The IVS Technology Development Center at the Onsala Space Observatory

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Abstract

The main development activity in 2004 was to investigate the stability of the Astrid Water Vapor Radiometer (WVR) at the Onsala Space Observatory in terms of its instrumental noise. We have investigated algorithms based on a model for the correlations between slant wet delays in different directions. Using these algorithms it is possible to estimate how much of the variability in the measured slant wet delays was due to the atmospheric variability and how much was due to instrumental noise.

1. Introduction

The Astrid WVR has been operating at the Onsala Space Observatory since 1980. Since 1993 it has been running almost continuously, observing the sky through sequential azimuth and elevation scans. From the WVR measurements it is possible to infer the slant wet delay of radio signals in the atmosphere.

A new control and data acquisition system was installed in the Astrid WVR during the end of 2002 and the beginning of 2003 [1]. Results from an investigation on the stability of the WVR before and after the upgrade were presented in our Technology Development Center Report of 2003 [2]. This investigation assessed the stability of the WVR by calculating the Allan variances for data taken in the zenith direction. Only measurements in the same direction (in our case zenith) could be used since the horizontal variations of the atmospheric water vapor are too large. Here we present the results from another investigation on the WVR stability, in which we use a theory of atmospheric turbulence to describe the variability of water vapor. This makes it possible to use all of the data from the normal WVR data acquisition, i.e. continuous scanning on the sky.

2. Results

In order to use ordinary WVR observations to characterize the stability of the WVR we need to know how much of the observed variability in the slant wet delays comes from the variability of the atmosphere and how much from the WVR instrumental noise, respectively. For our application it is reasonable to assume that the temporal variations can be neglected for short time intervals (less than 5 minutes). The contribution from spatial variations in the atmospheric water vapor can be described using the theory of atmospheric turbulence [3].

The model used to describe the spatial variability of the water vapor [3] gives the correlations between the slant wet delays in two different directions. We have adopted a model for the variance of the WVR noise as a function of elevation angle for the observed slant delays mapped to the zenith direction:

$$Var[N] = \frac{A}{m(\epsilon)} \tag{1}$$

Here $Var[N]$ is the variance of the noise, A is the variance of the noise in the zenith direction, and $m(\epsilon)$ is the mapping function at the elevation angle ϵ [4]. We have shown that the expectation value squared difference between the measured zenith mapped slant wet delay in two different

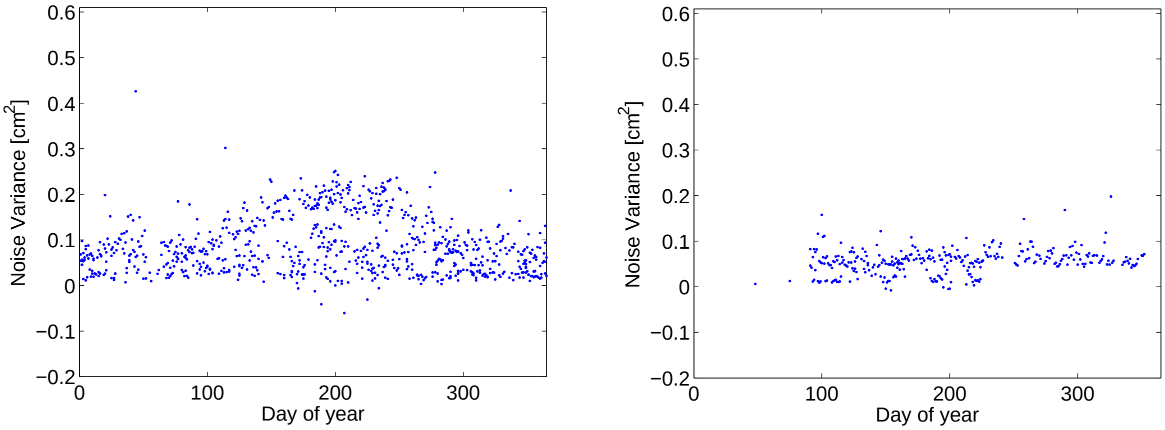

Figure 1. Results of the variance of the radiometer noise for the periods 1992–2002 (left) and 2003–2004 (right). Each point represents one single day. The negative noise variances retrieved for some days indicate that for these days the atmospheric turbulence model did not describe the WVR observations well.

directions can be expressed as the model prediction for the difference plus the sum of the variances of the noise [5]:

$$\left\langle(\hat{l}_i - \hat{l}_j)^2\right\rangle = k^2 \left\langle(l_i - l_j)^2\right\rangle + \left(m(\epsilon_i)^{-2} + m(\epsilon_j)^{-2}\right) \cdot A \qquad (2)$$

Here $\hat{l}_i$ and $\hat{l}_j$ are the measured equivalent zenith wet delays in the two directions i and j, $\langle(l_i - l_j)^2\rangle$ the model prediction for the difference between the two equivalent zenith wet delays, and k^2 a constant describing the magnitude of the atmospheric turbulence [5]. We can then assess the measurement noise of a WVR by making a least-squares fit to the WVR data to (2) in order to estimate k^2 and the WVR noise variance.

Figure 1 shows the variance of the noise retrieved as a function of the day of the year. Shown are results from before (1992–2002) and after (2003–2004) the upgrade. As seen the variance of the noise is on the average lower and more stable for the period after the upgrade of the WVR. Before the upgrade the average variance is 0.087 cm^2 and after the upgrade it is 0.055 cm^2. For the time after the upgrade there are almost no data from the January–March period. This is because the upgrade was not completed until the end of March 2003, and during the beginning of 2004 the radiometer was being repaired.

Before the upgrade the WVR sometimes produced measurements which were clearly incorrect (outliers). These were most likely caused by a failing A/D converter. We made an investigation designed to determine if these incorrect observations were still present after the upgrade. These observations explain why some of the retrieved noise variances in Figure 1 are negative (which is obviously an incorrect result due to a non valid model). If we remove all obvious outliers from the WVR data (observations of equivalent zenith wet delay having a large deviation from neighboring observations), the effect of the remaining incorrect observations can approximately be accounted for by including an additional, elevation-angle independent noise term in the least-squares fit:

$$\left\langle(\hat{l}_i - \hat{l}_j)^2\right\rangle = k^2 \left\langle(l_i - l_j)^2\right\rangle + \left(m(\epsilon_i)^{-2} + m(\epsilon_j)^{-2}\right) \cdot A + B \qquad (3)$$

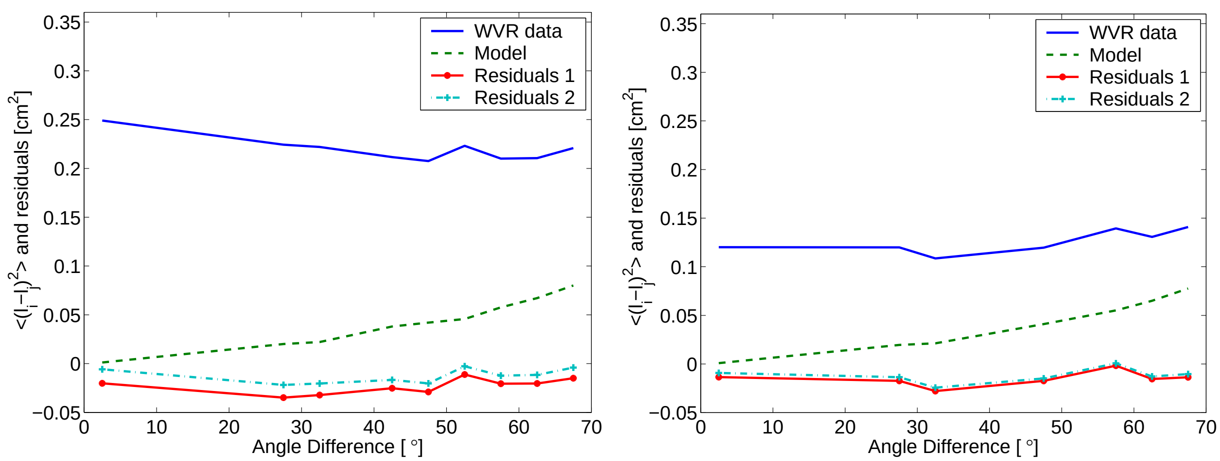

Figure 2. Comparison of the results using the two different models (Equations (2) and (3)). Shown are results from May 11–15 2002 (left) and May 11–15 2004 (right). The measured and predicted variations in equivalent zenith wet delay and the residuals for the two different models for the WVR noise are displayed as function of difference in elevation angle. Residual 1 is the residual using (2) and residual 2 is for (3).

Here B is the variance of the additional noise.

The results clearly show that an improved agreement between the model and the WVR data when the model for the outlier observations is included in the analysis of the data for the period before the upgrade. For the period after the upgrade the improvement is not that obvious. This is displayed in Figure 2 using the results from five days in May 2002 and five days in May 2004. Displayed are the measured differences in equivalent zenith wet delay, the model prediction for this difference (without any noise), and the residuals when not including (residual 1) and including (residual 2) the model for the outlier observations, plotted as a function of their difference in elevation angle. Due to difficulty in displaying all data in a clear way (the difference will depend on the angle between the two observation directions and the two elevation angles) only data where one of the directions is in the zenith are shown. The improvement when considering the incorrect observations is more obvious for the 2002 period, i.e. before the upgrade. Hence we can conclude that the number of outlier observations has been reduced by the upgrade of the WVR data acquisition system.

3. Future plans

We propose that the model developed can be used as a tool to continuously monitor the variability of the atmosphere and the stability of the WVR using observations spread over the sky. As the instrument will continue to acquire more data the impact of the upgrade will also become more evident. We have not yet been able to make an investigation on the impact of the upgrade for a whole year, including all seasons, since we are lacking data for the the period January–March.

References

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