Use of integrated profiling techniques (IPT) for testing radiative transfer schemes

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1. Introduction

Goal: The measurements of the ARM Mobile Facility (AMF) during the *Convective and Orographically-induced Precipitation Study* (COPS) in the Black Forest allow 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 CLimate Mode of the model (CCLM).

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. Though 3D effects will lead to some discrepancies between simulated and observed fluxes, statistical comparisons and auxiliary information, e.g. aerosol measurements, will allow an assesment of the model's radiative transfer scheme.

2. Measurements

The AMF was deployed in the Black Forest, Germany (N48°32', E08°24'), from April 1 to December 31, 2007. Together with data from the multispectral microwave radiometers of the University of Cologne, a set of long-term continuous measurements is available to apply the IPT to.

Baseline Instruments and Data for IPT:

- **Cloud Radar**: AMF W-Band (95 GHz) Cloud Radar → radar reflectivity Z
- **Microwave Radiometer**: → brightness temperatures TB
  - 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. 1)
  - DPR (Dual Polarization Radiometer): 3 channels (90 GHz, two orthogonal polarisations at 150 GHz)
- **Radiosondes** → a priori profiles of temperature T, q and LWC

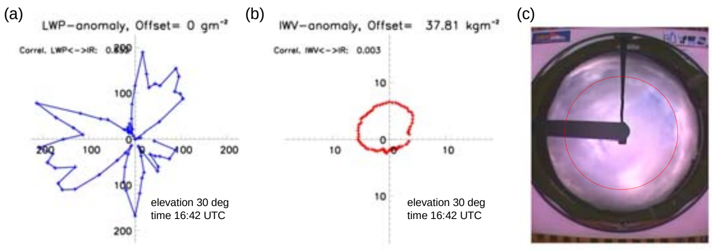


Fig. 1: Example of a 30 deg azimuth scan of HATPRO radiometer on August 9, 2007, 16:42 UTC. (a) HATPRO-LWP-anomaly (gm^{-2}); (b) HATPRO-IWV-anomaly (kgm^{-2}); (c) sky image of AMF Total Sky Imager.

3. Retrieval of atmospheric profiles

(A) Integrated Profiling Technique

- MWR **TB**s
- Radar reflectivity **Z**
- a priori information of **T**, **q**, **LWC**

→ **optimal estimation** with forward model

$$\mathbf{F}(\mathbf{T},\mathbf{q},\mathbf{LWC}) = \begin{Bmatrix} RTO(\mathbf{T},\mathbf{q},\mathbf{LWC}) \\ a\cdot\mathbf{LWC}^b \end{Bmatrix} = \begin{Bmatrix} \mathbf{TB} \\ \mathbf{Z} \end{Bmatrix}$$

→ continuous atmospheric profiles of **T**, **q** and **LWC** and error estimates

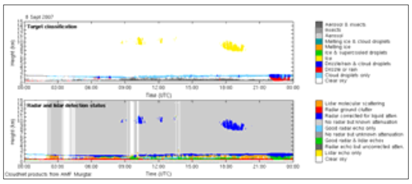
Fig. 2: Schematic overview of the IPT

The IPT is used to derive physically consistent atmospheric profiles of T, q, and LWC (see Fig. 2). Physically consistent means that measurements are reproduced within the measurement accuracy, if a forward model F is applied to the retrieved atmospheric state.

(B) 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. 3: Example of a target classification for the AMF site in the Black Forest: September 8, 2007. Cloudnet Target Classification (top) and radar/lidar detection status (bottom). During day, strong radar signals occur due to insects in the boundary layer.



4. Radiative transfer scheme

The results of the IPT are used as input data for a stand-alone, single-column version of the COSMO model radiative transfer scheme:

- developed by *Ritter and Geleyn* (1992)
- δ-two-stream approximation
- 3 solar and 5 thermal broadband spectral intervals
- homogeneous, coplanar scheme: no interaction between different vertical columns
- scattering, absorption and emission by cloud droplets, aerosols and gases in each part of the spectrum
- cloud optical properties are related to the cloud liquid water content

5. IPT results

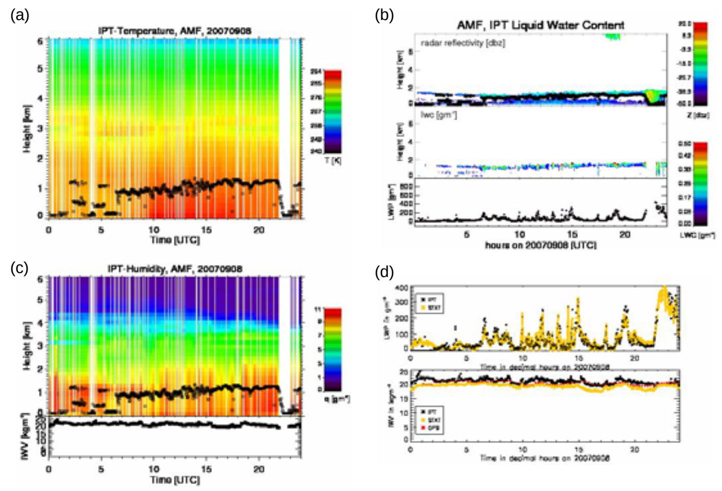


Fig. 4: Examples of retrieved T- , q-, and LWC-Profiles on September 8, 2007. (a) Temperature (K); (b) radar reflectivity (dbZ), liquid water content (g m^{-3}), and liquid water path (g m^{-2}); (c) absolute humidity (g m^{-3}) and integrated water vapour (kg m^{-2}); d) comparison of IPT-LWP (g m^{-2}) and IPT-IWV (kg m^{-2}) to a statistical HATPRO retrieval (yellow) and GPS measurements (red).

6. Results of radiative transfer simulations

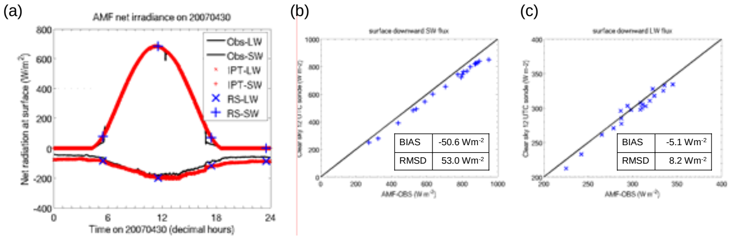


Fig. 5: Clear-sky surface flux comparisons. (a) surface shortwave (upper curve) and longwave (lower curve) net radiation fluxes on April 30, 2007: observed fluxes (black), fluxes calculated using IPT results (red) and fluxes calculated using radiosonde data (blue); downwelling shortwave (b) and longwave (c) fluxes calculated using 12 UTC clear sky radiosonde data (April-December 2007) plotted against observed fluxes.

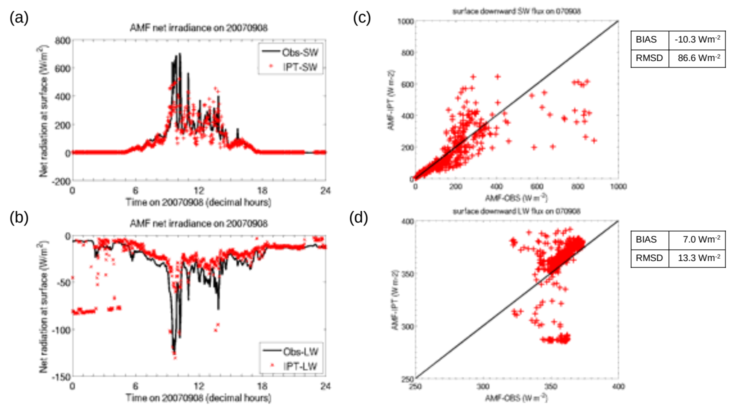


Fig. 6: Cloudy-sky surface flux comparisons on September 8, 2007. Surface shortwave (a) and longwave (b) net radiation fluxes: observed fluxes (black), fluxes calculated using IPT results (red); downwelling shortwave (c) and longwave (d) fluxes calculated using IPT results plotted against observed fluxes. The bias and RMSD values have been calculated omitting the 0-4 UTC results.

7. Summary and outlook

- IPT-LWP/IWV in good agreement with results from statistical retrieval and GPS measurements
- First simulations with radiative transfer scheme of COSMO model reveal:
  - clear sky cases: systematic underestimation of downwelling shortwave flux
  - cloudy case: tendency to underestimate the amount of downwelling SW flux at the surface and to overestimate the amount of downwelling LW flux at the surface
- Next step: application of the IPT to the whole AMF / HATPRO / DPR data set of 2007 and subsequent radiation calculations (including sensitivity studies)
- Application of a Z-N-LWC relationship
- Information on horizontal cloud inhomogeneities (provided for example by azimuth scans of the HATPRO radiometer) will be taken into account in the evaluation process

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References:
Löhnert, U., S. Crewell, O. Krasnov, E. W. O'Connor and H. W. J. Russchenberg, 2008: Advances in continously profiling the thermodynamic state of the boundary layer during LAUNCH 2005: Integration of measurements and methods. *J. Atmos. Oceanic Technol.*, in press
Illingworth, A. J., R. J. Hogan, E. J. O'Connor, D. Bouniol, M. E. Brooks, J. Delano, D. P. Donovan, J. D. Eastment, N. Gaussiat, J. W. F. Goddard, M. Haeffelin, H. Klein Baltink, O. A. Krasnov, J. Pelon, J.-M. Piriou, A. Protat, H. W. J. Russchenberg, A. Seifert, A. M. Tompkins, G.-J. van Zadelhoff, F. Vinit, U. Willn, D. R. Wilson, and C. L. Wrench, 2007: Cloudnet. *Bull. Amer. Meteor. Soc.*, **88**, 883-898
Ritter, B., and J.F. Geleyn, 1992: A Comprehensive Radiation Scheme for Numerical Weather Prediction Models with Potential Applications in Climate Simulations. *Mon. Wea. Rev.*, **120**, 303-325.

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