Atmospheric Attenuation At 100 and 300 GHz Estimated with Radiosonde Data

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***Abstract*—The study of atmospheric propagation impairments at submillimeter and THz frequencies is becoming increasingly relevant due to the strong effects caused by the composition of the troposphere and the phenomena occurring in it. The present paper is devoted to the estimation of total attenuation at 100 GHz and 300 GHz under non-rainy scenarios. With this purpose, 4 years of meteorological data from Madrid have been collected, including radiosoundings from Madrid-Barajas Airport and co-site SYNOP observations. This volume of data has been analyzed with the aim of also introducing a detection method of rain conditions, which cannot be easily identified in radiosounding profiles. Finally, the method has been used to discard several probable events which would be responsible of scattering conditions and, hence, yearly CDFs of total attenuation have been obtained. It is expected that the statistics would be closest to the ones obtained by experimental techniques under similar atmospheric conditions.**

I. Introduction

The THz band covers a broad frequency range comprised between 100 GHz and 10 THz, which corresponds to wavelengths from 3 mm to 30 μm, respectively. An important number of exhaustive reviews covering current technological approaches and applications can be found in the literature [1], [2]. Along with the growing interest in this frequency range, the study of the strong influence of the atmosphere on the propagation of frequencies above 100 GHz is an important research area for atmospheric science applications [3] and future THz telecommunications systems [4].

The TeraSense project [5] is a collaborative initiative joining the efforts of sixteen spanish research groups specialized into different scientific areas. The project aims to increase the knowledge on several submillimeter (a.k.a sub-THz) and THz bands and to develop experimental instruments from a radio perspective, including simulation and modelling of radiation-matter interactions. In this context, a series of studies are being carried out at Universidad Politécnica de Madrid (UPM), one of them specifically concentrated on atmospheric propagation on non-scattering conditions at 100 and 300 GHz. This study is being developed with the perspective of obtaining sky brightness levels, using single-frequency radiometric measurements.

Under the previously mentioned conditions, absorption of radiation through the atmosphere is mainly caused by gases and clouds. The effect of gaseous absorption is evaluated as the sum of the attenuation due to water vapor and oxygen. Both contributions are tipically estimated using well-established physical models as the proposed ones by Liebe [6] or Rosenkranz [7]. Absorption due to the presence of non-rainy clouds is evaluated under the Rayleigh approximation, which is considered valid up to 300 GHz for clouds containing spherical and small water particles, typically with radii below 30 μm [8]. Therefore, assuming this regime, cloud attenuation caused by water droplets is linearly related to the liquid water content. The calculation of this parameter, as well as the detection of cloud layers, can be achieved using cloud identification algorithms, well detailed in the literature [9]–[11], based on data extracted from vertical meteorological profiles.

First-order statistics, such as cumulative distribution functions (CDF) of attenuation, are one of the tools used in order to evaluate some channel propagation characteristics and, thus answer to systems requirements. A previous work [12], using the attenuation models referenced in the paragraph above, allowed to obtain CDF's of gaseous and cloud attenuation, both at 100 and 300 GHz, using radiosoundings data in Madrid. Since the main scenario considered at the frequencies of interest is a non-scattering atmosphere, in the present work these yearly statistics are refined using a suitable method of detection of rain condition events, occurring during radiosoundings.

In this paper, a description of the meteorological data employed is discussed in Section II. Following, in Section III, a general description of the rain detection algorithm is introduced. In Section IV, the method of filtering events under rain conditions is evaluated and yearly statistics of total attenuation are presented as main results. Conclusions and future perspectives are exposed in Section V.

II. Meteorological data

The Barajas Airport station (40.50 N; 3.57 W; 633 m amsl) in Madrid is the source of meteorological data used in the frame of the present paper. Madrid is located in the central area of the Iberian Peninsula. It is characterised by a continental climate, with hot and dry summers and cold winters. Following an overview of relevant aspects concerning the two different meteorological databases having been exploited in this work is summarized.

A. Radiosoundings

Vertical profiles of temperature, pressure and relative humidity are collected from radiosoundings launched routinely twice a day (00 and 12 UTC) at Barajas. These are the input data of gaseous and cloud attenuation models. A selection and check procedure has been established with the aim of identifying non-existing and invalid soundings. With this purpose, considerations about the minimum and maximun height attained by the radiosonde and non-realistic measured temperature values have been verified. The possible horizontal displacement of the radiosonde, due to the effect of wind, is not considered.

B. SYNOP observations

Reports of surface synoptic observations (a.k.a SYNOP reports) are registered generally four times a day (00, 06, 12 and 18 UTC) at Barajas. As it is well-established by the World Meteorological Organisation (WMO), the information provided by these reports is coded according to the alphanumeric data format FM-12 [13]. This special coding scheme is designed for the exchange of meteorological measurements made at automatic and manned weather stations.

A decoding process has been carried out with the aim of extracting the whole meteorological informations given by these observation procedures. Specifically, a set of relevant information relative to the presence of rain events has been extracted from the following parameters, typically available at SYNOP reports:

- SYNOP Present Weather parameter (ww code): Numerical code describing weather conditions at observation time.
- SYNOP Liquid Precipitation parameter (RRR code): It represents the liquid precipitation amount in (mm) during the previous 6 h (for reports registered at 00 and 12 UTC) or 12 h (for reports registered at 06 and 18 UTC) before the SYNOP observation.

III. Rain Detection Method

The detection method proposed below allows to filter out events with rain conditions during the sounding launching or its ascent. At the frequencies of interest, these kinds of atmospheric scenarios would be responsible of scattering processes caused by the interactions between water particles and submillimeter radiation. Therefore, with the purpose of obtaining CDF of total attenuation (i.e. gases and cloud absorption effects) under non-scattering conditions, it is necesary to introduce a detection algorithm to discard rain conditions events.

The following assumptions and considerations have been previously defined:

- Non-availability of co-site rain gauge data. If they were available, they would be the most important source of data.

TABLE I
Summary of rain detection criteria based on SYNOP parameters

Criterion	Description
CR1	Present Weather Parameter (at 00 and 12 UTC): Rain at Observation Time
CR2	Liquid Precipitation Parameter (at 00 and 12 UTC): Accumulated Rain in previous 6 h $> 1\,\mathrm{mm}$
CR3	Liquid Precipitation Parameter (at 06 and 18 UTC): Accumulated Rain in following 6 h $> 1\,\mathrm{mm}$

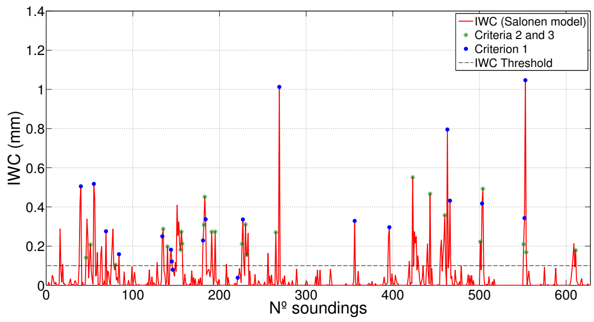


Fig. 1. Rain events identified by CR1, CR2 and CR3. Year 2007

- Given a series of yearly atmospheric profiles from radiosoundings, it is not possible to easily separate rain and non-rain events analyzing a unique parameter, such as the IWV (Integrated Water Vapor content) or IWC (Integrated liquid Water Content) of each profile.

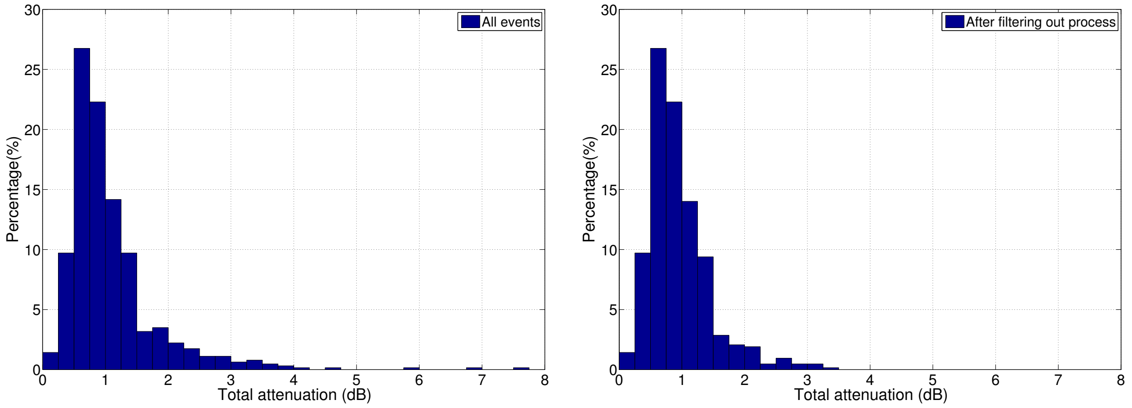
The algorithm makes use of the frequency-independent parameter IWC, expresssed in (mm), for each time-coincident radiosounding launching and SYNOP observations, estimated by the Salonen cloud detection algorithm [9].

A set of three identification criteria (hereinafter, CR1, CR2 and CR3) have been defined based on the SYNOP Present Weather Parameters and the SYNOP Liquid Precipitation Parameters. Table I summarizes the information analyzed by each criterion in order to discard probable rain conditions events. Besides, an IWC threshold, IWC_{th} = 0.1 mm, has been introduced with the aim of evaluating those probable falsely detected events by CR2 and CR3, which in some cases are associated to almost zero or thin-cloud related IWC values.

In summary, a rain event is identified if one of the conditions below is verified:

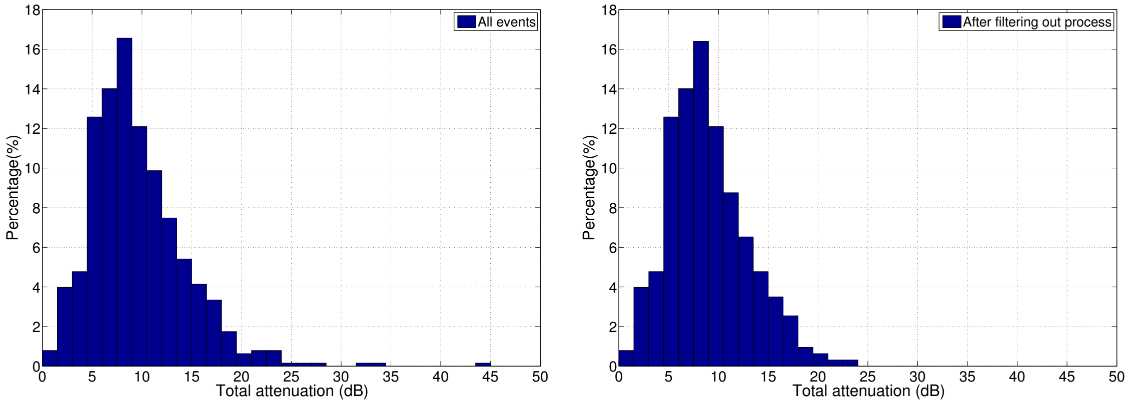
1) CR1 is satisfied during SYNOP observation. CR1 is established as the most reliable identificator of presence of rain during a radiosounding.
2) IWC $>$ IWC_{th} during events CR2 and CR3 (and not previously detected by CR1).

Fig. 1 shows an example of the use of the method. Meteorological profiles of 2007 have been used to calculate the corresponding yearly IWC time series. Following, the CR1, CR2 and CR3 have been used as well as the IWC_{th}, which has also been plotted. The events detected by CR1, and by the



(a) (b)

Fig. 2. Yearly histogram of Total Attenuation at 100 GHz a) using all radiosoundings, and b) the effect of filtering out process. Year 2007



(a) (b)

Fig. 3. Yearly histogram of Total Attenuation at 300 GHz a) using all radiosoundings, and b) the effect of filtering out process. Year 2007

combination of CR2 and CR3 are clearly observed.

An in-depth description and evaluation of the method has been discussed in a recent paper [14].

IV. Results

A. Evaluation of the rain detection method

The effect of the rain method on yearly distributions of total zenith attenuation A_T, expressed in (dB), has been evaluated for the year 2007. Statistics of A_T have been obtained in the form of histograms at both frequencies. The value of A_T, corresponding to each sounding, is expressed as the sum of attenuation caused by atmospheric gases A_G (dB) and clouds A_C (dB). Assuming a stratified atmosphere model, the value of A_G along the path has been computed using the line-by-line calculation procedure included in the ITU-R Rec. P.676 [15]. Using the same layered model, the Salonen cloud detection algorithm has been used to predict the presence of clouds and to estimate the values of specific attenuation due to clouds. From them, the value of A_C has been obtained directly by a linear integration procedure.

Histograms computed at 100 and 300 GHz can be observed in Fig. 2 and 3, respectively. Fig. 2a and 3a show the statistics of A_T, evaluated for all time-coincident radiosounding and SYNOP observations events. It can be reasonable to consider that the statistics follow a log-normal distribution form. The effect observed when events are filtered out at both frequencies is observed in Fig 2b and 3b. It can be verified that high attenuation values on the tails of both distributions are removed. These values would be associated to scattering scenarios, which can not be evaluated by the propagation models implemented in this work.

B. Yearly CDF's of Total Attenuation. Period 2007-2010

CDF's of total attenuation from 4 years of data have been calculated and plotted using vertical profiles for the period between 2007 and 2010. Results at 100 and 300 GHz are shown in Fig. 4 and Fig. 5, respectively. Each plot includes the CDF obtained using all soundings, which is defined as a reference level, and also the CDF obtained after the events filtering process.

At 100 GHz (see Fig. 4) the behavior of statistical distributions is similar along the four years as well as the total attenuation levels estimated. On the whole, the variations between the reference levels and the cumulative distributions obtained after the filtering process are considerable. Total

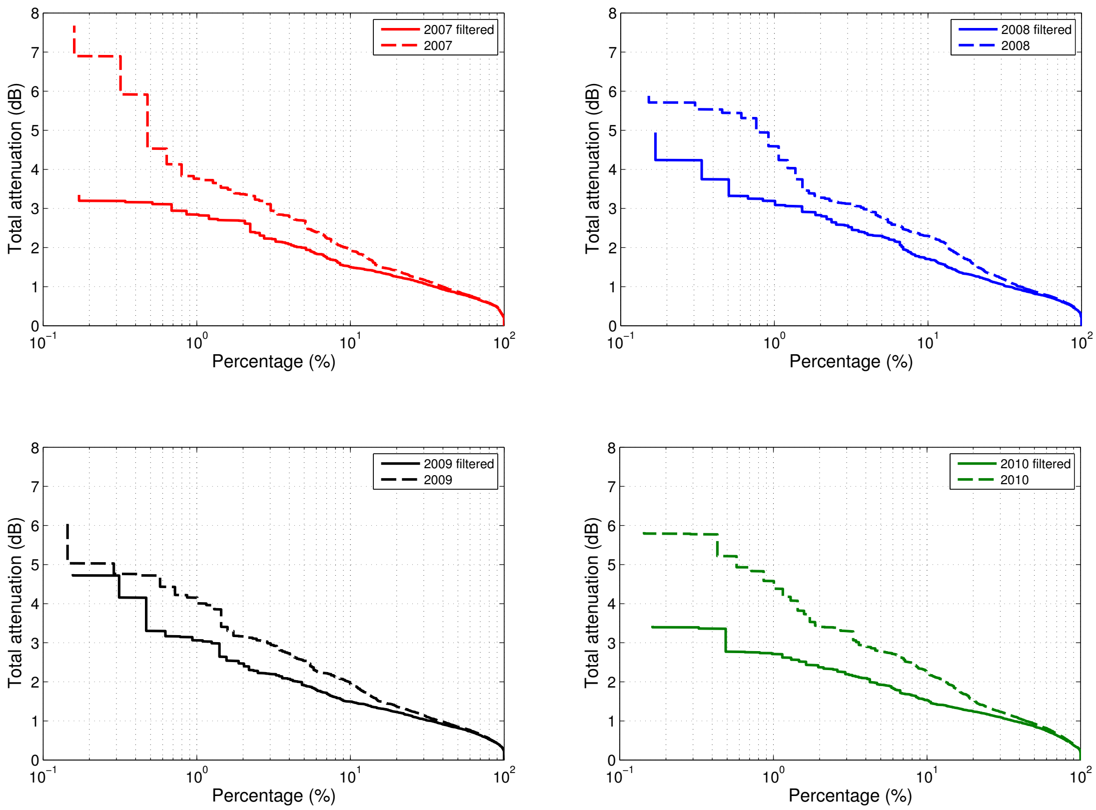


Fig. 4. Comparison of CDF's of total attenuation at 100 GHz for different years. The reference level in dashed line corresponds to the CDF obtained with all radiosoundings. CDF obtained after discarding probable rain events is represented by a continuous line.

attenuation values exceeded between 1 and 10% of time are in the order of 2 and 3 dB. It is also remarkable that after discarding rain events in four years, the predicted value of A_T exceeded 20% of time is quite similar and about 1.3 dB. A noticeable effect can be pointed out for the year 2010. For this period of time, it is observed that the effect of the rain detection method is more pronounced, which is likely due to a higher quantity of probable precipitation events detected in that period.

Regarding the first-order statistics at 300 GHz (see Fig. 5), the effect of the rain detection method on the cumulative distributions of expected values of total attenuation seems to be less relevant in the four years. In comparison with 100 GHz, it can be certainly observed that, in relative terms, the variations with respect to the reference level are not so significant. The explanation to this observation can be based on the strong influence and more relevant presence of gaseous attenuation at 300 GHz. For this reason, once rain events are filtered out, the yearly CDFs computed are, in general terms, very similar between each other. At 100 GHz, year to year variability is more evident, due to the stronger relative influence of cloud absorption.

V. Conclusions

In the framework of the TeraSense project, meteorological data from Madrid have been used to develop an atmospheric propagation study at 100 and 300 GHz on non-scattering conditions. Radiosoundings launched at Barajas Airport have been used to extract meteorological vertical profiles and estimate yearly IWC time series. Then, a rain detection method based on data from co-site SYNOP reports and an IWC threshold has been introduced.

According to the results obtained for this location, the proposed detection criteria have demonstrated to be a useful analytic tool to filter out probable rain condition events. After discarding events using the proposed method, statistics of total attenuation have been obtained. It is expected that they would be closest to the ones obtained from experimental measurements under clear sky or thin cloudy conditions.

Further studies regarding the detection method will be carried out in the following steps of this research, including:

- Use of co-site rain gauge data with the aim of validating the algorithm proposed in this paper.
- Inclusion of cloud information from SYNOP data corresponding to the discarded rain-condition events.
- Use of data from other spanish locations, characterized by different climates, with the aim of testing the method.

Moreover, an important perspective of this work is focused on the upcoming implementation and calibration of a ground based radiometer at 100 GHz with the aim of measuring sky brightness temperature. Based on the proposed rain detection method it is also posible to estimate yearly statistics of

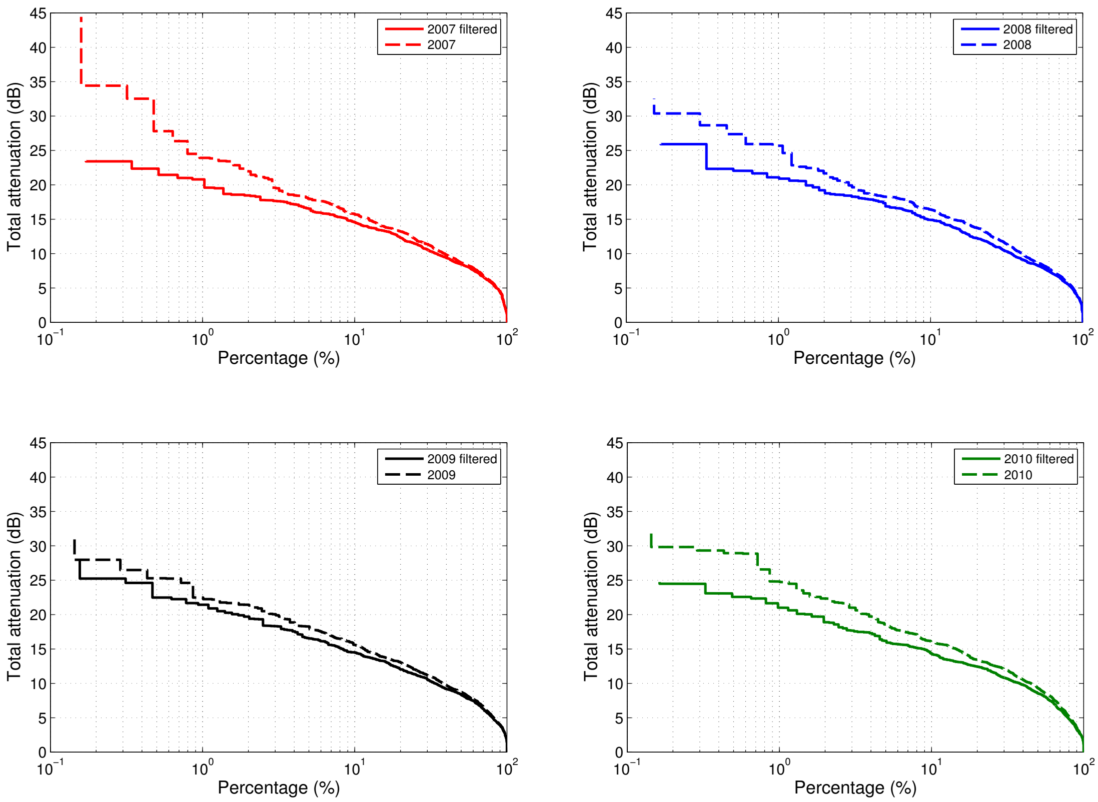


Fig. 5. Comparison of CDF's of total attenuation at 300 GHz for different years . The reference level in dashed line corresponds to the CDF obtained with all radiosoundings. CDF obtained after discarding probable rain events is represented by a continuous line.

the expected values of sky brightness temperature during non-scattering conditions, which can be compared with the measurements. Finally, some hardware extensions would be proposed with the aim of increasing the frequency of work of the radiometer up to 300 GHz.

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