Atmospheric Channel Simulator for the Simulation of Propagation Impairments for Ka Band Data Downlink

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Abstract—This paper describes a methodology to model the propagation conditions for Earth observation data downlink operating at Ka band. It relies on the use of numerical weather forecast models to perform local high resolution reanalysis of the meteorological conditions on which the propagation effects can be computed. From the meteorological simulations spanning long durations, time series representative of attenuation between an orbiting satellite and a ground station are extracted, knowing orbital and RF characteristics of the system.

***Index Terms*—Earth observation data downlink, ka band, attenuation ground station, rain, numerical weather forecast models.**

I. Introduction

The current X band data downlink of Earth Observation (EO) satellites is a bottleneck for the always increasing data acquisition rate, driven mainly by the increase in sensors resolution and swath. The lack of bandwidth dedicated to those kinds of links at X band motivates the use of a portion of Ka band for the generation of observation satellite currently in development both in US and in Europe where a much larger bandwidth is available [1-3].

One of the technical difficulties raised by the use of this frequency bands is induced by the higher propagation impairments induced by the troposphere. An accurate assessment of the impairments affecting those links is essential for a proper design of the physical layer and for the performance evaluation of the system. So far there exists only a limited collection of data representative of this configuration [4,5]. Though, on the contrary, the propagation channel at Ka band has been characterized for a relatively long time for geostationary satellites, models and measurements collected in this framework can hardly be employed to investigate the performance of high-frequency EO transmission systems due to the different geometry of the Earth-space link. Especially an accurate representation of the propagation channel at low elevation angle and of the coupling between the evolution of the propagation conditions around the receiving ground station and the evolution of the link seems of prime significance. This requires a depiction of the meteorological conditions in space and in time around the ground station.

All the atmospheric parameters needed to describe the propagation conditions can not be quantified on a generic basis with remote sensing data. Thus, to characterize the channel state for this kind of links, a solution relying on the use of non hydrostatic meso-scale weather forecast models has been developed. The main principles and preliminary results from the simulator are described in this paper.

II. Description of the simulator

The aim of the simulator developed is to perform local reanalysis of past weather conditions using WRF (Weather Research and Forecasting) model and then to turn them into propagation parameters for a LEO to ground link [6,7]. The main algorithmic steps performed by the simulators are described on Figure 1.

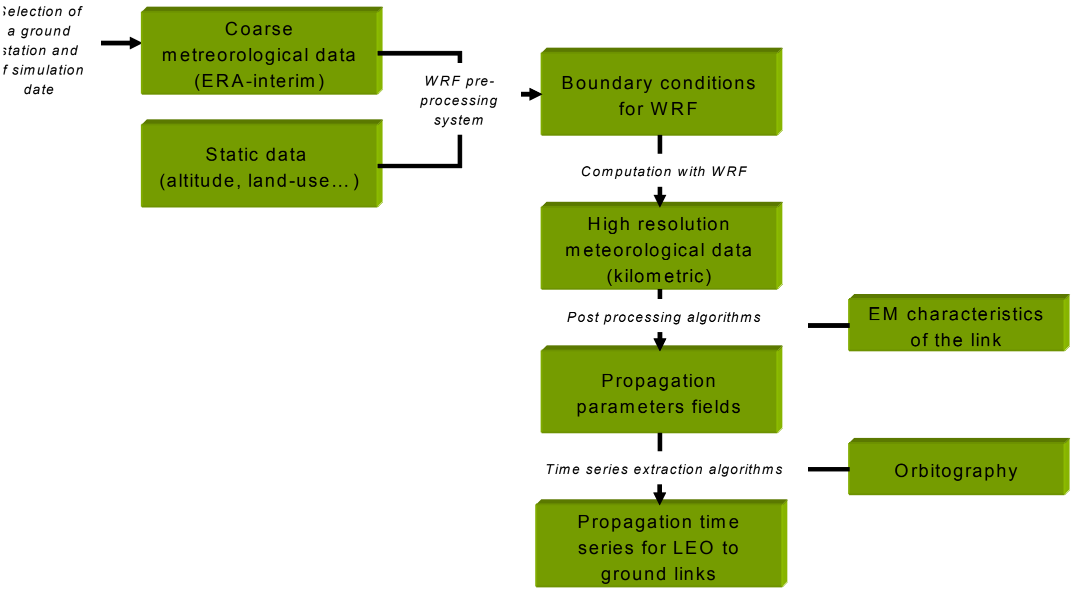

Figure 1: Flow chart of the simulator

The first step is to define the period of simulation and position of the ground station. WRF model is initialized using given boundary conditions from ERA-interim reanalysis for the area around the ground station and the considered period. Three nested domains with a finer resolution are used by the model as illustrated on Figure 2. The final resolution of the output is of 2 km in a square of 180 km around the position of the ground station. To get a temporal depiction of the channel state compatible with the available data storage and the time step of the model used for microphysic computation, data are generated every 5 min. Generated data include among other profiles of temperature, pressure, specific humidity, wind and hydrometeor content on model levels. Temperature and pressure profile are needed to compute oxygen attenuation while the water vapour attenuation requires also the water vapour content. Among the hydrometeors related variables considered in the microphysic scheme used in WRF (single moment 6 classes), rain specific content and cloud liquid water content are used to account respectively for rain attenuation and cloud attenuation.

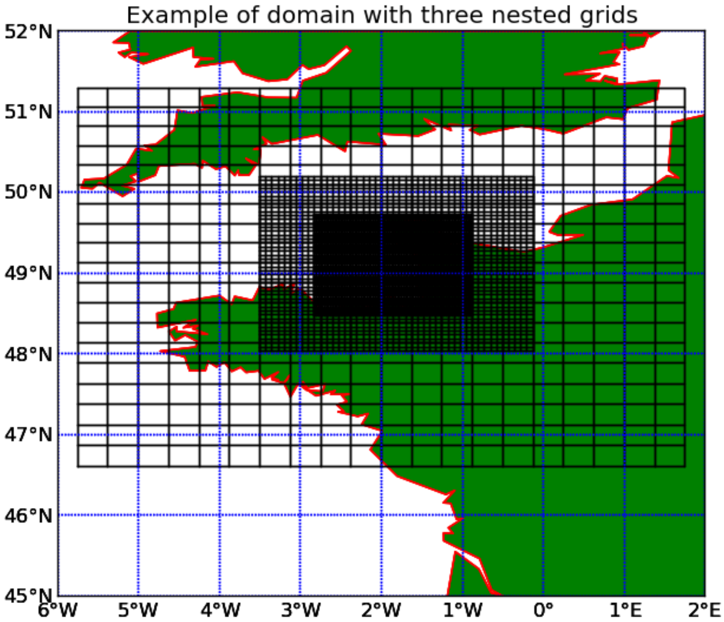

Figure 2: Example of simulation domains defined to reach a resolution of 2 km from ERA-interim reanalysis data.

The way to convert the various meteorological fields at a given time into specific attenuation can be found in [6]. Unlike the attenuation computation algorithm from numerical weather prediction models proposed in [8], the specific attenuation is directly computed using the hydrometeor content given by the model, using a lookup table containing the specific attenuation function of the specific rain water content and of the temperature, assuming Mie scattering.

A methodology to compute the scintillation characteristics from the output of the models is also described in [9]. The specific attenuation fields are then turned into 2D fields representing the azimuth and elevation for each pointing direction of the antenna. Knowing the orbitography of the satellite of interest and the position of the ground station, the time series of elevation and azimuth can be computed. The attenuation time series are extracted by a tri-linear interpolation in the time, azimuth, elevation domain of the generated attenuation fields as illustrated on Figure 3.

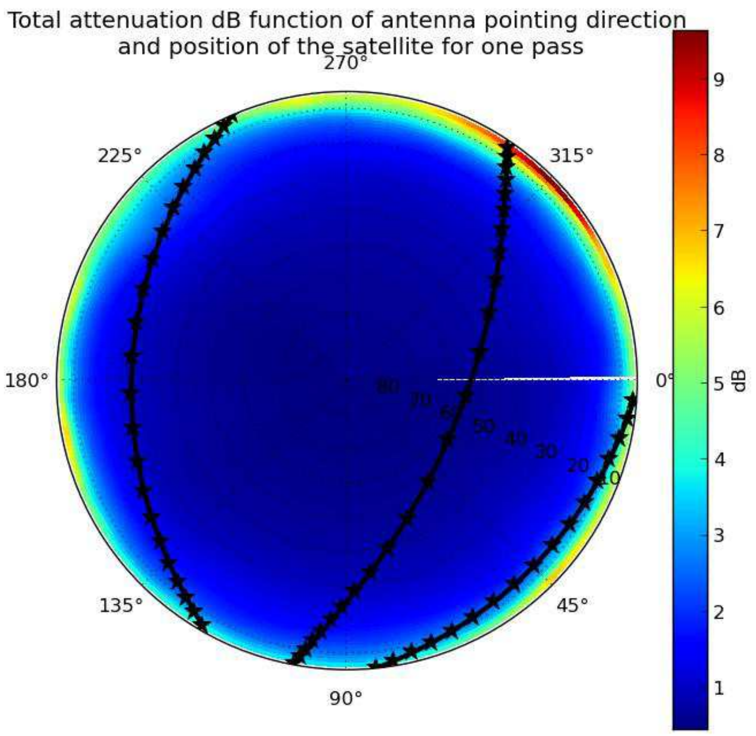

Figure 3: Example of azimuth elevation gridded attenuation fields and extraction of the time series for three consecutive visibility periods.

III. PRELIMINARY RESULTS AND VALIDATION METHODOLOGY

The simulator described in the previous section has been used in order to generate time series of total attenuation for long duration on locations that could be foreseen to host a ground station of future Earth observation satellites (mainly in high latitude areas to maximize the contact time with quasi polar satellites). An example is shown on Figure 4 for a ground station located in Fairbanks (64°50’N, 147°42’W).

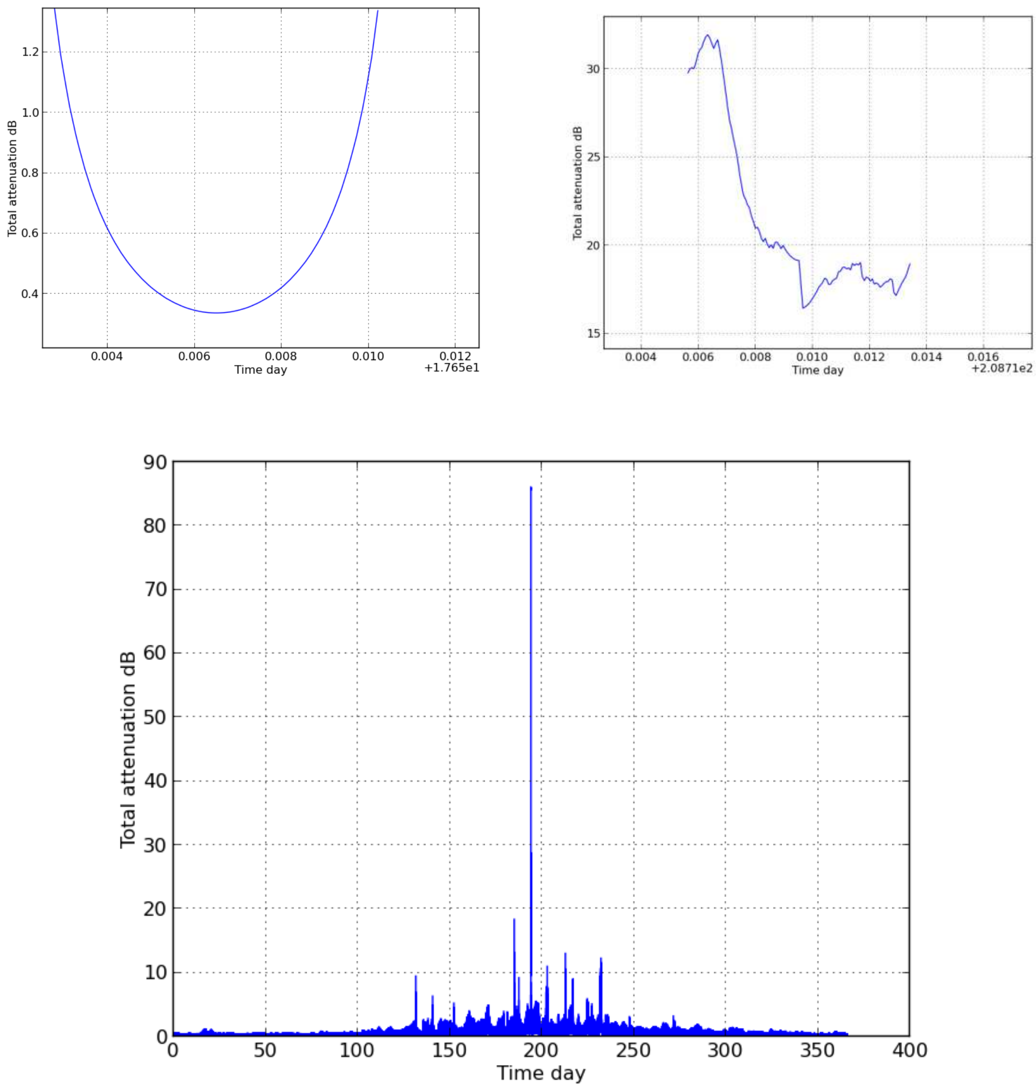

Figure 4: Example of simulated attenuation time series at 26GHz between a satellite with a METOP like orbit and a ground station in Fairbanks. Left picture: one year time series. Right picture: zoom on specific visibility period.

It has to be kept in mind that the visibility time for satellites at low altitude represents not more than 10% of the time (maximum 16 min, each epoch for a LEO satellite at 800 km of altitude). Thus the uncertainty associated to conditional statistics on the elevation angle for instance is high due to this short duration. To increase the duration of the time-series in the analysis, the inclusion of time series generated with slightly different orbital parameters (as the longitude ascending node) but keeping the same azimuth elevation distribution can be interesting. It could allow increasing the duration of the analysis for a duration spanning the one of the meteorological simulations.

To get an idea of the accuracy of the methodology, statistics generated with the simulator can be compared to existing models and experimental results. An example of the statistics obtained for various elevation angles from one year of simulations are compared on Figure 5 with the complementary cumulative distribution function given by ITU-R Rec P.618-10.

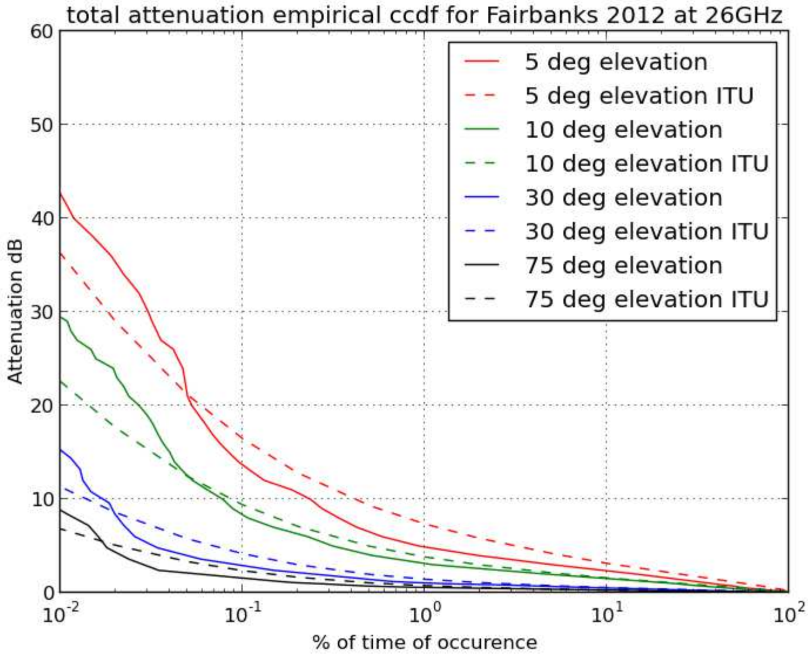

Figure 5: Comparison of ITU Rec P.618 for Fairbanks for links at 26GHz at various elevations with statistics computed from simulations from 2012

For most elevation, angles the statistics extracted from the simulation are comparable to ITU-R model (it has to be noticed that the year 2012 was very close to the long term average in term of rainfall amount in Fairbanks).

The ability of the simulator to reproduce results from past propagation experiment is also under investigation. It has been parameterized to reproduce the measurements made in Spino d'Adda (Italy) during the ITALSAT campaign. Outputs of the simulator over Spino d'Adda for 1996 for the same azimuth, elevation, polarization and frequency as the experimental link have been compared to the experimental results.

A comparison of the statistics collected during the ITALSAT experiment with the statistics computed from the simulator is illustrated on Figure 6. Figure 6 shows that the total attenuation statistics at 18.7 GHz computed from the simulated time series are comparable to the ones computed from the time series compute from ITALSAT experiment. It tends to imply that the outputs of the simulator are statistically representative of the attenuation in this area.

A scatter plot illustrating the dispersion between the simulated attenuation values to the concurrent experimental values is illustrated on Figure 7. An extremely large dispersion can be observed on the scatter plot with a linear correlation coefficient slightly higher than 0.2.

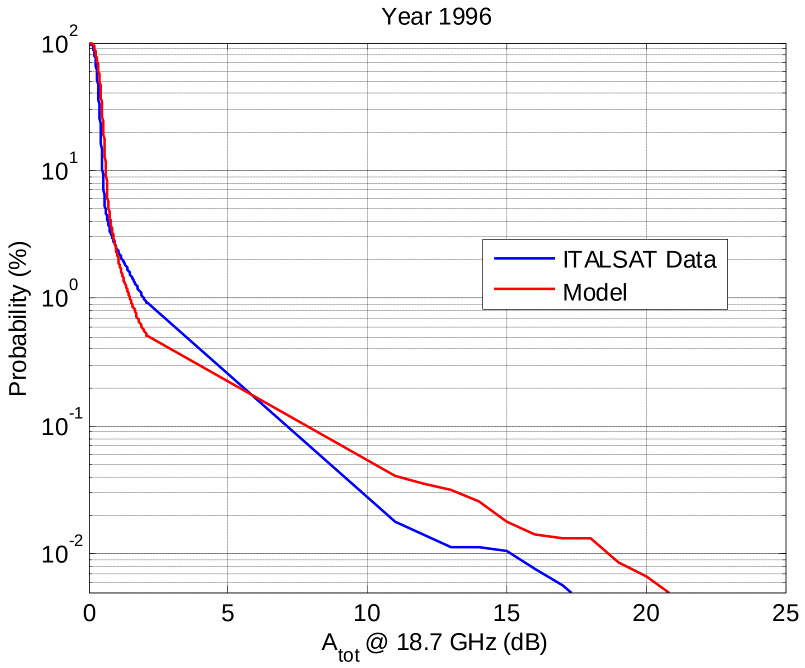

Figure 6: Comparison of the empirical distributions computed from ITALSAT data and from the simulator on the same configuration

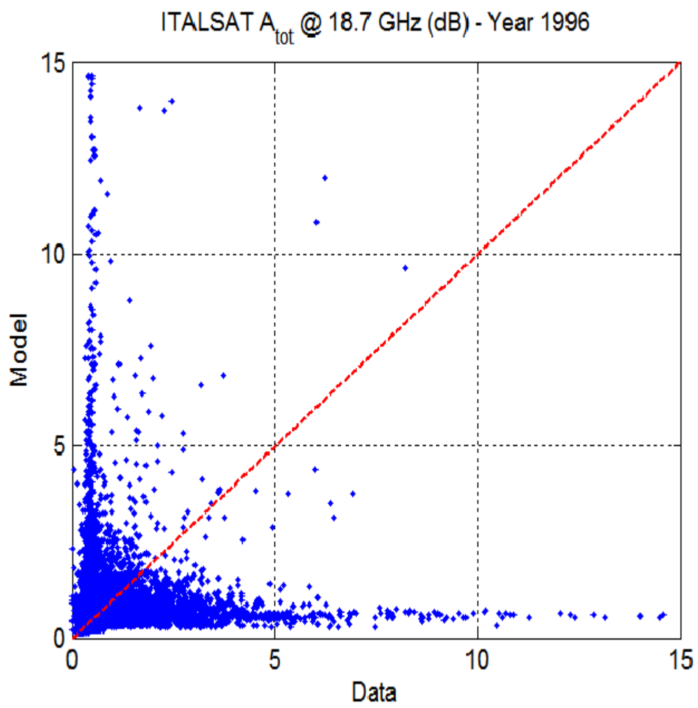

Figure 7: Sample by sample comparison of the data generated by the simulator with measured ITALSAT data

The results of Figure 7 are not excessively surprising as meteorological models fail often to get a good representation of the conditions at a particular time and a particular location.

It is however anticipated that the structure of the precipitations, clouds and water vapor will be representative of the one observed over the location of interest due to the physical modeling of those processes.

IV. CONCLUSION AND WAY FORWARD

This paper has presented a methodology to simulate propagation conditions from the output of high resolution non-hydrostatic meteorological forecast models to supplant the lack of data for the sizing of LEO to ground links.

The outputs from the meteorological models are used to describe the propagation medium, and classical propagation computation methods are used to account for the attenuation losses. The main interest of this methodology is to have a simultaneous description of all the atmospheric parameters at a sufficient resolution to compute the propagation effects directly from them. The description of the meteorological parameters is supposed to obey to local climate specificities due to the inclusion of a high resolution land-cover and terrain model in the model. Furthermore seasonal or inter-annual trends are reproduced using this methodology as intrinsically contained in the large scale input to the model. With this methodology attenuation fields with a resolution around 1 km and a temporal resolution of 5 min can be generated. This methodology could be applicable to various kinds of problems and may possibly act as fictitious experimental data for some problems (gateway margin optimization, ground to UAV links…), but need first to be further validated.

Validation is on-going and expected to give bounds on the current accuracy of such an approach. Encouraging results have been obtained by comparing statistical results from the ITALSAT campaign with simulations made so that it reproduces the experimental configuration. Simulator’s outputs have been found to be statistically representative of ITALSAT measurements for one year. Further test on other propagation experiments in various places and for longer durations will be carried out in a near future. A particular emphasis will be put on areas of interest for future ground station for the reception of Earth observation data download link.

The presented simulator shows obvious limitations in terms of ease of usability and of IT infrastructure needed to get the results as for instance the simulation of one year of data requires more than 3To of memory and approximately 400 CPU days combining simulation and post-processing. More flexible and generic approach could be of interest in order to get a channel description at a lesser computational cost. Those models will be developed in the next phase of the study from a statistical analysis of the outputs of the simulator.

ACKNOWLEDGMENT

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REFERENCES

[1] Cossu M, L'Abbate M, Lupi A, Roscigno R, Svara R, Rosello J, Riva C, Berger L. VCM performance for Ka-band downlink with multiple ground stations. *In 5th ESA International Workshop on Tracking, Telemetry and Command Systems for Space Applications*. *ESA-ESTEC, the Netherlands, 21–23 September 2010*.

[2] Toptsidis, N., Arapoglou, P.-D. and Bertinelli, M., Link adaptation for Ka band low Earth orbit Earth Observation systems: A realistic performance assessment. Int. J. Satell. Commun. Network., 30: 131–146. doi: 10.1002/sat.1002, 2012.

[3] Arapoglou, P. D., and Panagopoulos, A. D. “A tool for synthesizing rain attenuation time series in LEO Earth Observation satellite downlinks at Ka band”. Proceedings of the 5th European Conference on Antennas and Propagation, pp. 1467-1470, 2011

[4] Kostulski T, Reisenfeld S. Variable slant-path Ka-band propagation measurements on the Australian LEO microsatellite ‘FedSat’. Proceedings of the 6th Australian Communications Theory Workshop, 2005; 102–106.

[5] Chen C. K. and K. Tseng "ROCSAT-1 Ka-band experimental communication payload operations", *Proc. AIAA SpaceOps*, 2002.

[6] Outeiral Garcia, M.; Jeannin, N.; Feral, L.; Castanet, L., "Use of WRF model to characterize propagation effects in the troposphere," *Antennas and Propagation (EuCAP), 2013 7th European Conference on* , 1377-1381, 8-12 April 2013.

[7] Skamarock W. C. Klemp J. B. Dudhia J. Gill D. O. & Barker D. M. (2005). Coauthors 2008: A description of the Advanced Research WRF version 3. NCAR Tech. Note NCAR/TN-4751 STR.

[8] Hodges, D. D., Watson, R. J. and Wyman, G.. An attenuation time series model for propagation forecasting. IEEE Transactions on Antennas and Propagation, 54 (6), pp. 1726-1733, 2006.

[9] Pereira C., Vanhoenacker-Janvier D., Jeannin N., Castanet L., Martellucci A., “Simulation of tropospheric scintillation on LEO satellite link based on space-time channel modeling” , 8th European Conference on Antennas and Propagation (EUCAP), The Hague, The Netherlands, April 2014.