Instruments, Data and Techniques for the Assessment of the Atmospheric Noise Emission in Satcom Ground Stations

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Introduction. The objective of this contribution is the review of remote sensing and navigation data input data in order to provide a clear picture of meteorological related parameters that can be used as input of propagation modelling up to W band, of propagation data useful to assess the accuracy of the models and for their improvement, and of all data and satellite observations applicable for propagation impairment mitigation techniques (PIMTs).

Both ground measurements and satellite observations will be considered as for meteorological related parameters. Beacon, radiometer and radar data will be considered as for propagation related parameters. The reviewing activity will be described as for ground measurements (meteorological station, radiometer, radar, GNSS receiver) and for satellite observations (Earth observation missions). The review will take into consideration the various constituent of the atmosphere such as water vapour, cloud liquid water, rain water content, ice water content and turbulence in terms of spatial distribution and microphysical properties which impact on the radiopropagation channel modelling for both terrestrial space communications.

Synergy among COST actions devoted to electromagnetic propagation (e.g., IC0802) and to tropospheric profiling (e.g., ES0702) will be also addressed.

Microwave radiometry. Within the microwave spectral range the atmospheric transmission (Fig. 1) is controlled by atmospheric gases and hydrometeors, i.e. cloud and rain water. The thermal emission (sky noise) of atmospheric components arises from resonant features such as the 22.235 GHz rotational water vapour line at K-band and the 60 GHz oxygen absorption complex at V-band as well as non-resonant emission by cloud droplets and rain drops. The emission of cloud droplets is roughly proportional to the frequency squared and depends on the bulk liquid water amount but not on the exact drop size distribution (DSD). For precipitating drops the size of the atmospheric particles is in the same size range as the wavelength and therefore the scattering process and thus the DSD becomes important [1]. It should be noted that ice clouds are transparent for lower microwave frequencies (<90 GHz). Larger crystals, i.e. snow, produce a strong scattering signal in the microwave region, whereas emission is nearly negligible due to the characteristic ice refractive index. The scattering signal strongly depends on the assumption of snow crystal shape and the snow size distribution [2]. A good overview on absorption and scattering by atmospheric hydrometeors is given by Battaglia et al. [3].

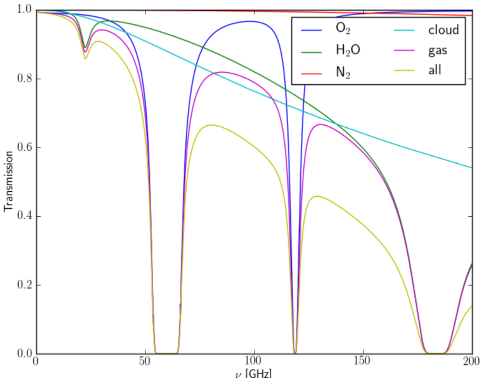

Fig. 1 Atmospheric transmission in the frequency range from 1 to 100 GHz due to atmospheric gases and a liquid water cloud of 250 gm^{-2} added to the U.S. standard atmosphere.

When the spatial distribution of atmospheric components is known radiative transfer models can be used to calculate the atmospheric sky noise expressed as brightness temperature, the atmospheric attenuation and the excess path length for different frequencies and viewing angles. In the simple clear sky case the input can be taken from radiosoundings providing the vertical distribution of temperature and humidity. Because no routine soundings or aircraft measurements for determining the liquid water content (LWC) profile exist, simple cloud diagnostic schemes have been proposed to retrieve LWC from radiosonde observations [4]. Radiosoundings do not provide spatial coverage and high temporal resolution. Therefore output from atmospheric models used in numerical weather prediction (NWP) can be used as input for radiative transfer calculations. However, such models still suffer from limitations in particular within their cloud microphysical parametrizations. In following we provide a review how water vapour and cloud properties being most important for atmospheric transmission can be derived from remote sensing.

Applications to radio-propagation. Ground-based microwave radiometers have been widely used in propagation applications for the experimental characterization of the atmospheric radio-propagation channel. In all space geodesy applications, microwave radiometers have been used for the accurate estimation of the path delay due to the water vapour and for model development and were the reference instrument, together with radiosondes, for the validation of PWV (precipitable water vapor) retrieval methodology by using GNSS receivers.

The ability of water vapour radiometers to calibrate changes in tropospheric delay was also demonstrated during very long baseline interferometer (VLBI) observations at Goldstone, California. A specific study devoted to the development of retrieval algorithm techniques and to the identification of radiometer calibration and stability requirements, is given in the framework of the Cassini radio science experiment, for meeting the Cassini specifications for the calibration of fluctuations in the line-of-sight wet delay. Results indicated that a three-channel (e.g., 22.2-, 23.8-, and 31.4-GHz) water vapour radiometer and a two-channel microwave temperature profiler (54.4 and 57.97 GHz) were needed in order to meet the accuracy goals, leading to the development of the Media Calibration System (MCS). Their model-based Bayesian inversion techniques provided substantially better accuracy than statistical retrieval methods, providing a retrieved path delay bias less than 0.1 mm. Measurements of the troposphere induced wet path delay from radiometers belonging to MCS, were also analyzed at Goldstone in order to characterize the troposphere-delay fluctuations in a statistical sense. Their results suggested that the MCS system at Goldstone is able to provide correction up to the 95% of the troposphere-induced, line-of-sight propagation noise, over minute to multi-week time scales.

A specific module of the Deep Space Mission Systems (DSMS) Telecommunications Link Design Handbook (available at http://eis.jpl.nasa.gov/deepspace/dsndocs/810-005/), module 105 [10], is devoted to provide information concerned with propagation effects, in order to design a telecommunication link at L-, S-, X-, and Ka-band frequencies used by the NASA Deep Space Network (DSN). The Ka-band model is based on actual water vapor radiometer noise temperature measurements made at 31.4 GHz at all three DSN sites (Goldstone, Canberra, and Madrid) and L-/S-band and X-band statistics were created from the Ka-band statistics through frequency scaling.

Microwave radiometers can play an important role in the calibration of beacon receivers as demonstrated during the European Program Olympus. The power level available at the receiver output of a beacon receiver station depends on the status of the radio channel. However, absolute attenuation measurements are not possible because the received power depends also on system parameters such as the satellite EIRP, the gain of the receiver chain and so on, the value of which cannot be determined and/or known at any time with high accuracy. A technique is the use of a radiometer collocated with the beacon receiver as a reference for path attenuation due to the water vapour and clouds, determining the 0-dB level relative to which atmospheric attenuation is measured. The availability of collocated radiometric data provide a very accurate source of information to evaluate time series of attenuation values, as well as they can provide adequate CD statistics in a few years. This presentation will describe physical aspects and statistical approach that guide such procedure and the general use of MWR for propagation applications.

REFERENCES

[1] F.S. Marzano, “Modeling antenna noise temperature due to rain clouds at microwave and millimeter-wave frequencies”, IEEE Trans. Antennas and Propagat., vol. 54, pp. 1305-1317, 2006.

[2] S. Kneifel, U. Löhnert, A. Battaglia, S. Crewell, D. Siebler, “Snow scattering signals in ground-based passive microwave measurements”. J. Geophys. Res., 115, D16214, 2010.

[3] A. Battaglia, C. Simmer, S. Crewell, H. Czekala, C. Emde, F.S. Marzano, M. Mishchenko, J. Pardo and C. Prigent, “Ch. 3. Emission and scattering by clouds and precipitation”, in *Thermal microwave radiation: application for remote sensing*, C. Matzler Ed.,. London: IET Press; 2006.

[4] V. Mattioli, P. Basili, S. Bonafoni, P. Ciotti, and E. R. Westwater, “Analysis and improvements of cloud models for propagation studies”, *Radio Sci.*, 44, RS2005, 2009.

[5] E. R. Westwater, Crewell, S. and C. Mätzler, “A review of surface-based microwave and millimeter-wave radiometric remote sensing of the troposphere,” *Radio Science Bulletin*, No. 3010, pp. 59-80, September 2004

[6] T. Rose, S. Crewell, U. Löhnert, and C. Simmer, “A network suitable microwave radiometer for operational monitoring of the cloudy atmosphere,” *Atmos. Res.*, vol. 75, no. 3, pp. 183-200, 2005.

[7] S. Crewell S, U. Lohnert, D. Noerenberg et al., “Development of Ground Equipment for Atmospheric Propagation Assessment from 10 up to 90 GHz” 3rd European Conference on Antennas and Propagation, MAR 23-27, 2009 Berlin, Germany, vol. 1-6,Pages: 1923-1927, 2009.

[8] U. Löhnert, U., D. Turner, S. Crewell, “Ground-based temperature and humidity profiling using spectral infrared and microwave observations: Part 1. Simulated retrieval performance in clear sky conditions”. Journal of Applied Meteorology and Climatology, 48(5), 2009.

[9] J.H. Schween, S. Crewell, and U. Löhnert, 2011: “Horizontal-humidity gradient from one single-scanning microwave Radiometer”, IEEE Geosci. Remote Sens. Lett. 8(2), 336-340.

[10] S. Crewell, and U. Löhnert, “Accuraccy of cloud liquid water path from ground-based microwave radiometry. Part II. Sensor accuracy and synergy, “ *Radio Science*, vol. 38, no. 3, 2003.

[11] G.L. Stephens *et al.,* “The CLOUDSAT mission and the A-Train“. *Bulletin of the American Meteorological Society*, 83, 1771–1790, 2002.

[12] U. Löhnert, S. Crewell, O. Krasnov, E. O’Connor, H. Russchenberg, “Advances in continuously profiling the thermodynamic state of the boundary layer: Integration of measurements and methods”. *J. Atmos. Oceanic Technol.*, 25, 1251–1266, 2008.