Experimental Assessment of Atmospheric Stability Using Ground Microwave Radiometers

Alberto Graziani[1], Antonio Martellucci[2]

[1]*II Facoltà di Ingegneria – DIEM, Università di Bologna, via Fontanelle,40, 47100 (FC) Italy, alberto.graziani@unibo.it*
[2]*ESA/ESTEC, Keplerlaan, 1, PB 299, NL-2200, AG Noordwijk, The Netherlands antonio.martellucci@esa.int*

ABSTRACT

In the framework of radio science experiments based on deep space missions, it is very important to calibrate the troposphere slant path delay (SPD) along the line of sight from the ground station to the space probe antenna by means of the use of a microwave radiometer (MWR). Among the various issues, the stability of the atmosphere and of the calibration system is one of the most relevant. The overall calibration stability, which is usually characterized by means of statistics of the Allan Standard Deviation (ASD) parameter over different time scales, is affected by atmospheric components (gases, clouds and rain) and instrumental effects. By means of a sky scanning MWR, the evaluation and modeling the atmospheric turbulence can also of the scale lengths. A preliminary campaign test has been performed using the ESA radiometers, installed in the atmospheric remote sensing station of Cabauw, The Netherlands of the KNMI (Dutch Meteorological Office), in the framework of the Dutch CESAR project.

The paper describes the measured atmosphere and instrumental stability and structure functions, for time scales ranging from few seconds up to 1000 s. the important time scales for radio science experiment. In the second part of the paper has been presented the test campaign overview with a detailed description of the different experiments.

1. INTRODUCTION

For radio science experiments and deep space probe navigation the tropospheric delay is one of the main error sources related with transmission media. In particular the wet component should be very well estimated. Due to the non-dispersive nature of the tropospheric delay, this have to be measured in a completely autonomous way (i.e. GPS or MWR measurements). Both the two techniques should be evaluated in order to understand how precise and stable is the measurements itself.

In this work a very accurate evaluation of the stability has been undertaken, using MWR data collected by two ESA instruments installed in the atmospheric remote sensing of Cabauw (NL), in the framework of the Dutch CESAR project.

Two different experiment setup has been evaluated and the data has been processed in order to evaluate the stability of each instrument.

An important aspect of the evaluation of the test campaign is the correlation of the wet delay measured by the instrument and the wet delay in the line of sight of the deep space antenna (DSA). Even if the MWR will be installed as close as possible to the DSA the two measured wet delay will be slightly different. And in presence of clouds and atmosphere turbulence the difference will be greater.

An important result of the Cabuw test campaign is the estimation of the turbulent state of the atmosphere using the temporal structure function. In this stage of the test the time varying turbulence has been estimated in order to evaluate the minimum time step which can be considered in order to use the wet delay measured by the MWR [7].

2. SLANT PATH DELAY

The presence of the atmosphere cause a delay in the radio signal coming from the space. This delay is caused by the different refraction index of the different layer of the atmosphere itself:

$$L_{atm} = \int_S (n-1)ds, \qquad (1)$$

Where L_{atm} is the slant path delay due to the troposphere, n is the tropospheric refractive index and S is the effective path, see Figure 1.

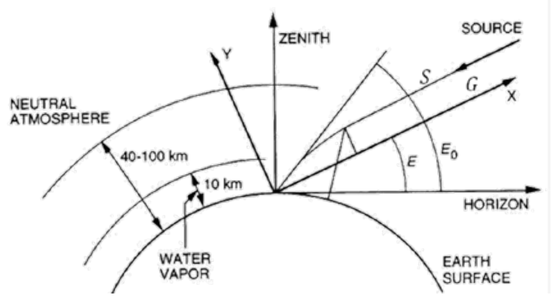

Figure 1 Schematic representation of the tropospheric path delay

The tropospheric path delay can be split in two components: hydrostatic delay L_h and wet delay L_w. Generally speaking the tropospheric slant delay can be related with the elevation angle ε of the transmitting source, and reported into the zenith thanks to a mapping function $m(\varepsilon)$.

The relation between the two components and the elevation angle is:

$$L_{atm} = l_h m(\varepsilon) + l_w m(\varepsilon) \qquad (2)$$

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While the hydrostatic component is in static equilibrium and its contribution can be very well estimate with mathematical models like [1].

On the other hand the wet component represent an unstable component very hard to estimate which can cause a completely loss of the information of the content in the radio science residuals.

3. STABILITY ESTIMATION

The study of the atmosphere stability has been carried out with the analysis of the ASD [2].

If we define a process $y(t)$ sampled at regular intervals to provide n samples in the acquisition time T, the series of samples is broken into m subgroups of samples where each subgroups have length $\tau = n\Delta t/m$. Each subgroups is averaged in order to provide the averaged series having terms:

$$\overline{y_k} = \frac{1}{\tau}\int_{t_k}^{t_{k+1}} y(t)dt \qquad (3)$$

Where $t_{k+1} = t_k + \tau$ with $k = 0,1,2,...$ and t_0 is the arbitrary starting point. The Allan Standard Deviation varying with τ is defined as:

$$\sigma_y(\tau) = \left(\left\langle \frac{\left(\overline{y}_{k+1} - \overline{y}_k\right)^2}{2} \right\rangle\right)^{1/2} \qquad (4)$$

The use of the ASD is request in order to split the effective stability of the atmosphere and the radiometer itself.

A different mathematical operator has been used for the evaluation of the turbulence state: the temporal structure function (TSF).

Considering $y(t)$ a regular sampled process, with all the characteristics of the ASD case. The TSF is defined as:

$$TSF(\tau) = \left\langle (y(t+\tau) - y(t))^2 \right\rangle^{1/2} \qquad (5)$$

4. TEST CAMPAIGN

A very specific test campaign has been undertaken using data collected by ESA MWRs of the KNMI remote sensing site of Cabuw: a RESCOM MWR [3] and a RPG ATPROP MWR [4]. In the technology and construction point of view the two instruments are quite different. The RESCOM is a three channel MWR (21.8, 23.4 and 31.4 GHz) built in 80's, on the other hand the ATPROP is a state of the art, developed in 2008 in the ESA ARTES project with 15 channels (7 channels in the vapor lines, 7 channel in the oxygen lines and a 15 GHz channel and a 90 GHz channel). A common characteristics of the two instruments is the calibration system: based on Dicke switch technology. Even if the two instruments were built with a time space of about 20 years, common Dicke switch technology was considered very important for the choice of the instruments for the tests.

Two different test setup have been undertaken taking into account two different days where the MWR were pointed in different ways.

The first test was undertaken considering the 21st April 2008 [5]. In this day the RESCOM MWR was pointing azimuth 250 deg and elevation 60 deg, while the ATPROP MWR was zenith pointing. During the measurements the linear distance between the two instruments was about 25 m., see Figure 2

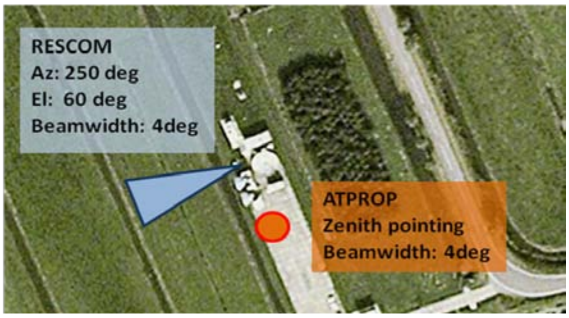

Figure 2 Test setup of the 21st April 2008 (picture credits: Google Maps)

The second test has been undertaken during the month of July 2009. In this test the ATPROP MWR was moved in a different position and pointed in the same direction of the RESCOM. In particular due to technical characteristics of the RESCOM, this MWR has only the elevation rotor while it is fixed in azimuth. Moreover the zenith pointing is not recommended for this instrument due to water infiltration. For this reason the RESCOM was pointed at 70 deg of elevation and pointed in azimuth in the same direction of the previous test. On the other hand the ATPROP which present a very precise azimuth and elevation rotor system was pointed in the same direction of the RESCOM Figure 3.

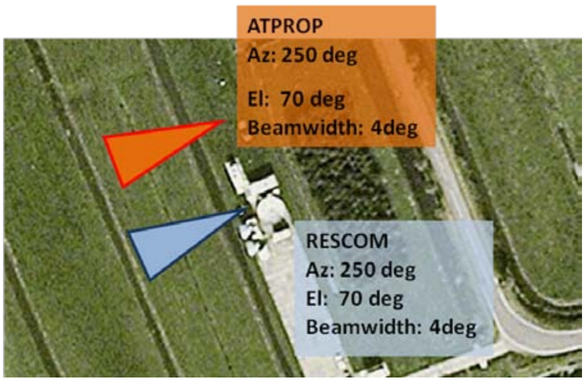

Figure 3 Test setup of July 2009 (picture credits: Google Maps)

For both the test campaign form the two instruments was collected the brightness temperature for each channel and the wet delay scaled at zenith with a Niell mapping function [6].

Different comparison was undertaken in order to evaluate the stability of the instruments, the stability of the atmosphere and the presence of turbulence in the line of sight of the instruments.

A differencing measurements of the ZWD rate was undertaken, in order to evaluate the stability of the instruments. In this case the ZWD measured by the RESCOM was differenced with the one measured by the ATPROP. For the resulted difference was measured the ASD and compared with single measurements results.

Due to the noise difference of the two instruments a different test has been undertaken comparing the brightness temperature of a common channel of the two instruments. This test has been carried out considering days with no liquind content in the atmosphere. If the liquid content is zero or in smaller than the sensibility of the instrument it is possible to retrieve the vapour content and so the ZWD using a single channel measurements. The retrieve algorithm used was obtained by a linear interpolation of radiosonde data collected in Cabauw between 1990 and 1999 and selecting only data with no liquid content.

5. CONCLUSIONS

The technological difference of the two instruments show some difficulties to define the stability of the instruments and the stability of the atmosphere for the considered days. In this work a different technique for the evaluation of the atmosphere status will be presented in order to estimate the presence of turbulence.

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