THE STRUCTURE OF TROPICAL RAIN FROM ATTENUATION AND RAIN EXCEEDENCES

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Abstract

Propagation attenuations on the AUSSAT beacon and channel 14 BMAC signals have been measured against sky temperature and rainfall rate. In this rain forest region rainfall is always high, of the order of 200 to 400mm per month. The wet monsoonal season is characterised by stratiform conditions, with some correlation between rainfall rate, sky temperature and attenuation, indicating a uniform distribution of rain. In the dry season, when conditions are convective with heavy rain storms accompanied by thunder, the variations in attenuation, sky temperature and rainfall rate show inconsistencies that can only be explained by assuming cell diameters of a few hundreds of metres and with heights exceeding the 0 degree isotherm for rainrate greater than 100mm/Hr. A single raincell has been assumed to enter the beam at any time because of the high elevation angle at 73 degrees. The paper describes the experimental method and compares the results with some models for the prediction of attenuation from rainfall rates.

Introduction

Following the launch of the first INTELSAT V satellite in 1980, the 11/14GHz band has been increasingly used. The effects of rain on attenuation generally increase with frequency, becoming significant above 10GHz. Since the early 80's INTELSAT has conducted world-wide slant path 11/14GHz attenuation and concurrent point rainfall measurements[1], but only a small number of these have been in tropical regions[2]. Most tropical path attenuations have been derived from passive radiometer measurements of sky temperature[3][4] with a limited dynamic range only slightly in excess of 10dB. There is also uncertainty about the medium temperature and poor angular resolution due to full pattern integration.

There was an extensive slant path attenuation and rainfall rate measurement campaign carried out in temperate regions in the USA, Japan[5] and Europe[6] in the decade up to the mid 80's and these results have been incorporated into CCIR recommendations[7]. A limited programme of beacon, radiometer and rainrate measurements is now taking place in tropical areas, notably at James Cook University in Australia, Subaya in Indonesia and Lae in Papua New Guinea, at elevation angles of 50, 15 and 73 degrees, respectively[1]. This wide range of angles will yield important information on the variability of physical temperature of the medium and on the vertical and horizontal distribution of rain.

The experiment at Lae is a joint co-operative programme with INTELSAT using two locally built beacon receivers and an AIL/COMSAT radiometer. This paper describes some of the results from the first year of data collection.

System Description

Lae is situated at 7 degrees south and 147 degrees east and is classified as between the M and P zones on the CCIR rain climatic regional map. The Australian satellite AUSSAT1 was chosen for the experiment because from Lae its elevation angle is 72.8 degrees. It does not have a well conditioned signal format, because the beacon carries PCM data on a phase modulated carrier with a peak deviation of 32KHz. The carrier remains constant for long periods but at unpredictable times during telemetry activities the levels change. Again the TV channel is frequency modulated and special methods have to be used to extract the carrier level. The methods to overcome these disadvantages were described at the URSI Symposium F Conference in Brazil [8].

Signal and Medium Characteristics

The system layout in Figure 1 shows a radiometer at 11.4GHz, a beacon receiver and a TV channel receiver. Two rain gauges are concurrently monitored with the attenuation measurements. Radiometer, beacon and channel data are sampled at 10 second intervals but in quiet conditions only a running average of 5 minutes of previous 10 second samples is recorded every 10 minutes. An event is defined as a departure by more than 0.5dB from the previous running average in any channel. When this occurs attenuation and sky temperature data is recorded at 10 second intervals. At all times a tip of either rain gauge causes a recording of all data including the tip time. The 5 minute running average is used to reduce the data captured to manageable levels by eliminating scintillation. It is effectively a low pass filter with a bandwidth of 0.003Hz. Measurements by Karasawa and Matsudo, at 11-14GHz, on satellite signals at low elevation angles showed that there were no scintillations below a cut off frequency of 0.01Hz [9]. Scintillation at Lae reaches peak values of about 2dB and would cause almost continuous collection of data on a 0.5dB criterion.

Rain and Attenuation Annual Exceedances

The results of 12 months of measurements are shown in figures 3 and 2 for rain and attenuation respectively. The beacon receiver became unreliable during August and is not shown in figure 3. Until its failure there was good agreement between all three methods, including the beacon.

The two rain gauges show differences during heavy rain because one gauge is close to the edge of the building and suffers from thermal updraughts. Both rain gauges are on the roof close to the radiometer antenna with gauge 2 placed in the centre of the roof.

Comparison with Theoretical Models

(a) Rain Rate Exceedances

None of the regional CCIR M, N and P models shown alongside the measured results in Figure 3 gives good agreement with the measured results. There is a marked break in the slope at R , the rain intensity exceeded for 0.01 % of the time. The break has been found at other tropical sites and some coastal areas where large expanses of water or mountains are found. Lae is situated close to the sea and is surrounded by mountain ranges with heights up to 3-4,000 metres. Moupfouma has given an atlas of u values in a model for rainfall rate given by [10]

$$P(R >= r) = \frac{a \exp(-ur)}{r^b}$$

where $P(R >= r)$ is the probability of the rainrate R exceeding any rain rate r and the constants a, b are found from the measured or estimated values of $R_{0.01}$.

Moupfcuma states that higher values of u are sometimes required for $r > R_{0.01}$ and that these conditions are associated with mainly stratiform rainfall. In contrast, Lae has highly convective rainfall for much of the year with rain column diameters considerably less than 2km. We have already seen that the high elevation angle to the AUSSAT beacon and TV channel has allowed single rain columns to be clearly distinguished. With u = 0.035 or 0.06 for rain exceedances less than or greater than $R_{0.01}$, respectively, the experimental results show good agreement with the Moupfuma model.

The high rainfall rates, in excess of 150mm/hour are not statistically significant, because there is only one event in excess of 170mm/hour and 195mm/hour respectively in each case. As more data is collected it is assumed that their mean level will approach the u_1 curve in figure 3. This has been taken into account by adjusting the u_2 curve to the upper rainfall limit of each event as represented by a horizontal line of data points.

(b) Attenuation Exceedances

Measured results for attenuation exceedances are compared in figure 4 with the improved CCIR model for high rainfall rate areas. The rainrate reduction factor, $r_{0.01}$, is 0.85 for Lae at an elevation angle of 72.8 degrees and the characteristic length L_0 is 6.35km. The rain height used in the model was reduced from 5 to 4km to get agreement with the accumulated time factor model of Hansson [11] at an attenuation of 12dB. Up to about 15dB this CCIR prediction is within 1dB of the measured results but it always over predicts.

There is a marked similarity between the smoothed rainrate exceedences in Figure 3 and the attenuation exceedences in Figure 2. In particular there is a change of slope at a rainrate of 110mm/Hr corresponding to the 0.01% exceedence level. Hansson [11] has given a model for the prediction of slant path attenuation exceedences from rain rate statistics. All rain cells are assumed to be circular with constant rain rate over the cell and to maintain a constant attenuation during passage through the propagation path. When cell diameters are less than the projected slant path, the accumulated time for attenuation is greater than that for rain, because rain measurement is at a point and attenuation is along a line. From this Hansson derives an accumulation time factor by which the rain statistics are multiplied to get the attenuation statistics. Attenuation is found from the product of the specific attenuation for the rain and the propagation length in a cell. It follows that each point on the rainrate exceedences will map to a unique point on the attenuation exceedences curve, and that the shapes will be similar if raincell diameters do not change significantly with rainrate. With these assumptions the most easily identified correspondence is the breakpoints at 110mm/Hr on the rain exceedences and 12dB on the attenuation exceedences. Hansson defines an accumulation time factor (ACCF) as the ratio of the probabilities of the point pairs of exceedences, from which the ratio of the projected slant range, L, to raincell diameter, D_{cell} can be determined. At the breakpoint of the two curves the ACCF is $10^{-1.48}/10^{-2} = 3.31$. Following Hansson, we have $L/D_{cell}+1 = 3.31$.

If A is the attenuation and s(f,R) is the specific attenuation at frequency f and rainrate R the cell diameter is

$$D_{cell} = \frac{A\cos\theta}{s(f,R)} \qquad (2)$$

where θ is the elevation angle. Substituting A = 12dB and s(f,R) = 5.25dB, we have D_{cell} = 675 metre and a rain height of 6.56 km.

If the cell diameter remains constant we may choose a rainfall rate of 25mm/Hr with a percentage exceedence of 0.35. The specific attenuation at 25mm/Hr is 1dB/km, giving from equation 2 an attenuation of 2.3dB and an ACCF, from the ratio of the exceedence probabilities, of 2.2. This leads, from Hansson's ratio integration, to a rainfall height of 2.8km. A similar calculation for rainfall at 155mm/Hr gives an equivalent attenuation of 19.4dB and a rainfall height of 26km. This is clearly unlikely and leads to the conclusion that raincell diameters increase with rainfall rate. For example, for an attenuation of 19.4 dB at a rainfall rate of 135mm/Hr the cell diameter from equation 2 is 913 metre and the height is again at about 6.56km. If these assumptions are correct, light rain appears to form at lower heights than for heavy rain. Cell diameters increase with rain intensity, and the height exceeds the 0 degree isotherm at rates above about 100mm/Hr. The curve labelled RNATT in Figure 4 assumes a constant rain height of 6.25km with increasing cell diameter from the breakpoint to 19.4dB and a constant cell diameter with decreasing height from the breakpoint to 1dB attenuation. It is not possible to determine whether the height exceeds the freezing level above 140mm/Hr, because our dynamic range limits the attenuation to 20dB.

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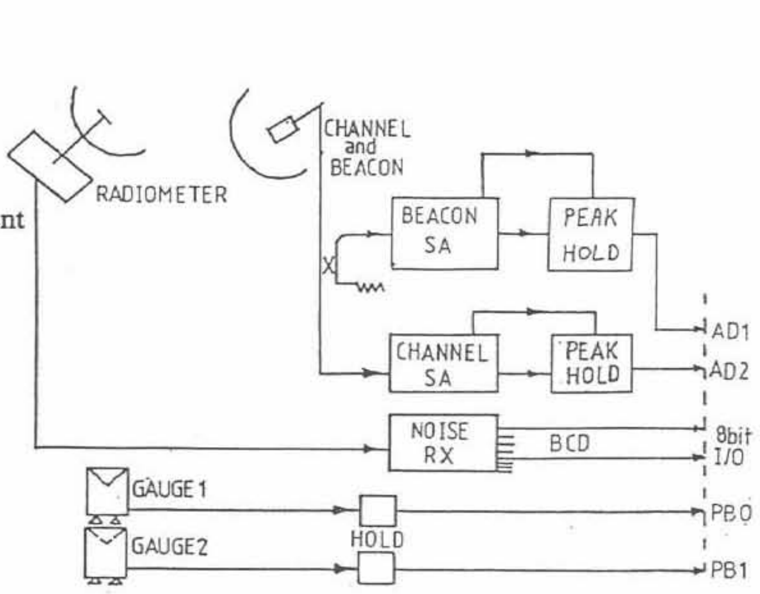
Figure 1 System arrangement



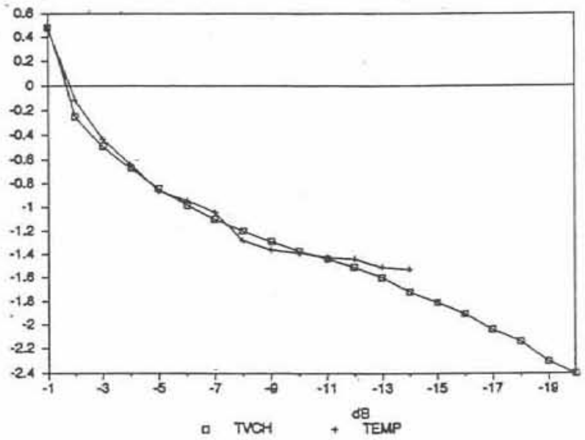


Figure 2 Attenuation

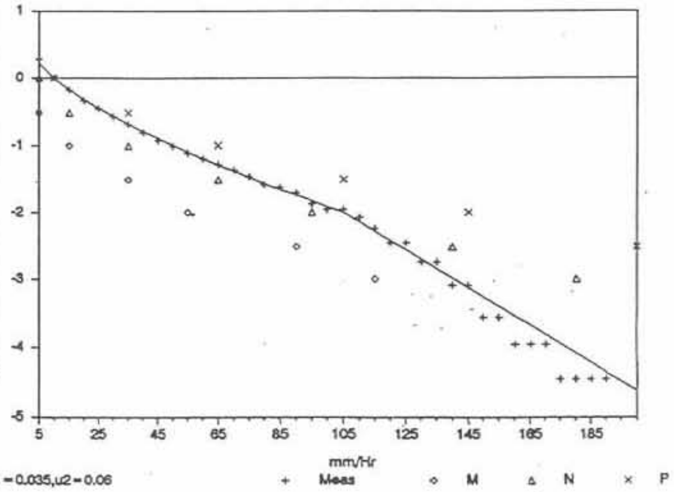


Figure 3 Smoothed rainrate compared with CCIR M, N and P regions

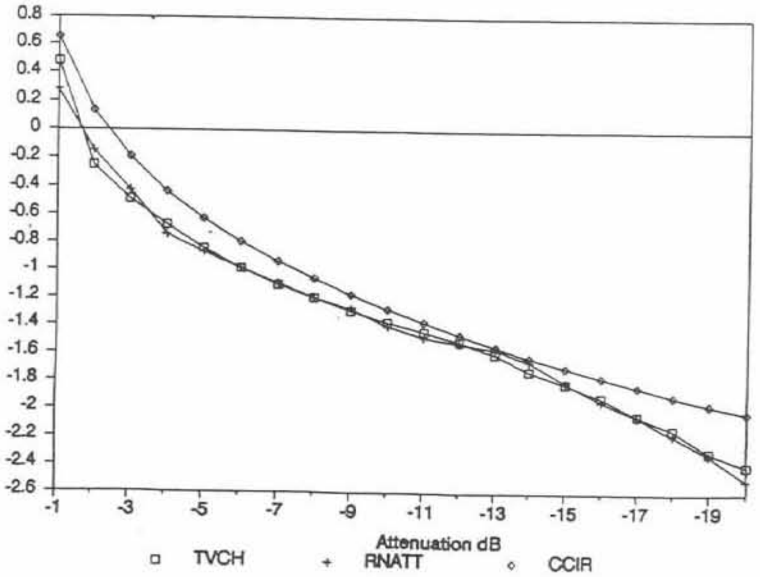


Figure 4 Attenuation exceedences compared with CCIR and acc. time factor model