Effects of Convective Clouds on the Ku-band Satellite Communications Link in the Tropics

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Abstract

Rain attenuation characteristics of the Ku-band up-link satellite signals of Superbird C are investigated at Equatorial Atmosphere Radar Observatory (EAR) in Indonesia. Similar rain attenuation statistics are obtained from the X-band radar observations. Radar observations of convective clouds are shown to be effective to estimate path loss in the tropics.

Keywords : Rain attenuation, Satellite communications, X-band meteorological radar, Tropics.

1. Introduction

Recently, high-speed broad-band satellite communications links of domestic geostationary-orbit satellites tend to use higher frequency bands, such as Ku (14/12G Hz) and Ka (30/20 GHz) bands, in addition to C (6/4 GHz) band. In these higher frequency bands, however, rain attenuation of the radio wave becomes significant for operations of high-quality communication services. Also, demand for high capacity satellite communications using Ku and Ka bands is rapidly increasing in new developing areas such as the South-East Asia, which is one of the world heaviest rain regions. Therefore, it is urgent to investigate detailed rain attenuation characteristics in the tropics [1]-[4].

This study mainly presents rain attenuation characteristics of up-link (14GHz) radio waves of Ku-band satellite communications obtained in Indonesia during the one year of 2005. This satellite communications link connects Research Institute for Sustainable Humanosphere of Kyoto University (RISH) in Japan to Equatorial Atmosphere Radar Observatory (EAR; 0.2 S, 100.3 E) in Indonesia [3], [5], using Japan's domestic communication satellite Superbird C (144 E in orbit). The distribution of rain clouds along the satellite propagation path is examined by the X-band meteorological radar observations simultaneously conducted at the EAR Observatory [3]. Also, the attenuation along the same propagation path is estimated from the radar echo intensities, to reveal the effects of tropical convective clouds on the slant path.

2. Measurement Systems

The satellite links that connect RISH and EAR uses Superbird C. At RISH, the up-link transmission carrier frequency is 14.1292GHz and the down-link receive carrier frequency is 12.7351GHz. At EAR, on the other hand, the up-link transmission carrier frequency is 14.4651GHz and the down-link receive carrier frequency is 12.3992GHz. At both stations, the up-link radio waves use the vertical linear polarization, while the down-link radio waves use the horizontal linear polarization. The elevation angle is about 40 deg at EAR, while it is about 50 deg at RISH. Also, both VSAT systems have an off-set Gregorian parabola dish with diameter of 1.8 m and a data transmission rate of 128 kbps. For our data acquisition systems, personal computers (PCs) equipped with 16-bit A/D converter boards are used at both EAR and RISH stations, to measure Automatic Gain Control (AGC) voltage of the In Door Unit (IDU) of the VSATs that indicates the received signal level [6].

The measured data is stored in their internal hard disk drives every second. In this experiment, the up-link rain attenuation that is usually difficult to measure at each site is successfully estimated from the down-link signal level received at the opposite site in fine weather conditions, since both terminals use an SCPC (Single Channel Per Carrier) signal linearly amplified by the satellite transponder without saturation [7]. An Optical Rain Gauge (ORG) was installed at EAR by a Shimane University group and we can utilize their 1-mim rainfall rate data for this study. At the RISH station, we installed a rain gauge with 0.1 mm tipping buckets and started measurement of 1 min rainfall rates.

The X-band meteorological radar system was also introduced by the Shimane University group at the EAR site. This meteorological radar has an operational frequency of 9.74GHz and a peak transmitting power of 40 kW. The diameter of the parabola dish is 1.2m, the range resolution is 100 m, and the maximum range is 30 km. The horizontal beam scanning rate is 2 rpm, and the radar can present CAPPI and RHI displays every 10 min using 16 elevation angles.

3. Observational Results

3.1 Comparison with the radar echoes

In this section, rain cloud structures and rain distributions in the direction of the satellite propagation paths are investigated from X-band meteorological radar observations which have been simultaneously conducted at the EAR site in Indonesia. The radar is operated using CAPPI (Constant Altitude PPI) scans, and the radar echo intensities are obtained in the form of radar reflectivity factors (Z or dBZ).

Figure 1 shows an example of radar echo distribution along the propagation path observed in the convective storm on May 1, 2005. The radar echoes are displayed on RHI in the east-west direction containing the propagation path of the satellite link, which is indicated by a solid-line arrow in Fig.1. It is found that intense echoes of more than 40 dBZ are confined to 2-3 km around the core of the cloud. The size of the core thus seems to be about 2 km in both horizontal and vertical dimensions.

3.2 Estimation of rain attenuation using the radar echoes

The echo intensities are then converted to rainfall rates R [mm/h], basically using the well-established relationship between Z and R. It should be, however, noted that the radio wave of the X-band radar is also attenuated by raindrops along the two-way propagation path between the radar and an observational point. Thus, the radar reflectivity factor at the observational point should be corrected by the attenuation that occurs along the path between the radar and the observational point. The rain attenuation at each point of the rain clouds is then calculated from the rainfall rates corrected against these path loss effects of the radar signals. The attenuation calculations of the satellite signals use the ITU-R models that give specific attenuation for each frequency, elevation angle, and polarization [8]. The attenuation values obtained at each observational point are then accumulated along the entire propagation path with the range resolution of 1 km.

At EAR, however, the elevation angles of the CAPPI scans are at most 30 deg as shown by a dashed-line arrow in Fig.1, while that of the satellite propagation path is about 40 deg, exceeding the highest one of the radar observations by about 10 deg. Note that in Fig.1, the radar echoes with elevation angles of higher than 30 deg on the east-west RHI are obtained from interpolation or extrapolation of the CAPPI echoes in other azimuth directions. Hence, the rain attenuation here is calculated more exactly at the elevation angle of 30 deg, and then converted to that of 40 deg by multiplying the factor of sinusoidal functions for each angle. The time resolutions for the radar estimation of the satellite propagation path attenuation are about 10 min. Figure 2 depicts Ku-band up-link (14 GHz) attenuation estimated from the radar observations (dashed line) and that obtained from the satellite signal observations (solid line), together with ground rainfall rates at 10 min intervals on the same day as in Fig.1. It is found from Fig.2 that the nearly the same attenuation values are extracted from the radar observations for the rainfall event when fairly large cloud cells have passed over the EAR site.

3.3 **Yearly statistics of rain attenuation**

From January to December in 2005, calculations of the Ku-band up-link attenuation are similarly made using the X-band radar echoes observed during this period. Figure 3 shows the results of radar estimation and direct measurement in the form of cumulative time percentages for the attenuation during the one year of 2005. A thin line indicates the prediction values of the ITU-R recommendations [8] based on the yearly 0.01% rainfall rate of 83.5 mm/h at EAR in 2005.

Thus, the radar estimated values are in good agreement with the satellite observations of the up-link signal attenuation, statistically indicating validity of this attenuation estimation using the radar echoes. Also, both values, as a whole, agree well with the ITU-R predictions up to the attenuation of about 14 dB. However, they begin to deviate from the ITU-R predictions in the attenuation range of higher than 15 dB and tend to show lower time percentages. This tendency is considered to reflect the effects of convective clouds characterized by a localized structure as typically indicated in Fig.1.

4. Conclusions

The rain attenuation of Ku-band up-link satellite signals that occurred at EAR in Indonesia is successfully detected using the down-link signal levels measured at Kyoto in Japan. The estimation of the up-link attenuation using the simultaneous X-band radar observations along the propagation path at EAR is in good agreement with the direct measurement of the satellite signals. Annual statistics for the cumulative time percentages of the rain attenuation are also estimated from the radar observations, and they are in fairly good agreement with those directly obtained from the satellite signal measurement at EAR.

This agreement suggests that long term radar observation of the tropical precipitating clouds is very effective to estimate the attenuation statistics of satellite propagation path, when earth stations or satellite signals are not available. Note that large discrepancies may happen between the attenuation statistics and the ITU-R predictions based on rainfall rate statistics in the attenuation range of higher than about 15 dB due to localized structures of such convective clouds, even if rain gauge data are available in the tropics. Therefore, the radar observation of rain distribution along the propagation path seems to be essential to exactly know the equivalent path length through tropical rain areas.

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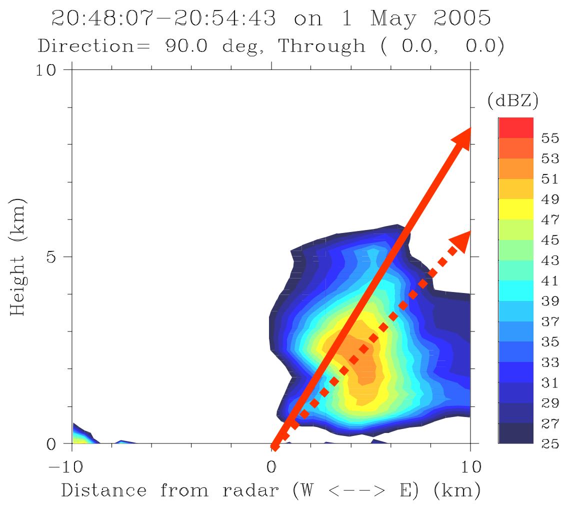

Figure 1: Example of X-band radar echoes along the path of satellite signals.

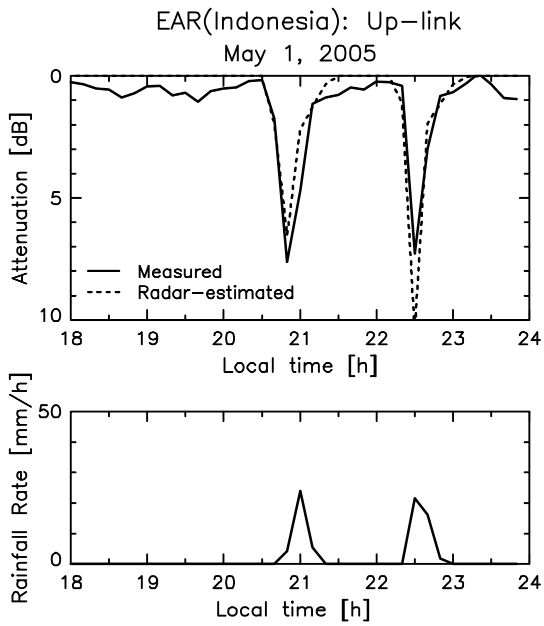

Figure 2: Up-link attenuation obtained from satellite signals and radar estimation.

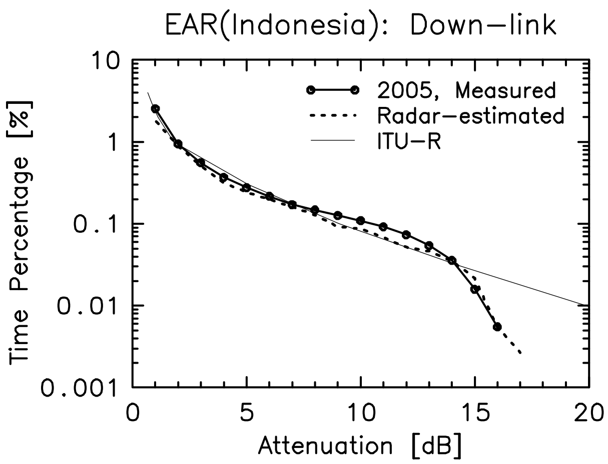

Figure3: Yearly cumulative time percentages obtained from satellite signals and radar estimation. Thin line is the ITU-R predictions based on yearly rain statistics.