# Ground-based Remote Sensing of Cloud Thermodynamic Phase

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## 1. Introduction

**Goals**

- evolution of cloud microstructure
- phase transition and droplet growth and freezing mechanism
- warm and cold precipitation formation

**Applied Techniques**

Combined measurement of:

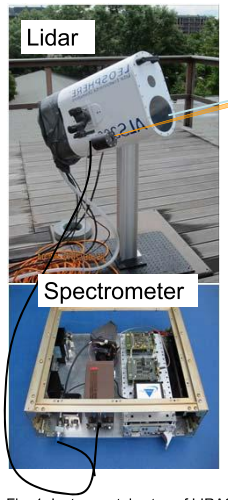
- spectral reflections from edges of convective clouds and depolarization

Retrieval of:

- vertical profiles of the thermodynamic phase
- effective radius ($R_{eff}$) based on 3D radiative modeling

## 2. Measurement Setup: LIRAS

**(LIdar and RAdiation System for cloud profiling)**




Tab. 1: Technical Specifications of LIRAS

| | Zeiss-Spectrometer | Lidar (Leosphere ALS300) |
|---|---|---|
| Wavelength (nm) | 350 -2000 | 355 |
| Spectral resolution (nm) | $FWHM_{VIS} \approx 3$<br>$FWHM_{NIR} \approx 16$<br>$\Delta\lambda_{VIS} \approx 0.8$<br>$\Delta\lambda_{NIR} \approx 5$ | - |
| Accumulation Time (s) | 1 | 10 -30 |
| Field of View (°) | 1 | 0.014 |
| Polarization | - | Vertical and Parallel |
| Scanning Device: Angular resolution: 1° | | |

Fig. 1: Instrumental setup of LIRAS

VIS: visible, NIR: Near InfraRed

## 3. Methods

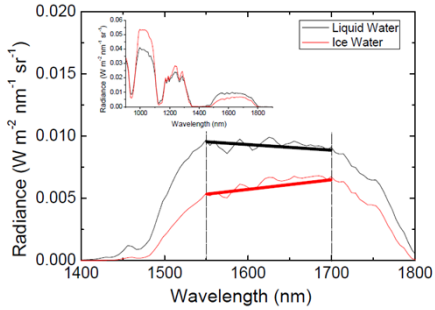



Fig. 2: Measured spectral radiance of cloud edges with ice water cloud particles and liquid water cloud particles in the NIR spectral range

### (a) Spectral Slope Method

- spectral slope of radiance $I$ differs for ice and liquid water in the wavelength range of 1.5 -1.7 µm
- ice index: $I_s = \frac{I_{1550\,nm} - I_{1700\,nm}}{I_{1700\,nm}}$

positive → ice
negative → liquid water

### (b) Depolarization Method

- linear depolarization ratio δ: ratio of the perpendicular and parallel polarized backscattered intensities
- single scattering approximation:

→ no change of polarization for spherical particles, but depolarization for ice crystals

- multiple scattering increases δ for liquid water clouds with increasing penetration depth:

→ the slope of δ has to be examined

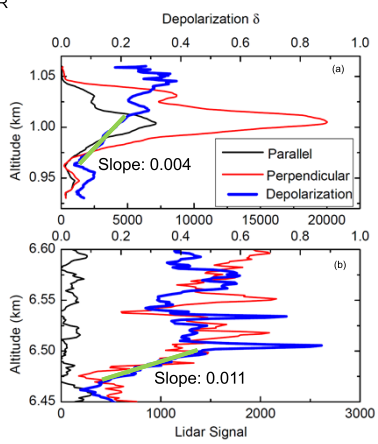



Fig. 3: Lidar signal and depolarization for (a) liquid water cloud and (b) ice cloud.

## 4. 3D Radiative Transfer Simulations

**M**onte **C**arlo **A**tmospheric **Ra**diative **T**ransfer **S**imulator MCARaTS

- forward-propagating Monte Carlo photon-transport algorithm

### (a) Monodisperse Clouds

- ice indices of clouds with identical microphysical parameters depend significantly on scattering angle

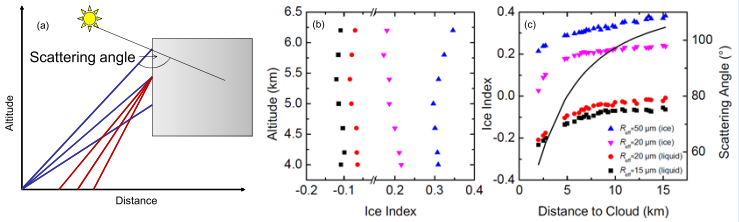



Fig. 4: (a) Viewing geometry, (b) ice index derived from one observing point, (c) ice index of one cloud area, derived from different observing points

### (b) Polydisperse Cloud

- clear separation between ice and liquid phase possible, even mixed phase area observable
- small ice particles (< 20 µm) might be misinterpreted as liquid particles, because of high SSA (>0.98)

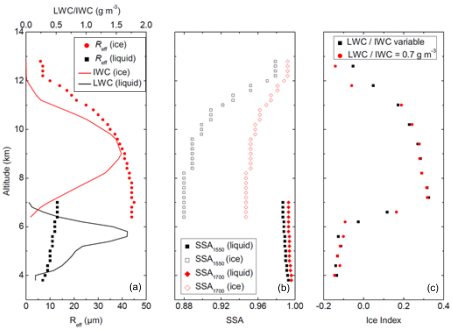



Fig. 5: (a) Vertical profile of $R_{eff}$ and water content, (b) single scattering albedo (SSA), and (c) ice index for one fixed geometry

## 5. Case Study

- observations of convective cloud field passing Leipzig on June 25th 2012
- measurements taken at altitudes between 0.9 and 2.8 km (geometry information from Lidar data)
- mixed phase (1), ice phase (2) and water phase (4) were observed
- maximum of ice index at (3) results from transmitted radiation of high convective cloud with ice phase which affects spectrum

Tab. 2: Comparison of ice indices and lidar depolarisation slopes; * $R_{eff}$ = 35 µm, ** $R_{eff}$ = 10 µm

| | Mixed Phase (1) | Ice Phase (2) | Liquid Phase (4) |
|---|---|---|---|
| Lidar δ-slope | 0.01 | 0.02 | 0.005 |
| Ice Index | 0.02 | 0.33 | -0.17 |
| Simulated Ice Index | - | 0.31* | -0.14** |

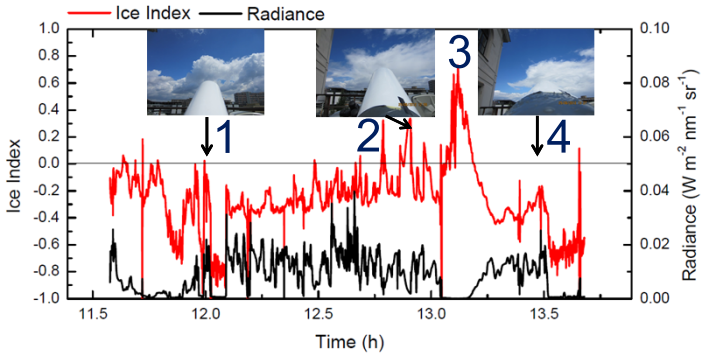



Fig. 6: Time series of spectral radiance at 1550 nm wavelength (black) and derived ice index (red).

## 6. Outlook

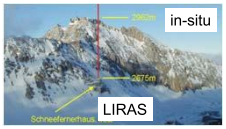



Fig. 7: Zugspitze

- field campaign in September 2012 (Zugpitze)
- in-situ measurements at the summit, remote sensing at Schneefernerhaus
- in addition also $R_{eff}$ retrievals

[1] Pilewskie, P. and Twomey, S, 1987: Discrimination of ice from water in clouds by optical remote sensing, *Atmos. Res.* **21**, 113–122.

[2] Ehrlich, A., E. Bierwirth, M. Wendisch, J.-F. Gayet, G. Mioche, A. Lampert and J. Heintzenberg, 2008: Cloud phase identification of low-level Arctic clouds from airborne spectral radiation measurements: Test of three approaches, Atmos. Chem. Phys. 8, 7493-7505.

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