Towards a combined ground- and satellite-based retrieval of the atmospheric state using the Integrated Profiling Technique

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1. Introduction

Context: The Integrated Profiling Technique (IPT, Löhnert et al., 2008) has been successfully applied to derive profiles of temperature, humidity and liquid water content (LWC) by a Bayesian based combination of ground-based microwave radiometer (MWR), cloud radar and a priori informaton. Moreover, Löhnert et al. (2009) combined MWR measurements with spectral infrared measurements in the framework of the IPT to derive profiles of temperature and humidity for clear-sky cases.

Aim of this study: Within the project ICOS (Integrating Cloud Observations from Ground and Space – a Way to Combine Time and Space Information), we want to develop a flexible IPT which includes

- a combination of ground-based measurements (cloud radar, microwave and IR radiometer)
- satellite infrared brightness temperatures from Meteosat SEVIRI.

in order to retrieve profiles of temperature, humidity, LWC and effective radius (r_{eff}).

3. JOYCE – Jülich Observatory for Cloud Evolution

The JOYCE site is maintained by the University of Cologne together with the Research Center Jülich and hosts various remote sensing instruments for long-term cloud observations (Fig. 2).

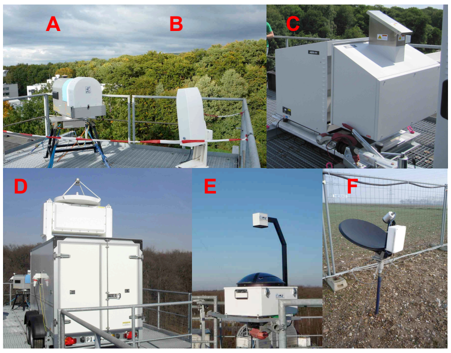

Fig. 2: JOYCE instrumentation:
(A) Scanning MWR HATPRO: 2 bands (22.335-31.4 GHz, 51-58 GHz), 7 channels in each; 2 broadband IR radiometer (10.2-11.9 μm, 11.1-12.8 μm)
(B) Ceilometer CT25K
(C) Spectral infrared radiometer AERI: two detectors (550-2000 cm⁻¹, 1800-3000 cm⁻¹) with 2500 channels in each
(D) Scanning cloud radar MIRA36s: 35.5 GHz
(E) Total sky imager
(F) Micro Rain Radar

Spatial information on the cloud field is available from TSI images and from the measurements of the scanning cloud radar and MWR (Fig. 3). Synchronized cloud radar and MWR scans are currently under development.

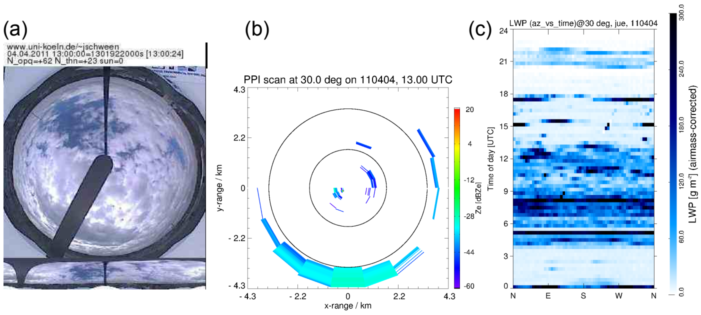

Fig. 3: (a) Total sky image on 4 April 2011 at 13 UTC; (b) Radar reflectivity (dBZ) of a PPI scan at an elevation of 30°. The inner (outer) circle is the 1 km (2 km) height isoline; (c) HATPRO LWP as a function of azimuth angle and time for an elevation of 30°.

The Cloudnet target categorization (Fig. 4) as well as further Cloudnet retrieval algorithms (Illingworth et al., 2007) will be applied to the JOYCE measurements.

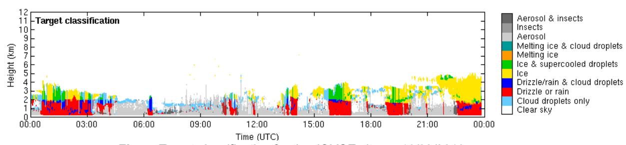

***Fig. 4**: Target classification for the JOYCE site on 16/09/2010.*

2. ICOS

The overall aim of ICOS is to add temporal and spatial information from satellite data to ground-based cloud observations at different supersites (Fig. 1). In addition to the extension of the IPT, we thus want to

- assess the spatial representativeness of ground based column observations using
  - → SEVIRI measurements, in particular the HRVIS channel
  - → scanning ground-based instruments
- determine the temporal evolution (history) of the air mass which transports the cloud:
  - → extend cloud tracking algorithm for flexible tracking of different cloud types
  - → combine tracking with operational MSG products
- analyse the radiative effect of the observed clouds using radiative transfer simulations and observations

***Fig. 1**: RGB composit of Meteosat-8 SEVIRI's 0.6, 0.8 and 1.6 μm channels on 2 June 2011 (12 UTC) for the domain of interest. The brightness temperatures at 10.8 μm have been used as an additional weighting factor. The red dots indicate the location of the supersites Cabauw (C), JOYCE (J), and Lindenberg (L), for which the IPT will be applied.*

4. Retrieval of atmospheric profiles

On the basis of the Cloudnet target categorization, the IPT combines measurements with a priori information to provide physically consistent atmospheric profiles and corresponding uncertainty estimates. The extended version will combine ground-based with satellite information.

optimal estimation equation

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

$\mathbf{x}$=($\mathbf{T}$, $\mathbf{q}$, $\log_{10}$($\mathbf{LWC}$), $\mathbf{r}_{eff}$)
$\mathbf{y}$=($\mathbf{TB}_{MWR}$, $\mathbf{Z}$, $\mathbf{I}_{IR}$, $\mathbf{TB}_{SEVIRI}$)

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

forward model

$$\mathbf{F}(\mathbf{x}) = \left\{ \begin{matrix} RTO(\mathbf{T},\mathbf{q},\mathbf{LWC}) \\ \frac{48\exp(6\sigma^2)}{\pi\rho_W} LWC \cdot r_{eff}^3 \\ FASTAERI(\mathbf{T},\mathbf{q},\mathbf{LWC},\mathbf{r}_{eff}) \\ RTTOV(\mathbf{T},\mathbf{q},\mathbf{LWC},\mathbf{r}_{eff}) \end{matrix} \right\} = \left\{ \begin{matrix} \mathbf{TB}_{MWR} \\ \mathbf{Z} \\ \mathbf{I}_{IR} \\ \mathbf{TB}_{SEVIRI} \end{matrix} \right\} = \mathbf{y}$$

5. Outlook

- currently, implementation of a flexible combination of radar, microwave and IR measurements in the IPT framework
- update of the IR forward model to improve the calculation time of the Jacobian
- evaluation of the retrieval on the basis of synthetic data using simulations of the COSMO-DE model with a spectral bin microphysics scheme (Grützun et al., 2008)
- information content studies for different measurement combinations

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