Water vapor estimation using the propagation delay of digital terrestrial broadcasting waves

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Abstract – **The feasibility of measuring water vapor from the propagation delay of digital terrestrial broadcasting waves is under investigation. A real-time delay measurement system with software-defined radio technique is developed. In this paper, experimental results with this system using reflected waves are reported. We have succeeded in observing the propagation delay between the observing point and the reflector from the balance between phases of direct waves and reflected waves. Data obtained with this technique may contribute to improve numerical forecast of localized severe weather phenomena through data assimilations.**

Index Terms — **Propagation delay, water vapor, digital terrestrial broadcasting wave.**

1. Introduction

Severe weather phenomena such as localized heavy rain storms in urban area are social issues these days. Their dimensions are small in time and space, and it is still difficult to predict when and where they occur. Many studies are being conducted to get a longer lead time to alert people in various viewpoints, by using phased array weather radars, numerical models, data assimilations, and so on. Water vapor is an essential parameter for weather forecast, and it is one of the most difficult physical quantities to measure with remote sensing technique. If we can monitor water vapor near the ground surface with high time and space resolutions, we may be able to get a longer lead time to predict localized heavy rainfalls because water vapor is the origin of rain drops.

In this study, we derive water vapor concentration from the propagation delay of digital terrestrial broadcasting waves. The basic idea of using the propagation delay is the same as the idea of retrieving the PWV (precipitable water vapor) by using GPS's vertical propagation paths [1]. In this study we use horizontal propagation paths to derive water vapor information. Our target is water vapor near ground surface. Radio towers transmit high SNR radio waves modulated with OFDM (Orthogonal Frequency Division Multiplexing). If many small receivers are deployed, 2D water vapor variations can be monitored with high time and space resolution.

2. Method

We are developing a real-time delay measurement system with software-defined radio technique. SPs (scattered pilots) are extracted from OFDM modulated signals and delay profiles are calculated. We can measure propagation delay using the phase variation of delay profiles with time resolution of about 4.5 ms.

Because the delay due to water vapor is quite small, very precise measurements (at least several tens of pico-second order) are needed for effective observations. Phase fluctuations of local oscillators at the radio towers and the receivers are major error factors. We propose two configurations (A and B) to derive water vapor concentration using digital terrestrial broadcasting waves. They are shown in Figs. 1 and 2. In configuration A (Fig. 1), we measure the propagation delays at the two receiving points on the line that includes the radio tower. Delays at

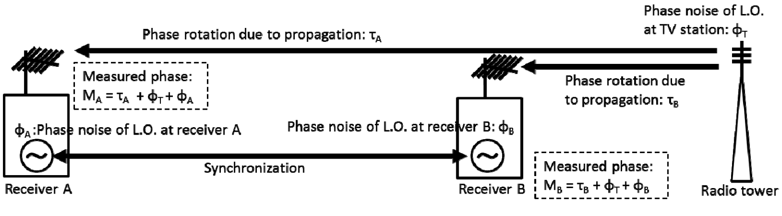

Fig. 1. Proposed configuration of water vapor measurement system (A).

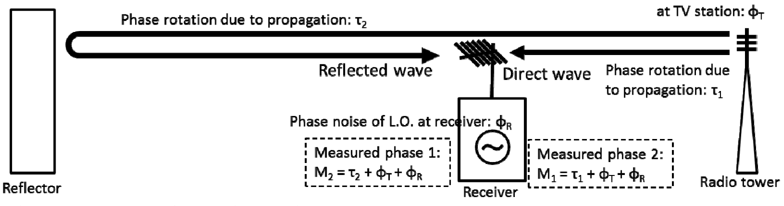

Fig. 2. Proposed configuration of water vapor measurement system (B).

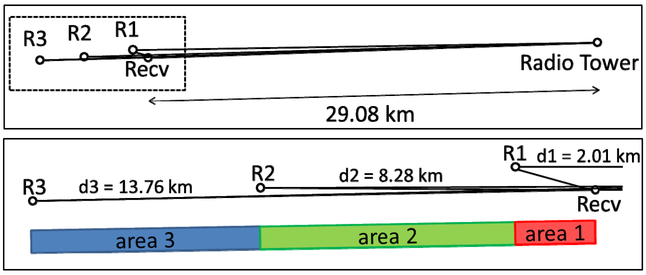

Fig. 3. Positional relationship of the experiments. The dashed rectangle in the top panel is enlarged in the bottom.

each receiving station include phase fluctuations of the local oscillators at the radio tower and the receiver. Phase fluctuations of the local oscillator at the radio tower are canceled out by taking the difference. We can estimate the water vapor concentration between the two receiving points by synchronization of the receivers' local oscillators. The two local oscillators can be synchronized by connecting them with an optical fiber [2]. We are planning a proving test in this configuration using an optical fiber or other means.

In this paper we report a method and results of water vapor measurements without synchronization of the local oscillators as shown in Fig. 2 (configuration B). In this configuration, we observe phase variations of digital terrestrial broadcasting waves at a single receiving site. If there is a reflector at the opposite side from the radio tower, we can receive direct and reflected waves at this point simultaneously. Measurements are conducted using a single local oscillator at the receiver site. We can measure a round trip propagation delay between the observing point and the reflector without the need of synchronization of local oscillators.

3. Experiments and results

The positional relationship of the experiments is shown in Fig. 3. National Institute of Information and Communications Technology (NICT), which is the receiver site shown as "Recv" in Fig. 3, is located at about 29 km westward from the radio tower named Skytree. Three reflectors (R1-R3), two buildings and an iron tower, are located at about 1 km, 4 km, and 7 km westward from NICT. Direct waves and reflected waves from the three reflectors can be measured at NICT. Differences of the propagation path lengths between the direct waves and reflected waves (d1-d3) are 2.01 km, 8.28 km, and 13.76 km, respectively. The corresponding peaks can be seen in the delay profile shown in Fig. 4.

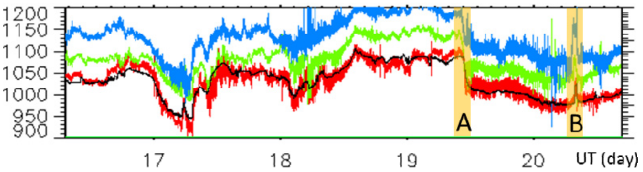

Fig. 5. Normalized propagation delays (ps). Delays per km are shown. Red, green, and blue lines correspond to the areas shown in Fig. 3.

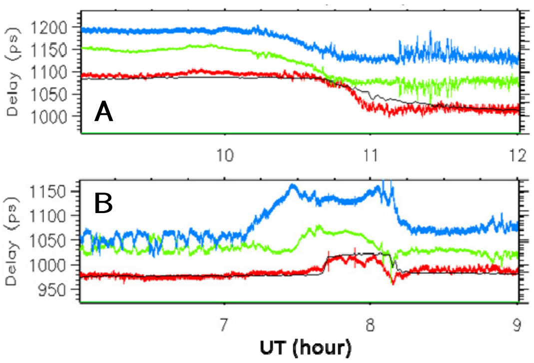

Fig. 6. Enlarged plots of period A and B shown in Fig. 5.

Figs. 5 and 6 show the normalized propagation delays (delay per km). Each color corresponds to the area shown in Fig. 3. For visibility, green and blue lines are shifted upward by 50 and 100 ps, respectively. We have ground-based meteorological observatory equipment at the receiver site. Propagation delay can be calculated using the temperature, pressure, and humidity data on the assumption that the data are representative of the meteorological conditions around there. The black line shows the calculated delay that corresponds to the observation at R1 (red line). Shifted variations of the delays at different areas shown in Fig. 6 suggest that some meteorological phenomena passed through from west to east.

4. Summary

Propagation delay due to water vapor can be observed with digital terrestrial broadcasting waves. Data obtained in this method may contribute to improve the numerical forecast of localized severe weather phenomena through data assimilations.

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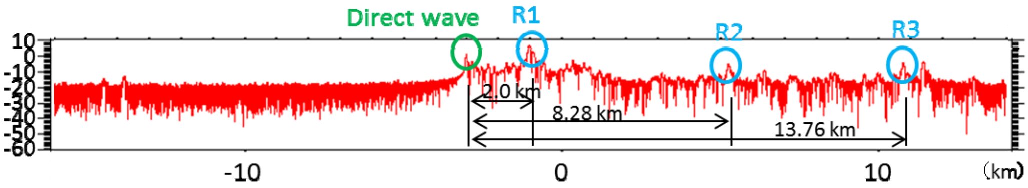

Fig. 4. An example of delay profile.