Measurements of tropospheric scintillation on millimetre-wave satellite link

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Tropospheric scintillation statistics in the millimetre-wave band have been obtained in Madrid, using the ITALSAT satellite beacon at 50 GHz. Few studies have been conducted previously at this band. The UCL radiosonde-based method predicts fairly well the mean variance and the distribution of amplitude in the summer months, when scintillations are stronger. The ITU-R prediction model, based on surface meteorological parameters, performs worse.

Introduction: Tropospheric scintillation is caused by small-scale fluctuations of the refractive index owing to turbulence and produces random fades and enhancements of the received signal amplitude. This may seriously affect satellite–earth links at millimetre-wave frequencies, in particular when low margin systems are operated. Scintillation intensity has a strong dependence on the meteorological conditions of the troposphere [1]. While most of the existing prediction methods are based on ground measured parameters, the use of upper air data from radiosoundings can improve the performance of the estimations [2]. In this Letter, one year of scintillation measurements on a slant path at 50 GHz (horizontal polarisation) is analysed using statistical distributions of variance and attenuation. These are compared to predicted ones using the UCL method [2], which requires standard low-resolution radiosonde data, and the ITU-R model [3], which needs only surface meteorological parameters.

Measurement setup: The experimental station, installed on the premises of the Universidad Politécnica de Madrid, consisted of an ITALSAT beacon receiver and a radiometer at the same frequency, 49.49 GHz [4]. It was equipped with a 1.2 m antenna at 40° elevation angle. The sampling rate of the signal was 18.66 Hz, sufficient for a detailed study of tropospheric scintillation, whose power density is usually only significant for Fourier frequencies up to a few hertz. A meteorological station, placed at the same site, provided several surface parameters such as temperature, humidity and rain intensity. Two additional sources have been employed: synoptic and radiosonde data. Both sets of data were registered at a manned station in Barajas airport, 14 km away from the University. To extract reliable scintillation statistics, the beacon measurements were separated from the slowly varying signal components by a Butterworth highpass filter with a cutoff frequency of 0.025 Hz.

Estimation of scintillation from radiosoundings: In the theory of propagation through a turbulent medium [5] the scintillation variance is related to the vertical profile of the refractive index structure parameter, C_n^2. This parameter cannot be directly estimated from standard radiosonde data because of their low vertical resolution and the sparse sampling rate of the soundings (typically two per day). The UCL method resolves this limitation determining long-term scintillation distributions from statistical features of the structure parameter, extracted from the analysis of a sufficient amount of radiosonde ascents (at least one month).

This method has been applied to five years of sounding data, from 1997 to 2001, one of them coincident with the period of beacon measurements. The mean, median and standard deviation of C_n^2 have been obtained for each month and year. For example, Fig. 1 shows the average vertical profiles of the structure parameter for January and July 2000. In summer, strong turbulence occurs in two different tropospheric layers: in the first hundreds of metres above surface, due to high temperatures, and in a higher range between 1 and 4 km, mostly related to the presence of clouds. As expected, for winter months C_n^2 is much lower than in summer.

The next step in the method is the determination of the mean scintillation variance on a monthly basis, which is shown in Fig. 2. The average curve exhibits the typical behaviour of the variance in a temperate climate, with higher values between May and September, due to the high temperatures and a significant presence of convective clouds, such as cumulus and cumulonimbus. There is a relatively high variability in the variance of the same month from year to year. This can be attributed to the natural weather variability, and also to the high sensitivity of the calculation of the C_n^2 profiles [6], which uses several derivatives of meteorological parameters; in fact, it is necessary to check carefully the radiosonde data in order to eliminate outliers. Finally, the monthly and annual statistics of C_n^2 are used to derive long-term cumulative distributions of scintillation variance and attenuation.

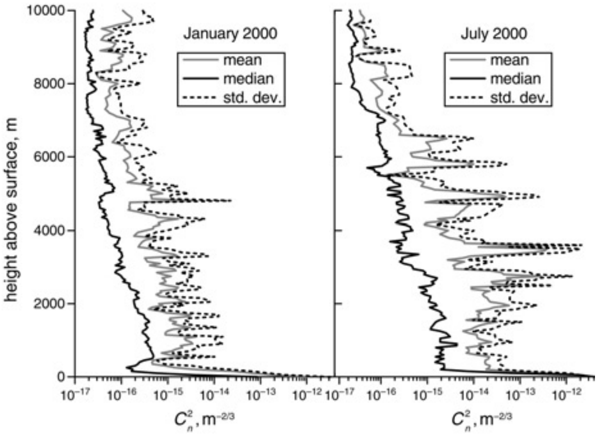

Fig. 1 *Profiles of refractive index structure parameter (mean, median and standard deviation) for January and July 2000*

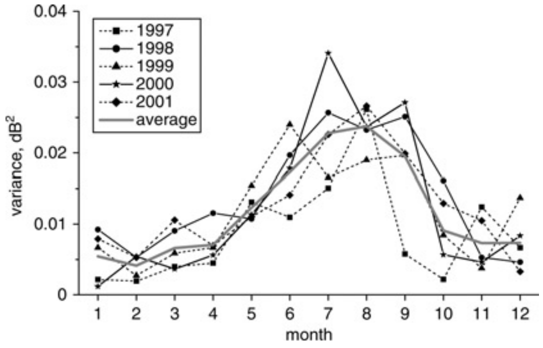

Fig. 2 *Mean monthly values of scintillation variance inferred from radiosonde data*

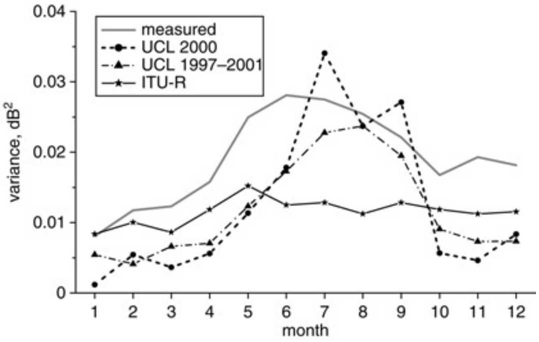

Fig. 3 *Comparison of monthly values of scintillation variance: measurements and predictions*

Comparison with measurements: In Fig. 3, the measured variance also displays a remarkable seasonal dependence, with mean variances in summer more than doubling the winter values. The UCL method, using both the simultaneous period (year 2000) and the five years, agrees with the measurements between July and September, underestimating them for the rest of the year. The values predicted by the current ITU-R Recommendation have been included in the Figure as a representative of models (most of them collected in [1]) based on surface meteorological parameters. The ITU-R model is recommended up to 20 GHz and uses the wet part of the refractive index, N_{wet}, evaluated from surface temperature and humidity. In general, all these models have been validated only in the microwave band and underestimate the measurements, especially in the summer months. In the comparison with the ITU-R model it must be noted that N_{wet} is extraordinarily low in summer, owing to the extremely dry climate of Madrid. Besides, almost none of the models uses information about the presence of clouds, which contribute decisively to the occurrence of scintillation phenomena at millimetre frequencies. On the other hand, [2] states that the UCL method provides fair estimates of the intensity caused by cloud induced turbulence. With regard to the attenuation caused by scintillation, values up to 3 dB have been measured in strong events. The annual statistics are shown in Fig. 4 and two examples of monthly distributions, for January and July, are collected in Fig. 5. The UCL method presents an excellent fit to experimental values for July and the full year in the percentages below 1%, while the ITU-R model agrees only with the measurements in January.

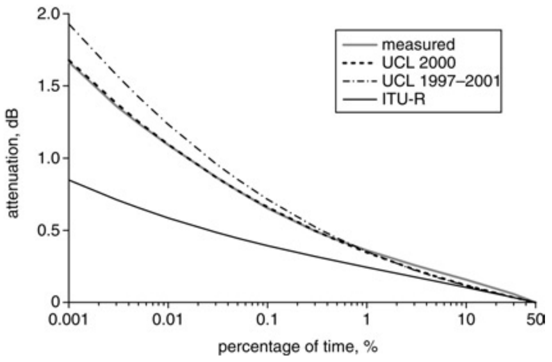

Fig. 4 *Cumulative distribution of scintillation attenuation: full year*

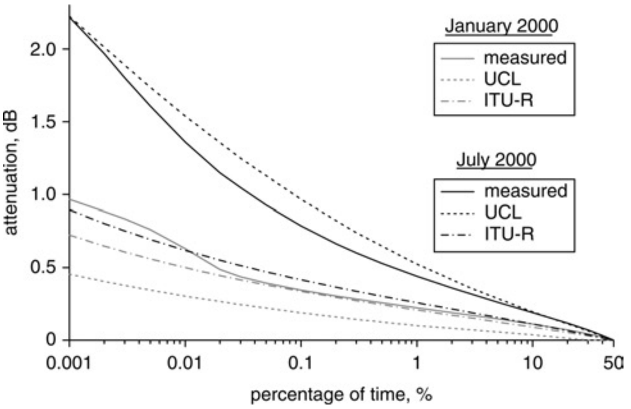

Fig. 5 *Cumulative distribution of scintillation attenuation: January and July 2000*

From the above results it could be inferred that the UCL method is useful to predict scintillation intensity caused by strong turbulence, very common in summer, since the parameters involved in the calculations (wind speed, temperature and humidity) suffer large vertical variations/fluctuations. However, in winter, the capacity of the method to detect weak turbulence is limited by the resolution of the radiosoundings, which is typically higher than the thickness of the turbulent layer.

Conclusions: The results presented in this Letter may be used to characterise tropospheric scintillation in the millimetre-wave band, since very few studies have been conducted in frequencies above 30 GHz on slant path links. As expected, scintillation intensity is highly correlated with the presence of convective events, more likely in the summer months. Most of the existing models, which are based on experimental studies and predict scintillation intensity from ground meteorological parameters, do not achieve a good fit to the real observations at 50 GHz. The UCL method presents several advantages over the former models because it does not include empirical relationships based on propagation experiments whereas it uses radiosonde data to estimate the refractive index structure parameter, which is directly related to scintillation intensity. This model yields good results predicting the strong scintillations of the summer months, which are the most interesting for a satellite operator, while it provides relatively poor estimates in winter, which can be attributed to the low resolution of the soundings.

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