Microwave Attenuation measurements in atmospheric water vapor estimate

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ABSTRACT – In this paper we describe an active system to estimate the atmospheric water vapor based on normalized differential attenuation measurements in the 18-22 GHz range. These measurements can be made using a transmission system based on simple amplitude modulated signals. Using a microwave propagation model for atmosphere and radiosonde data, we simulated the atmospheric attenuation measurements. The correlation between the atmospheric water vapor content and the normalized differential attenuation is shown. The columnar water vapor content can be well estimated with direct measurements at 19 GHz. The simulated data set was generated using one year of data of the radiosonde site of S.Piero Capofiume (Bologna - Italy).

I. INTRODUCTION

The growing use of communication systems in the Ku and Ka band induces to study the potential of active systems in these microwave bands also for remote sensing. In particular, the water vapor absorption line at 22.235 GHz induced us to check the possibility to measure the tropospheric water vapor content through the analysis of the total spectral attenuation along a vertical transmitter-receiver link such as that Fig 1 (referring to a ground-satellite path). We showed in [1] that making total attenuation measurements at multiple frequencies in the 18-22 GHz range, it is possible to exploit the variations of the absorption characteristics with height, which depend in turn on the height variations of temperature and pressure, to retrieve information about the vertical profile of water vapor.

In this paper we report results obtained by simulating the received signals of a transmission system like that of Fig. 1. It was assumed that an amplitude modulation is used and additive white noise is the only disturbance at the receiver. Normalized differential attenuation measurements were based on the Millimeter Propagation Model (MPM) by Liebe [2] and on one year of radiosonde data. The simulation results were used to compute spectral parameters that can be directly exploited to estimate the columnar value from normalized differential attenuation measurements made around 19 GHz.

II MICROWAVE ATTENUATION THROUGH THE ATMOSPHERE

Referring to Fig 1, the spectral power P_{rx} received at the receiver's position z_{rx} can be expressed using the exponential attenuation law [3] :

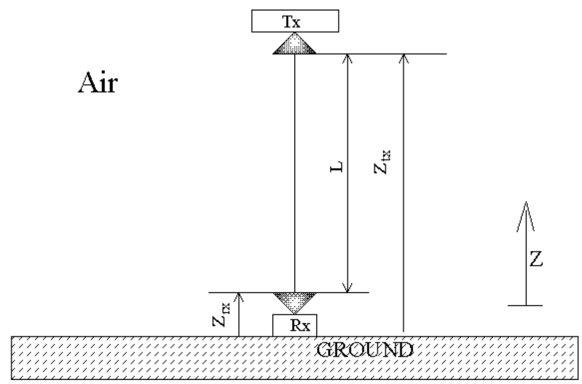


Fig. 1. Sketch of the transmission system.

$$P_{rx}(f) = \alpha P_{tx}(f)\exp(-\tau(f)) \tag{1}$$

where $\tau(f)$ is the optical depth, P_{tx} is the transmitted spectral power and α accounts for the link geometrical characteristics. Defining the spectral attenuation $A(f)$ as the ratio between the transmitted and received spectral power, and the sensitivity function $S(f)$ as the ratio between the first derivative of $A(f)$ and $A(f)$ itself, from (1) we have:

$$A(f) = (1/\alpha)\exp(\tau(f)) \tag{2}$$

$$S(f) = \frac{d}{df}\left[\tau(f)\right] \tag{3}$$

$\tau(f)$ depends on the extinction coefficient k along the link and is given by:

$$\tau(f) = \int_{z_{tx}}^{z_{rx}} k(z,f)dz \tag{4}$$

In dry air conditions (relative humidity less than 100%), the MPM permits to compute $k(f,z)$ once pressure, temperature and water vapor density at the altitude z are given [2]. In dry air conditions, $\tau(f)$ accounts for the main absorption contributions, i.e. those due to water vapor, oxygen and nitrogen along the propagation path.

III TRANSMISSION SYSTEM FOR THE SENSITIVITY MEASUREMENTS

Assume that the transmitted signal is an amplitude modulation signal, the modulating signal being a sinusoidal wave. The two spectral lines around the carrier of such a signal can be exploited for making sensitivity estimates at the carrier frequency. In fact, the sensitivity function can be estimated measuring separately the power of the two side lines. In [4] a receiver scheme for this purpose is reported. The output of the receiver was simulated assuming typical values of the transmission parameters of a geostationary satellite for telecommunications. Results indicated the possibility to perform sensitivity measurements in the 18-22 GHz range with errors lower than 5%.

IV WATER VAPOR PARAMETERS

To analyze the time variations of the tropospherical water vapor and to compute the optical depth in all plausible atmospheric conditions, we referred to one year of radiosonde data. 560 radiosonde profiles gathered in year 2000. These were provided by the United Kingdom Meteorological Office and were collected in the WMO radiosounding site of S.Piero Capofiume (Bologna). The time variations of the water vapor content were computed by dividing the first 15 km of the atmosphere in n layers (with n ranging from 1 to 5). We carried out therefore 5 different analyses on data referring to

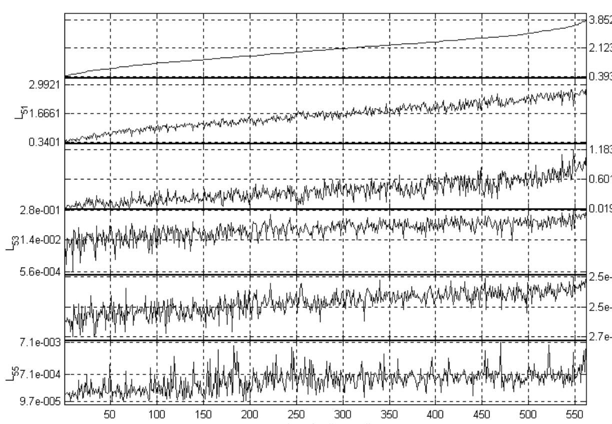


Fig. 2. Yearly water vapor content in the tropospheric layers. From top to bottom: $L_{11,}$ (0-15 km): $L_{51,}$ (0-3 km) $L_{52,}$ (3-6 km): $L_{53,}$ (6-9 km): $L_{54,}$ (9-12 km): $L_{55,}$ (12-15 km).

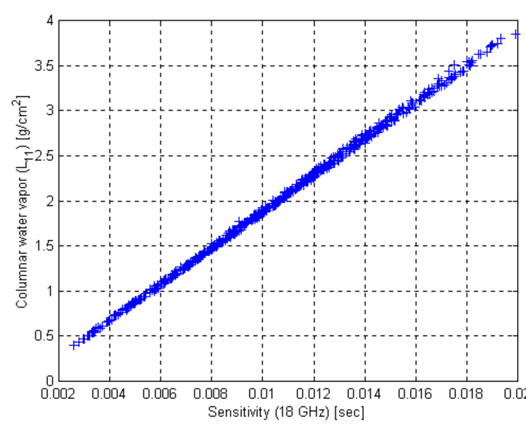
layers with a thickness of p=15/n km. Let us define L_{ni} the water vapor content in the layer from (j-1)p to jp km (e.g. for n=5 we have p=3: L_{53} is thus the water vapor content in 6-9 km). For problems of space, we report here only the analysis pertinent to n=5, since it allows better insight on variations. Fig 2 shows the yearly state of L_{11} and of all the five L_{5j}. L_{11} are ordered for increasing values, and L_{5j} are ordered accordingly.

Notice that the yearly range of variation of L_{11} is about one order of magnitude; L_{11} is mainly due to the L_{51} and the L_{52} contributions; L_{51} and L_{52} have an increasing trend similar to that of L_{11} , while that of L_{53} , L_{54} and L_{55} is less remarkable. Notice also that, for any given value of L_{11}, L_{52} values cover approximately one order of magnitude, while L_{53}, L_{54} and L_{55} may even vary much more.

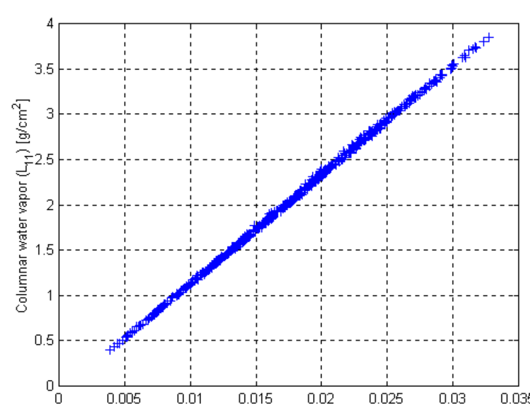
V. CORRELATION BETWEEN WATER VAPOR AND SENSITIVITY MEASUREMENTS

The same radiosonde data used for the computation of the water vapor content was utilized to compute the attenuation effects to simulate the measurement of $S(f)$ according to (3). We used five frequencies (18, 19, 20, 21 and 22 GHz): therefore, for each radiosonde profile we simulated five sensitivity measurements. These values were correlated to the columnar water vapor content, that is given by L_{11} as defined in the preceding section. Fig (3) shows $S(f)$ at the five frequencies.

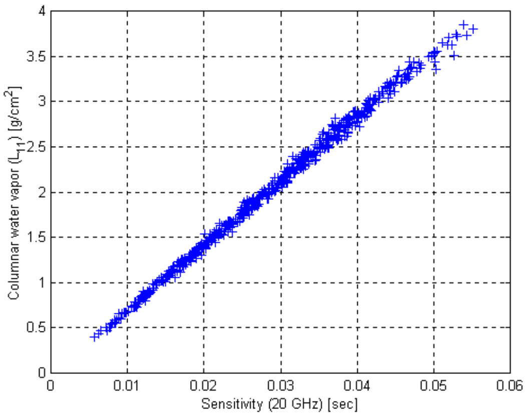
It is evident that there is a linear correlation between $S(f)$ and L_{11} at 18 and at 19 GHz on the whole radiosonde data set considered; moreover, at 19 GHz the variation range of sensitivity is greater than that at 18 GHz. By increasing the frequency, the scatter around the linear trend increases: this means that, at the parity of columnar water vapor (L_{11}), the shape of the profiles directly influences the sensitivity variations. The columnar water vapor can thus in general be



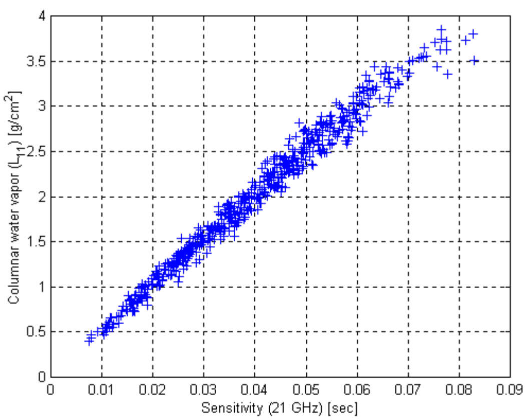
(a)



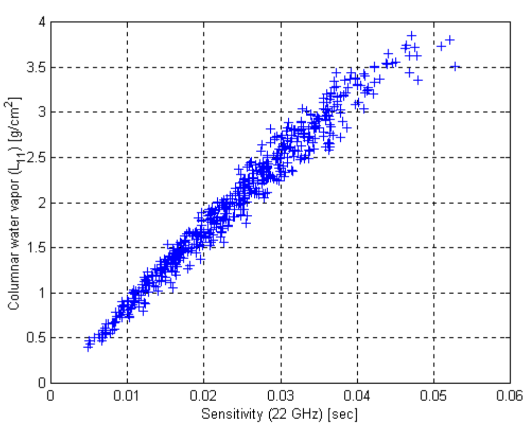
(b)



(c)



(d)



(e)

Fig. 3. Sensitivity *S(f)* versus columnar water vapor L_{11}: (a) f=18 GHz, (b) f=19 GHz, (c) f=20 GHz, (d) f=21 GHz, (e) f=22 GHz.

estimated through a linear law depending on *S(f)* at 19 GHz (S_{19}) thus:

$$l_{11} = aS_{19} + b \qquad (5)$$

where l_{11} is the estimate of L_{11}. The coefficients a and b were computed through linear regression using the data set shown in Fig, 3 (c). Their values are a=120.54 g/sec cm^2 and b= -0.078 g/cm^2.

CONCLUSIONS

This work contributes to assess the feasibility of atmospheric water vapor retrieval by means of an active system in the 18-22 GHz band. In particular, it comes out evidently that estimates of a particular spectral absorption function (the sensitivity function) at 19 GHz can be directly used to perform a very good estimate of the columnar water vapor. Measurements of the sensitivity function at a given frequency can be obtained using a satellite transmission system based on the reception of the two side lines of an amplitude modulated signal with sinusoidal modulation.

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REFERENCES

[1] Cuccoli F., Facheris L., Tanelli S., Giuli D.; "Microwave attenuation measurements in satellite-gruond links: spectral analysis for water vapor profiles retreval" ; Geoscience and Remote Sensing, IEEE Transactions on , Volume: 39 Issue: 3 , March 2001, Page(s): 645 -654.

[2] H.J. Liebe, G.A. Hufford, M.G. Cotton, "Propagation Modeling of Moist Air And Suspended Water/Ice Particles at Frequencies below 1000 GHz", Presented at an AGARD Meeting on "Atmospheric Propagation Effects through Natural and Man-Made Obscurants for Visible to MM-Wave Radiation", May 1993.

[3] F.T. Ulaby, R.K.Moore, A.K. Fung, *Microwave Remote Sensing,* Cap 4, Vol I, Artech House Inc. 1986

[4] Cuccoli F.,Tanelli S.,Facheris L.,Giuli D.; "A novel algorithm for tropospheric water vapor retrieval through multifrequency attenuation measurements at microwaves"; Proc. of EOS/SPIE Symposium, San Diego, CA (USA), 31 Luglio - 3 Agosto. 2000, vol. 4125, pagg.169-178.