# PROPAGATION CHARACTERISTICS OF BROADCASTING-SATELLITE SIGNALS UNDER PRECIPITATING CONDITIONS

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## 1 Introduction

Rain attenuation of signals from satellites have been intensively studied to establish statistics required in designing earth-satellite communication channels (*e.g.*, Morita, 1980, Misme and Waldteufel, 1980, Stutzman and Dishman, 1982). Most of these studies focused their attention on the occurrence probability of strong attenuation which may affect the quality of communication. The result is usually expressed in terms of a simple regression curve which relates the rain intensity to the expected attenuation. Although this type of approach is effective for prediction of possible breakdowns of some communication channel, it cannot predict attenuation for individual precipitation event since the attenuation is a function of the drop-size distribution of the rain as well as the rain intensity.

The object of our study is to examine the characteristics of the signal strength under precipitating conditions in more details for the possible use of the rain attenuation as a tool of monitoring rain intensity. One of the difficulties in experimental studies of the relation between the rain characteristics and the attenuation of radio waves has been the lack of direct means of measuring the characteristics of rains such as the drop-size distribution along the signal path.

Recently, it was found that large VHF Doppler radars have unique capability of measuring the drop-size distribution simultaneously with the background atmospheric conditions such as the mean wind and the intensity of turbulence (Fukao *et al.*, 1985, Wakasugi *et al.*, 1986, 1987). We make use of this capability of the VHF MU radar located at Shigaraki, Shiga, Japan as a reference in measuring the rain attenuation of the signals transmitted from the Broadcasting Satellite-2 (BS-2) of Japan. We have measured the mean attenuation and fluctuation of signal strength continuously, and compared the results with the data obtained by the MU radar.

## 2 Experimental Techniques

Television signal of BS-2 at the 12-GHz band is monitored by a commercial receiving system located at the MU radar cite. It consists of an offset parabola antenna with the effective diameter of 1 m, a 12-to-1 GHz frequency converter installed at the feedpoint of the antenna, and a receiver which further converts the 1-GHz IF signal down to the UHF band. The strength of the RF carrier signal is obtained from an AGC output of the receiver by a personal computer at a sampling rate of 1 s, and digitally recorded for off-line processing. The personal computer also records the digital output of a drop-counter type rain gauge, which has a resolution of 0.002 mm $\text{hour}^{-1}$.

The MU radar is a 46.5-MHz monostatic Doppler radar with an active-phased-array antenna of 103 m in diameter and with 1-MW peak output power (*e.g.*, Kato *et al.*, 1986). Among the various operational modes used for the MU radar, the troposphere mode is used for the observation of precipitation. The troposphere mode utilizes 1-$\mu$s single pulse, and observes the echo power spectra from a height region of 1.5–10 km at a height and time resolution of 150 m and 1 min, respectively. Five beam directions of the vertical, and the north, east, south and west directions with 10° zenith angle are observed. The beam directions are switched every IPP of 400 $\mu$s in a cyclic manner.

While the observed echo power spectrum contains one spectral component corresponding to the atmospheric turbulence echo for a clear-air condition, a spectral component with negative Doppler shift due to falling raindrops or ice crystals add to this component under precipitating condition. The drop-size distribution and the number density of the raindrops, as well as the mean wind velocity and the strength of the atmospheric turbulence, are estimated by fitting theoretical spectra in a least-squares sense.

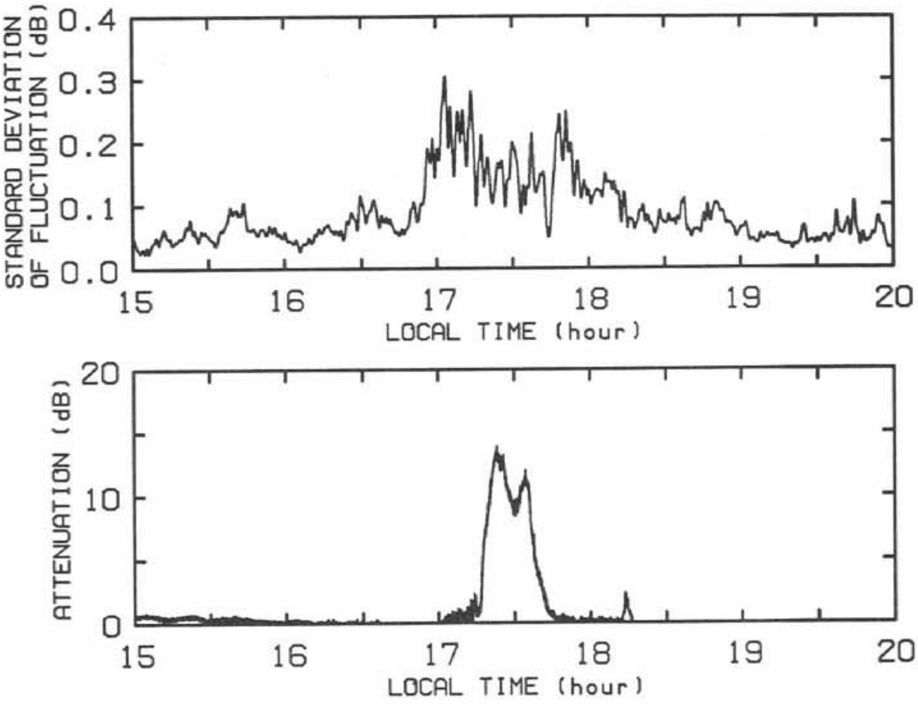

**Fig. 1.** An example of the measured time series of the BS-2 signal strength. The top panel shows the the fluctuation of the signal strength, and the bottom panel shows the mean attenuation observed during 15–20 JST on August 4, 1987.

## 3 Signal Characteristics

Figure 1 shows an example of the measured attenuation for a precipitation event versus time. The top panel shows the fluctuation of the signal strength defined as the standard deviation around a 20-min running mean, while the bottom panel gives the mean attenuation. Apparently, the fluctuation shows a clear enhancement for a much longer duration than that of the attenuation, suggesting that the fluctuation is caused by an independent but closely related process to that of the mean attenuation, which is mainly determined by the rain intensity.

The most plausible source of this fluctuation is the tropospheric scintillation caused by disturbances in the radio index of refraction due to atmospheric turbulence. The spectral width of the atmospheric echo component observed by the MU radar represents the r.m.s. velocity caused primarily by the turbulence inside the volume cell observed with the radar. Since it is directly related to the strength of the atmospheric turbulence (Sato and Woodman, 1982), we can compare it with the observed fluctuation of the BS-2 signal strength. Figure 2 shows temporal variations of the rain intensity measured on the ground (top panel), magnitude of the BS-2 signal fluctuations (middle panel), and the spectral width of the MU radar echo power spectra (bottom panel) observed for about 12 hours on July 14–15, 1988.

The general agreement between the fluctuation and the spectral width suggests that the observed fluctuation is due to tropospheric scintillation caused by turbulent motion of the atmosphere inside the precipitating clouds. Examination of other measurements revealed a tendency that the correlation is good especially when a strong precipitation is observed, which tendency is readily understood by considering the enhancement of disturbances in the refractive index due to water vapor.

## 4 Spatial Correlation Determined from Multiple-Station Measurements

The results presented above are based on observations made by the MU radar and the BS-2 receiving station located on site the MU radar. It should be noted that there is a spatial difference of a few kilometers between the volumes observed by the two techniques, because the elevation angle of the BS-2 signal is about 40° while the MU radar is observing directions within 10° from the zenith. We have

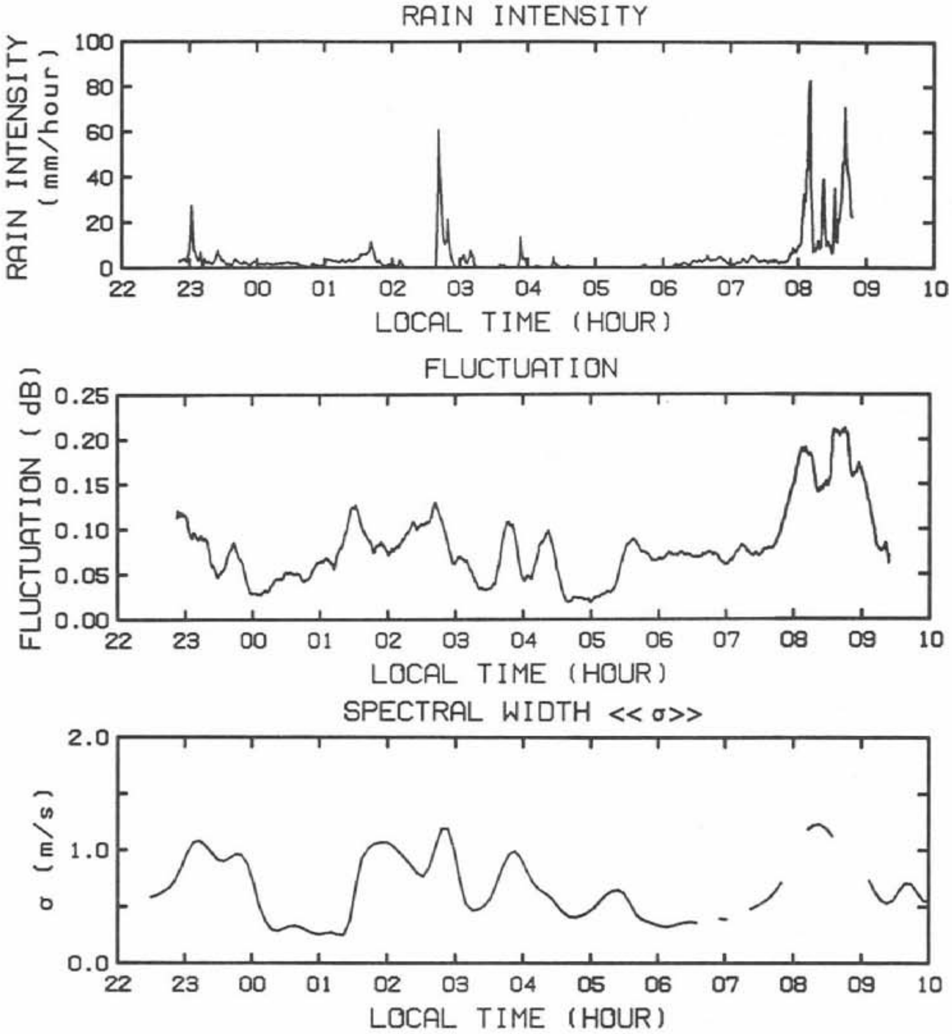

**Fig. 2.** Temporal variations of the rain intensity measured on the ground (top panel), magnitude of the BS-2 signal fluctuations (middle panel), and the spectral width of the MU radar echo power spectra (bottom panel) observed for about 12 hours on July 14–15, 1988.

recently installed two more receiving stations for the BS-2 signal which together constitutes a triangle of about 2 km size. One of the two stations is located at the point where the BS-2 signal passes above the MU radar at a height of 2 km so that the radar can observe the same volume of the atmosphere as observed by the attenuation measurements.

Figure 3 shows the cross correlation functions of the BS-2 signal strength between the main station at the MU radar site and each of the two substations. The maximum value of the correlation function provides the correlation distance of the precipitation in the horizontal direction, and the time lags for the maximum correlation indicate the bulk motion of the precipitation. The example in Fig. 3 shows that the precipitation is moving toward north-northeast at 3.5 $\mathrm{m\,s^{-1}}$, and has a horizontal correlation distance of 3 km.

## 5 Summary

We have measured strength of 12 GHz signal of the BS-2 of Japan under precipitating conditions in order to utilize it for observations of precipitation characteristics. We compared the mean attenuation of the signal and its statistical fluctuation with the rain and atmospheric parameters measured simultaneously by the VHF MU radar. The fluctuations of the signal strength is most likely caused by scintillations even under precipitating conditions, and is found to have a close relation with the atmospheric turbulence intensity along the path. Preliminary results from multiple-station measurements are presented to examine the potential of the technique in studying the spatial structure of precipitation.

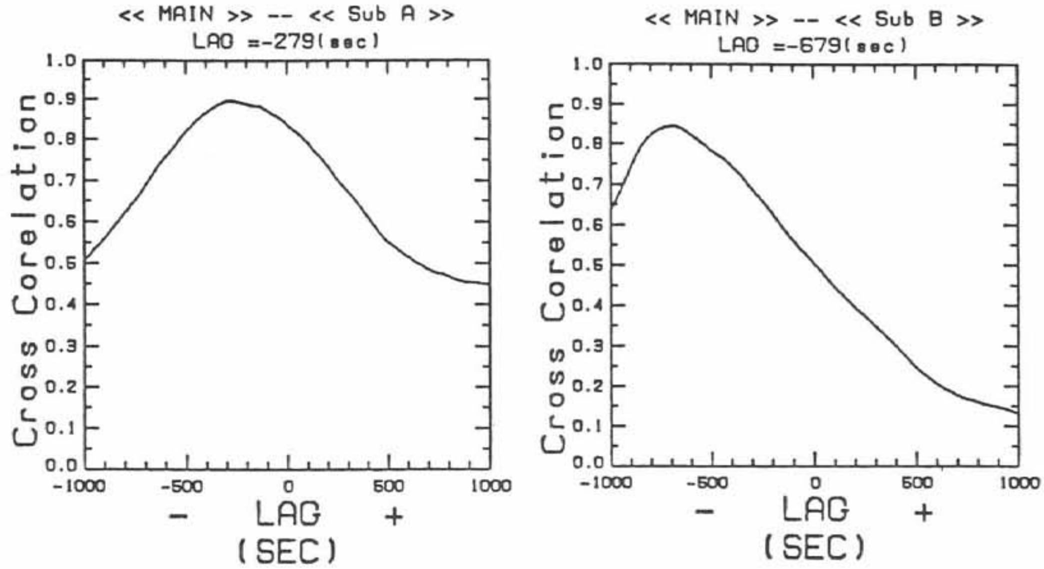

**Fig. 3.** Examples of the cross correlation functions of the BS-2 signal strengths between the main station and the substation A (left panel), and between the main station and the substation B (right panel).

## References

Fukao, S., K. Wakasugi, T. Sato, S. Morimoto, T. Tsuda, I. Hirota, I. KImura, and S. Kato, Direct measurement of air and precipitation particle motion by VHF Doppler radar, *Nature*, **316**, 712–714, 1985.

Kato, S., T. Tsuda, M. Yamamoto, T. Sato, and S. Fukao, First results obtained with a middle and upper atmosphere (MU) radar, *J. Atmos. Terr. Phys.*, **48**, 1259-1267, 1986.

Misme, P. and P. Waldteufel, A model for attenuation by precipitation on microwave earth-space links, *Radio Sci.*, **15**, 655–665, 1980.

Morita, K., Estimation methods for propagation characteristics on earth-satellite links in microwave millimeter wavebands, *Rev. of ECL*, **28**, NTT, Japan, 1980.

Sato, T., and R. F. Woodman, Fine altitude resolution observations of stratospheric turbulent layers by the Arecibo 430 MHz radar, *J. Atmos. Sci.*, **39**, 2546–2532, 1982.

Stutzman, W. L., and W. K. Dishman, A simple model for the estimation of rain-induced attenuation, along earth-space paths at millimeter wavelengths, *Radio Sci.*, **17**, 1465–1476, 1982.

Wakasugi, K., A. Mizutani, M. Matsuo, S. Fukao, and S. Kato, A direct method for deriving drop-size distribution and vertical air velocities from VHF Doppler radar spectra, *J. Atmos. Oceanic Technol.*, **3**, 623–629, 1986.

Wakasugi, K., A. Mizutani, M. Matsuo, S. Fukao, and S. Kato, Further discussion on deriving drop-size distribution and vertical air velocities from VHF Doppler radar spectra, *J. Atmos. Oceanic. Technol.*, **4**, 170-179, 1987.