Water vapor estimation using digital terrestrial broadcasting waves

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A method of estimating water vapor (propagation delay due to water vapor) using digital terrestrial broadcasting waves is proposed. Our target is to improve the accuracy of numerical weather forecast for severe weather phenomena such as localized heavy rainstorms in urban areas through data assimilation. In this method, we estimate water vapor near a ground surface from the horizontal propagation delay of digital terrestrial broadcasting waves. The basic idea of using propagation delay is the same as that of retrieving PWV by using GNSS, in which vertical propagation paths are used. In this study, we use horizontal propagation paths of digital terrestrial broadcasting waves to obtain water vapor information. The main features of this observation are, no need for transmitters (receiving only), applicability wherever digital terrestrial broadcasting is available, and its high time resolution. The vertical and horizontal observations would be complementary to each other.

When radio waves propagate at a 5 km distance, a 1% increase in relative humidity causes a propagation delay of about 17 ps (about 5 mm in length). Because the delay due to water vapor is quite small, very precise measurements (at least several tens of picosecond order) are needed for effective observations. We can derive delay profiles using the received digital terrestrial broadcasting signals. The delay profiles are determined as the power of a certain broadcasting wave as a function of path delay. Each peak in a delay profile corresponds to a signal from a certain source through a certain propagation path. Therefore, using delay profiles enables us to identify the radio waves in a multipath or a multisource. The range resolution of a delay profile, which corresponds to the resolution to identify each signal, is about 50 m because the bandwidth of each channel is 6 MHz. By measuring the phase at a peak of a delay profile continuously, we can monitor the variation of the propagation path length of a certain broadcasting signal. We can estimate the delay due to water vapor from the variation of the propagation path length. The wavelength of a broadcasting wave whose frequency is 500 MHz is about 60 cm. If we measure the phase at a peak of a delay profile of this broadcasting wave with the accuracy of a degree, the accuracy of the propagation path change is about 1.7 (= 600/360) mm. Thus, we can monitor the variation of the propagation path change (i.e., delay) in millimeter order. The ISDB-T system, which is adopted in Japan, uses Orthogonal Frequency Division Multiplexing (OFDM) for the modulation. The bandwidth of a single channel is 6 MHz, and 5617 carriers are used within it. In each carrier, scattered pilots (SPs, known signals) are embedded every 4 symbols. A symbol is the base unit of OFDM modulation, whose length is 1.134 ms. Therefore, the transfer functions, i.e., the Fourier transforms of the impulse responses, are calculated every 4.536 ms using SPs. The delay profiles are derived as the inverse Fourier transforms of the transfer functions with this time resolution. We can measure the variation of propagation delay in millimeter order using the phase of a delay profile in principle.

However, there remains a technical problem. Because the propagation delay is quite small, phase noises of local oscillators at radio towers and receivers are major error factors. Threfore, we observe direct and reflected waves at a single receiving site. If there is a reflector at the opposite side from the radio tower, we can observe direct waves and reflected waves simultaneously. Measurement is conducted using single local oscillator at the observing point. The phase noises of this local oscillator and the radio tower, which

remain in sampled signals of both direct and reflected waves, are cancelled out by taking the difference between both signals. We can measure a roundtrip propagation delay between the observing point and the reflector without synchronizing the local oscillators. The data obtained using digital terrestrial broadcasting waves show good agreement with those obtained by ground-based meteorological observation.

Keywords: water vapor, propagation delay, digital terrestrial broadcasting waves