Development of a Compact Microwave Radiometer for Water Vapor Estimation with Machine Learning Method

Masahiro Minowa[1] ,Yuya Takashima[1], Tetsuro Sakaguchi[1], Kentaro Araki[2], Akira Kuwano-Yoshida[3]

1: Furuno Electric Co., Ltd., Japan, 2: Meteorological Research Institute, Japan, 3: Kyoto University, Japan

1. Introduction

Localized severe weather causes serious damage on our life. To prevent dangerous disasters such as typhoons, heavy rains, fog and hail, real-time observation of Precipitable Water Vapor (PWV) and water vapor profiles efficiently detects the precursor phenomenon. Generally, radiosondes (SONDE) have been used to observe atmospheric profiles, but only twice a day. On the other hand, Microwave Radiometer (MWR) enable observations every few minutes and provide an effective solution for real-time atmospheric observation. However, conventional MWRs are large and heavy, and local meteorological and network observations are not easy. Based on this background, FURUNO research department developed a compact and light-weight MWR as shown in Fig. 1 and Fig. 2. This report shows results of evaluation of compact MWR.

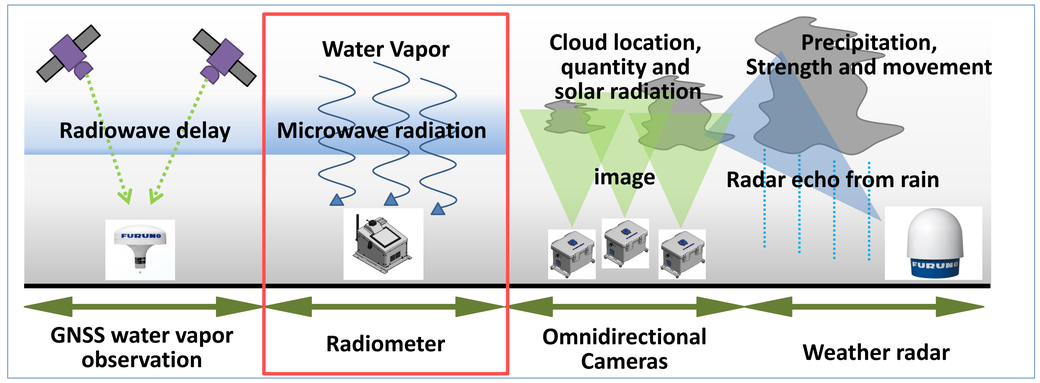
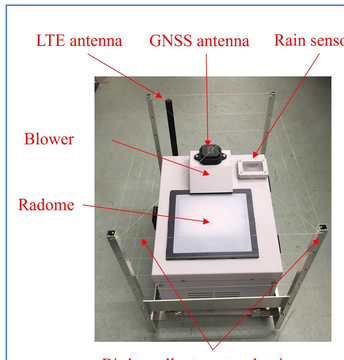


Fig. 1 Meteorological measurement instrument and target



KASMI-100	
Measurement radio frequency	17.9 ~ 26.4 GHz 34 Ch（Band width 5 MHz：17.9, 18.0, 18.1, 18.4, 18.5, 18.6, 19.0, 19.5, 20.5, 22.1, 22.2, 22.3, 22.9, 23.0, 23.1, 23.2, 23.3 GHz) (Band width 78 MHz：20.9, 21.0, 21.1, 21.4, 21.5, 21.6, 22.0, 22.5, 25.1, 25.2, 25.3, 25.9, 26.0, 26.1, 26.2, 26.3, 26.4 GHz)
Beam width	22.0 deg (17.9 GHz) ~ 15.4 deg (26.4 GHz)
Observation time resolution	1 min
Receiver resolution	0.007 dBm
Receiver noise temperature	~ 400 K
Power consumption	18 ~ 23 W（Blower +30 W）
Dimensions	H 403 × W 340 × D 393 mm
Weight	10.7 kg
Operating temperature range	-20 ℃ ~ +50 ℃
Proof performance	IP25（※IEC IP rating）
Equipment	Rain sensor, GNSS antenna, Bird repellent post and strings

※IEC（International Electrotechnical Commission）

Fig. 2 The appearance of the MWR and specifications

2. Data and methods

In this study, the PWV and water vapor profiles observed by MWR were evaluated. To estimate PWW and profiles, machine learning was used as shown in Fig. 3a,b. GNSS and SONDE were used as training data for PWV and water vapor profile, respectively. Data from June 2021 to March 2022 were used for training, and data from April 2022 to March 2023 were used for evaluation. For the evaluation, we compared three meteorological observation systems in Tsukuba, MWR (by FURUNO), SONDE (by Japan Meteorological Agency) and GNSS (by FURUNO). For the evaluation of PWV, data estimated by MWR, PWV obtained from SONDE, and PWV obtained from GNSS were compared, respectively. For the evaluation of profiles, MWR and profiles obtained from SONDE were compared. To confirm that the PWVs obtained by GNSS used for training data is accurate, we compared them to PWVs derived from SONDE (Fig. 3c). To investigate the characteristics of the PWV obtained by GNSS used for training, a histogram of the PWV was plotted (Fig. 3d). Since there are enough data points with a PWV of 60 mm or less, the training model can be expected to reproduce a variety of conditions from dry to wet environments.

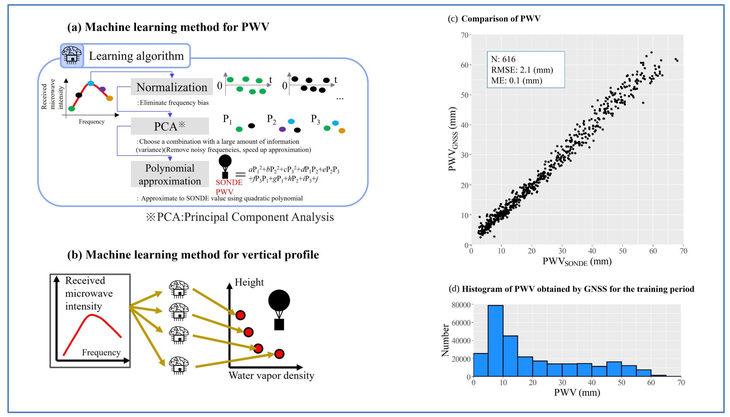


Fig. 3 The flowchart of ML and accuracy of GNSS PWV

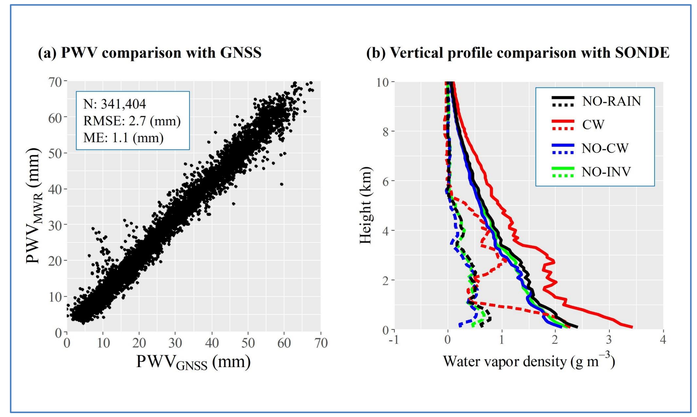


Fig. 4 RMSE and ME between MWR and SONDE

3. Results

The root-mean-square error (RMSE) of MWR-derived PWV compared to GNSS-derived PWV was 2.7 mm, and MWR-derived water vapor density compared to SONDE at the lowest layer of the atmosphere was 2.4 g m-3 as shown in Fig. 4a,b. The solid and broken lines indicate the RMSE and the ME, respectively. The black, red, blue, and light green lines respectively indicate NO-RAIN, CW, NO-CW, and the cases without an inversion layer with a vertical water vapor density difference of 3.0 g m-3 or more (NO-INV). Considering the effect of cloud water, the maximum RMSE and ME were 3.4 g m-3 and 2.3 g m-3 for CW and 2.1 g m-3 and 0.5 g m-3 for NO-CW, respectively, in the lower layer of the atmosphere. This indicates that the estimation of water vapor profiles is prone to errors in the presence of cloud water.

MWR-derived PWV showed better agreement with SONDE-derived PWV than with GNSS-derived PWV as shown in Fig. 5. Although the PWV observed by MWR contains errors due to precipitation, the MWR and GNSS are considered to capture more detailed temporal variations compared to the SONDE.

It was also found that the estimation of the water vapor profile performs well for cases with simple vertical structures but less accurate for cases with complex structures, such as those involving water vapor inversion layers as shown in Fig. 6a,b.

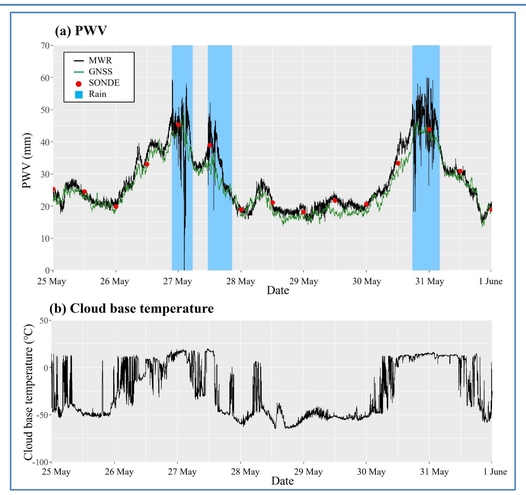


Fig. 5 Comparison between MWR, SONDE, GNSS

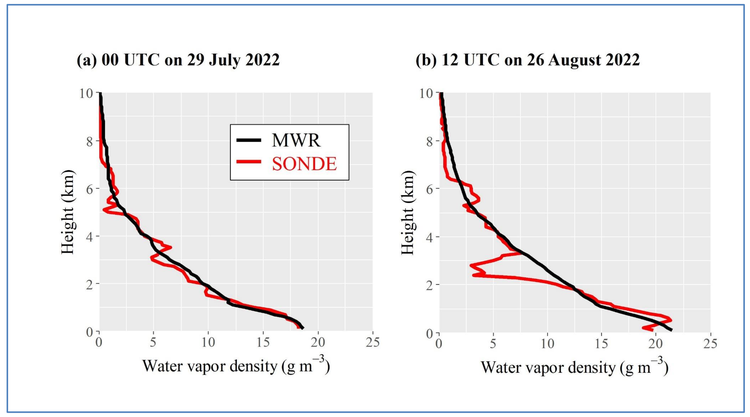


Fig. 6 Results of the MWR water vapor profile observations compared to the SONDE

4. Conclusions

We have developed a compact, lightweight, low-cost ground-based MWR that uses a machine learning methods to estimate water vapor. This study demonstrates that even a compact MWR can observe water vapor with good accuracy. The water vapor observation data obtained by our compact MWR can be used for data assimilation and it could contribute to weather forecasting. As a future work, we plan to incorporate ground weather data (such as temperature, pressure, humidity) into machine learning models to improve PWV and water vapor profile estimations. The simplicity and mobility of our compact MWR will enable deployment in areas where water vapor observations have been challenging, such as on ships, and it will facilitate innovative water vapor observations.

***"Compact Microwave Radiometer for Water Vapor Estimation with Machine Learning Method"**
Minowa, M., K. Araki, and Y. Takashima, 2024: SOLA, doi: 10.2151/sola.2024-045.
***This work was supported by JSPS KAKENHI Grant Numbers JP23H00519, JP23H00221, JP22K18733, JP20H04306.**