formation of a stationary rainband was observed in western or eastern Kanto, a typhoon or front which provides a source of moist air existed over the Southern ocean and a strong southerly wind was flowing around the Kanto area. Because the generating points of small elementary cells were distributed over the mountainous region of Izu or Boso peninsula, it is assumed that the generation of small elementary cells composing the rainband was due to
the trigger action of such topographies. Furthermore, it is considered that the
generation of cells and the formation of a stationary rainband may depend on the
strength of trigger action, atmospheric flow pattern, the degree of atmospheric in-
stability and the moisture distribution in the atmosphere.

2. Radar observation of stationary rainbands

1) Tropical storm case

Stationary rainbands were frequently observed by radar in western Kanto when
a typhoon center was located at several hundred kilometers west or south-west of
Tokyo (in Kyushu or its vicinity). The tracks of three typical typhoons in which
stationary rainbands were observed are shown in Fig. 1. The locations of the
typhoon center at the time when rainbands were observed by radar are shown in
acs on the track of typhoons in Fig. 1.

An analysis was made of the stationary rainband which was observed on 18~19
August 1954 (typhoon GRACE). At 2100 JST on 18, the first rainband was observ-
ed near Ninomiya about 60 km southwest of Tokyo. At this time, the typhoon
center was located in Shikoku District. Fig. 2a shows the surface weather map.
At 1900 JST, the wind direction at Nagatsuro changed from southeast to southwest the wind speed being 25 m/sec. Figs. 2b and 2c show the surface weather map of another typhoon when stationary rainbands were observed in the same area.

Series of radar photographs are shown in Fig. 3 in which the stationary characteristic of a rainband is expressed. These bands were formed by development of small elementary cells and its first cell had been continuously generated at a specific area, namely the southern end of rainbands. Fig. 4 shows the generating points of the first cell. Because these points were distributed to the northeast of Izu peninsula, it is estimated that the generation of these elementary cells are related to the topography of the peninsula.
Small elementary cells move to the north-northeast along the rainband, and its velocity is obtained to be 20 m/sec, which is about the same as that obtained for other isolated echoes. The time interval of cell generation is about 5 min. Its cell was apparently developed upon reaching the coast line near Ninomiya and more developed to intense echo near Atsugi. An example of these behavior is shown in Fig. 5. At 0815 JST, these echoes were slightly developed and formed a stationary rainband at 0850 JST. This rainband was separated at 0921 JST about 20 km northwest of the radar station and diminished at 0935 JST. Fig. 6 shows the time variation of the new elementary cells distributed in a circle which were observed at 0750 JST near Ajiro about 90 km south-southwest of the radar station.
Fig. 4. Distribution of first echoes around the Izu peninsula.

Fig. 5. Time variation of radar echo for August 19, 1954.

Fig. 6. Time variation of small elementary cells distributed in a circle for August 19, 1954.
These phenomena continued to the morning of 19 and hardly any other echoes were observed in the radar range of 120 km.

2) Uniform air mass case

When the Kanto District is covered with a southerly wind air mass in summer and at about 0900 JST, a southerly wind of 5 m/sec or more begins to blow, small elementary cells were frequently observed over the southern area of Boso peninsula. The greater part of these elementary cells were diminished in the morning, but on occasions, these cells were developed and formed stationary rainbands.

A typical example of the stationary rainband in eastern Kanto occurred on 5
August 1957. Fig. 7 shows the surface weather map for 1500 JST and Fig. 8 shows the local surface maps for 0900 JST and 1500 JST. The surface map at 0900 JST shows a weak surface front over the Southern ocean. The surface map of other days in which small elementary cells were observed in southern Boso peninsula were in almost the same synoptic situation.

At 0944 JST on 5 August 1957, scattered elementary cells were observed in northern Boso peninsula, and these cells moved to the north along the Chiba coast line. Its velocity is obtained to be 10 m/sec. At 1040 JST, small elementary cells were developed and formed a stationary rainband. Fig. 9 shows the stationary rainband observed in eastern Kanto. It is found from radar observation that small elementary cells composing the rainband had been continuously generated at the southern end of the rainband, namely the southwestern area of Boso peninsula. Fig. 10 shows the generating points of elementary cells and some points distributed over the ocean were observed between 1540~2000 JST. From the generation of elementary cells over the ocean, it is assumed that the weak front over the ocean was developed and detectable clouds were formed over the ocean.
Fig. 9. Series of radar photographs around the Boso peninsula for August 5, 1957.
Fig. 11 shows the time variation of small elementary cells generated at 1505 JST. These cells were slightly developed upon reaching the coast line near Chiba and apparently developed to intense echo at 1718 JST. Furthermore, these echoes were
developed to thunderstorm near Tateno and thunder and lightening were frequently observed. The maximum height of echo observed by RHI was about 10 km and the height of small elementary cells was 4 km.

The total amount of precipitation is shown in Fig. 12 between 0900~2400 JST. This precipitation pattern associated with the distribution of stationary rainbands. A precipitation rate of 10~20 mm/hr was observed between 1100~1400 JST at Mito, but between 1700~1900 JST, a precipitation rate of about 10 mm/hr was observed at Chiba and in southern Boso.

3. The relationship between small precipitation echo motion and atmospheric flow

The apparent horizontal movement of the column of hydrometers obtained from radar is controlled by upper atmospheric flow, and it is assumed that the echo moves with velocity of the mean wind in the layer in which they are embedded. The relationships have been found between precipitation echo movement and wind aloft at various levels or in certain uniquely defined layers of the atmosphere.

LIGDA (1953) noted by comparison of the radar echo movement with upper-air flow that a much closer correlation existed at 700 mb than at either of the other two levels, 850 mb and 500 mb. Most frequently a cumulus development takes place when the wind direction and wind velocity are practically constant with height, so that the movement of a convective shower is representation of the flow of a deep layer of the atmosphere in which it is embedded. It is shown by the results of the Thunderstorm Project that the thunderstorm moves with the mean wind vector of the wind field between the gradient level and 20,000 feet.

In this study, the comparisons of atmospheric flow and radar echo movements are shown in Figs. 13, 14 and 15. The wind data obtained with Rawin observation

![Graph showing comparison of upper wind flow and radar echo movement for August 19, 1954.](image)
made at Tateno, about 70 km north-east of radar station, and the radar data show the frequency distribution of the direction and velocity of radar echo movement.

Fig. 14. Same as Fig. 13 but for September 6, 1957.

Fig. 15. Same as Fig. 13 but for August 5, 1957.
In the case of a tropical storm, the wind direction from steering level to near the 500 mb level was characterized by the presence of an appreciable vertical wind shear, for the direction of radar echo movement was almost closed with the wind direction of various levels. This close was found in the comparison of velocity, in which the velocity of precipitation echo was estimated to be 25 m/sec. Also, the orientation of stationary rainbands were closed with wind flow of these layers. From the above results, the formation of a stationary rainband was found to be in need of these upper-wind conditions.

In the case of a uniform air mass, the upper limit of almost the same wind direction was about 5 km, the relation was closed with the wind of the lower layer. The velocity of radar echo was estimated to be about 10 m/sec and its velocity was closed with the wind velocity in the layer of about 1~7 km. This upper-wind condition was found on other days when stationary rainbands were observed in eastern Kanto.

4. A consideration of the formation of elementary cells

At the southern end of stationary rainbands were observed the small elementary echoes, and the echo top observed by RHI observation was about 4 km. The radiosonde data taken at Tateno were given in Fig. 16, showing that the freezing level was at 6 km on 19 August 1954 and at 4.6 km on 5 August 1957. The temperature at the echo top was about +6°C and +3°C. From this it is considered that these small elementary echoes were reflected from non-freezing cumulus clouds.

Fig. 16. Upper-air condition for observed stationary rainband.

Study of the formation of cumulus cloud in the vicinity of a coast or peninsula has been done by many investigators. Bowen (1950) calculated the formation of rain by coalescence in a non-freezing cloud and showed that in Australia showers frequently develop in the way his theory suggests. Ludlam (1951) calculated the
growth of unusually large cloud droplets by coalescence within isolated convective clouds. He has demonstrated that if their initial radii are about 20 or more, then growth to raindrops may readily occur, and showed that raindrop nuclei of this size may be provided by spray in a maritime air mass. Spray is continuously formed over the ocean and near the coast by strong wind and enter the moist low layer by topographic updraft.

The formation of small elementary cells usually requires some trigger action, and it is concluded in this study that the generation of cells is due to the trigger action by the topographies. As shown in Fig. 4 and Fig. 10, the generating points of small elementary cells were distributed on the lee of the mountainous region of the peninsulas. These observations were suggested a lee effect of the wind flow over the mountain.

In order to examine the effect of topographies, the author calculated the distribution of updraft by topographies. 5 km mesh was adopted to compute the topographical updraft on such a small scale as the formation of the small elementary cells.

Updraft is described approximately by the following equation:

$$\omega = -\rho g \left( \frac{\partial h}{\partial x} + \nu \frac{\partial h}{\partial y} \right)$$

where: $\rho$ is the air density,
$g$ is the gravitational acceleration,

$$\left( \frac{\partial h}{\partial x} \right)_{i,j} = \frac{h(i+1,j) - h(i-1,j)}{2d}, \quad \left( \frac{\partial h}{\partial y} \right)_{i,j} = \frac{h(i,j+1) - h(i,j-1)}{2d} \quad (d=5 \text{ km})$$

For computation, the wind speed and direction were considered by the results of upper wind observation at Tateno and Hachijojima. In August 1954, the wind speed was about 25 m/sec, and the wind direction was about 190°, and the distribution of $\omega$ in this case is shown in Fig. 17. In August 1957, the wind speed was about 10 m/sec and the wind direction was about 190°, and the distribution of $\omega$ is shown in Fig. 18.

A comparison of the $\omega$-distribution and echo-generating points suggested that these points were distributed on the lee of the updraft area in the $\omega$-distribution. However, a point-for-point comparison of the two maps indicates rather poor correlation between updraft area and echo-generating area. In this comparison there is apparently a time lag. From Fig. 4, the generating points were distributed from 20 to 50 km on the lee of the updraft area and the time lag was estimated to be about 15 to 30 min with $V=25$ m/sec in the case of a tropical storm. In the case of a uniform air mass, this time lag was estimated to be about 20 m/sec with $V=10$ m/sec. Because the minimum detectable precipitation rate of the radar used was about 1 mm/hr at the radar range of 100 km, it is estimated that the radar reflectivity ($Z$) of small elementary cells was about 200 mm$^6$/m$^3$. Furthermore, the radar reflectivity of cumulus clouds was found to vary between $10^{-3}$ mm$^6$/m$^3$ to $10^{-4}$ mm$^6$/m$^3$, and it is assumed that these time lags were due to the growth rate of cumulus clouds. Namely, after small nuclei entered by topographic updraft, cumulus clouds flow to the lee by upper wind before radar detection.

By radar observation, echo behavior, generation-growth-diminishing, was
Fig. 17. Distribution of vertical velocity ($w$) in m/sec around the Izu peninsula.

Fig. 18. Distribution of vertical velocity ($w$) in cm/sec around the Boso peninsula.
associated with topography. As example of this behavior shown in Fig. 19 (1629~1650 JST), small elementary cells observed over the ocean were developed at the coast of Boso peninsula and these echoes were more developed in the western peninsula. From Fig. 17, this western area of the peninsula was associated with the updraft area. However, in the central or eastern peninsula, these developed echoes were diminished soon after the echoes reached the coast. This diminished area was associated with the downdraft area in Fig. 17. Namely, no radar echo was observed in the central or eastern peninsula. Furthermore, as shown in Fig. 11, the echoes developed in the western peninsula are apt to segment into two or more separated small echoes over the Tokyo bay and these separated echoes were developed to a large echo at the coast in the neighbourhood of Chiba. These behaviors were found around Iso peninsula.

During the growth of a droplet to a large size by the coalescence process, cloud thickness is important. Cloud thickness is influenced by the vertical wind shear which causes a slope in the cloud axis. Ackerman (1956) has shown that the ability of tropical cloud to produce a precipitation echo is a function of the vertical wind shear. A large percentage of the clouds developed to echoes when the vertical wind shear was small (the upper limit being about 6 feet/sec/1,000 feet) and the percentage frequency of echoes in 1 ~ 3 feet/sec/1,000 feet was 100 per cent. Also, Battan (1958) has studied that the principal factors governing precipitation initiation are stability, vertical wind shear and depth of the moist layer.

In order to examine the effect of vertical wind shear on the formation of small elementary cells, the vector difference between the wind velocities at 1 km and 5 km was obtained from the rawin data at Tateno. During the period in which stationary rainbands were observed, the vertical wind shear was only about 5 m/sec/4,000 m. On the other hand, when no stationary rainbands were observed, its value was 10 m/sec/4,000 m. From these results, it can be seen that the smallness of the vertical wind shear in the cases studied was very important for the occurrence of stationary rainbands.

5. Conclusion

An analysis was made of the principal factors governing the formation of stationary rainbands as observed by radar, and it was found that the factors are the upper wind conditions (wind direction, vertical wind profile, etc) and the trigger action of topographies.

A more detailed analysis in the case of small elementary cell generation will be undertaken in the future, using a high-sensitivity radar and also improving the calculation of $\omega$-distribution.

Furthermore, in order to make a more detailed investigation of the physical aspects of cell generation, it is necessary to observe the following parameters:

1. Moisture distribution of the air which flows into the generating area from the southern ocean.
2. Updraft around the generating area.
3. Degree of atmospheric instability.
4. Surface heating and local weather situation.
Acknowledgements——The author wishes to express his hearty thanks to Dr. J. Imai for his instruction in this study and to the members of the Typhoon Research Laboratory for their help in the radar observation. He also expresses his thanks to Mrs. T. Yanase for her assistance in preparing the paper.

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