SUPERSENSITIVE REMOTE SENSING SYSTEM OF ATMOSPHERIC WATER VAPER DISTRIBUTINS USING LEO SATELLITE BEACONS

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1. Introduction

In the lower troposphere atmospheric water vapor distribution is quite inhomogeneous and shows time variations in wide time range from milliseconds to few hours or more. The spatial and temporal fluctuation of the atmospheric water vapor distribution causes time variation of atmospheric propagation delay of radio waves, and causes the degradation of the measurement accuracy and the sensitivity in radio interferometric measurement such as the radio astronomical observations and geodetic GPS measurements. Statistical characteristics of the atmospheric water vapor fluctuations at centimeter and millimeter waves are theoretically studied [1][2], and observations are also made with short-baseline interferometers [3][4], long-baseline interferometers [5][6], and water vapor radiometers [7][8]. Recently, measurements of atmospheric water vapor distribution using geodetic GPS networks are made in various institutes.

The method using radio interferometer is quite sensitive one for spatial and temporal variations of the water vapor distributions. In previous measurements fixed radio sources such as radio beacons of gestational satellites or strong cosmic radio sources such as cosmic water maser sources are used as reference sources. In the method using the beacons of geostationary satellites measurements are restricted to a fixed direction of the hemisphere at the observation site. While, in the method using the cosmic radio sources, time resolution is limited due to poor SN ratio in cosmic radio source observations. The measurement using the water vapor radiometer has strong dependence to droplet components, and its accuracy is degraded in cloudy or rainy conditions. The method using the geodetic GPS networks has an advantage to measure a slant path delay between a GPS satellite and a GPS receiver. However, the motion of the GPS satellite across the hemisphere at the observation site is relatively slow and it is quite hard to measure the spatial water vapor distributions. In addition, the measurement accuracy of the atmospheric excess path is an order of centimeter. In order to overcome disadvantages of the above mentioned methods, we have developed a radio interferometric system dedicated for the atmospheric water vapor distribution measurement [9][10]. In this paper, the outline of the newly developed radio interferometric system and its performance are described.

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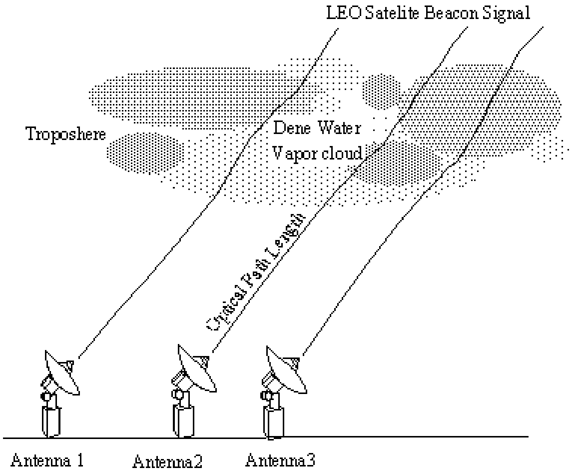

Fig. 1 Schematic diagram of the measurement system.

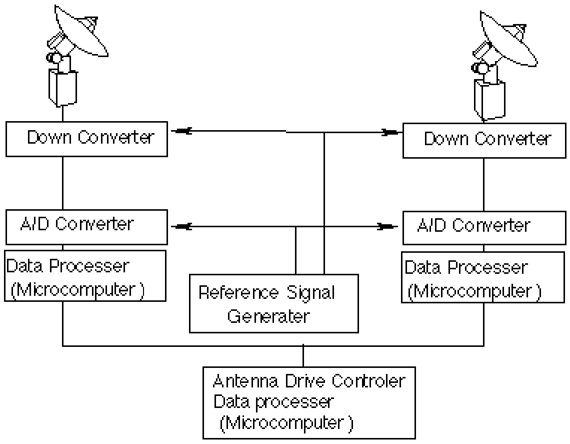

Fig. 2 Block diagram of the observing system

2. Observation System

The schematic diagram of the measurement system is shown in Fig. 1. The system is a radio interferometer consisting of three 1.4-m diameter antennas located a few ten meters apart from each other. These antennas are controlled to track a LEO satellite, and the differences of the arrival time of a beacons signal of the satellites among the antennas are measured with this system. When the atmospheric structure is plane parallel, measured time is simply given by the ‘geometrical path difference’, that is the inner product of the baseline vector and a unit vector directed from the antennas to the satellite position, divided by the wave velocity. When the inhomogeneous atmospheric water vapor distribution exists, the measured time include both the excess path delays caused by the geometrical path difference and the atmospheric water vapor distributions. As the baseline vector and the satellite position are well determined within accuracy sufficient for our measurements, the differences of the arrival time caused by the atmospheric water vapor distributions are estimated form the time difference measured with the system. As the satellites move across the celestial hemisphere in a few ten minutes, we can obtain fluctuations of the arrival time of the satellite beacons across the satellite trajectory, which include fluctuations caused by the irregularity of the atmospheric water vapor distributions.

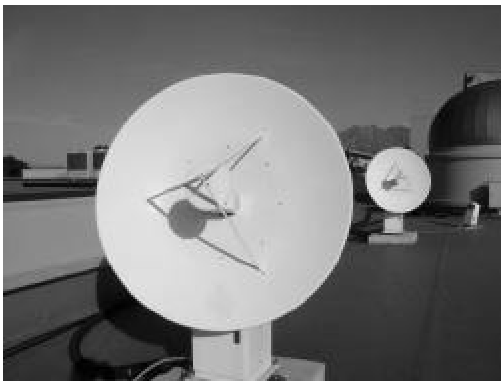

Fig. 3 Outlook of the element antenna

The block diagram of the observing system is shown in Fig. 2. The outlook of the element antenna is shown in Fig.3. That system is installed in a campus of Kagoshima University. The three antennas are aligned on an east-west baseline. The baseline length between the easternmost and the westernmost antennas are about 47 m, and that between the easternmost and middle antennas are about 8 meters. The signals received with the antennas are amplified and down-converted with a receiver unit attached to the backside of the antennas. The signals output from the receiver unit are sampled and converted to digital data at the antenna site, and are transmitted to a central unit via an optical fiver cable, where cross-correlation between the signals is calculate with PC.

The beacon signals used in the measurement system are those of a mobile communication satellite system, called ‘Globalstar’. The frequency of the beacon waves is about 7GHz. The system consists of 48 LEO satellites at the altitude of 1400 km, and each satellite crosses the hemisphere of the sky of the observation site in about 20 minutes.

3. Observations

An example of the measurement results is shown in Fig. 4. Upper three panels of Fig. 4 are the measured phase variations for three baselines, where baseline length is 39m, 8m and 47m, respectively. The horizontal axes are time in second and the vertical axes are phase in degree. A bottom panel of Fig. 4 is the closure phase calculated from measured phase variations of three antenna combinations. The phase variations are plotted after removing the geometrical phase variations caused by the satellite motion. In Fig. 4, the magnitude of phase variation is small around the center of the horizontal axis, where the elevation angle of the satellite reached maximum, and tends to increase as going to left and right ends of the horizontal axis. Comparing the phase variations on baseline lengths of 39 m and 47 m with those on the baseline length of 8m, we can see that the magnitude of the phase variations of longer baselines is larger than that of shortest one even though the fast fluctuations are same for three baselines.

Combining three cross-correlation phase values obtained by three antennas combinations, we can obtained the “closure phase”, in which the phase variations caused by the atmospheric water vapor distributions are cancelled out and only the variations relating with the system phase noise is resumed. Comparing the calculated closure phase (bottom panel in Fig. 4) with the measured phase variations we can find that most of the measured

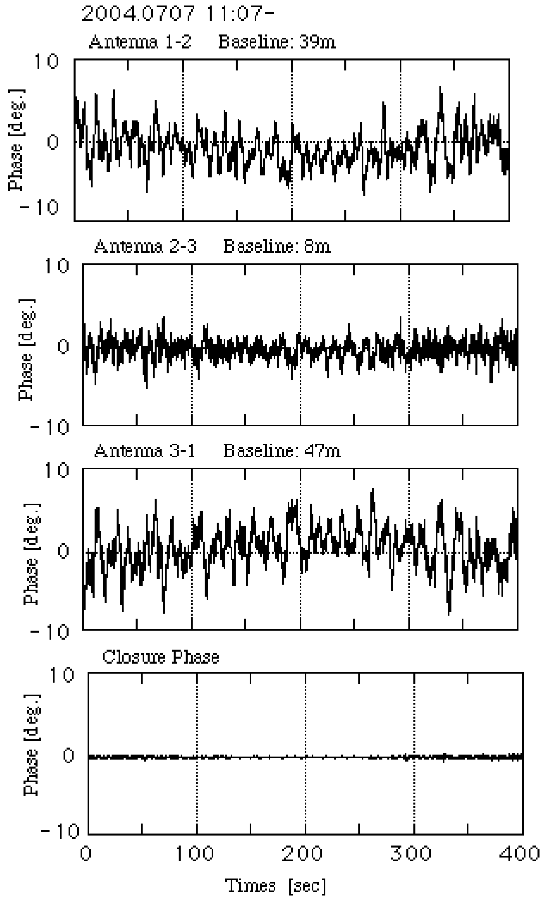

Fig. 4 Measured phase variations on three baselines and the closure phase calculated form these data.

phase variations is originated form the atmospheric water vapor distributions. From this result, we can conclude that the minimum detectable value of the atmospheric path length variations of our system is 0.1 millimeter or less, which is two orders higher than that obtained by using the GPS network.

4. Summary

The observation system of the atmospheric water vapor distributions are developed, which is a radio interferometer dedicated for receiving low earth orbit satellite (LEO satellite) beacons as reference signals. The data obtained with three different baselines of the system showed different phase variation profiles, which was related with different spatial structures of water vapor distributions. Combining the data of these three baselines, the magnitude of system phase noise was estimated, which was quite smaller than that of the measure phase variations.

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