A NEW GLOBAL PREDICTION MODEL OF RAIN ATTENUATION THAT SEPARATELY ACCOUNTS FOR STRATIFORM AND CONVECTIVE RAIN

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INTRODUCTION

At frequencies above 10 GHz, one of the most important impairments on radio wave propagation is attenuation due to rain. This contribution is aimed to present an improved version of the EXCELL rain attenuation model [1], which, analogously to the original one, predicts attenuation through a rain cellular representation. The new model allows the calculation of attenuation contributions from stratiform and convective rain separately. The rationale of this proposal is the attempt to develop an even more physical prediction model of rain attenuation. In this approach, two different physical rain heights, derived from the ERA-15 database, are used for stratiform and convective rain respectively. Moreover, when considering stratiform rain, the bright band contribution to attenuation is added.

STRATIFORM AND CONVECTIVE *P*(*R*)

Although the classification of rain in statiform or convective is quite a rough way to describe the complexity of the meteorological situations and, therefore, in no way an easy task, nevertheless the overall impact on radiowave propagation at the different frequencies of interest of diffuse light rain with limited vertical extent and a well defined bright band aloft is very different from the one of intense showers extended in height but area limited. It was therefore assumed worthwhile to develop a tool able to distinguish between stratiform and convective contributions to the yearly $P(R)$ and from them to the yearly $P(A)$. This result has been achieved through an algorithm based on the EXCELL model, in particular, on its last modification, referred to as "lowered EXCELL", in which a cell lowering factor R_{low} is introduced so that the surface of the rainy area of the cell and the CDF of the rainfall intensity do not diverge when R approaches to zero. Rain is represented by an ensemble of exponential shaped cells, defined by:

$$R(\rho) = (R_M + R_{low})\, e^{-\frac{\rho}{\rho_0}} - R_{low} \tag{1}$$

where R_M is the peak rain rate of the cell and ρ_0 is its radius such that $R(\rho_0) = (R_M+R_{low})/e - R_{low} \approx R_M/e$, if R_{low} is small enough with respect to R_M, i.e $R_{low} \leq 2$ mm/h. Each cell has a probability of occurrence $N(\rho_0, R_M)$ [2] which depends on the local meteorological situation.
For every class in which ρ_0 is subdivided, the peak value R_M^* is calculated so that the mean value of rain rate averaged over 1 km^2 (typical radar pixel) equals a rain intensity threshold set to 8 mm/h (boundary between stratiform and convective rain). $R_{M,mean}$ is the average value of all the determined R_M^* peaks, each one weighted with the probability of occurrence associated to that cell. In other words, the threshold on the rain intensity (8 mm/h) is translated into a threshold on the peak rain rate of the exponential cells:

$$R_{M,mean} = \frac{\sum_{\rho_0} R_M^{\ *}\, N\left(\rho_0, R_M^{\ *}\right)}{\sum_{\rho_0} N\left(\rho_0, R_M^{\ *}\right)} \quad \text{(mm/h)} \tag{2}$$

Every cell with $R_M < R_{M,mean}$ contributes to the stratiform $P(R)$, the remaining cells generate the convective $P(R)$.
Figure 1 shows the application of the proposed model (hereinafter referred to as "strat-conv EXCELL" model) on the long-term annual $P(R)$ in Spino d'Adda (45.46° N, 9.56° E) and Miami (25.65° N, 80.43° W).

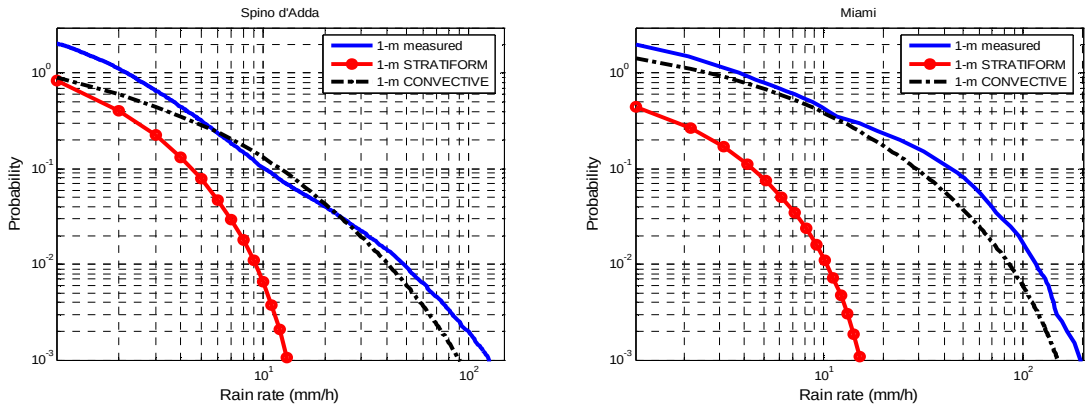

Figure 1: the strat-conv EXCELL model applied to the long-term annual $P(R)$ in Spino d'Adda (1) and Miami (2)

The model cannot be easily tested because of the lack of measured stratiform and convective $P(R)$, but some efforts have been made to assess its reliability, both by applying it to monthly CDFs which can be likely considered as mainly stratiform or mainly convective and by comparing the results to rain CDFs obtained by time series, whose samples have been previously divided into stratiform or convective (considering a threshold on peak rain intensity).
A by product of the star-conv EXCELL model is the development of a tool to convert rain rate statistics from one integration time to another, (for example from one hour to one minute). The tool is based on the use of the cell model for simulating rain gauges, operating with different integration time, by simply translating over a point rain cells, carried by winds blowing at high altitude (600 hPa). Wind speed is different for stratiform and convective rain.

RAIN HEIGHT

The original EXCELL model predicted the attenuation due to rain, by considering all the rain cells acting separately and having the vertical rain intensity profile constant. Rain height was derived from ITU-R Rec P.839-3, which gives the average value (over the whole year) of the 0 °C isotherm height. The strat-conv EXCELL model instead makes reference to the ERA-15 database, provided by ECMWF, and evaluates two separate rain heights for statiform and convective rain as the mean values of monthly 0 °C isotherm height (conditioned to the presence of rain) h_i, weighted according to the monthly mean 6-hour probability values p_i and the monthly mean amounts of stratiform ($r_{i,str}$) and convective ($r_{i,cnv}$) rain. Eventually, the computed convective rain height is increased by the tenth percent of its value to allow for the highly convective processes which very likely cause the rain height to be higher than the 0° C isotherm height.

Table 1: rain height from ITU-R Rec P.839-3 and the ERA-15 database (in km) for Spino d'Adda

ITU-R Rec P.839-3	ERA-15 stratiform (h_{str})	ERA-15 convective (h_{cnv})
2.8421	2.4035	3.1036

THE BRIGHT BAND CONTRIBUTION

The presence of bright band along the path has an influence on the wave propagation, causing extra attenuation. Many experiments have shown that a definite impact of the bright band is only in stratiform phenomena, while, generally, it is negligible in convective events, where strong up or down drafts do not allow the formation of a layer of transition from ice to water. For this reason, the strat-conv EXCELL model adds the bright band contribution only to stratiform rain.
The investigation on the bright band effect has been performed by means of an anisotropic model of the melting layer [3], which accurately describes the propagation of an electromagnetic wave in presence of rain, ice and melting ice by giving a complete physical description of the vertical profile. The simulator gives the possibility to set some input parameters and to calculate various propagation variables, and among them the attenuation in the bright band.

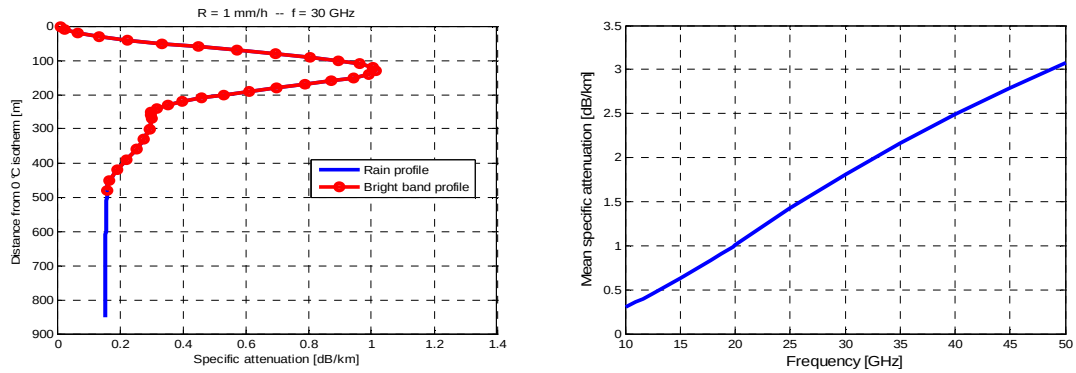

Figure 2: example of a bright band profile (1) and mean bright band specific attenuation (2), function of frequency

Figure 2.1 shows an example of the specific attenuation vertical profile, in which it is easy to notice the bright band contribution. In order to deeply investigate the impact of the bright band on propagation, the simulator has been run with the following parameters as input:

- initial density of the melting particle: 0.16 g/cm^3
- DSD: Marshal & Palmer distribution
- frequencies: from 10 GHz to 50 GHz in 5 GHz step
- rain rate: from 1 to 8 mm/h.

Only rain rate values ranging from 1 to 8 mm/h were chosen because, for greater values, the melting layer presence is unlikely. For every frequency, the simulator was run with all the chosen rain rate values and, afterwards, results were averaged. Figure 2.2 shows the trend of the mean specific attenuation with frequency, while Figure 3.1 shows the variation with frequency of the physical depth of the melting layer.

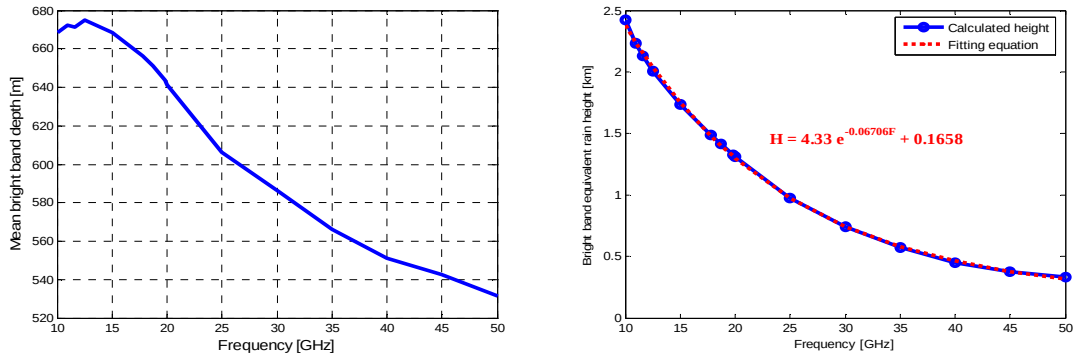

Figure 3: mean physical melting layer depth (1) and mean equivalent rain height due to the melting layer (2)

The aim of the investigation was to obtain an equivalent rain height filled by rain (as below), which could represent the bright band attenuation, to be added to the physical rain height. Therefore, the equivalent rain height H_{BB} has been derived through:

$$H_{BB}(f) = E[Att_{BB}(f)]/E[\gamma_{rain}(f)] \quad \text{(km)} \tag{3}$$

where $E[Att_{BB}(f)]$ is the average value (1 mm/h < rain rate < 8 mm/h) of the total attenuation only due to the bright band and $E[\gamma_{rain}(f)]$ is the average value (1 mm/h < rain rate < 8 mm/h) of the specific attenuation of rain. The result of the investigation is shown in Figure 3.2, where the equivalent rain height due to bright band is plotted against frequency. The function has been also fitted through the exponential law:

$$H_{BB}(f) = 4.33\, e^{-0.06706\, f} + 0.1658 \quad \text{(km)} \tag{4}$$

As it can be easily seen in Figure 3.2, the additional attenuation due to the melting layer decreases as frequency increases. The strat-conv EXCELL model therefore allows a frequency dependent estimation of the bright band contribution to total attenuation, while the EXCELL model accounted for the melting layer presence, through a fixed equivalent rain height (0.3571 km) to be added to the yearly mean 0 °C isotherm altitude from ITU-R Rec P.839-3.

ATTENUATION ESTIMATION THROUGH THE STRAT-CONV EXCELL MODEL

The complete procedure for the estimation of the attenuation due to rain, through the strat-conv EXCELL model, consists in the following steps:

- derive stratiform and convective $P(R)$ from the local annual $P(R)$
- calculate the frequency dependent equivalent rain height due to the melting layer, through (4)
- calculate the stratiform rain height through the ERA-15 database and add the equivalent rain height due to bright band
- calculate the convective rain height through the ERA-15 database and increase it by the tenth percent of its value
- estimate the stratiform rain contribution to attenuation through the EXCELL model, using the stratiform $P(R)$ and stratiform rain height as input
- estimate the convective rain contribution to attenuation through the EXCELL model, using the convective $P(R)$ and convective rain height as input
- combine the stratiform and convective contributions.

Figure 4 shows the predictions of the EXCELL and the strat-conv EXCELL models, against the measured ITALSAT data recorded at the experimental station of Spino d'Adda, from 1994 to 2000. 1-minute sampled rain gauge data, from 1992 to 2001, have also been recorded at Spino d'Adda. Exploiting both the attenuation and the rain gauge databases, it was possible to select concurrent attenuation and rain events. Results shows the increased accuracy of the new model.

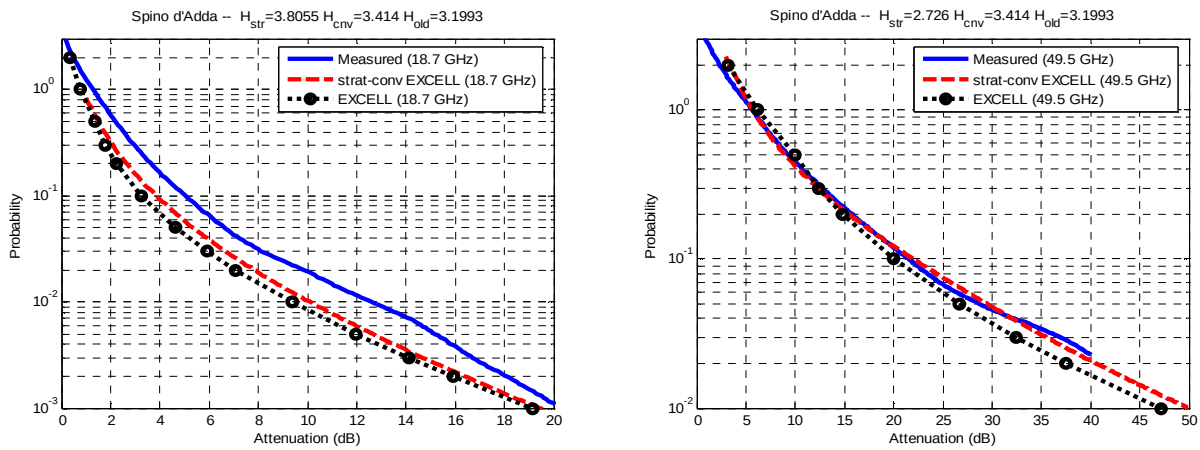

Figure 4: comparison of the EXCELL and strat-conv EXCELL models on ITALSAT data (18.7 and 49.5 GHz)

CONCLUSIONS

The strat-conv EXCELL model here presented adds three main features to the original EXCELL model:

- separated contributions to attenuation from stratiform and convective rain
- physical rain height from ERA-15 database (0 °C isotherm height) instead of ITU-R Rec. P.839-3 height
- bright band contribution

The applied modifications allow the strat-conv EXCELL model to more physically represent the attenuation process and, in fact, compared to the previous EXCELL model, it gave better results concerning some tests performed on Spino d'Adda ITALSAT data. More tests are needed to evaluate the effectiveness of the strat-conv EXCELL model.

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