

Millimeter Wave Radiometric Arctic Winter Experiment

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Introduction

The arctic is a highly variable and sensitive region in the global climate system. There is growing recognition that arctic climate conditions strongly influence the world climate. Furthermore, the arctic is a sensitive indicator of global-scale climate change. Proper characterization of the arctic atmosphere is essential to improving our understanding of the coupling mechanisms between the arctic and global climates, and between the atmospheric, land, and oceanic components of the climate system. Water vapor and clouds are particularly important because of their ability to regulate the polar energy budgets. Conventional measurements of water vapor profiles have relied on radiosondes; however, during cold arctic conditions, radiosonde accuracy is an important issue. Experience at the Southern Great Plains (SGP) central facility has clearly illustrated the value of ground-based Microwave Radiometers (MWRs) for determining the reliability of radiosonde humidity soundings (Liljegren and Lesht 1996). In particular, soundings of precipitable water vapor (PWV) from the MWR have been used to scale entire humidity soundings. This procedure has led to much better agreement with collocated measurements of emission spectra as obtained by the Atmospheric Radiation Measurement (ARM) Fourier Transform Infrared Radiometers (Clough et al. 1992). For more than 30 years, ground-based dual-frequency radiometric measurements on the wings of the 22.231-GHz water vapor absorption line and in the neighboring absorption window around 31 GHz have been used to derive PWV and liquid water path (LWP). However, there are concerns about the ability of the MWR to derive accurate measurements of PWV during the coldest and driest of conditions, because of the relatively weak response of the 22-GHz emission to PWV amounts below about 5 mm.

Based on theoretical predictions by Jones and Racette (1998), the Millimeter-Wave Radiometric (MMWR)-Arctic experiment was designed and conducted to verify if radiometric measurements around the much stronger 183-GHz absorption line can improve measurements of PWV during the extreme cold conditions. This experiment was conducted during March 1999 at the North Slope of Alaska/Adjacent Arctic Ocean Cloud and Radiation Testbed (NSA/AAO CART) site to investigate millimeter-wave radiometry for measuring PWV in extremely dry conditions. The National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory (ETL) teamed together to deploy several radiometer systems at the NSA/AAO CART site for a three-week period in March 1999. Four MWR systems with a total of 24 radiometric channels ranging in frequency from 20.6 GHz to 340 GHz were deployed for this experiment. The location of the 24 radiometer channels used in the experiment (see Table 1) is shown overlaid on the atmospheric absorption spectrum in Figure 1. Figure 2 shows a photograph of three of these instruments at the experiment site. In addition to the NASA/NOAA microwave measurements and operational CART site instrumentation, additional surface meteorological data were collected, daily radiosondes and five chilled mirror frost-point humidity sensors were launched during the experiment, Radiometrics Corporation operated their Multi-channel Microwave Profiler, and State University of New York (SUNY) at Albany operated their Rotating Shadowband Spectroradiometer (RSS). Only the NASA Millimeter-Wave Imaging Radiometer (MIR) (see Table 1) and ARM MWR data are presented in this report.

Table 1. Instruments deployed during the millimeter wave radiometric arctic winter experiment.

Instrument	Organization	Frequencies (GHz)
MIR	NASA/GSFC	89, 150, 183.31 ± (1, ± 3, ± 7), 220, 340
DOE Multi-channel Microwave Radiometer (DoER)	NASA/GSFC	20.735, 21.485, 22.235, 22.985, 23.735, 36.5, and 89
Circularly Scanning Radiometer (CSR)	NOAA/ETL	20.6, 31.65, 183.31 ± (0.5, ± 1, ± 3, ± 5, ± 7, ± 12, ± 15), 325 ± (1, ± 3, ± 8), 340 H & V, 10 μm
Scanning O ₂ Radiometer	NOAA/ETL	60.5
Vaisala and Chilled Mirror Surface Met.	NOAA/ETL, National Center for Atmospheric Research (NCAR)	
Vaisala and Chilled Mirror Radiosondes	ARM	

Observations of Water Vapor

Presently, ARM operates at their NSA/AAO CART site an MWR, which measures downwelling radiation at 23.8 GHz and 31.4 GHz from which PWV and LWP are retrieved. Data from this instrument represent the baseline from which millimeter-wave observations will be compared. For

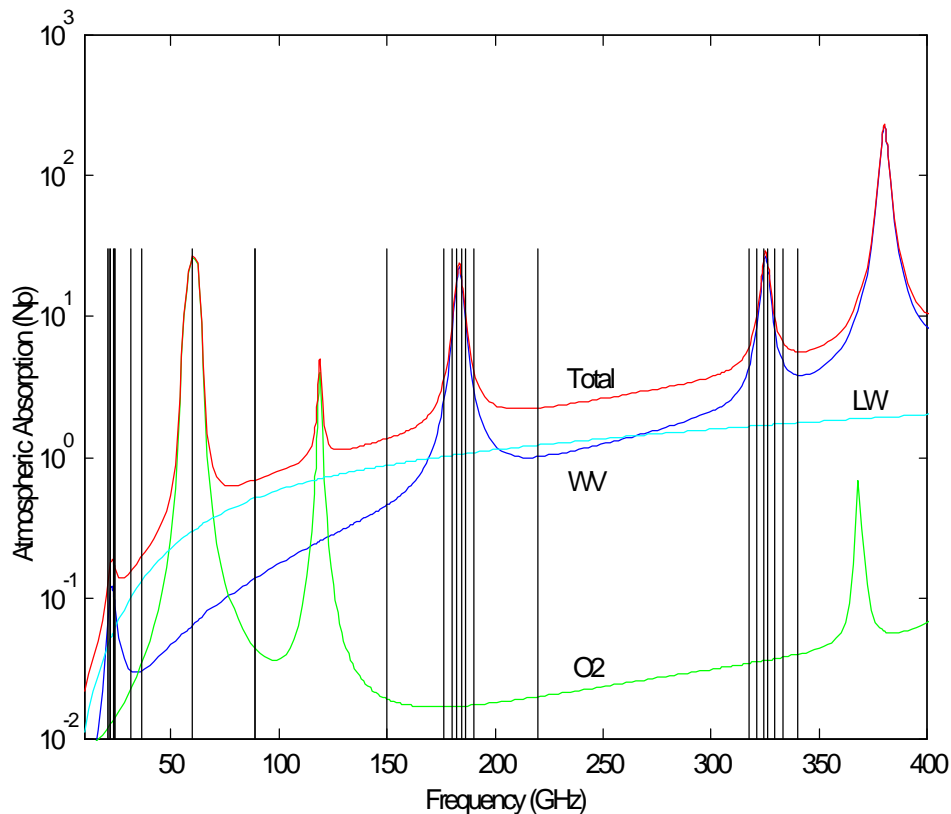


Figure 1. The location of the 24 radiometric channels are shown overlaid on the atmospheric absorption spectra of water vapor (WV), oxygen (O₂), liquid water (LW), and total absorption. A concentration of channels are located near the 22.2-GHz, 183-GHz, and 325-GHz water vapor absorption lines.

PWV amounts greater than 1 cm, this pair of frequencies is able to obtain accurate measurement. When the atmosphere becomes very dry the absorption around the 22.231-GHz water vapor line becomes weak. Thus, the relative uncertainty in retrieved PWV increases with decreasing water vapor. The 183-GHz absorption line is about 100 times stronger than that of the 22.231-GHz line. Improved estimates of low PWV can be obtained by taking advantage of the much stronger 183-GHz water vapor line. A preliminary look at our data demonstrates the greater sensitivity of the mm-wave frequencies. Responses of seven of the radiometer channels from March 11 are plotted in Figure 3. The PWV for this day is less than 2 mm and the temperatures were colder than -37°C . The brightness temperature values at 5:00 Universal Time Coordinates (UTC) has been subtracted and the temperature differences for the remainder of the day are shown. The response of the channels at 23.8 GHz and 31.4 GHz vary by no more than ~ 1 degree. The mm-wave channels on the other hand exhibit variations of 10 to 20 degrees. Further analysis of this data will yield estimates of the errors associated with retrieving PWV using various combinations microwave and mm-wave frequencies.

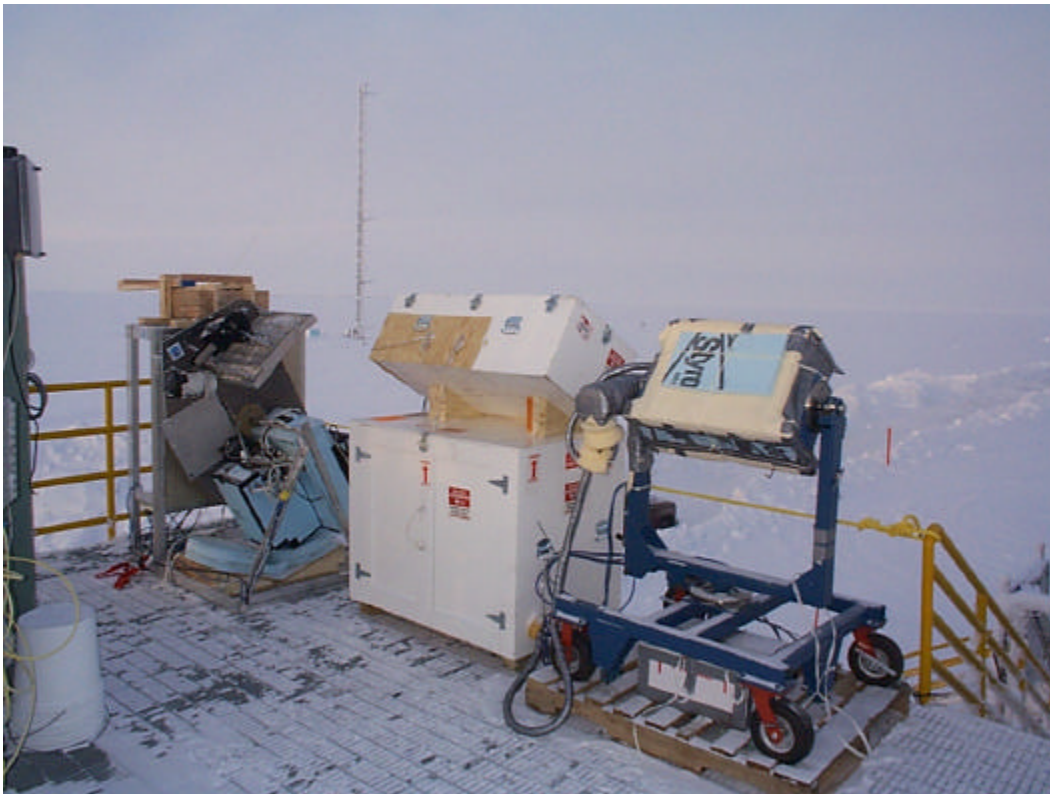


Figure 2. Three MWR systems are on the high instrument platform at the NSA/AO CART site. The CART site is located just a few miles outside Barrow, Alaska.

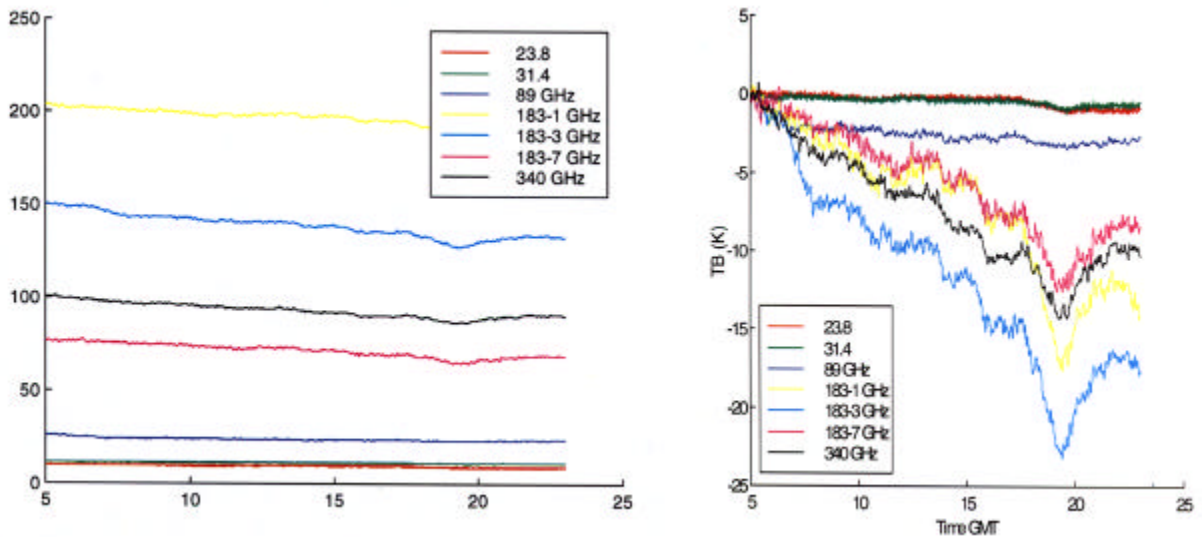


Figure 3. The response of seven of the channels are plotted as differences in brightness temperature referenced to 5:00 UTC on March 11. The microwave channels exhibit small response, whereas the mm-wave channels detect the changes in the atmosphere on this clear dry day.

Observations of Clouds

As is seen from Table 1, scanning radiometers from 20 GHz to 340 GHz were available to observe both liquid bearing and ice clouds. Figure 4 shows preliminary images from the MIR on March 10, 1999. After subtraction of the baseline values, the difference response to clouds is evident. It is planned to compare these data with backscatter data from both lidar and cloud-radar that were operating at the NSA/AAO during this experiment.

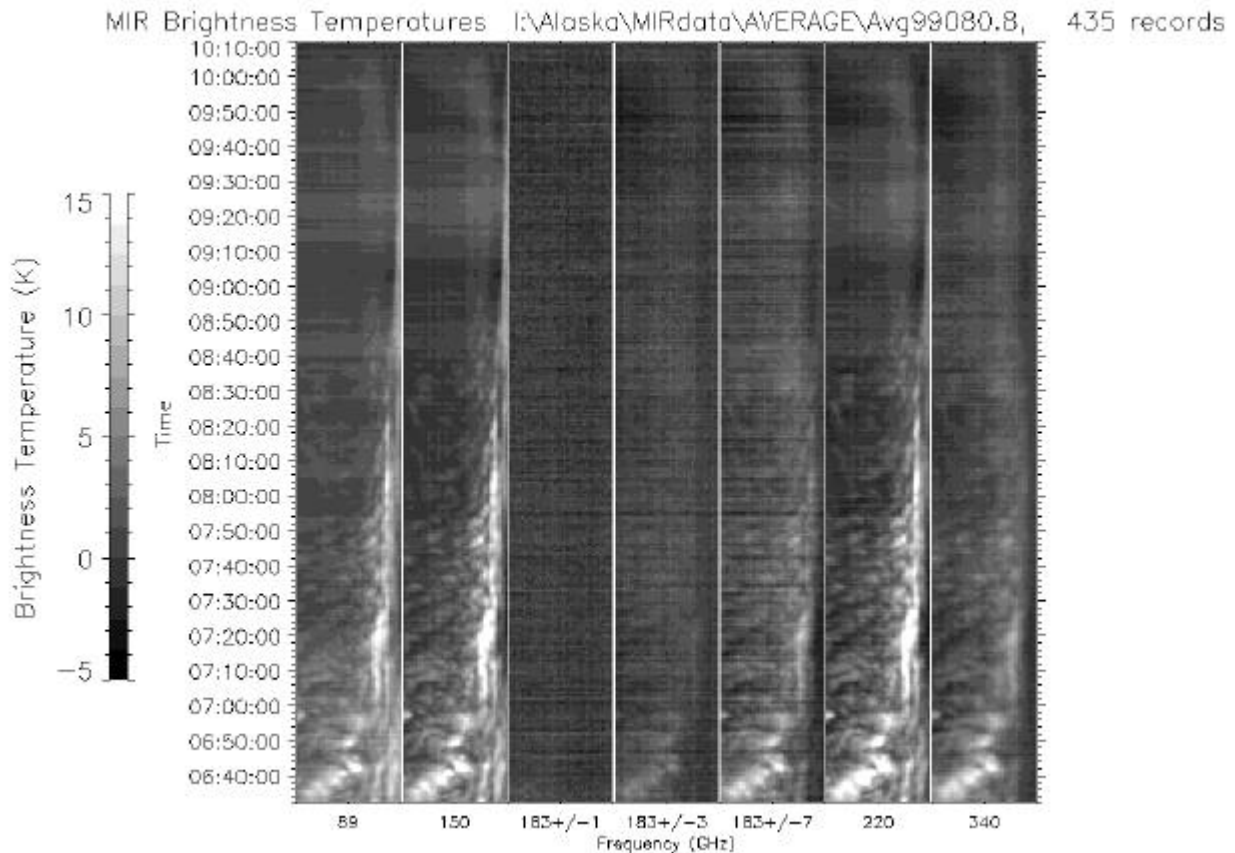


Figure 4. The above images show brightness temperatures with the baseline values subtracted measured by the seven channels of the MIR on March 14. The instrument scans from -80 to +20 degrees in elevation, hence the brightening to the right-hand side of the images. The figure reveals the presence of clouds in the MIR field of view.

Conclusions

The PWV at the NSA/AAO varied from 1.7 mm to 5.5 mm during the course of the experiment. The response of the MIR channels to changes in vapor during these cold and dry events was at times 50 times as large as those from the ARM MWR. We intend to analyze previous radiosonde data to determine the percentage of time that a MIR-like instrument can improve the PWV retrievals over those of the MWR. The signatures of the millimeter and sub-millimeter channels also showed promise in

determining characteristics of arctic winter clouds. More information about this experiment may be found at <http://neptune.gsfc.nasa.gov/~per>.

References

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