RAIN ATTENUATION RESEARCH IN BRAZIL

Jorge L. Cerqueira(1), Mauro S. Assis (2), L.A.R. da Silva Mello(3)

(1) Pontifical Catholic University of Rio de Janeiro and Military Institute of Engineering
Rua Pinto Guedes 140 apt. 303 – Rio de Janeiro – RJ, 20511-320 – Brazil - **jlcerq@terra.com.br**

(2) Fluminense Federal University - Rua Coelho Neto, 17 apt. 301 – Rio de Janeiro – RJ, 22231-110 – Brazil - **msassis@openlink.com.br**

(3) Pontifical Catholic University of Rio de Janeiro - Centre for Telecommunication Studies
Rua Marques de São Vicente 225 – Rio de Janeiro – RJ, 22453-900 – Brazil- **smello@cetuc.puc-rio.br**

ABSTRACT

This paper describes some preliminary results and the activities in progress of a research program on rain attenuation in the Amazon region. This program is part of a broad project, named CT-Amazônia, covering different aspects of science and technology, which is being developed under the responsibility of the Military Institute of Engineering (IME) with financial support from the National Scientific and Technological Development Council (CNPq). The following topics are being investigated in this program: a) Precipitation rate behaviour based on rain gauge and radar measurements and b) Rain attenuation prediction modelling for terrestrial and slant paths.

INTRODUCTION

The research on rain attenuation in Brazil has started around 1970 [1]. Reference to the work prior to 1996 may be found in [2] and [3]. This paper presents some preliminary results related to rainfall characteristics, as well as, the research program now in progress. This research is the theme of the doctoral thesis of the first author and includes two main topics: a) Precipitation rate distribution and radar measurements in the Amazon region and b) Rain attenuation prediction models for terrestrial and slant propagation paths. Referring to rainfall rate studies, a very broad rain gauge network was implemented in the Amazon region. Figure 1 shows the locations where the gauges were placed. On other hand, considering the well-known relation between radar reflectivity and rain rate, measurements from a radar network is being used as a complement for these studies. This radar network belongs to SIPAM (Amazon system protection) and covers the same locations as the rain gauge network. Radar data will be also used in the definition of rain cell shape and dimension. With this procedure, it is hopped to derive an attenuation model closely fitted to physical reality of rain structure.

KÖPPEN CLIMATE CLASSIFICATION

According to preliminary results of this research program, the combined use of precipitation and radar data, Köppen climate classification [4] and the mathematical model adopted by the ITU-R Recommendation P.837-4 [5] appears to be an useful tool for the prediction of rainfall rate cumulative probability distribution. This approach can also be used to improve contours of homogeneous climatic areas, as well as to better characterize the transition between different climates.

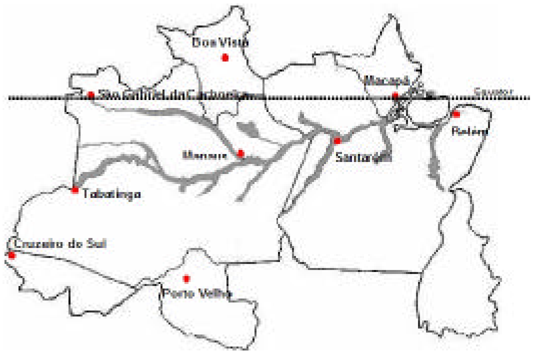

Fig. 1 Amazon region – rain gauge and radar networks.

Köppen classification was adopted because its structure depends on temperature, precipitation and vegetation, factors that can be related to the statistical distribution of rain in a given area. In the Amazon region only Köppen climate A (tropical rainy) can be identified with the following subtypes:

a) Rainy Equatorial (Af) - with a large annual rainfall (over 2000 mm) and practically no dry season;
b) Monsoon Tropical (Am) – the annual rainfall is equal to or larger than Af, but there is a short dry season (one to three months);
c) Wet-and-dry tropical (Aw) – where the rain and dry seasons are well defined.

PRECIPITATION RATE DISTRIBUTION

When there is no information about the local cumulative distribution of rain, an alternative is to use a mathematical model based on meteorological parameters available in the region under study. In this paper it was adopted the Salonen-Baptista model, which is the basis of the ITU-R Recommendation P.837-4 [5]. This model depends on the following parameters:

- ❖ Average annual convective rainfall amount, $\boldsymbol{M_C}$ (mm);
- ❖ Average annual stratiform rainfall amount, $\boldsymbol{M_S}$ (mm);
- ❖ Probability of rainy 6h periods, ***Pr6.***

which can be obtained from the data available in the Brazilian Meteorological Institute.

Taking this mathematical model together with precipitation and radar data, a detailed analysis of the cumulative distribution of rain in the Amazon region is being carried out. Figure 2 shows a comparison between the cumulative distribution measured at Cruzeiro do Sul, from January 2004 to December 2004, with the corresponding predicted values from the Salonen-Baptista model adjusted with meteorological local data. An acceptable agreement between the two curves is observed.

Z – R RELATION

Radar reflectivity factor (Z) in mm^6/mm^3 is related to rainfall rate (R) in mm/h through an empirical relation of the type $Z = aR^b$. Based on rain gauge [7.36^0S;72.80^0W] and radar measurements [7.36^0S ; 71.56^0W] carried out at Cruzeiro do Sul, it was found the following values for these parameters: a = 207 and b = 1.53.

The relation $Z = 207\ R^{1.53}$ will be used throughout in this paper. Details about the derivation of “a” and “b” are being published elsewhere [6]. Figure 3 shows a comparison between the cumulative distribution of precipitation rate from rain gauge measurements and the corresponding distribution obtained by the conversion of radar data. An excellent agreement is observed for percentage of time up to 0.005 %. For smaller percentages of time the difference of values between the two procedures is probably due to rain gage saturation.

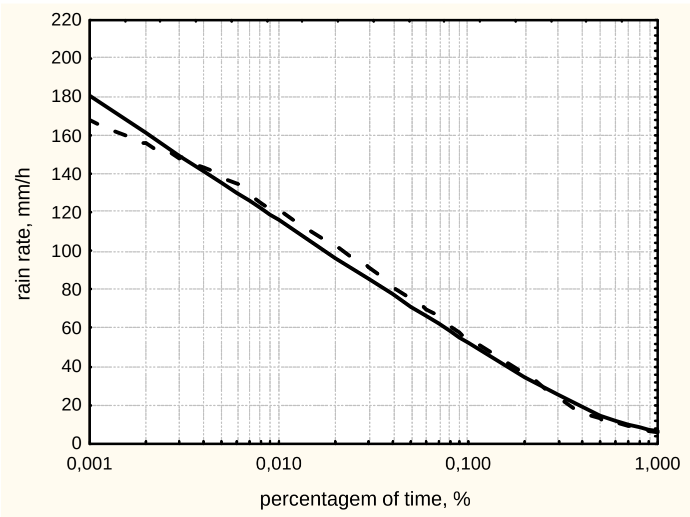

Fig. 2 Cumulative distribution of rainfall rate in Cruzeiro do Sul (7.36°S ; 72.80°W) - Comparison between rainfall rate measurements (—) and Salonen-Baptista prediction model (- - -).

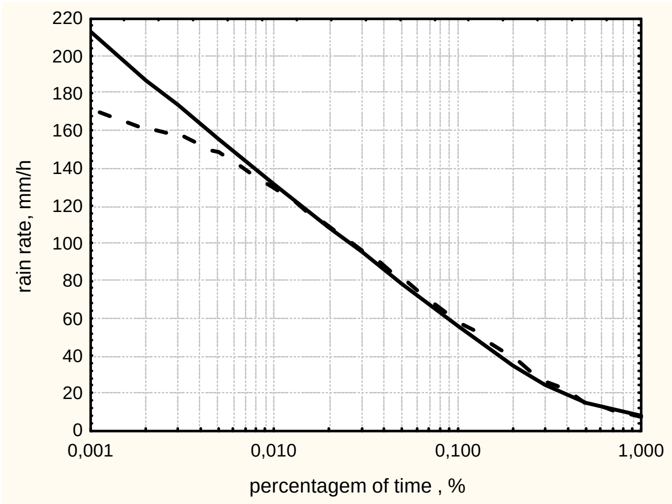

Fig. 3 - Cumulative distribution of rainfall rate in Cruzeiro do Sul - Comparison between rainfall rate measurements from rain gauge (- - -) and radar data (—)

PREDICTION OF RAIN ATTENUATION

An example of a rain cell measured at the radar station of Cruzeiro do Sul is given in Figure 4. Taking into account the non-uniform aspect of the rain cell shown in this figure, it is clear the difficulty to model it by a simple geometrical shape. Most of prediction models use the concept of path length factor (or distance factor) for solving the problem of non-uniformity of rain along the propagation path. However, considering that is not feasible to derive a rigorous mathematical expression for this factor, an alternative is the use of experimental data for fitting an empirical solution based on a given rain cell model. Taking as reference a truncated exponential rain cell, promising results were obtained by Timóteo da Costa and Assis [7]. An important reason for choosing this model was because, through a combination of cylindrical and exponential shapes, it is avoided the restriction associated to a measured path length factor greater than one, common to other predicting methods.

Observing Figure 4, once the rotational symmetry assumed above is not in accordance with the shape of the rain cell, a limitation to this model could be raised. However, a detailed analysis of the cell core, where precipitation is more intense, indicates that this approximation seems to be acceptable. There is not a good agreement in the tail of the rain cell, where the precipitation is low and, consequently, less important for rain attenuation.

On the other hand, weather radar observations [8] show that, on average, the rain intensity does not vary from the surface of the Earth up to the 0°C isotherm (h_o). Based on this result, h_o has been used along the years as reference for modelling the rain height. However, in the Amazon region (and probably in other low latitude locations) this point deserves a more detailed investigation, once radar data indicate the existence of heavy rain well above the 0°C isotherm. An example is given in Figure 6 with data from the radar station of Tefé [3.22^{0}S; 64.42^{0}W]. This figure shows vertical profiles of Z measured at 8 points separated by 250 m in a range of 2 km. Considering that the isotherm of 0°C is around 4500m, the rain is approximately constant up to 2 h_o, i. e. 9000m.

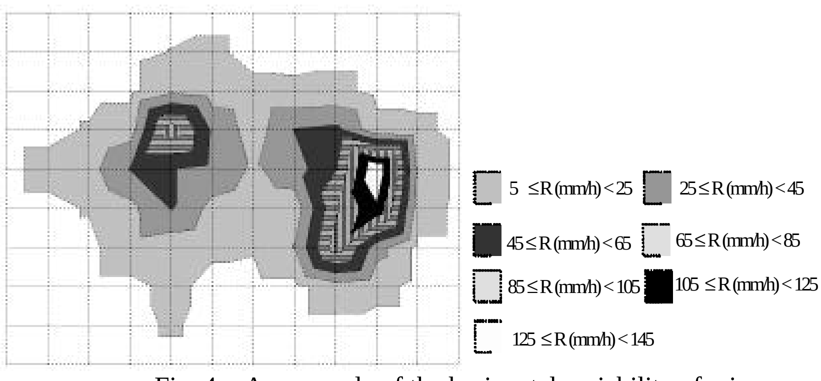

Fig. 4 – An example of the horizontal variability of rain

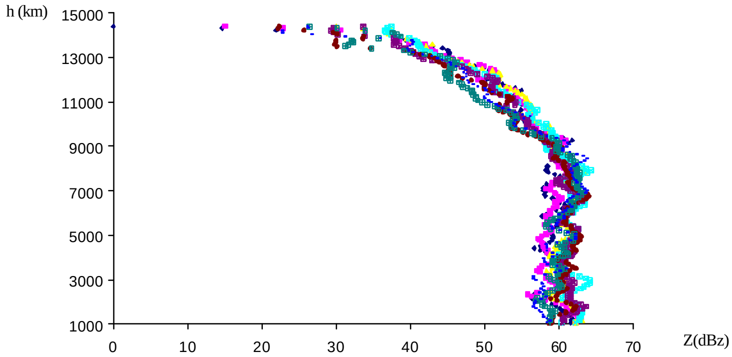

Fig. 5 An example of the vertical variability of rain.

The concept of equivalent rain height seems to be an adequate way to solve this question. However, as it was pointed out by Assis [9], this solution should be considered only after solving the problem of the horizontal distribution of rain. An study by Timóteo da Costa and Assis [10] has shown large errors when comparing rain height corresponding to -2°C isotherm height, as adopted in the ITU-R model [11] with the effective rain height derived from experimental data in latitudes between 30°N and 30°S.

CONCLUDING REMARKS

According to the preliminary results described in this paper, it is clear that the combined use of precipitation and radar data, Köppen climate classification and Salonen-Baptista mathematical model appears to be an useful tool for the prediction of rainfall rate cumulative distribution. This approach can also be used to improve contours of an homogeneous climatic area, as well as, to better characterize the transition between different climates. As expected for convective rain, the non-uniformity of precipitation in the horizontal plane constitutes an obstacle for modelling the cell. In spite of that, considering that the core of the rain cell can be treated as homogeneous, a model referenced by a truncated exponential rain cell is being investigated. Regarding vertical variability, once for convective precipitation radar signals can be detected well above the 0°C isotherm, the concept of effective rain height seems to be an adequate way to face the question. However, taking into account the totally empirical basis of this concept, it must be used only after the problem of horizontal distribution has been solved.

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