Use of integrated profiling techniques for testing radiative transfer schemes

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1. Introduction

Context: Numerical weather prediciton (NWP) and climate models strongly vary in the representation of the interaction of clouds and radiation. However, a precise modeling of this interaction may be a crucial ingredient for long-term climate applications as well as for convective precipitation forecast.

Aim of this study: The measurements of the ARM Mobile Facility (AMF) during the *Convective and Orographically-induced Precipitation Study* (COPS) in the Black Forest permit a detailed investigation of the interaction of clouds and radiation and the evaluation of radiative transfer schemes. We want to focus on the evaluation of the radiation scheme of the German Weather Services *COSMO-Model* which is also used within the regional climate model *CLM*.

2. Strategy

We will proceed in two steps. First the atmospheric state has to be derived from measurements taken by a combination of multiple wavelength active and passive remote sensing instruments. This is done with an *Integrated Profiling Technique* (IPT, *Löhnert* et al. (2007)). Secondly, the derived atmospheric profiles are used as input data for the radiative transfer calculations (Fig.1).

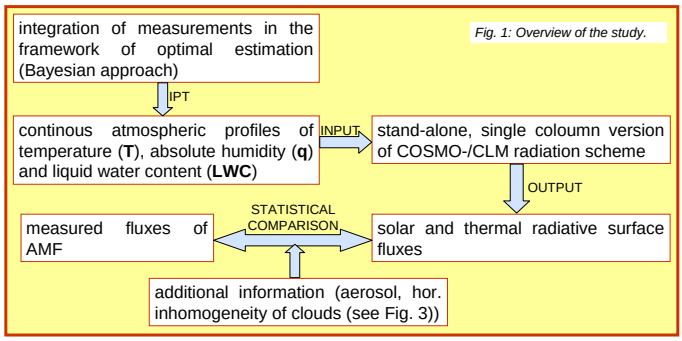

Fig. 1: Overview of the study.

3. Measurements

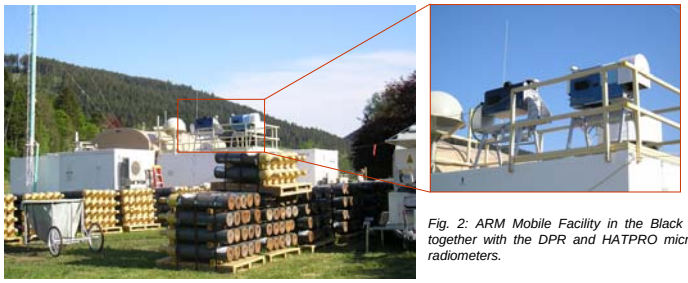

Fig. 2: ARM Mobile Facility in the Black Forest together with the DPR and HATPRO microwave radiometers.

The AMF (Fig. 2) is deployed in the village of Heselbach, Black Forest, from 1st April to 31st December 2007. Together with the multispectral radiometers of the University of Cologne, a set of long-term continous measurements will be provided to apply the IPT to in near realtime.

Baseline Instruments and Data:

- **Cloud Radar**: AMF W-Band (95 GHz) Cloud Radar ⇨ radar reflectivity factor Z, Doppler velocity v_d
- **Lidar**:
  - AMF Micropulse Lidar
  - Vaisala CT25K

  ⇨ extinction, cloud base height
- **Microwave Radiometer**:
  - HATPRO (Humidity And Temperature PROfiler): 2 bands (22.335-31.4 GHz, 51-58 GHz), 7 channels in each, availability of elevation and azimuth scans (see Fig. 3)
  - DPR (Dual Polarization Radiometer): 3 channels (90 GHz, two orthogonal polarisations at 150 GHz)

  ⇨ brightness temperatures TB
- **Radiosondes**

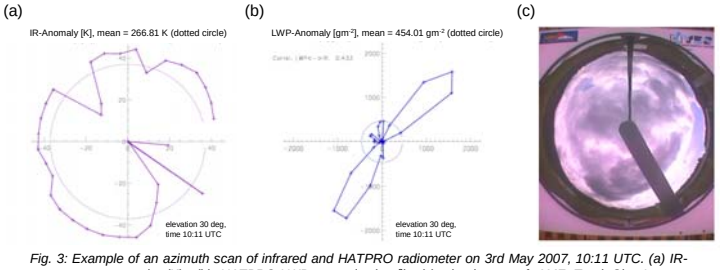

Fig. 3: Example of an azimuth scan of infrared and HATPRO radiometer on 3rd May 2007, 10:11 UTC. (a) IR-temperature-anomaly (K); (b) HATPRO-LWP-anomaly (gm^{-2}); (c) sky image of AMF Total Sky Imager. LWP reveals strong horizontal inhomogeneities.

4. Retrieval of atmospheric profiles

(A) Cloudnet Target Classification

The IPT can not be applied in cases of significant precipitation or to atmospheric columns containing melting layers. To identify those regions, the Cloudnet target classification product *(Illingworth* et al., 2007) developed at the University of Reading, UK, has been included in the IPT.

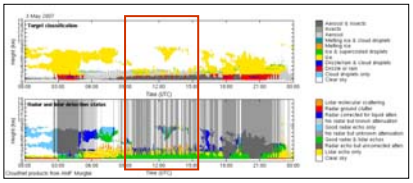

Fig. 4: Example of a target classification for the AMF site in the Black Forest: 3rd May 2007. Cloudnet Target Classification (top) and radar/lidar detection status (bottom). During day, strong radar signals occur due to insects. The red frame indicates the time slot to which the IPT has been applied (see Fig.5).

Core instruments for target retrieval:

- Cloud Radar → sensitive to large particles (rain, drizzle drops, ice particles, insects)
- Lidar Ceilometer → sensitive to higher concentrations of smaller particles (cloud droplets, aerosol)
- Microwave Radiometer
- Rain Gauge

+ radiosonde data or output of NWP model to account for the attenuation of the radar due to atmospheric gases and liquid water

(B) Integrated Profiling Technique

Given the brightness temperatures of the HATPRO and the DPR radiometer and the radar reflectivities, we want to retrieve physically consistent atmospheric profiles of T, q, and LWC. Physically consistent means that measurements are reproduced within the measurement accuracy, if a forward model F, namely a microwave radiative transfer operator (RTO) or a Z-LWC-relationship, is applied to the retrieved atmospheric state. To restrain the solution, a priori information of the the atmospheric state, e.g. radiosonde data, is added.

optimal estimation equation: $$\mathbf{x}_{i+1} = \mathbf{x}_i + \left(\mathbf{K}_i^T \mathbf{S}_e^{-1} \mathbf{K}_i + \mathbf{S}_a^{-1}\right)^{-1} \times \left[\mathbf{K}_i^T \mathbf{S}_e^{-1} (\mathbf{y} - \mathbf{y}_i) + \mathbf{S}_a^{-1} (\mathbf{x}_a - \mathbf{x}_i)\right] \quad (1)$$ with $$\mathbf{K}_i = \frac{\partial \mathbf{F}(\mathbf{x}_i)}{\partial \mathbf{x}_i} = \frac{\partial \mathbf{y}_i}{\partial \mathbf{x}_i}$$

$\mathbf{x}$=(**T**,**q**,$\log_{10}$(**LWC**))
$\mathbf{y}$=(**TB**,**Z**)

$\mathbf{x}_a$: a priori profiles of T, q, $\log_{10}$(LWC)
$\mathbf{S}_a$: a priori covariance matrix
$\mathbf{S}_e$: forward model error covariance matrix

forward model: $$\mathbf{F}(\mathbf{x}) = \begin{Bmatrix} RTO(\mathbf{T},\mathbf{q},\mathbf{LWC}) \\ a \cdot \mathbf{LWC}^b \end{Bmatrix} = \begin{Bmatrix} \mathbf{TB} \\ \mathbf{Z} \end{Bmatrix} = \mathbf{y} \quad (2)$$

iteration of Eq. 1 leads to an optimal estimation of the atmospheric state

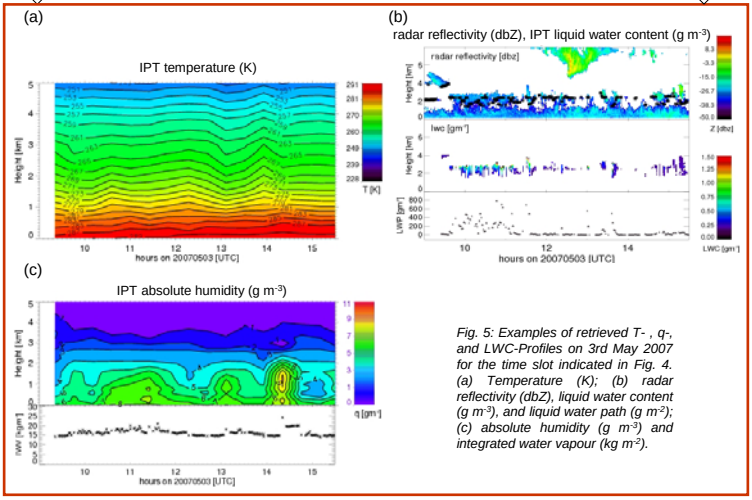

Fig. 5: Examples of retrieved T- , q-, and LWC-Profiles on 3rd May 2007 for the time slot indicated in Fig. 4. (a) Temperature (K); (b) radar reflectivity (dbZ), liquid water content ($g\ m^{-3}$), and liquid water path ($g\ m^{-2}$); (c) absolute humidity ($g\ m^{-3}$) and integrated water vapour ($kg\ m^{-2}$).

5. Summary and outlook

- application of the IPT to the long-term AMF / HATPRO / DPR measurements results in an extensive data basis for the evaluation of radiation schemes
  - start with the LM/CLM radiation scheme
  - further studies with the ECHAM scheme are planned
- inclusion of aerosol measurements in the radiation scheme
- azimuth scans of HATPRO radiometer provide information on horizontal cloud inhomogeneities → will be taken into account in the evaluation process
- currently: problems with target classification (signals presumably due to insects classified as ice or drizzle/rain)
- IPT will be extended to derive IWC and effective radii, for both liquid and ice clouds

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