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# A DEVELOPMENT OF SIGNAL PROCESSING ALGORITHM FOR WATER VAPOUR RADIOMETER OPERATING IN INTENSIVE PRECIPITATION


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**Abstract**: The paper presents the results of development of an adaptive signal processing algorithm for the output signal of a water vapor radiometer (WVR) operating in quasi real-time. Land based WVR is used for continuous monitoring of the troposphere parameters, including periods of intensive precipitation. The algorithm is implemented in LabVIEW and uses Singular Spectrum Analysis (SSA) "Caterpillar" method and fuzzy logic techniques.

**Keywords**: remote sensing; adaptive data processing; water vapor radiometer; singular spectrum analysis; fuzzy logic.

## Introduction

Radiometric remote sensing method can measure several important atmospheric parameters such as integral water vapor density, condensed water density in clouds, height-temperature profile of the atmosphere. This data can be used to calculate the "wet" tropospheric delay (WTD) of a radio signal that is important in solution of several scientific and applied problems. The WTD influences the positioning accuracy of the GLONASS national navigation satellite system, it is essential for Very Long Baseline Interferometry (VLBI) data processing and accuracy and reliability of weather forecasts.

Currently WVRs are among the most accurate tools for measuring WTD, providing continuous data in quasi real-time with high time and spatial resolution [1–3]. However, despite its advantages, radiometric method produces anomalous results during periods of intensive precipitation, when the attenuation of a radio signal is significantly increased due to the presence of water droplets or wet snow in the beam. In practice intensive precipitation causes partial or complete loss of accuracy. Depending on the local climate the amount of data lost can reach 25–30 %.

## Water vapor radiometer

The observatories of the Russian VLBI complex "Quasar-KVO" are equipped with troposphere monitoring radiometers [3]. The instruments in the observatories include a water vapor radiometer (WVR), temperature profile meter MTR-5 and weather station MK-15 that allow to monitor the Q and W parameters in real time [1–3]. The block diagram of a radiometric complex of a radio astronomical observatory is shown in Fig.1. WVR and MTR-5 use microwave modulation receivers which register the total power of a radio signal.

WVR has two channels with the central frequencies of $f_1$= 20,7 GHz (channel A) and $f_2$= 31,4 GHz (channel B) that measure the atmospheric brightness temperatures $T_{f1}$ and $T_{f2}$ respectively [1, 2].

MTR-5 is a single channel scanning radiometer with the central frequency $f_3$= 56,7 GHz [1].

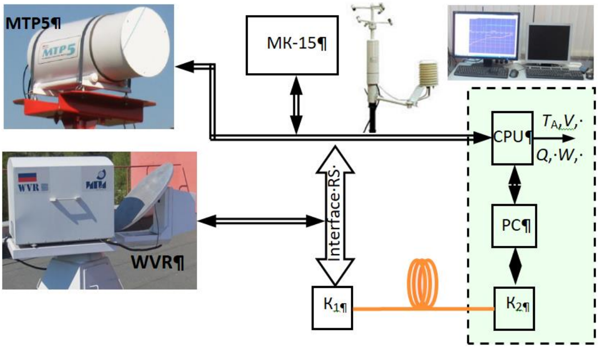


Fig. 1. Functional scheme of the ground-based automated radiometric complex.

Corresponding inverse problems are solved in quasi-real time using information about $T_{f1}$, $T_{f2}$, $T_{f3}$ and current weather conditions [1], giving the values of the $Q$ and $W$ parameters and the tropospheric delay τ.

### Signal processing algorithm for WVR

Digital signal processor receives a time series of samples of the integral content of water vapor $Q_i$ and information from a precipitation sensor with the period of 60 seconds. A fuzzy logic module determines if the $Q_i$ value is anomalous using Mamdani algorithm [4, 5]. If the current value of Q is not anomalous then the Singular Spectrum analysis (SSA) “Caterpillar” algorithm [6–8] is used to find the dominant trend component of the time series of Q values and suppress the noise component. Otherwise the algorithm works in vector prediction mode using SSA "Caterpillar" method [6, 7]. Our research shows that this approach to the problem produces the most accurate results.

### Examples of WVR signal processing

Fig.2 shows a comparison of the integral content of water vapor Q obtained using a WVR in a radio astronomical observatory

"Zelentchukskaya" in August 2016 to the GNSS measurements during the same period. As it is shown in Fig.2, during the 48 hour measurement time, intensive precipitation was present for 14 hours and during these periods the signal processing algorithm operated in prediction mode.

The difference between the values of Q measured by two independent methods (WVR and GNSS) in this case is not more than ±0.4 g/cm$^2$ for the whole duration of the experiment. The mean squared error of the difference between the two methods is 0.15 g/cm$^2$. The MSE is not equal to measurement error but its low value demonstrates that the Q values measured by a WVR and GLONASS GNSS are very close.

## Conclusion

The use of the SSA "Caterpillar" method and fuzzy logic techniques helps to develop an effective algorithm for signal processing in ground based WVR used for troposphere parameters monitoring in quasi-real time. The algorithm helps to reduce the loss of observation time during periods of intensive precipitation without significant loss in measurement accuracy.

The Q parameter measurements made by a ground based WVR and GLONASS GNSS produce similar results. The MSE of the difference between the two methods during 48 hours is 0.15 g/ cm$^2$ (Fig.2).

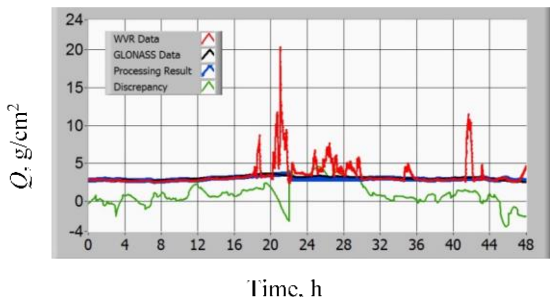


Fig. 2. Time series of WVR data (red), GNSS data (black), processing results (blue) and difference between processing result and GNSS data multiplied by 10 times (green).

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