The previous models of σ_χ^2 deal with clear air scintillation, however it is known that scintillation displays a different behaviour during rainy conditions. The Matricciani model [99] permits to redefine σ_χ^2 as $\sigma_{r\chi}^2$ in rain such that

$$\sigma_{r\chi}^2 = \begin{cases} \sigma_\chi^2 A_{rain}^{10/12} & \text{if } A_{rain} > 1\,\text{dB} \\ \sigma_\chi^2 & \text{otherwise} \end{cases} \tag{2.113}$$

where A_{rain} [dB] is the rain attenuation.

Furthermore, the scintillation variance is also affected by the dimensions of the receiving antenna, as on a larger aperture antenna the turbulence-induced fluctuations in the wave front are averaged out. The recommendation ITU-R P.618-13 §2.4.1 [5] proposes an example of such an antenna averaging factor, and similar expressions are also found e.g. in [96].

Finally, assuming the PSD $W_\chi(\omega)$ is reconstructed from σ_χ^2 and ω_c, a time-varying filter may then be built from it and used to synthesize amplitude scintillation time series starting from a gaussian white noise. This strategy is described in [38].

2.5 Propagation beacon and excess attenuation

Now that the main Earth-space propagation impairments have been presented, this sections explores what their direct measurements entail, similarly to [81]. Part of the attenuation can indeed be recovered by measuring the signals received on the ground from single frequency spaceborne propagation beacons.

2.5.1 Beacon signal power and total attenuation

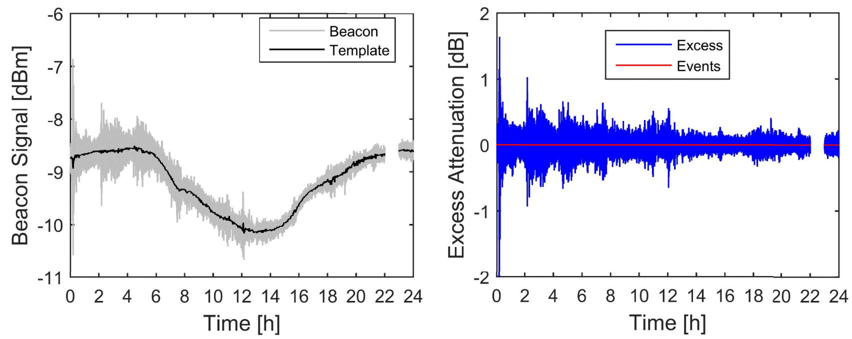
The power P_r [W] received from the satellite beacon at the ground station is usually expressed with respect to a reference power P_0 [W] as the received power level L_r such that

$$L_r = 10 \log_{10}\left(\frac{P_r}{P_0}\right) \tag{2.114}$$

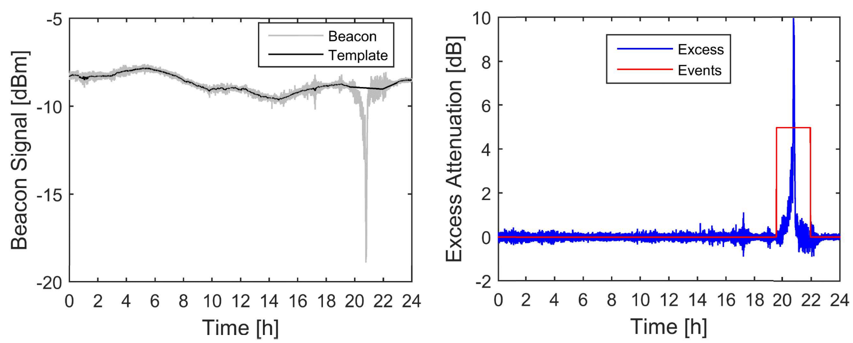
and, oftentimes $P_0 = 1\,\text{mW}$ so that L_r is expressed in dBm. The value of L_r depends on the whole system and is not a universal metric of the atmospheric attenuation. This metric would be the total attenuation A_{tot} [dB] given here in terms of powers by

$$A_{tot} = -10 \log_{10}\left(\frac{P_r}{P_{na}}\right) \tag{2.115}$$

where P_{na} [W] is the received power in hypothetical conditions of absence of the atmosphere. In practice, however, P_{na} cannot be known with high accuracy [100, 101], as it also depends on several system parameters that might vary in time. Only some of the attenuation components are usually extracted from a propagation beacon signal with good accuracy: the rain attenuation and the log-amplitude scintillation. The next section explains the reasons why.



(a) 2015-07-10, clear-sky conditions



(b) 2015-05-02, rain event

Figure 2.7 – Example of rain event identification, template construction, and excess attenuation extraction from the Alphasat 19.701 GHz at Spino d'Adda

2.5.2 Identification of precipitation events and extraction of the excess attenuation from the measured signal

Figs 2.7 (a) and (b) show examples of the measured co-polar beacon signals (on the left) and the result of their processing (on the right) for the link between Alphasat and Spino d'Adda (IT) at 19.701 GHz. Fig. 2.7 (a) shows the 10th July 2015, a day with clear-sky conditions. Fig. 2.7 (b) shows the 2nd May 2015, a day with a strong rain event.

In the left part of Fig. 2.7 (a), the beacon signal (in grey) has the general trend to vary between around −8.5 dBm near midnight and around −10 dBm near noon. On top of this trend, there appears to be a random fluctuation of the signal which varies in intensity over time. The general trend is mainly due to the satellite motion, whereas the fluctuations are characteristic of scintillation. What is called the template (in black) is this trend found by filtering the scintillation out of the signal. Then, in the right part of the figure, the filtered out scintillation constitutes what is called the excess attenuation (in blue).

In the left part of Fig. 2.7 (b), a trend and fluctuations, as those observed for the clear-sky day, are also visible. The most striking feature of the beacon signal (in grey) is however the marked negative peak in the evening. This peak is caused by a rain event. To be able to build a smooth template (in black) from the signal, it is necessary to accurately flag the rain event and remove it from the signal, e.g. by a linear interpolation between the start and end of the event. The right part of the figure shows how the limits of the event were defined (in red). It also shows the resulting excess attenuation (in blue) found by subtracting the beacon signal from the template. This time, the excess attenuation contains contributions from both the log-amplitude scintillation and the rain attenuation.

More generally, the processing of the beacon signal implies the construction of a template where, during rain events, L_r is replaced by a linear interpolation and the scintillation is filtered out. The rain events can be flagged either by visual inspection or by means of some semi-automatic methods. The scintillation can be removed by a low-pass filter which exploits its known spectral properties [99, 102]. In other words, this template is the level L_{nr} of the power P_{nr} that would have been measured without rain and turbulence. By subtracting the beacon signal from the template, we obtain the excess attenuation A_{exc} [dB]

$$A_{exc} = L_{nr} - L_r = -10 \log_{10} \left(\frac{P_r}{P_{nr}} \right) \tag{2.116}$$

a metric including only the effects of rain and turbulence. The relation between A_{exc} and A_{tot} is, from (2.115) and (2.116),

$$A_{tot} = A_{exc} + A_{nr} \tag{2.117}$$

$$A_{nr} = -10 \log_{10} \left(\frac{P_{nr}}{P_{na}} \right) \tag{2.118}$$

where the nonrainy attenuation A_{nr} [dB] appears as a quantity that must be estimated independently from the beacon signal in order to obtain the total attenuation. From what has been seen before in this chapter, the components of the nonrainy attenuation are due to the gases and to the clouds.

It must be noted that, because the presence of clouds and rain are correlated, because the identification or rain events is not always straightforward, or simply because there are discrepancies in the processing/filtering methods, what is included in practice in the excess attenuation is susceptible to variation between an experiment and another. The accuracy of the excess attenuation from propagation beacon experiment has been estimated to be $\sim 0.2 - 0.5$ dB in the range $20 - 50$ GHz [16].

2.6 Radiometers and brightness temperature

Another type of apparatus which relates to the atmospheric attenuation is the ground-based microwave radiometer. It is a passive device measuring the thermal noise of the atmosphere for a certain number of frequencies. This section explains, similarly to [81], how the nonrainy attenuation may be estimated from radiometric measurements.