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About the Impact of NWP Models' Temporal Resolution on Rain Attenuation Forecasts

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Abstract

The ever increasing demand for more data transmission capacities also includes the field of satellite communications. Satellite links with higher frequencies provide large bandwidths, but are more prone to degradation by atmospheric phenomena on the earth – space path. Reliable short term forecasts of weather and channel characteristics will ease appropriate mitigation, like employment of diversity techniques or adaptive code modulation. Numerical weather prediction (NWP) models area available on global scale as a potential basis for such forecasts. Rain is the strongest effect, with the rain rate being highly variable in time. This study discusses, what rain rate integration time and thus NWP forecast step width is suitable for forecasting satellite channel characteristics. The link attenuation is calculated on basis of disdrometer measurements for various integration times and the resulting fade slope statistics compared against the expectation by the ITU-R P.1623 model [1]. It is shown, that NWP models with forecast steps of 5 minutes or less are interesting for such purpose.

1. Introduction

To meet the demands of the market for higher transmission bandwidths, in satellite communications nowadays Ka-band frequencies are in operational use and recent research efforts also consider the Q-, V- and W-frequency bands. Especially these high frequencies are severely impaired by atmospheric phenomena. Mitigation cannot be ensured by mere provision of a power margin any longer, as this may be done with the relatively low attenuations in Ku-band and below. More complex mitigation schemes require a dynamic reconfiguration of certain link parameters. Literature reports about a few attempts of short term forecasts of satellite channel characteristics for this purpose, e.g. by Hodges and Watson [2] and Watson and Hodges [3]. Since the dominating contribution is caused by rain, the high time variability of the rain rate needs to be correctly reflected. This is a critical requirement, since appropriate high time resolution is not commonly available in current NWP forecasts. Schönhuber et al. [4] discuss the rain rate average effect within 15 minutes steps, which in NWP modelling already is considered a very short interval. Though [4] concludes with encouraging results, the deviation of 15 minutes averages from the detailed time series resolved by 15 seconds may still be considerable. The question arises, which interval is suitable to reflect the time variability and dynamics of rain attenuation in satellite links. The present study is dedicated to this discussion, with the methodology given in the following chapter.

2. Methodology

To assess the suitability of certain rain rate integration times for forecasting satellite attenuation, it seems appropriate to use empirical rain data. Herein measurements by a 2D-Video-Distrometer (2DVD) are used, providing single rain drops with their precise time stamps. This allows to choose any arbitrary rain rate integration time. From the rain drop size distribution (DSD) within such interval the rain attenuation of a certain satellite link may be derived, by use of rain drops' scattering amplitudes and link geometry parameters. In a first step given in this study, the resulting channel characteristics are compared with the ITU fade slope model [1], revealing if the typical fade slope dynamics may be reflected. In a later second step, the DSD-derived attenuations for certain integration intervals should be compared against measured channel characteristics.

In view of a later application using NWP models for link characteristics forecasts, in this study the measured DSDs represent the rain data forecasted by the NWP models. In the comparison of DSD-derived fade slopes with the ITU model it may be considered as a necessary criterion, that the DSD-derived fade slopes are equal or faster than the model expectations. Otherwise – in case they are slower – the forecasted attenuation time series will not be able to follow the dynamics of the actual link characteristics. It should be pointed out, that still this is not a sufficient criterion. But it can be assumed, that attempts to forecast satellite link characteristics are interesting, once their fade slopes are fast enough to follow the measured values. Certainly this does not yet answer a number of further questions, e.g. if rain may be assumed to be homogeneous within a NWP model grid space and others more.

2. Data Set

The 2DVD data used for this study were collected in Graz / Austria in the year 2014. Snow data were removed from the data set, resulting in some 12 million rain drops or 804

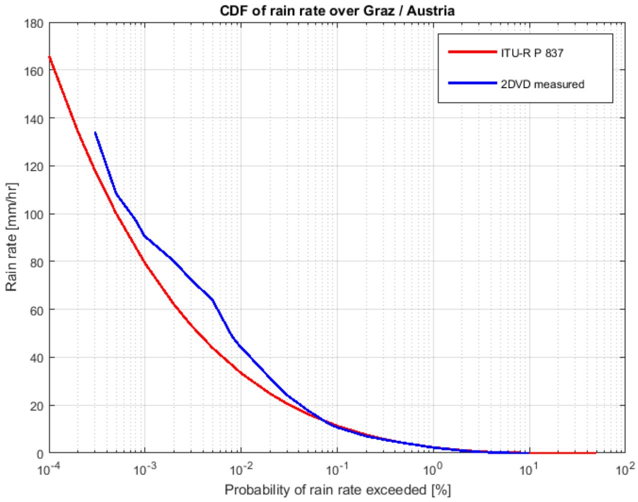

Figure 1: CDF of rain rate predicted for Graz / Austria by ITU-R P 837 [5] and 2DVD measurements from 2014, without snow data.

mm of rain. Figure 1 presents the resulting cumulative distribution function (CDF) of 1 minute rain rates, in comparison to the model values obtained from ITU-R P.837 [5]. It is obvious that in this year the measured rain rates exceeded the model expectation, also the long term annual precipitation average was exceeded by more than 20 %.

3. DSD-derived attenuations

From the 2DVD-measured DSDs slantpath attenuations were derived for a frequency of 19.701 GHz, an elevation angle of 35 deg and a rain height of 3.33 km, as predicted by ITU-R P.839 [6] for the latitude of Graz / Austria. For the calculation of rain drops' scattering amplitudes a point matching algorithm was used. The integration interval again was set to 1 minute. Figure 2 shows the resulting CDF, in comparison to the model expectation by ITU-R

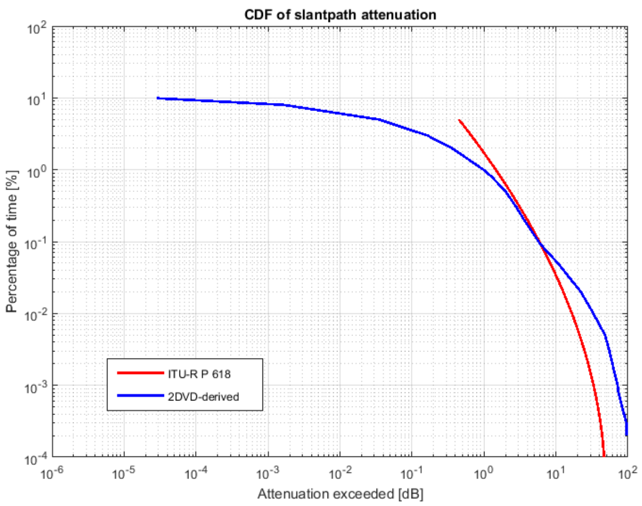

Figure 2: CDF of slantpath attenuation, for 19.701 GHz, 35 deg elevation, rain height of 3.33 km, 1 minute integration time.

P.618 [7]. The fact observed in Figure 1, that the ITU model underestimates the measured rain rates of 2014, is reflected again in Figure 2, which here is converted into an underestimation of higher attenuations. Regarding the differences visible in Figure 2, the effects caused by applying point monitoring measurements for the integral parameters over the full slant path are also to be kept in mind.

4. Fade slopes for various integration times

Having prepared the required the data set and tools, in the next step fade slopes obtained from DSD-derivations and from predictions by ITU-R P1623 [1] are compared. Herein a set of integration times was used, including 1, 5, 15 and 60 minutes. The calculation of attenuation time series followed the same procedure and parameters described in above section 3, with the only difference to vary the integration time. To obtain statistically significant results, this procedure was applied in the way of a running mean over the rain rate time series, thus yielding a sufficiently number of samples also for 60 minutes integration times. It is inherent, that for longer integration times the derived fade slopes are lower.

Figure 3 presents the fade slope CCDFs obtained at an attenuation level of 1 dB. The red line denotes the ITU model [1], the cyan, blue, black and magenta lines stand for 1, 5, 15 and 60 minutes integration time. It is clearly seen, that the fade slopes resulting from 15 and 60 minutes integrations cannot follow the dynamics of attenuation events, as expected by the ITU model. Whereas the results from 5 and 1 minute integrations principally allow fast enough changes. Figure 4 shows the fade slope CCDFs at an attenuation level of 5 dB, with the same color code as in Figure 3. The magenta line representing 60 minutes integration time disappeared, since attenuation levels at such long integration time do not reach 5 dB. Again it is clearly visible, that the 15 minutes integration cannot follow the expected dynamics. Also the 5 minute integrations are partly too slow, but this refers to less than 1 percent of the observed slopes. The dynamics of the 1 minute integration seems to be significantly faster than the expectation by the ITU model.

5. Conclusions and Outlook

Summarizing the results of above section 4 it may be stated, that rain rate integration times or NWP model step widths of 5 minutes or less seem to be interesting for short term forecasts of satellite link characteristics, whereas integration times of 15 minutes or more hardly can follow the expected dynamics. As a limitation to this statement it is to be kept in mind, that rain attenuation at the investigated Ka-band frequency may rise to much higher levels than 5 dB. As Figure 2 shows, this refers to less than 1 % of the time and presently is considered as a minor percentage of time.

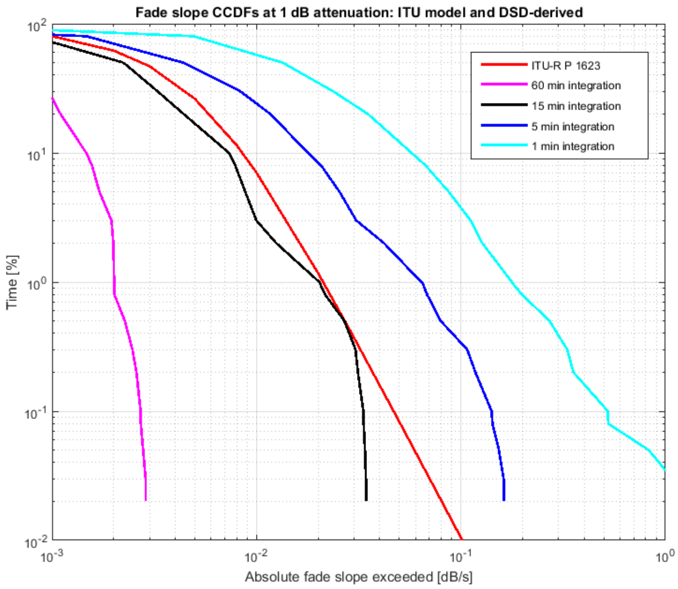

Figure 3: fade slope CCDFs obtained at an attenuation level of 1 dB. The red line denotes the ITU model [1], the cyan, blue, black and magenta lines stand for DSD-derived fade slopes, at 1, 5, 15 and 60 minutes integration time

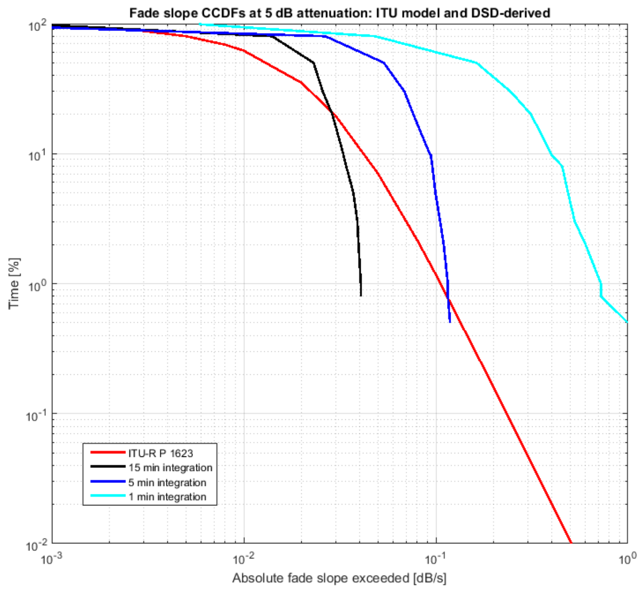

Figure 4: same as Figure 3, but at 5 dB attenuation. The results of 60 minutes integration do not reach 5 dB attenuation any longer.

Future work will include a comparison of DSD-derived attenuations with actually measured slant path attenuations at various integration times. Typically this is done using measurements of a satellite beacon signal, e.g. of the Alphasat satellite. As the next step further the data of 5 minutes NWP will be used. Though 5 minutes temporal resolution is far from being common in NWP models, there are a few attempts to be noted, as e.g. the rapid-INCA model, mentioned by Kann et al. [8]. Again the resulting attenuations based on such data will be verified with satellite beacon measurements.

The outlook to an operational scenario includes a fast online access to NWP forecasts, which are immediately converted to satellite channel characteristics and these are used for supporting optimal real-time link configurations.

6. Acknowledgements

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