Half-year Comparison of Precipitable Water Vapor Retrieved with Novel Ground-based Microwave Radiometer and GPS Receiver at Tsukuba and Numerical Weather Analysis Data

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Abstract We have developed a state-of-the-art microwave radiometer named KUMODeS (KEK Universal Moisture and Oxygen Detection System) using millimeter-wave spectroscopy in order to monitor water vapor behavior. We have carried out comparative measurements of precipitable water vapor (PWV) in order to investigate the potential of KUMODeS/PWV measurements. Although further investigation is required to evaluate the performance of KUMODeS quantitatively, the preliminary results of PWV comparisons imply that the KUMODeS technology will be useful for retrieving the accurate behavior of water vapor with high temporal resolution.

Keywords water vapor radiometer, millimeter-wave spectroscopy, GNSS, precipitable water vapor

1 Introduction

Wet troposphere delay (wet delay) especially causes serious errors for precise positioning using GNSS and VLBI measurements as is well known in space geodesy. The wet delay issue is also important for improving the accuracy of GNSS-based time and frequency (T&F) transfer using GNSS. We have developed a state-of-the-art microwave radiometer named KUMODeS (KEK Universal Moisture and Oxygen Detection System) using millimeter-wave spectroscopy for the high-resolution and high-precision monitoring of water vapor behavior. We expect that KUMODeS will be a useful tool for space geodesy, T&F measurements, and related study fields. Thus, we have carried out comparative measurements of precipitable water vapor (PWV) in order to investigate the potential of KUMODeS/PWV measurements.

2 KUMODeS

The High Energy Accelerator Research Organization (KEK) has developed a state-of-the-art microwave radiometer named KUMODeS in order to observe the rapid increase in water vapor content within one hour, which is a sign of severe weather [2]. A commercial water vapor radiometer (conventional WVR) can only measure the temporal behavior of water vapor within 4–6 minutes.

But, this temporal resolution is insufficient to predict rapid cloud generation that causes heavy rain fall. KUMODeS has a millimeter-wave spectroscopy system for the high-resolution and high-precision monitoring of water vapor behavior. KUMODeS measures spectra using two receivers with frequency bands of 20–30 GHz and 50–60 GHz as shown in Figure 1. The low-noise amplifier of the first receiver and a cold calibration source are implemented in a cryostat, which is maintained at 10 K in order to improve the sensitivity in the detection of the characteristic broad peak of water vapor at around 22 GHz. The second receiver is used to measure the absorption peaks of oxygen (∼60

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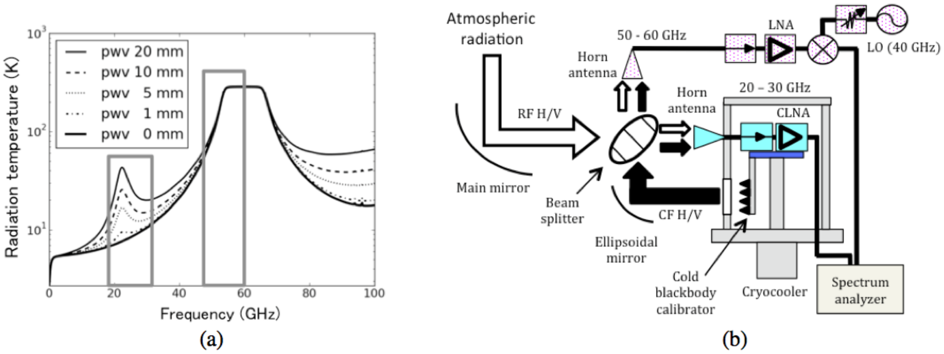


(a) (b)

Fig. 1 (a) Effective temperature of atmospheric radiation as a function of observed frequency. (b) Conceptual overview of KUMODeS. Atmospheric radiation is divided into two frequency paths, 20–30 GHz and 50–60 GHz, by using a wire grid beam splitter [after Tajima et al., 2016 [2]].

GHz). More details about KUMODeS are shown in other papers [1, 2].

3 PWV Estimation by GPS

The GPS-based PWV is estimated reliably with 1–2 mm accuracy according to previous studies. In our comparison, GPS PWV values are retrieved from zenith wet delays (ZWDs), which are computed by subtracting zenith hydrostatic delays (ZHDs) from GPS-based zenith total delays (ZTDs). GPS-based ZTDs are estimated using conventional precise point positioning (PPP) processing. In this procedure, ZHDs are obtained from the in situ surface pressure and temperature.

4 Measurements

We performed KUMODeS- and GPS-based PWV measurements at Tsukuba from December 20, 2016 to July 15, 2017 (see Figure 2). Figure 3 shows an approximately half-year time series of PWV values derived from KUMODeS, GPS, and radiosonde (ROBS) observations. In addition, we also processed PWV variations using the operational local analysis (LA) technique developed by the Japan Meteorological Agency (JMA) during the events of a cold-front passage from December 20–24, 2016. Precipitation data at three stations around KEK are also demonstrated in the time series. The PWV measurements derived from GPS and KUMODeS have temporal resolutions of 30 seconds and about two minutes, respectively. The estimates from the LA have a temporal resolution of one hour. The ROBS data is available every 12 hours.

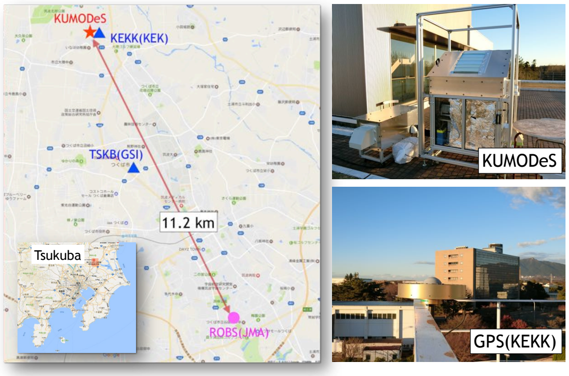


Fig. 2 Experimental setup. The KUMODeS station (star), the KEKK (KEK) and TSKB (GSI) GPS stations (triangles), and the JMA radiosonde launch site Tateno (circle) are indicated.

Comparisons of about half a year of PWV values derived from KUMODeS, GPS, and ROBS show good agreement with the amplitudes and phase as shown in Figure 3. A comparison of time-series data obtained during the cold-front passage also shows good agreement between the PWV measurements retrieved from KUMODeS, GPS, and the LA between December 20 and 22, 2016. GPS-based PWV values highly correlate with KUMODeS-based PWV values except in rainy events as shown in Figure 4. Because we did not conduct in situ precipitation measurements

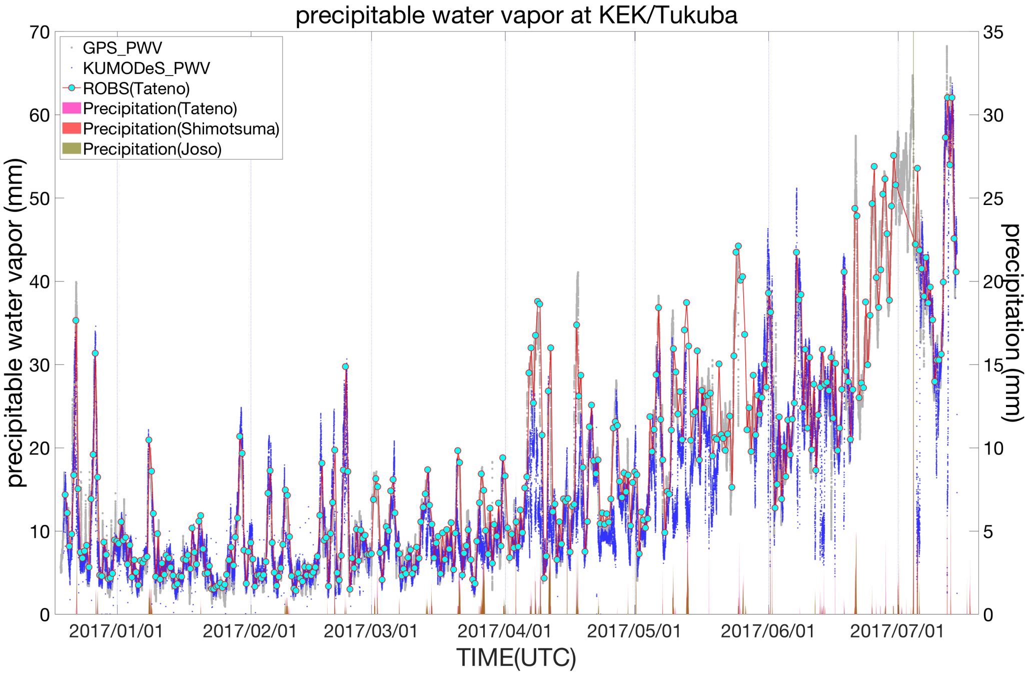


Fig. 3 Comparison of PWV values derived from KUMODeS (KEK), GPS (KEKK/KEK), and radiosonde (Tateno) in about six months during the period from December 20, 2016 to July 4, 2017. The precipitation data obtained around KEK are also shown in the time series.

near KUMODeS, we could not completely exclude the PWV estimates during rainy events from our comparisons. The correlation coefficient between the two data sets is 0.94.

5 Conclusions

We have developed a state-of-the-art microwave radiometer named KUMODeS using millimeter-wave spectroscopy. Although further investigation is required to evaluate the performance of KUMODeS quantitatively, the preliminary results of PWV comparisons imply the consistent performance and potential of KUMODeS technology.

6 Outlook

We have also developed a second prototype of KUMODeS. The characteristics of the second KUMODeS

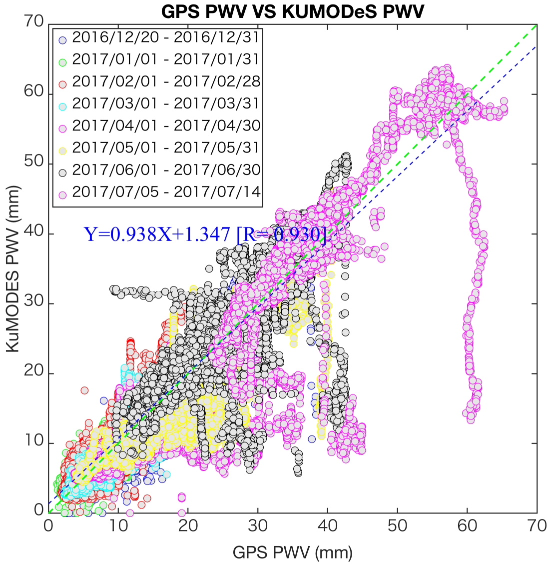
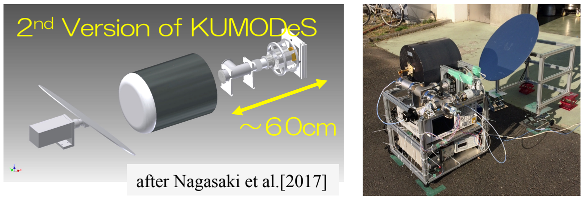


Fig. 4 Correlation plot. GPS PWV vs KUMODeS PWV estimates are shown. The regression curve for correlation and coefficients are also indicated in this figure.

prototype are compact form factor, light weight, and low power consumption. We are now planning to conduct test measurements using the second KUMODeS prototype in November 2018 (see Figure 5). In addition, we have started to develop a next-generation microwave radiometer that is suitable for field measurements such as monitoring volcanic activities and cumulonimbus cloud generation. We will implement accurate antenna pointing and azimuth-elevation driving in the new one. The new development will be completed at the end of the next fiscal year.



after Nagasaki et al.[2017]

Fig. 5 Second prototype of KUMODeS [after Nagasaki et al., 2017 [3]].

Acknowledgements

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