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Data Set Description:
PI: Dr. Axel Murk
Instrument: MIAWARA
Site(s): Bern, Zimmerwald, Switzerland
Measurement Quantities: Water vapor profile

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Reference Articles:
Bell, A., Sauvageat, E., Stober, G., Hocke, K., & Murk, A. (2025). Developments on a 22 GHz microwave radiometer and reprocessing of 13-year time series for water vapour studies. *Atmospheric Measurement Techniques*, 18(2), 555-567. https://doi.org/10.5194/amt-18-555-2025

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Deuber, B., Haefele, A., Feist, D. G., Martin, L., Kämpfer, N., Nedoluha, G. E., Yushkov, V., Khaykin, S., Kivi, R., & Vömel, H. (2005). Middle Atmospheric Water Vapour Radiometer (MIAWARA): Validation and first results of the LAPBIAT Upper Tropospheric Lower Stratospheric Water Vapour Validation Project (LAUTLOS-WAVVAP) campaign. *Journal of Geophysical Research*, 110(D13), D13306. https://doi.org/10.1029/2004JD005543

Instrument Description:
The instrument is a microwave spectrometer observing atmospheric thermal emission at 22.235 GHz from the ground. It consists of a heterodyne receiver and high resolution digital FFT spectrometer, and records the spectral lineshape of a water vapor rotational transition at an elevation angle of 20 degrees.

The spectra are calibrated by tipping curves and a balancing calibration in zenith direction. The instrument uses a corrugated feed horn with an half power beam width of 6 degrees, a low noise amplifier with about 180K receiver temperature, and a digital FFT spectrometer with 1 GHz bandwidth and 16384 channels of 62kHz resolution (Acquiris AC240). Only 100 MHz of the bandwidth are used for the water vapor retrieval, while the rest of the bandwidth can be used to characterize the spectroscopic baseline of the instrument. Observations continue 24 hours a day whenever weather permits. A water vapor mixing ratio profile as a function of altitude is retrieved from each of the measured spectra. Averages of the spectral data
every 24 hours are processed routinely, and the retrieved profiles are supplied to the NDACC database.

Algorithm Description:
A water vapor mixing ratio profile (ppmv) from 30-75 km is retrieved for every 24 hours using an optimal estimation retrieval method. We have attempted to include only those days on which the retrievals are judged to be most reliable, thus a number of days on which measurements were taken have not been included. The daily temperature and pressure profiles from ECMWF are used for the retrieval.

Expected Precision/Accuracy of Instrument:
Both the precision and accuracy are ~7% for most of the data. The total measurement error (assuming the terms add in quadrature) is therefore ~10%. The measurement error is somewhat smaller for more recent measurements, and somewhat larger for the earliest measurements. The 1992 Table Mountain measurements show smaller mixing ratios than subsequent measurements and have a calibration uncertainty of ~10%. WVMS2 measurements from 1994 to the present, and all WVMS3 measurements are made with an additional set of 50 kHz filters, and therefore should have better high altitude retrievals

Instrument description and History:
The MIddle Atmospheric WAter vapor RAdiometer (MIAWARA) measures the intensity of the pressure broadened emission of H2O molecules at a center frequency of 22.235GHz (Kämpfer et al., 2012).
Atmospheric pressure decreases exponentially with altitude and this information is reflected in the H2O line shape. The obtained spectra are used to retrieve water vapor profiles by means of radiative transfer calculations and the Optimal Estimation Method as described in Rodgers (2000) using the

retrieval software package ARTS/qpack (Eriksson et al., 2005; Buehler et al., 2005), and the new pyarts package using ARTS verions 2.6 (Buehler et al., 2025). MIAWARA is continuously operated on the roof of the building for Atmospheric Remote Sensing in Zimmerwald (46.88°N,7.46°E,907m a.s.l.), which is close to Bern, since September 2006. The reason why we only use data since April 2007 is a major upgrade of the instrument from optoacoustic to Fast Fourier Transform (FFT) spectrometry. In the course of this upgrade the spectral resolution increased from 25600 to 61kHz.

MIAWARA is part of the Network for the Detection of Atmospheric Composition Change (NDACC) and was initially built in the year 2002. The first water vapor radiometer for the middle atmosphere built at  the IAP is the MIddle Atmospheric WAter vapor RAdiometer (MIAWARA). It was built in 2002 and was operating on the roof of the building for Exakte Wissenschaften (ExWi) of the University of Bern until the end of 2006, when it was moved to the observatory in Zimmerwald, a rural area outside of Bern. MIAWARA is part of the Network for the Detection of Atmospheric Composition Change (NDACC). In the first years of operation, the detection device of the radiometer was an Acousto-Optical Spectrometer (AOS) with a spectral resolution of 600 kHz. In March 2007, the AOS was replaced by an Agilent Acqiris digital Fast Fourier-Transform Spectrometer (FFTS) with a spectral resolution of 61 kHz, which extended the upper measurement limit from approximately 60 km with the AOS to 75 km with the FFTS. The bandwidth of the FFTS is 1 GHz. The temporal resolution of the retrievals ranges from 1 hour during favorable conditions to 24 hours during the least favorable conditions, i.e., during hot periods with high opacities. MIAWARA has a rain cover which automatically closes in case of precipitation. The viewing direction of MIAWARA is towards the North to avoid crossings of the sun with the antenna beam. Measurement principle and Retrieval algorithm:

The 22 GHz water vapor line emission from the middle atmosphere is relatively weak. The difference in brightness temperature between the peak of the line shape and the wings is approximately 0.3 K. To obtain a sufficiently high signal-to-noise ratio, the individual measurements need to be integrated until the integrated spectrum reaches a noise level of 0.01 K or less. This is often reached within a six-hour integration time, but retrieval are made with a 24 hour integration time to allow more homogeneity in the dataset and ensure retrieval quality. To accurately measure such weak emission lines, very precise radiometers are required. However in reality, the measured spectrum is always affected by imperfect microwave components that lead to reflections within the signal chain, by frequency dependent antenna patterns or by nonlinearities of the signal detection device, i.e., the spectrometer. Gain non-linearities can be mitigated through a balancing calibration, whereby the difference between the sky an a reference signal with an average intensity approximately equal to the line signal is calibrated. The line measurement, i.e., the actual measurement of the water vapor emission line, is taken at a zenith angle of approximately 70 degrees. The reference signal, i.e., the signal to be subtracted from the emission line measurement, is a measurement of the sky in zenith direction including a small piece of microwave absorber, hereafter called the reference absorber, within the antenna beam. The reference absorber is needed in order to obtain the same average intensity with the reference signal as the line signal, because the pure sky measurement at zenith direction is weaker than at a zenith angle of 70 degrees. The zenith angle of the line measurement is constantly adjusted to match the average intensity of the reference signal. The Optimal Estimation Method (OEM) is used to retrieve vertical profiles of atmospheric trace species or temperature from ground-based microwave measurements.