Radar raingauge with volume-scanning function

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Abstract The volume-scanning radar has been operated for 10 years at the top of Mount Akagi in Japan, monitoring rain clouds three-dimensionally every 15 min with 20 kinds of angles in a 200 km radius. The authors attempted to develop the availability of the weather radar for operational use, especially for operation of dam reservoirs. The main topics of this paper are to present parameter development and selection of altitude for rainfall intensity estimation, variable B and β method, bright band elimination, and vertical profile observations of rain clouds for monitoring heavy rainfall for disaster prevention. The authors developed the variable B and β method by using the volume-scanning mode, then implemented the method successfully for rainfall observation by weather radar.

Key words bright band; radar; Japan; variable B and β method; vertical profile of rain cloud; volume-scanning radar

INTRODUCTION

Radar is, needless to say, useful to observe rainfall instantaneously in a wide area. The authors have worked for weather radar development to utilize it as a raingauge for 40 years (Kinosita, 1984). In Japan, 26 sets of radar raingauges are now operating for monitoring rainfall from a hydrological viewpoint. At the early stage of the radar development, it could only show rain clouds on the cathode-ray tube qualitatively. Later it became possible to measure rainfall quantitatively by digital technology. Radar is generally operating as PPI (plane position indication) mode, which displays rain clouds on the tube like a rainfall map. Volume-scanning radar, called three-dimensional radar, was introduced for the advanced use of weather radar for hydrological purposes about 10 years ago at the top of Mount Akagi, which is located 100 km northwest of Tokyo, Japan. It has 20 kinds of beam angles and observes rainfall within a 200 km radius (see Fig. 1). Scanning almost the whole space of the atmosphere in the radius, it can get the radar reflectivity at any altitude with horizontally homogeneous conditions. By using the observed data, the accuracy of rainfall estimation will be much improved (Nakagawa *et al.*, 1998). On the other hand, PPI radar can scan the atmosphere on a flat conic plane due to a slight beam angle. The beam is low near the radar site and high at places far from the radar site, which means the height of the observed rainfall is different depending on the location. In this paper, parameter development and selection of the observation altitude for rainfall intensity estimation by using the volume-scanning mode are described, and the variable B and β method is presented for better estimation of precipitation.

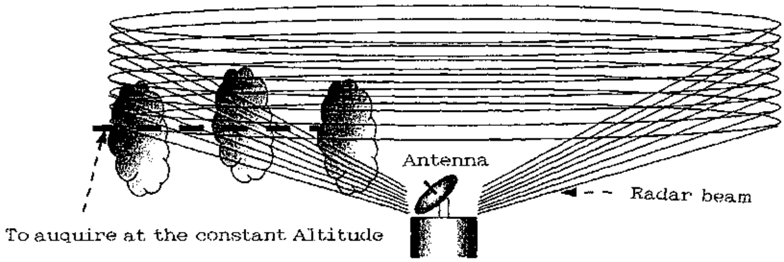

Fig. 1 Explanation of the volume-scanning mode.

APPLICATION

Parameter development

Conversion parameters B and β are indispensable to obtain rainfall intensity R from radar reflectivity Z. The relation is formulated as $Z = BR^{\beta}$ where B and β are dependent upon atmospheric and cloud-physical conditions. In most cases of parameter development, large numbers of observed R and Z pairs are collected and the regression line is empirically obtained. In contrast, in this paper, B and β are determined by limited numbers of pairs of R and Z at the most suitable sites. Two criteria were proposed to select preferable pairs of R and Z. First, radar data where the radar reflectivity is frequently missing are eliminated to identify the parameters. Second, rainfall data on ground sites at the radar shadows made by mountain topography are not used. These processes make the reasonable relations between R and Z, i.e. reasonable B and β.

Selection of altitude

As volume-scanning radar is operating three-dimensionally, any altitude can be selected for observation of rain clouds. For monitoring of rainfall on the ground, the radar beam should be as low as possible, but should not touch the ground. Even the ground clutter is removed by the MTI method. From the viewpoint of structures of rain clouds, a certain altitude may be the best height for Z measurement. It seems preferable to select the middle layer of rain clouds, because the atmosphere is perhaps well mixed and the raindrop distribution is uniform there. However, such layer changes depend on precipitation events. Thereby, from the topographical aspect, the Z measurement height is decided at 3000 m above mean sea level. The reason is that the radar site is located at 1600 m and mountains of 2000 to 2500 m height are located to the north and west of the radar site.

Variable B and β method

The conversion parameters B and β are usually given as fixed parameters, while atmospheric conditions change rapidly. The parameters should change due to changes

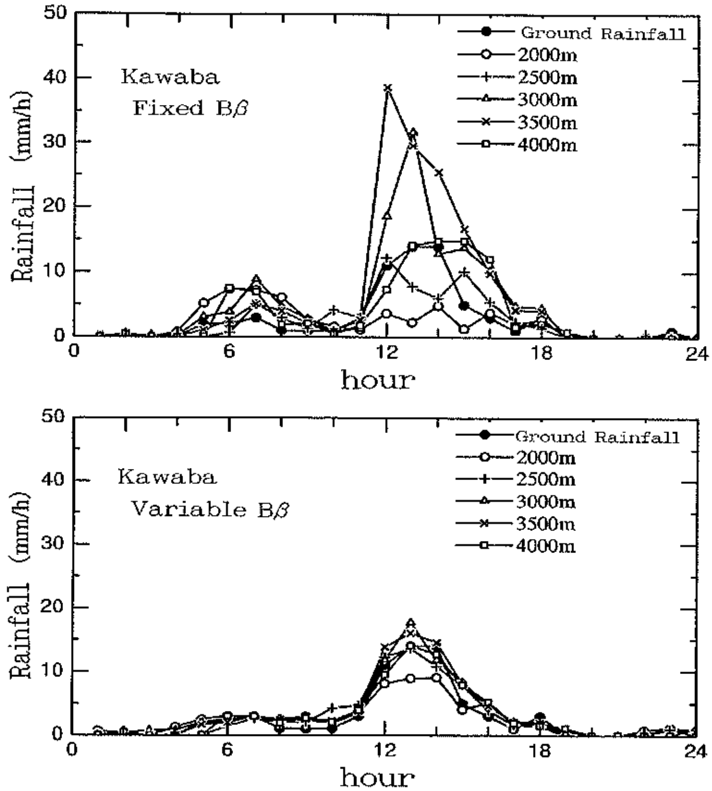

Fig. 2 Comparison of estimated precipitation used by fixed and variable B and β on 22 September 1996. Radar reflectivity at altitudes of 2000, 2500, 3000, 3500 and 4000 m above mean sea level were used.

in atmospheric conditions. The volume-scanning radar observes the reflectivity at various altitudes. Here, the parameters determined by the regression equation of R and Z were revised every hour by using telemetric rainfall data and the radar reflectivity at the adequate altitude. In Fig. 2, the upper figure shows the rainfall calculated by the fixed values $B = 200$ and $\beta = 1.6$. Dependent upon the altitude, converted rainfalls are different and also they do not coincide with ground rainfall. The lower figure is the estimated precipitation using the variable B and β. They show good agreement with the ground gauged rainfall.

Bright band

A bright band is sometimes found in radar observation. It looks like a doughnut on a PPI image. Erroneous reflectivity emerges in the layer of atmosphere just below 0°C, where liquid water attaches to ice particles in the layer. When a bright band appears, radar observation becomes erroneous in PPI mode. While in the volume-scanning mode, the problem of a bright band is avoidable. If a bright band appears on the

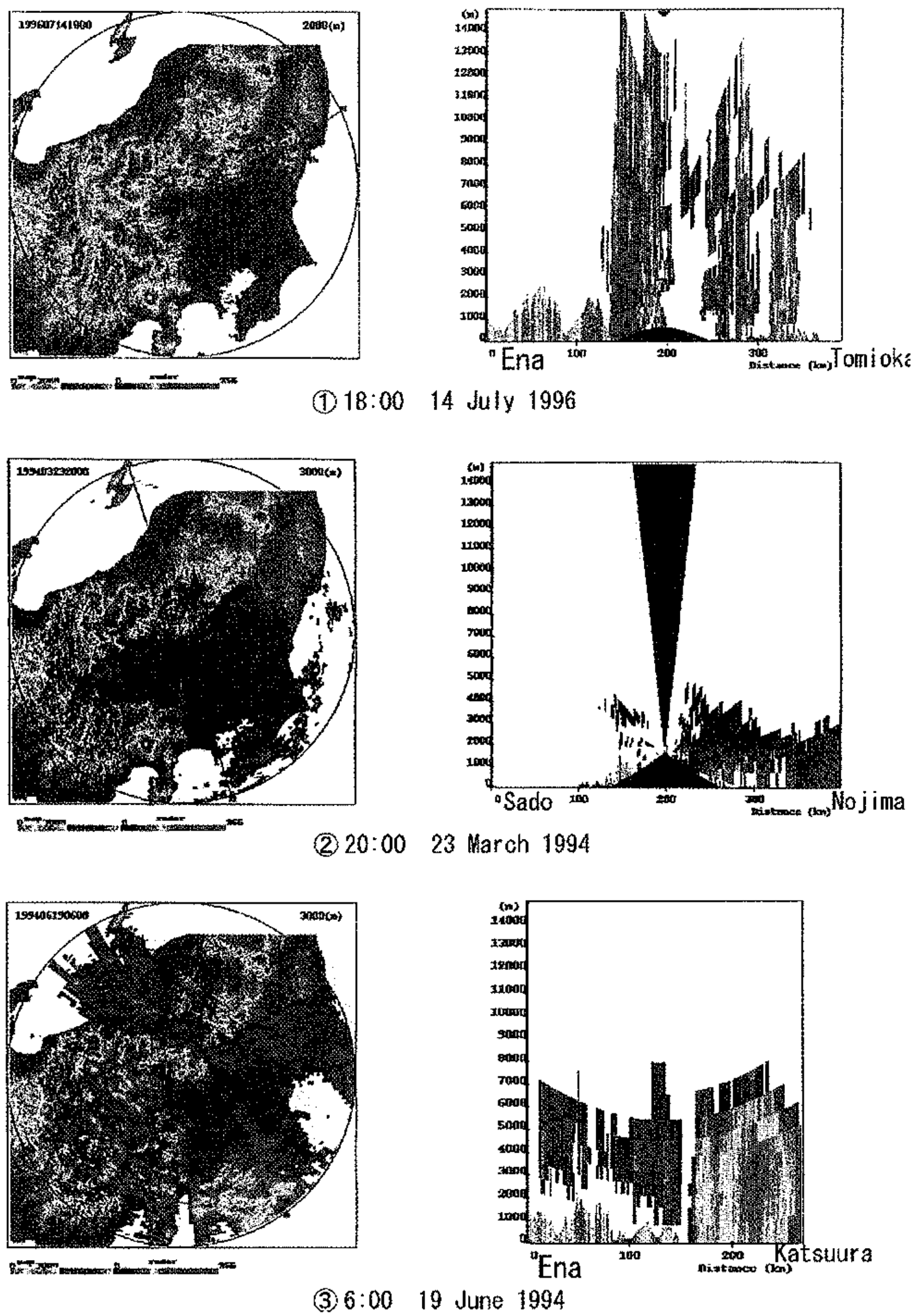

Fig. 3 Vertical profiles of rain clouds. The left images show plane indications of rain clouds at the altitude indicated at the upper right corners of the images. The right images show vertical profiles at the cross-sections indicated by a straight line between red and green points on the left image. In the right images, the abscissa axis distance is in km, and the ordinate is the altitude above mean sea level in m.

observation height, the variable *B* and β method automatically adjusts the parameters in accordance with the bright band; also *Z* values at other heights are used for avoiding the use of the bright band level reflectivity.

Vertical profile

The most beneficial volume-scanning function is to make images of a vertical profile. It is well known that RHI (range height indication) mode is available to show a vertical profile in radar. This profile is only made in the cross-section including the radar site, while volume-scanning radar can show any vertical profile in the observing area. Examples are shown in Fig. 3, a tall thundercloud whose top reaches 14 000 m higher than the tropopause, a low cloud cluster in spring, and a high rain cloud in a Baiu front, respectively. The images are useful to predict the movement of rainfall field for reservoir operation at least qualitatively (Nakagawa *et al.*, 1997).

CONCLUSION

The authors reported an advanced use of volume-scanning radar operated at Mount Akagi in Japan. Homogeneous reflectivity can be obtained by this mode, therefore the conversion of rainfall from the reflectivity is easy and accurate. By using the property, the variable *B* and β method was applied to obtain more reliable rainfall estimation in a real-time fashion for operational hydrology. The vertical profile of rain clouds is also drawn for monitoring of heavy rainfall.

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