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

2. Measurement Setup: LIRAS

(Lidar and Radiative System for cloud profiling)

<table>
<thead>
<tr>
<th>Zeiss-Spectrometer</th>
<th>Lidar (Leosphere ALS300)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (nm)</td>
<td>350 - 2000</td>
</tr>
<tr>
<td>Spectral resolution (nm)</td>
<td>FWHM = 3</td>
</tr>
<tr>
<td></td>
<td>FWHM = 16</td>
</tr>
<tr>
<td>Δλ_{\text{min}}</td>
<td>0.8</td>
</tr>
<tr>
<td>Δλ_{\text{max}}</td>
<td>5</td>
</tr>
<tr>
<td>Accumulation Time (s)</td>
<td>1 - 10 - 30</td>
</tr>
<tr>
<td>Field of View (°)</td>
<td>1 - 0.94</td>
</tr>
<tr>
<td>Polarization</td>
<td>Vertical and Parallel</td>
</tr>
<tr>
<td>Scanning Device: Angular resolution: 1°</td>
<td></td>
</tr>
</tbody>
</table>

3. Methods

(a) Spectral Slope Method
- spectral slope of radiances \( \lambda \) differs for ice and liquid water in the wavelength range of 1.5 - 1.7 \( \mu \)m
- index: \( I_{\lambda} = \frac{\lambda_{\text{1.555 \mu m}} - \lambda_{\text{1.725 \mu m}}}{\lambda_{\text{1.555 \mu m}}} \)
- positive \( \rightarrow \) ice
- negative \( \rightarrow \) liquid water

(b) Depolarization Method
- linear depolarization ratio \( \hat{\delta} \): 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 \( \hat{\delta} \) for liquid water clouds with increasing penetration depth:
  - the slope of \( \delta \) has to be examined

4. 3D Radiative Transfer Simulations

Monte Carlo Atmospheric Radiative Transfer Simulator
- forward-propagating Monte Carlo photon-transport algorithm

(a) Monodisperse Clouds
- ice indices of clouds with identical microphysical parameters depend significantly on scattering angle

(b) Polydisperse Cloud
- clear separation between ice and liquid phase possible, even mixed phase area observable
- small ice particles (\( \leq 20 \mu \)m) might be misinterpreted as liquid particles, because of high SSA (>0.98)

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 content at (3) results from transmitted radiation of high convective cloud with ice phase which affects spectrum

6. Outlook
- field campaign in September 2012 (Zugpilzte)
- in-situ measurements at the summit, remote sensing at Schneefernerhaus
- in addition also \( R_{\text{eff}} \) retrievals