Vertical distribution of ice crystals in Arctic mixed-phase clouds derived from airborne spectral radiation measurements

André Ehrlich\(^1\), Eike Bierwirth\(^1,2\), Manfred Wendisch\(^1\), Jean – François Gayet\(^2\), Guillaume Mioche\(^3\), Steffen Beirle\(^3\), Thomas Wagner\(^4\), Bernhard Mayer\(^4\)

\(^1\) Institute for Atmospheric Physics, Johannes Gutenberg University, Mainz, Germany
\(^2\) Laboratoire de Meteorologie Physique (LaMP), Université Blaise Pascal, Aubière Cedex, France
\(^3\) Max Planck Institute for Chemistry, Mainz, Germany
\(^4\) Institute for Atmospheric Physics, German Aerospace Center, Oberpfaffenhofen, Germany

1. Introduction

Arctic Boundary-Layer Mixed-Phase (ABM) Clouds

- Clouds (especially low-level) most important contributor to Arctic surface radiation budget
- Cloud radiative forcing is highly variable and depends on:
  - cloud water content,
  - fractional ice water content,
  - cloud particle size,
  - surface albedo,
  - aerosol

- Information on the vertical distribution of ice crystals is needed

Global coverage \(\xrightarrow{}\) Remote Sensing

2. SMART-Albedometer

(Spectral Modular Airborne Radiation Measurements system)

- Necessity for Arctic: \(\Delta R = 0.2\% - 1\%\) deviation in \(S_F\)
- Active system using servo motors
- Range: 6 nm Accuracy: 0.2% Time response 4 ms for angular velocities up to 3/s

Radiation Measurements

- 6 grating spectrometers
- 4 optical inlets for radiance \(L_i\) and irradiance \(F_i\)

Spectral Cloud Top Reflectance

\[ R(\lambda) = \frac{L_i(\lambda)}{L_{0i}(\lambda)} \]

3. ASTAR 2007 (Arctic Study of Tropospheric Aerosol, Clouds and Radiation)

- Campaign organized by Alfred Wegener Institute for Polar and Marine Research (AWI)
- Northerm cold of air outbreak initiated convection over the warm ocean
- Boundary layer mixed-phase clouds
- In situ measurements with (Polar Nephelometer, FSSP-100, CPI)
- Mixed-phase clouds showed liquid layer at cloud top precipitating ice below

4. Vertical Footprint of Reflectance Measurements

Air Mass Factor

- Characterizes photon path length \(L_i\) in the atmosphere and cloud
- Enhanced photon paths imply enhanced scattering and thus enhanced absorption by cloud particles

Box Air Mass Factor [2]

- Contribution of distinct cloud layers to the absorption
  - Assuming vertically homogenous clouds
  - Vertical footprint \(s_i\)

- Simulations with 3-dimentional Monte Carlo model, McArtim
- Cloud input of Case A
- Highest contribution close to cloud top (~10 m below)
- Differences between 1510 nm (high absorption)
  and 1710 nm (weak absorption)

- 1710 nm higher contribution from lower cloud layers
- 1510 nm higher contribution from cloud top layers

5. Observation of Backscatter Glory

- Single scattering feature of liquid water droplets
  - Backscatter angles larger than 175°
  - Indication for liquid water droplets at cloud top
  - Simultaneous observation of moderate ice inclusions

Simulation of Backscatter Glory [3]

- 3-dimensional Monte Carlo code MYSTIC
- Results converted into RGB colors (CIE system)

- Backscatter glory is reproduced by Case A and C, with less pronounced glory for Case C
- Mixed-phase cloud top layer (Case C) does not sustain the observations during ASTAR
- Case D dominated by ice crystals phase function (no mixture) located above the liquid water layer
- This case can be ruled out

6. Outlook

- Further systematic measurements are necessary
- Aircraft measurement campaign SoTPIC (Solar Radiation and Phase Discrimination of Arctic Clouds)

[References]