Monitoring system for atmospheric water vapor with a ground-based multi-band radiometer

meteorological application of radio astronomy technologies

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“FORECAST” of Cloud Generation

- New technology against for rapid weather changing

Rapid increase of water vapor

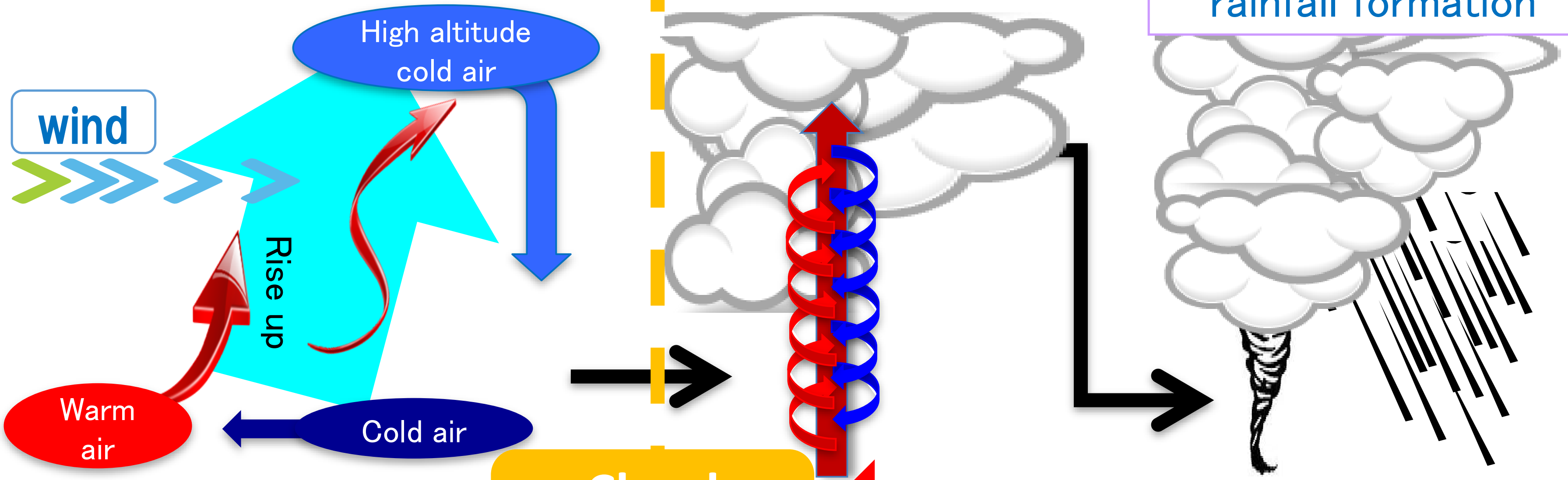
Suddenly, local

tornadic storms：≦few hundred m

Heavy rainfall：≦10km

“super-cell”

Tornado, heavy rainfall formation



Cloud generation

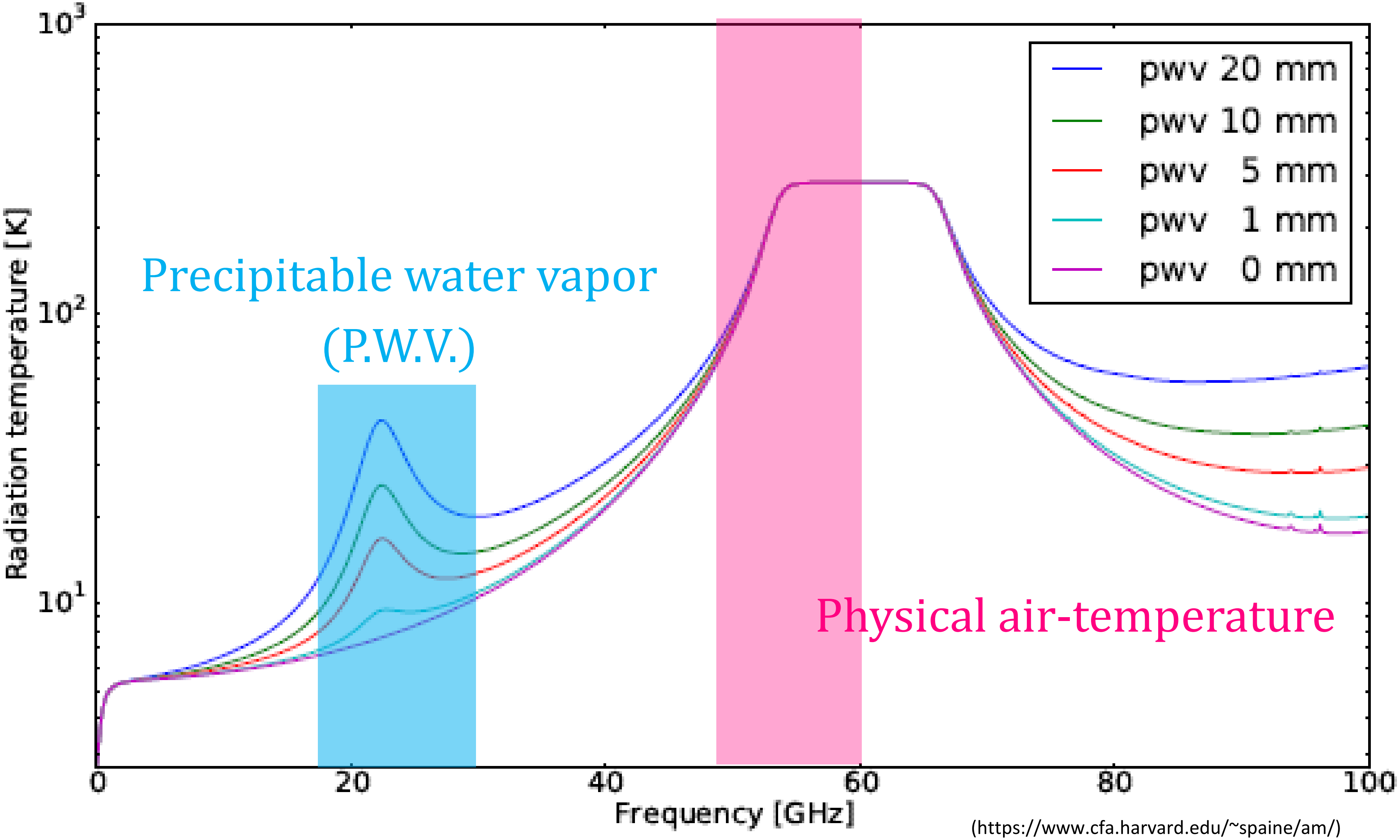
~ 10 minutes before

By radar

1 hour before !!

By radiometer

Approach for detection



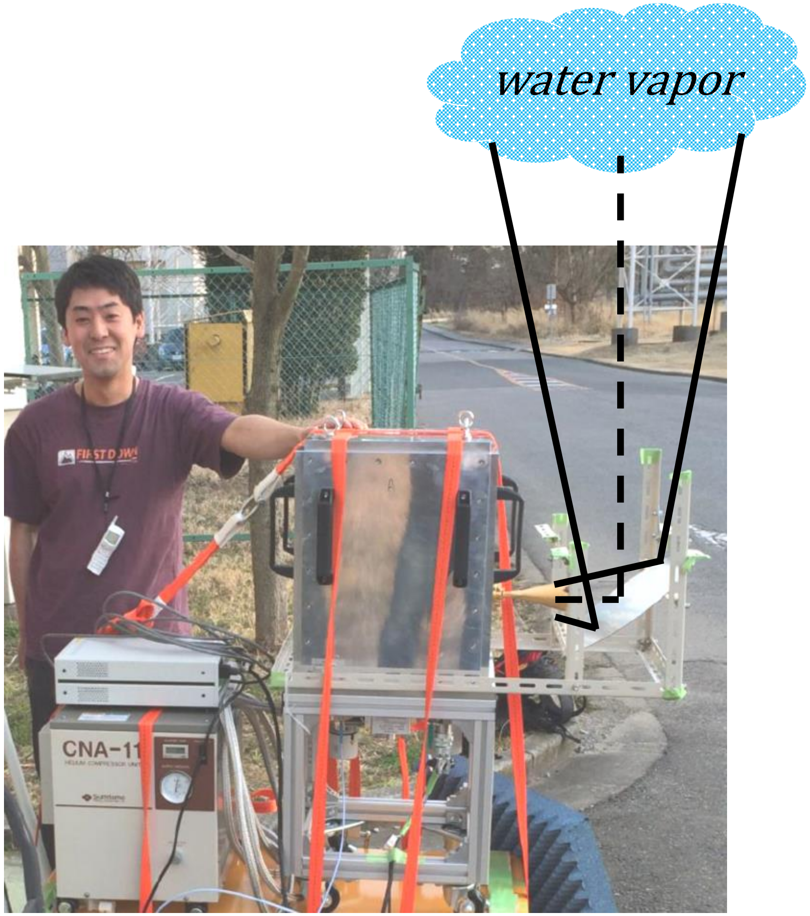
Precipitable water vapor (P.W.V.)

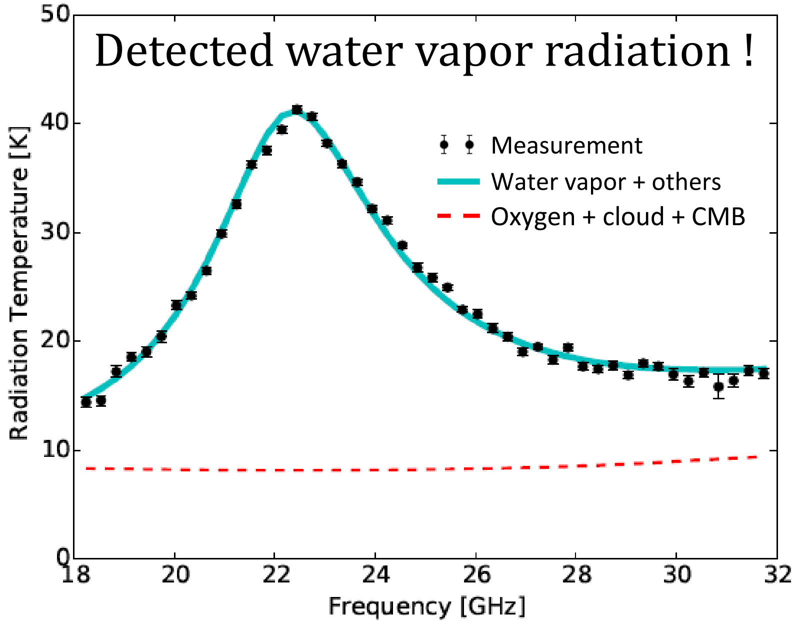
Physical air-temperature

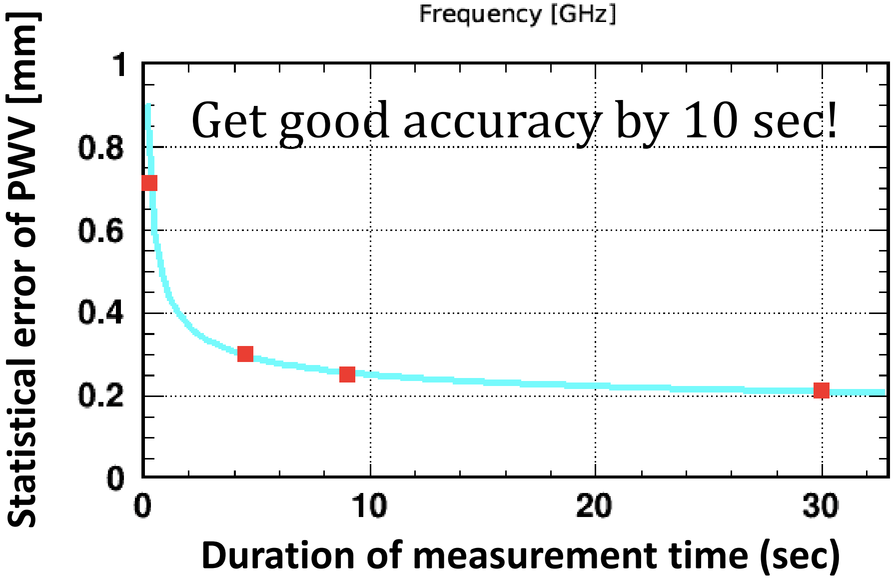
(https://www.cfa.harvard.edu/~spaine/am/)

Proof of concept by using prototype cold receiver

▹high-sensitivity system for measurement of water vapor, based on radio-astronomy technologies (e.g., 8 K cold receiver, cold calibrator, high speed scan…)

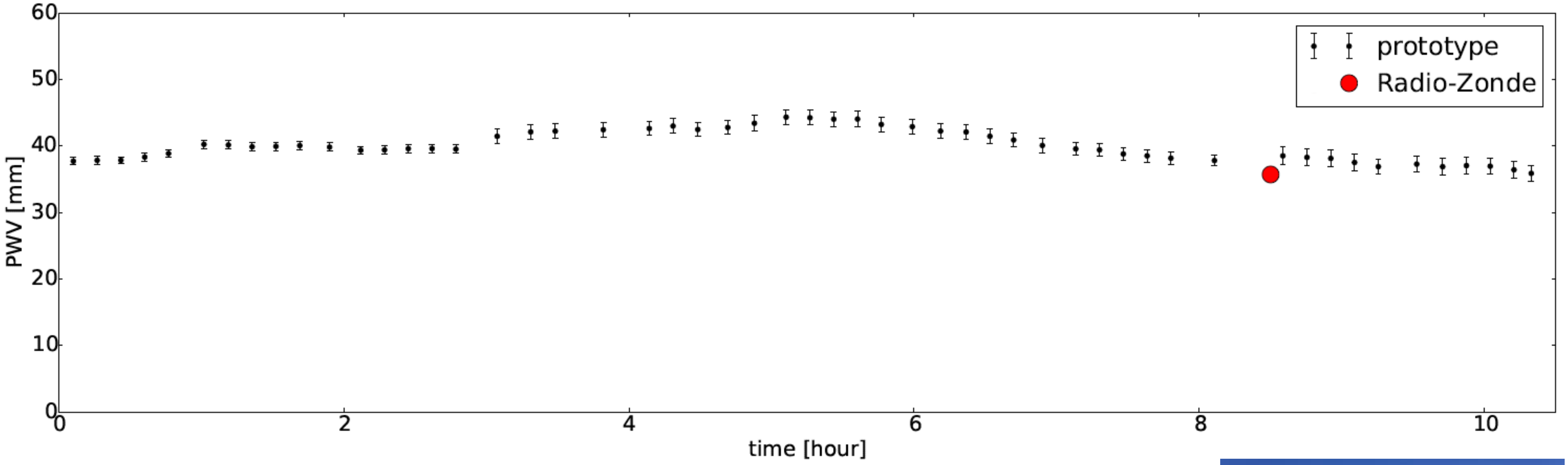


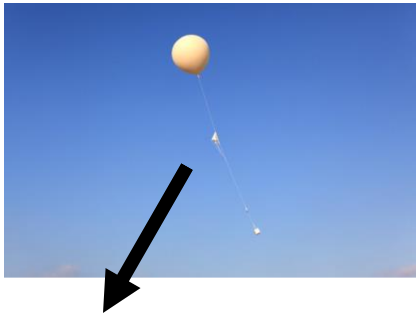

Detected water vapor radiation !


Get good accuracy by 10 sec!

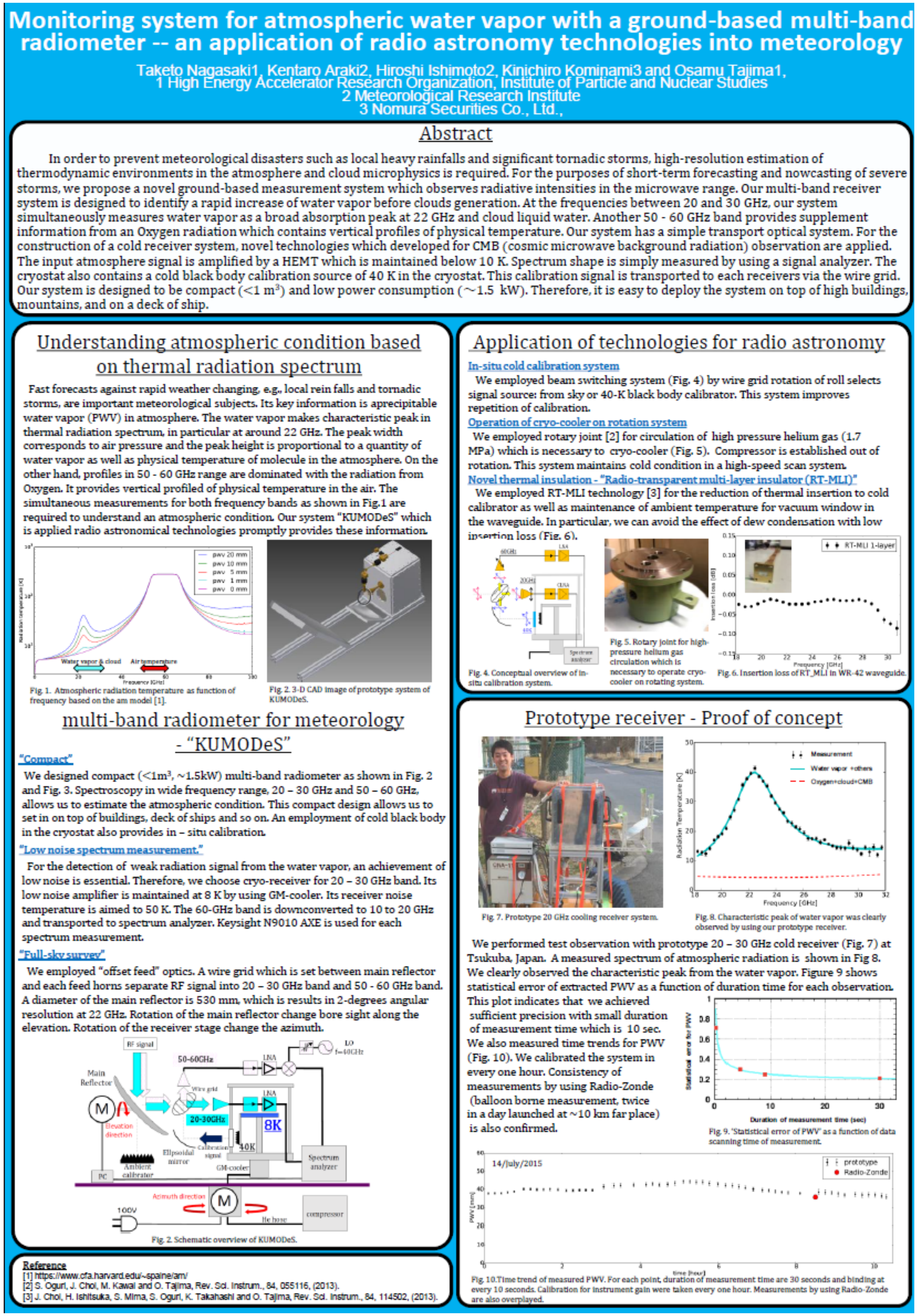
Consistency of measurement

- long time trend, about half-day
- Duration of measurement times are 30 seconds
- binding at every 10 minutes





Confirmed consistency among radiometer and radio-zonde!



Monitoring system for atmospheric water vapor with a ground-based multi-band radiometer -- an application of radio astronomy technologies into meteorology

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Abstract

In order to prevent meteorological disasters such as local heavy rainfalls and significant tornadic storms, high-resolution estimation of thermodynamic environments in the atmosphere and cloud microphysics is required. For the purposes of short-term forecasting and nowcasting of severe storms, we propose a novel ground-based measurement system which observes radiative intensities in the microwave range. Our multi-band receiver system is designed to identify a rapid increase of water vapor before clouds generation. At the frequencies between 20 and 30 GHz, our system simultaneously measures water vapor as a broad absorption peak at 22 GHz and cloud liquid water. Another 50 - 60 GHz band provides supplement information from an Oxygen radiation which contains vertical profiles of physical temperature. Our system has a simple transport optical system. For the construction of a cold receiver system, novel technologies which developed for CMB (cosmic microwave background radiation) observation are applied. The input atmosphere signal is amplified by a HEMT which is maintained below 10 K. Spectrum shape is simply measured by using a signal analyzer. The cryostat also contains a cold black body calibration source of 40 K in the cryostat. This calibration signal is transported to each receivers via the wire grid. Our system is designed to be compact (<1 m^3) and low power consumption (~1.5 kW). Therefore, it is easy to deploy the system on top of high buildings, mountains, and on a deck of ship.

Understanding atmospheric condition based on thermal radiation spectrum

Fast forecasts against rapid weather changing, e.g., local rein falls and tornadic storms, are important meteorological subjects. Its key information is aprecipitable water vapor (PWV) in atmosphere. The water vapor makes characteristic peak in thermal radiation spectrum, in particular at around 22 GHz. The peak width corresponds to air pressure and the peak height is proportional to a quantity of water vapor as well as physical temperature of molecule in the atmosphere. On the other hand, profiles in 50 - 60 GHz range are dominated with the radiation from Oxygen. It provides vertical profiled of physical temperature in the air. The simultaneous measurements for both frequency bands as shown in Fig.1 are required to understand an atmospheric condition. Our system "KUMODeS" which is applied radio astronomical technologies promptly provides these information.

Fig. 1. Atmospheric radiation temperature as function of frequency based on the am model [1].

Fig. 2. 3-D CAD image of prototype system of KUMODeS.

multi-band radiometer for meteorology - "KUMODeS"

"Compact"

We designed compact (<1m^3, ~1.5kW) multi-band radiometer as shown in Fig. 2 and Fig. 3. Spectroscopy in wide frequency range, 20 – 30 GHz and 50 – 60 GHz, allows us to estimate the atmospheric condition. This compact design allows us to set in on top of buildings, deck of ships and so on. An employment of cold black body in the cryostat also provides in – situ calibration.

"Low noise spectrum measurement."

For the detection of weak radiation signal from the water vapor, an achievement of low noise is essential. Therefore, we choose cryo-receiver for 20 – 30 GHz band. Its low noise amplifier is maintained at 8 K by using GM-cooler. Its receiver noise temperature is aimed to 50 K. The 60-GHz band is downconverted to 10 to 20 GHz and transported to spectrum analyzer. Keysight N9010 AXE is used for each spectrum measurement.

"Full-sky survey"

We employed "offset feed" optics. A wire grid which is set between main reflector and each feed horns separate RF signal into 20 – 30 GHz band and 50 - 60 GHz band. A diameter of the main reflector is 530 mm, which is results in 2-degrees angular resolution at 22 GHz. Rotation of the main reflector change bore sight along the elevation. Rotation of the receiver stage change the azimuth.

Fig. 2. Schematic overview of KUMODeS.

Reference
[1] https://www.cfa.harvard.edu/~spaine/am/
[2] S. Oguri, J. Choi, M. Kawai and O. Tajima, Rev. Sci. Instrum., 84, 055116, (2013).
[3] J. Choi, H. Ishitsuka, S. Mima, S. Oguri, K. Takahashi and O. Tajima, Rev. Sci. Instrum., 84, 114502, (2013).

Application of technologies for radio astronomy

In-situ cold calibration system

We employed beam switching system (Fig. 4) by wire grid rotation of roll selects signal source: from sky or 40-K black body calibrator. This system improves repetition of calibration.

Operation of cryo-cooler on rotation system

We employed rotary joint [2] for circulation of high pressure helium gas (1.7 MPa) which is necessary to cryo-cooler (Fig. 5). Compressor is established out of rotation. This system maintains cold condition in a high-speed scan system.

Novel thermal insulation - "Radio-transparent multi-layer insulator (RT-MLI)"

We employed RT-MLI technology [3] for the reduction of thermal insertion to cold calibrator as well as maintenance of ambient temperature for vacuum window in the waveguide. In particular, we can avoid the effect of dew condensation with low insertion loss (Fig. 6).

Fig. 4. Conceptual overview of in-situ calibration system.

Fig. 5. Rotary joint for high-pressure helium gas circulation which is necessary to operate cryo-cooler on rotating system.

Fig. 6. Insertion loss of RT_MLI in WR-42 waveguide.

Prototype receiver - Proof of concept

Fig. 7. Prototype 20 GHz cooling receiver system.

Fig. 8. Characteristic peak of water vapor was clearly observed by using our prototype receiver.

We performed test observation with prototype 20 – 30 GHz cold receiver (Fig. 7) at Tsukuba, Japan. A measured spectrum of atmospheric radiation is shown in Fig 8. We clearly observed the characteristic peak from the water vapor. Figure 9 shows statistical error of extracted PWV as a function of duration time for each observation. This plot indicates that we achieved sufficient precision with small duration of measurement time which is 10 sec. We also measured time trends for PWV (Fig. 10). We calibrated the system in every one hour. Consistency of measurements by using Radio-Zonde (balloon borne measurement, twice in a day launched at ~10 km far place) is also confirmed.

Fig. 9. 'Statistical error of PWV' as a function of data scanning time of measurement.

Fig. 10.Time trend of measured PWV. For each point, duration of measurement time are 30 seconds and binding at every 10 seconds. Calibration for instrument gain were taken every one hour. Measurements by using Radio-Zonde are also overplayed.

Poster number G3.35.