Advances in multi-instrument thermodynamic profile retrievals

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ABSTRACT

A novel synergetic retrieval approach that combines passive microwave radiometer and infrared spectrometer for temperature and humidity retrieval in cloudy sky conditions is presented. The simultaneous retrievable cloud parameters are cloud optical depth and cloud effective radius. The synergy of both instruments is most beneficial during low-liquid water path clouds (<100 gm^{-2}) clouds; here the sensitivity of solar and infrared radiation to changes in LWP is the highest.

1. IMPORTANCE OF SENSOR SYNERGY

The synergetic use of remote sensing instruments for retrieving profiles of atmospheric temperature and humidity as well as the water contents of liquid and frozen hydrometeors is still at a very early stage and far from being optimized. This is true for space-based as well as for ground-based applications. Most single instrument retrievals lack either sufficient spatial resolution or show a correlated sensitivity to multiple parameters and are thus unable to accurately retrieve them accurately, or both. This then leads to ambiguous and erroneous solutions. The synergistic idea is to find instruments that capture the desired parameters in a complementary way by using different spectral bands, active and passive methods, or scanning configurations. The advantage of a ground-based application is the possibility of continuous instrument monitoring (e.g., providing retrievals over the entire diurnal cycle) or updating the measurement configuration.

In this sense the deployment of the ARM Mobile Facility together with supplementary instruments from a wide variety of institutions participating in the COPS campaign [1] in the Black Forest, Germany during 2007 has provided a unique data set of active and passive remote sensing measurements for the application and evaluation of multi-instrument cloud property and thermodynamic profile retrieval methods. Data from four microwave radiometers (MWR) with frequencies between 21 and 150 GHz, as well as continuous infrared-spectrometer (AERI) data, cloud radar, ceilometer and micro-pulse lidar data provide valuable and complementary information on cloud parameters such as liquid water content, effective radius and cloud optical depth. Frequent upper air soundings (4 times daily) in combination with the profile sensitivity of the passive MWR and AERI sensors to temperature and humidity can be used to optimally retrieve these profiles as well as constrain the cloud property retrievals.

2. METHOD

The Integrated Profiling Technique [2] simultaneously determines temperature and humidity profiles in the lower troposphere together with macro- and microphysical properties of boundary layer clouds. In its original implementation, the IPT has been used to combine measurements of MWR, cloud radar, ceilometer and upper air sounding. Principally the method is suited for combining in an optimal way all on-site sensors bearing significant information content on the desired quantity, such as passive spectrally resolved microwave and infrared radiances, active remote sensing observations cloud radar and lidar, in situ observations and a priori data (e.g. from climatology). The IPT is an optimal estimation technique, and thus propagates the uncertainty in the observations and the sensitivity of the forward model to provide uncertainties in the retrieved properties (Fig. 1).

The latest IPT improvement includes the combination of MWR with high-spectral-resolution infrared observations from AERI. [3] have shown that high spectral resolution microwave and infrared observations have information on the vertical profile of temperature and water vapor during clear-sky cases. MWR and AERI sensors are both sensitive to the temperature profile due to the O_2 and CO_2 emission line characteristics, respectively, the humidity profile due to H_2O emission lines, and cloud microphysics in so-called atmospheric "windows".

Neither of these remote sensing approaches can match the vertical resolution of an upper air sounding,

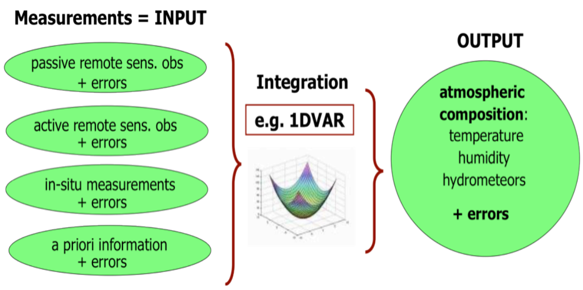

Fig. 1: *Schematic diagram of the Integrated Profiling Technique*

yet both methods are able to capture the broad features in the profiles to various degrees and provide data at significantly higher temporal resolution. [3] demonstrated that the spectral infrared data offer more information on the true profiles of temperature and humidity than the spectral microwave data. However, these results are for clear sky cases; a first analysis of the performance during a cloudy sky-situation is given here.

The nature of the problem demands that the cloud properties (i.e., effective radius and optical depth) are required for consistent temperature and humidity profile retrieval. Thus – together with reasonable a priori assumptions for all parameters at stake – we must additionally retrieve the effective radius (r_{eff}) and cloud optical depth (τ_c). Note that the AERI spectrum re-

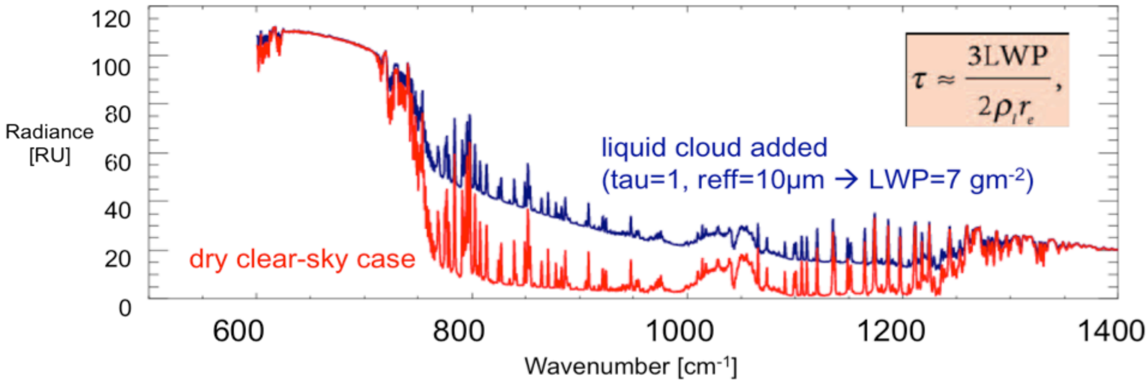

Fig. 2: *AERI simulation of a low-LWP cloud (blue) in contrast to a clear-sky simulation (red).*

corded is sensitive to the liquid cloud properties r_{eff} and τ_c (Fig. 2) when the liquid water path (LWP) is less than 60 g/m^2 [4], whereas MWR observations of liquid clouds are sensitive only to the LWP. However, the relationship τ_c=3LWP/($\rho_l r_{eff}$), which is valid if the extinction efficiency is in the geometric limit, directly relates MWR and AERI observations.

The data shown in the following is based purely on simulations and contains no real measurements, however it does show the potential of the IPT method.

3. EXAMPLE RESULT

The IPT is applied to each instrument separately, and the IPT has also been run incorporating measurements from both the AERI and MWR simultaneously (Fig. 3). The retrieval simulation results for a liquid cloud case with LWP = 50 gm^{-2}, r_{eff} = 10 µm and τ_c = 7.8 has been carried out. As can be observed in the retrieval applying only AERI data: a loss in humidity sensitivity above the cloud layer is explainable due to saturation effects resulting from the liquid cloud. Note that infrared-measurements at AERI wavelengths are completely saturated at LWP values around 60 gm^{-2} [4]. This also leads to the case that the IPT does not converge to a sensible r_{eff} value. In the MWR-only case, no sensitivity to the actual r_{eff} is observed and the humidity profile hardly shows any structure similar to the true profile. The best results are obtained when combining the MWR/AERI instruments – both for retrieving the r_{eff} and the humidity profile, where a humidity increase in the lower part of the troposphere is actually registered, however not exactly at the correct position.

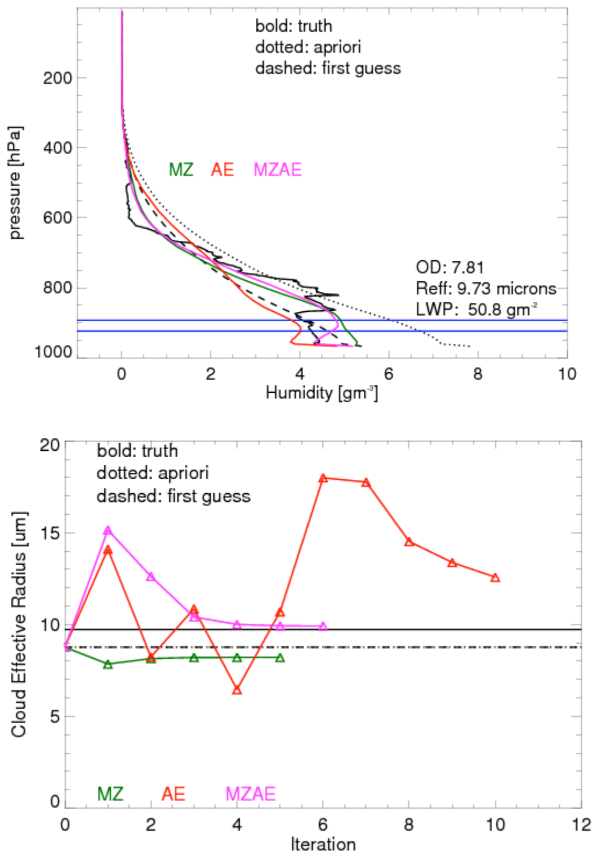

Fig. 3: *Retrieval simulation study of MWR (MZ), AERI (AE) and both (MZAE) instruments combined. The upper panel shows the true humidity profile, retrieved humidity profiles and a priori profile (climatology). The blue line shows the boundaries of a liquid cloud with the given microphysical and optical properties. The lower panel shows the retrieval convergence in terms of r_{eff} up to 10 iteration steps for the different instrument configurations. Additionally shown are truth and a priori values of r_{eff}.*

4. SUMMARY AND CONCLUSION

In future, we plan to apply the method to real COPS data and use the extensive supplementary data available at the AMF for evaluation purposes. Retrieval optimization will be performed on the basis of a "fast-forward" model in the infrared. As demonstrated for a single case study, we expect the combined MWR/AERI to be most beneficial in the LWP range of 30-60 gm^{-2}; at lower values we expect the AERI measurement to deliver the dominant information on cloud properties and at larger values we expect this for the MWR.

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