# Novel Real-time Observation of High-resolution Water Vapor Behavior for Detection of Precursors of Cumulonimbus Clouds and Investigation of Their Evolution

## Overview of the Research Project

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**Abstract** We have initiated a new research project to analyze the behaviors of precipitable water vapor with high spatial and temporal resolutions, using a dense global navigation satellite system (GNSS) network and next-generation microwave radiometers. Our research aims to investigate the generation mechanisms of cumulonimbus clouds and to mitigate geohazards using numerical weather prediction based on detailed temporal and spatial water vapor information. Additionally, the wideband receiver system in the new microwave radiometers will be made available for the entire range of research fields in VLBI measurements, such as geodesy, radio astronomy, spacecraft tracking, and time and frequency transfer.

**Keywords** GNSS, water vapor, precipitable water vapor, cumulonimbus cloud, microwave radiometer

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## 1 Introduction

Recently, line-shaped rainbands with extreme and hazardous characteristics have been occurring frequently in Japan, leading to disasters such as severe flooding and landslides. However, there is insufficient knowledge regarding the generation mechanism of cumulonimbus clouds within these rainbands. To comprehend the generation mechanism of cumulonimbus clouds within these rainbands, it is desirable to observe the behavior of water vapor using high-resolution and high-precision sensing. Therefore, we initiated a new research project aimed at implementing a geohazard mitigation system for predicting rapidly developing heavy rainfall events.

## 2 Research Project

Our project has four research sub-objectives:

1. To develop a novel microwave radiometer for use in millimeter-wave spectroscopy. This will enable the high-resolution and high-precision monitoring of the water vapor behavior. We will conduct field measurements using this radiometer to prove the concept.
2. To conduct high-resolution water vapor measurements using a dense network of low-cost GNSS receivers.
3. To conduct GNSS water vapor tomography for estimating precise temporal and spatial variations.
4. To predict weather numerically using dense-measurement water vapor datasets and refined GNSS tomography results.

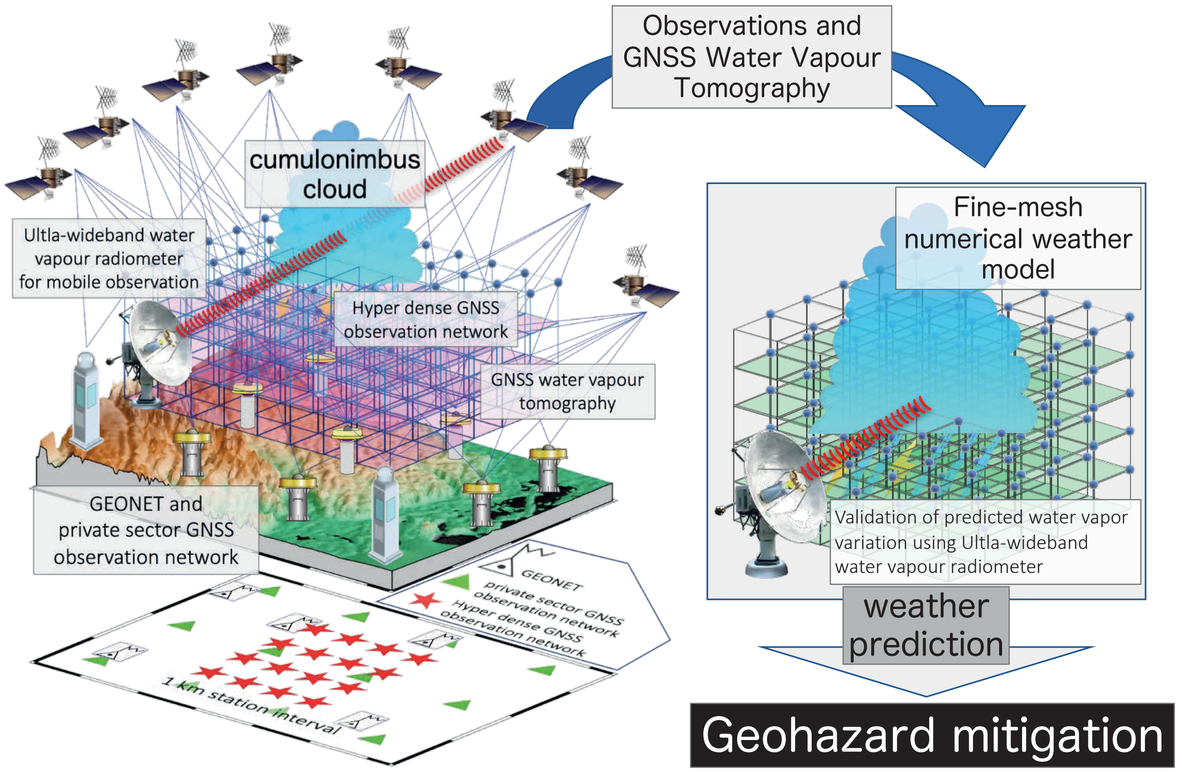


**Fig. 1** Schematic image of the research project.

Our project aims not only to advance mesoscale meteorology but also to apply space geodetic techniques such as VLBI and GNSS. The schematic image of our project is shown in Figure 1.

## 3 Field Experiment

For the observation of GNSS precipitable water vapor (PWV), we first installed a low-cost GNSS receiver and a commercially-based microwave radiometer at Kagoshima University in early November 2023 for a preliminary observation to understand the variability of water vapor in the southern Kyushu area (see Figure 2). In addition to the precipitable water vapor information obtained from this observation, we plan to investigate the variability of water vapor in this area based on the information obtained from the GNSS Earth observation network (GEONET) system of the Geospatial Information Authority of Japan (GSI) and a commercially-based GNSS observation network. Figure 3 compares the time series of the PWV at Kagoshima University, utilizing data sets from GNSS, the operational local analysis (LA) developed by the Japan Meteorological Agency (JMA), and a commercial microwave radiometer from Furuno Electric Co., Ltd. Figure 3 shows the PWV time series from November 22, 2023 to December 6, 2023 (upper) and those from March 13, 2024 to March 23, 2024 (lower). All PWV values agree well with each other, and correlation coefficient values and biases are shown in Figure 4.

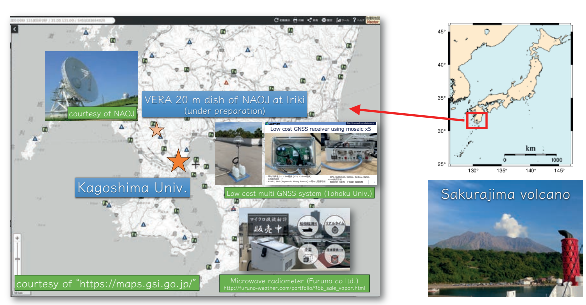


**Fig. 2** The research region and test observation sites.

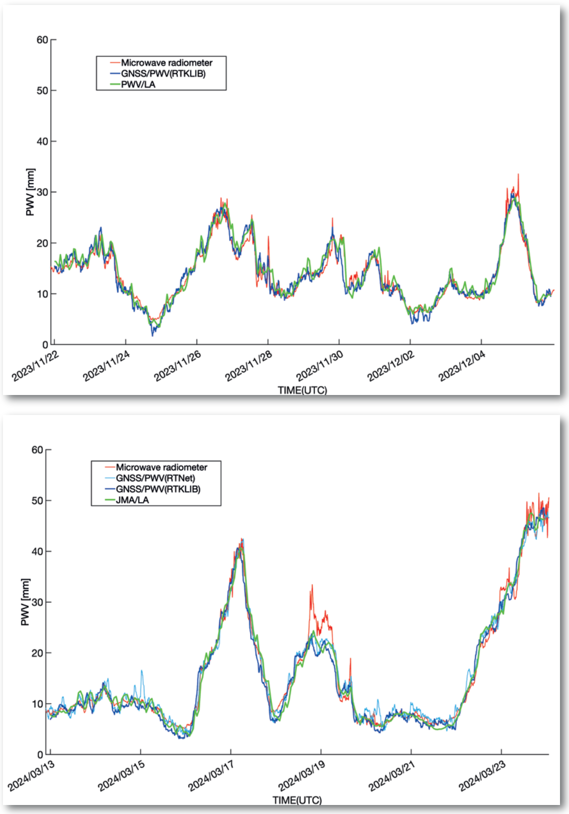


**Fig. 3** The PWV time series derived from local analysis of Japan Meteorological Agency (LA/JMA), water vapor radiometer of Furuno Co., Ltd. (WVR) and GNSS site at Kagoshima University (GNSS). The PWV time series from November 22, 2023 to December 6, 2023 (upper) and those from March 13, 2024 to March 23, 2024 (lower).

## 4 Development of Novel Microwave Radiometer

Regarding the first sub-objective in Section 2, significant progress has been achieved in the development of a next-generation microwave radiometer utilizing millimeter-wave spectroscopy since 2018. To date, we have successfully engineered a new frontend module equipped with an orthomode transducer (OMT) and a wideband feed. The prototype of the complete receiver system has a wide bandwidth feed spanning from 16 to 58 GHz, facilitating the measurement of two frequency bands: 16–28 GHz ($H_2O$) and 50–58 GHz ($O_2$). We anticipate that this receiver system will be applicable for achieving interoperability among VLBI stations with various purposes, such as geodesy, radio astronomy, spacecraft tracking, and time and frequency transfer.

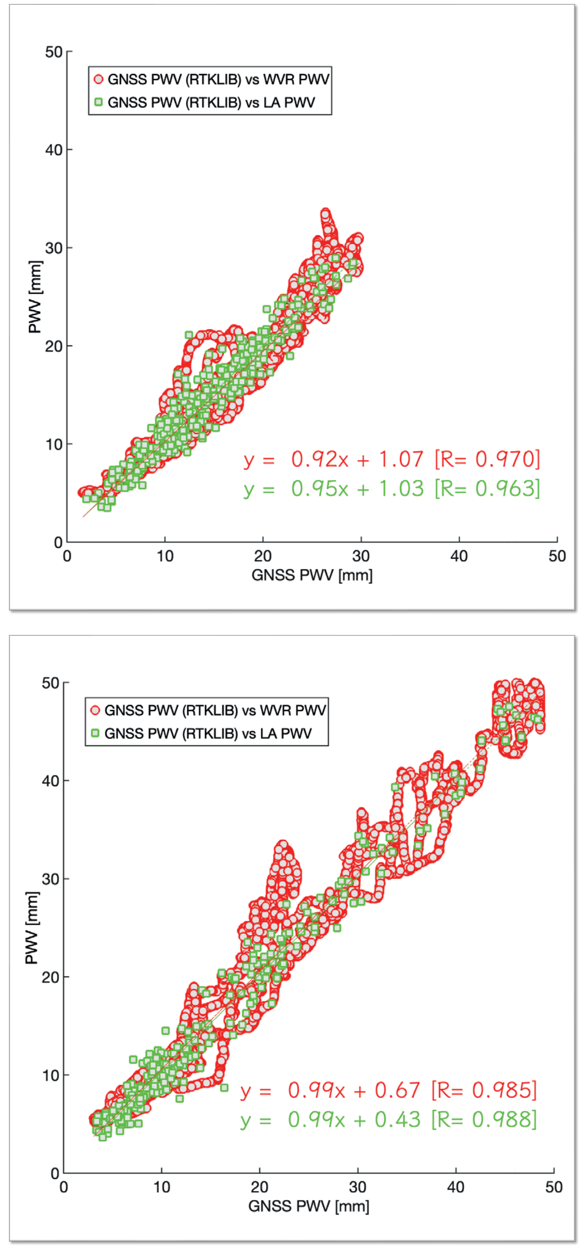


**Fig. 4** Scatter plots compare WVR PWV (red) with JMA/LA PWV (green) against GNSS PWV at Kagoshima University. The figures also display the regression curves for correlation and the corresponding coefficients. The upper figure displays scatter plots from November 22, 2023 to December 6, 2023, while the lower figure presents those from March 13, 2024 to March 23, 2024.

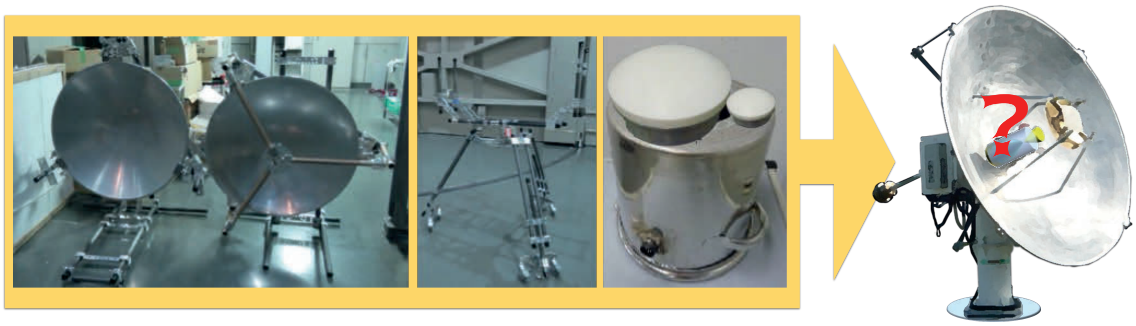

**Fig. 5** Wideband microwave radiometer under development.

## 5 Summary and Outlook

In order to capture more detailed temporal and spatial variations in water vapor, we intend to expand the number of GNSS observation stations in the southern Kyushu region. Furthermore, we plan to integrate the prototype of the wideband receiver system (see Section 4 and Figure 5) into a 45-meter dish telescope at the Nobeyama Radio Observatory of NAOJ this summer. This will allow us to evaluate its effectiveness in detecting variations in water vapor.

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