RETRIEVAL OF TROPOSPHERIC WATER VAPOUR PROFILES BY USING SPECTRA FROM A MICROWAVE SPECTRO-RADIOMETER AT 22 GHZ

René Bleisch and Niklaus Kämpfer

Institute of Applied Physics, University of Bern, Sidlerstr. 5, 3012 Bern, Switzerland

ABSTRACT

The Institute of Applied Physics, University of Bern operates the groundbased microwave radiometer MIAWARA (Middle Atmospheric Water Vapour Radiometer), measuring the 22 GHz water vapour line. The operational retrieval delivers profiles of the water vapour volume mixing ratio (vmr) in the middle atmosphere by using the optimal estimation method (OEM).

Additionally, tipping curve observations are used to retrieve tropospheric water vapour vmr profiles with reduced vertical resolution.

We present an approach to improve the performance of the tropospheric retrieval by using external informations (e.g. Ceilometer observations) as additional retrieval constraints in the OEM-retrieval.

1. INTRODUCTION

The Middle Atmosphere Water Vapour Radiometer (MIAWARA), operated by the Institute of applied physics, University of Bern is installed at Zimmerwald observatory in the south of Bern (46.88°N, 7.47°E, 905 m a.s.l.) and measures the pressure broadened 22 GHz emission line of water vapour. These observations are used for operational retrievals of middle atmospheric water vapour volume mixing ratio (vmr) profiles. Further, the total power spectra from tipping calibration are used to retrieve tropospheric water vapour profiles [1].

To improve the performance of the tropospheric retrieval algorithm, additionally available external information from in-situ observations (e.g. the surface value from the nearby meteo station) could be used to further constrain the retrieval [2].

Assuming a relative humidity of 100% at cloud base height, cloud informations from a ceilometer and an infrared sensor installed next to the instrument could be used as a further possible constraint (as e.g. done in [3]).

2. RETRIEVAL OF WATER VAPOUR PROFILES

From the observed spectra, water vapour vmr profiles are retrieved according the optimal estimation method (OEM, [4]) using the Arts/Qpack software-package [5, 6].

In the frame of NDACC (Network for the Detection of Atmospheric Composition Change), middle atmospheric water vapour profiles are retrieved operationally from balanced spectra, delivering profiles from $\sim$25-80 km (Fig. 1, top) with a time resolution of hours to days [7, 8]. For this retrieval, only a small part of the available bandwidth is used ($\sim$300 MHz around the line center).

Additionally, total power spectra at 60° elevation (derived from tipping curve observations) are used to retrieve tropospheric water vapour vmr profiles (Fig. 1, bottom). Thereby nearly the entire available bandwidth of 1 GHz is used.

The a priori profile is estimated from a monthly climatology of balloon soundings launched at Thun (20 km from the instrument location) during a campaign between June 2007 and June 2008, combined with the actual surface value from Zimmerwald meteo station.

This retrieval delivers profiles from $\sim$2 to 7 km with reduced vertical resolution (retrieval grid resolution: $\sim$1 km, real resolution: 4-5 km) [1, 9]. The resulting profiles correspond well with operational balloon soundings launched in Payerne (40 km from the instrument location) with a small wet bias of 10-20%.

In contrast to the retrieval of profiles in the middle atmosphere, the temporal resolution of tropospheric profiles is higher, as the noise level is lower. It is limited by the intervall of tipping curves to 1 spectrum each 20 minutes. Typically, 6-8 spectra are averaged corresponding to a temporal resolution of $\sim$2 hours.

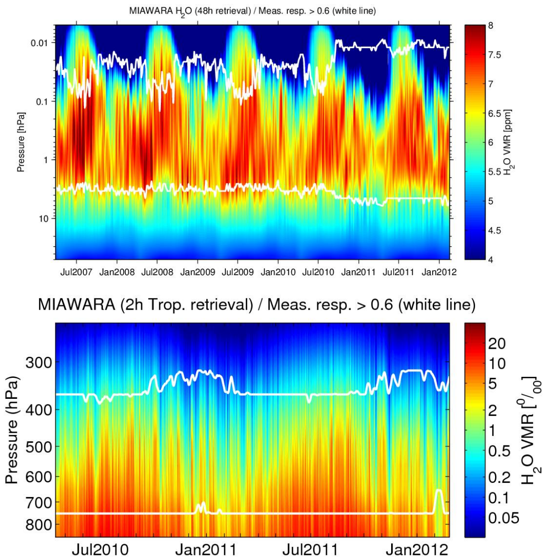

Figure 1. Timeseries of middle atmospheric retrieval (top, courtesy D. Scheiben) and tropospheric retrieval (bottom). The white lines define the boundary in altitude where the measurement response is above 0.6.

3. IMPROVING THE TROPOSPHERIC RETRIEVAL BY USING EXTERNAL INFORMATION AS ADDITIONAL CONSTRAINTS

To improve the performance of the tropospheric retrieval algorithm, additionally available external information from in-situ observations could be used to further constrain the retrieval [2]. Possible candidates are e.g. the surface value from the nearby meteo station or cloud informations from a ceilometer (as the relative humidity of clouds is always close to 100%).

As in such a case, the true value at a certain altitude is known, a "hard" constraining of the retrieved profile value at this altitude to the measured true value is desirable. However, such a fixing of the retrieved profile to a known value at a certain altitude (in the following called "fixed-point") is not initially foreseen by OEM-retrievals.

Hence an approach was developped to introduce "hard" constraints into optimal estimation retrievals by adapting the a-priori covariance matrix and in the following the retrieval grid, presented in [2]. Thereby the standard deviation at the altitude of the fixed-point is set to a low value (1%), which is low enough to ensure a fixing to the given value and high enough to prevent singularities. To prevent delta-peak like features in the standard deviation and unrealistic strong gradients in a-priori and retrieved profile, we propose to omit all levels of the retrieval grid which are closer to the fixed-point altitude than a certain vertical distance (500 m in the tests).

The approach was first applied on synthetic spectra derived from balloon soundings, where the cloud base (derived from the same balloon soundings) was used as fixed-point. Afterwards, the approach was also applied on real MIAWARA spectra using cloud informations from an infrared sensor attached to the instrument and a ceilometer which is also located at Zimmerwald observatory.

The simulated retrievals showed that introducing fixed-points at cloud base height may significantly improve the retrieval performance as the shape of the retrieved profile is closer to reality. The method works for one or several cloud layers and for all liquid water clouds except for fog cases. However, dry layers and other small scale features are still not resolvable by the retrieval due to the limited vertical resolution.

Essentially, the method is also applicable to real MIAWARA observations using the cloud base height delivered by a ceilometer. Fig. 2 shows an example case from spring 2010. A first retrieval (retrieval 1) was performed using the standard a-priori profile, derived as already mentioned in section 2 (a-priori 1). In the following, a fixed-point was derived from Ceilometer and IR-sensor measurements assuming a relative humidity of 100%. The fixed-point was then added to the a-priori profile (a-priori 2) and another retrieval was performed. The resulting profile (retrieval 2) corresponds well with the balloon sounding profile from Payerne (snd).

The performance is comparable to the simulations, however the comparison with the balloon soundings from Payerne is affected by the lateral distance. On one side, the surface value at Zimmerwald may significantly deviate from the value observed by the sonde at the same altitude. On the other side, the cloud coverage may strongly differ between the two places. Additionally, the fixed-point in our approach is strongly driven by relative humidity. However, the maximum of RH normally doesn't coincide with the maximum of vmr. Hence this can lead to the fact that we don't seee the maximum of vmr at the right altitude.

Further the application of the method to real MIAWARA data is limited, as we are currently not able to determine the vmr value at fixed-point altitude with suitable precision. The crucial issue is the strong dependence of the vmr value on the cloud base temperature, which is not known directly.

It is determined from the measurements of the infrared sensor installed aside the MIAWARA horn antenna or interpolated from ECMWF reanalysis data. However both methods lack on precision, as the spatial resolution of ECMWF-data is coarse and for a precise determination of the cloud base temperature from the IR measurements, first of all the atmospheric contribution needs to be quantified.

Alternatively, temperature data from our new radiometer TEMPERA may be used to derive the cloud-base temperature with higher accuracy. TEMPERA operates in the frequency range between 50 and 60 GHz (emission line of O_2) providing a temperature profile for the troposphere and in a further step also for the stratosphere.

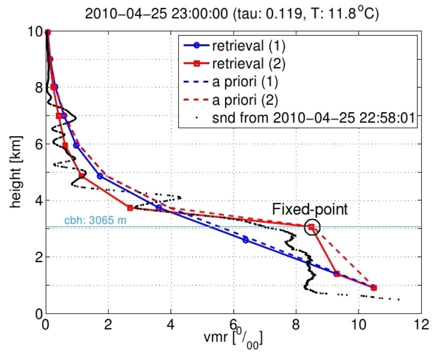

Figure 2. Example case of a tropospheric retrieval: retrieval 1 is the "standard" retrieval using the a-priori profile 1, retrieval 2 uses an a-priori profile complemented with the fixed-point derived from Ceilometer and IR-sensor measurements (a-priori 2). As comparison, a balloon sounding profile from Payerne is shown (snd).

4. SUMMARY AND OUTLOOK

MIAWARA is able to deliver water vapour vmr profiles from the surface to 7 km and from 25 to 80 km with reduced vertical resolution. Additional retrieval constraints, as e.g. the volume mixing ratio at cloud base height, can improve the performance of the tropospheric retrieval.

Both simulations using synthetic spectra calculated from balloon soundings and tests using real MIAWARA-spectra together with cloud-base height from a ceilometer and cloud-base temperature from an IR-sensor showed promising results.

Besides further improving the tropospheric retrieval algorithm, a major task in future will be to combine the tropospheric and middle atmospheric retrieval approach to one integrated retrieval setup and to fill the UT/LS gap with data from other sources.

ACKNOWLEDGMENTS

This work is part of a COST-action ES0604 project (WAVACS) and the GAW-plus project MIMAH. Balloon sounding data was kindly provided from MeteoSwiss, Payerne, Switzerland

REFERENCES

[1] René Bleisch, N. Kämpfer, and A. Haefele. Retrieval of tropospheric water vapour by using spectra of a 22 GHz radiometer. Atm. Meas. Tech., 4:1891–1903, 2011.

[2] René Bleisch and Niklaus Kämpfer. Adding constraints by in situ informations to optimal estimation retrievals of tropospheric water vapour profiles from microwave radiometry. J. Quant. Spectrosc. and Radiat. Transfer, 2012. under revision.

[3] Ulrich Löhnert, Susanne Crewell, O. Krasnov, E. O'Connor, and H. Russchenberg. Advances in continuously profiling the thermodynamic state of the boundary layer: Integration of measurements and methods. J. Atmos. and Ocean. Tech., 25:1251–1266, 2008.

[4] Clive D. Rodgers. Inverse methods for atmospheric sounding : Theory and practice. Series on Atmospheric, Oceanic and Planetary Physics, Vol.2. World Scientific, 2000.

[5] S. A. Buehler, P. Eriksson, T. Kuhn, A. von Engeln, and C. Verdes. Arts, the atmospheric radiative transfer simulator. J. Quant. Spectrosc. and Radiat. Transfer, 91:65–93, 2005.

[6] P. Eriksson, S. A. Buehler, C. P. Davis, C. Emde, and O. Lemke. ARTS, the atmospheric radiative transfer simulator, version 2. Journal of Quantitative Spectroscopy and Radiative Transfer, 112(10):1551–1558, July 2011.

[7] Beat Deuber, Niklaus Kämpfer, and Dietrich G. Feist. A new 22-GHz Radiometer for Middle Atmospheric Water Vapor Profile Measurements. IEEE Trans. on Geosc. and Rem. Sens., 42(5):974–984, 2004.

[8] A. Haefele, E. De Wachter, K. Hocke, N. Kämpfer, G. E. Nedoluha, R. M. Gomez, P. Eriksson, P. Forkman, A. Lambert, and M. J. Schwartz. Validation of ground based microwave radiometers at 22 GHz for stratospheric and mesospheric water vapor. J. Geophys. Res., 114:D23305, 2009.

[9] A. Haefele and N. Kämpfer. Tropospheric Water Vapor Profiles Retrieved from Pressure Broadened Emission Spectra at 22 GHz. J. Atm. and Oc. Techn., 27:167–172, 2009.