1 Motivation

Arctic boundary layer mixed-phase clouds

- Most frequent cloud type in the Arctic → Significant role in the Arctic energy budget
- Cloud phase determines cloud radiative forcing (cooling or warming)
- Cloud phase heterogeneity in up and downdrafts → Small scale phase spatial distribution may affect the large scale cloud radiative effects

2 Airborne hyperspectral imaging

Fig. 2: Eagle/Hawk hyperspectral cameras

Fig. 3: Eagle/Hawk measurement geometry (left) and top view of the instruments integrated in Polar 5 (right)

Fig. 4: Sample measurement of upward spectral radiance at 512 nm

3 Cloud phase discrimination

MIXED-PHASE CLOUDS

Can we retrieve the ice fraction from the phase index?

\[
IF = \frac{\text{TWP}}{\text{LWP} + \text{LWP}}
\]

Homogeneous

Mixed phase top

2 Layers

Phase index: \( I_i = \frac{100 \left( \Delta \lambda \right)_{\text{b}} \left( \Delta \lambda \right)_{\text{a}}}{\text{R}_{\text{eff}}} \)

Phase index: Homogeneous MPC

Phase index: Mixed-phase top MPC

Phase index: 2 Layers MPC

Fig. 6: Measurement campaigns over the Arctic (a).

Simulations of the cloud top reflectivity of two pure phase clouds over open ocean \( f_{\text{LWP}} = 14 \mu m, f_{\text{IWP}} = 25 \mu m, \tau = 6 \) (b). Phase index for different clouds over open ocean (c)

Fig. 7: Measurement campaigns over the Arctic (a).

Simulations of the cloud top reflectivity of two pure phase clouds over a snow surface \( f_{\text{LWP}} = 14 \mu m, f_{\text{IWP}} = 25 \mu m, \tau = 6 \) (b). Phase index for different clouds over a snow surface of grain size 100 \( \mu m \) (c)

Fig. 8: Slope phase index dependence on the vertical phase distribution, the cloud total water path and the liquid-ice partitioning

- Need for information on the vertical structure and on the total water content

4 Sensitivity of phase index in Arctic environment

Phase index over open ocean

Phase index over snow

1. Over open ocean

2. Over snow surfaces

PURE PHASE CLOUDS

3. Cloud top reflectivity

Fig. 1: Surface radiative forcing of mixed-phase clouds in dependence of the partition between liquid water and ice (ice fraction). Total water path was fixed at 100 g/m², with cloud droplet and ice crystal effective radius of 15 \( \mu m \) and 90 \( \mu m \)

Observations of small scale cloud phase distribution needed

5 Conclusions

- Capability for phase discrimination of pure phase clouds over open ocean and snow surfaces (but caution for optically thin clouds)
- Capability for detecting the presence of ice if TWP > 20 g/m². Otherwise, clouds are systematically classified as pure liquid water clouds
- Quantitative retrieval of ice fraction limited by knowledge on cloud vertical structure
- A priori information on the TWP and the cloud vertical structure (i.e. cloud phase vertical distribution) is needed

6 Outlook

- Further development of phase discrimination methods
  - Use of full spectral range (principal components analysis, spectral fitting)
  - Extend wavelength range (use of the absorption band around 2000 nm)
- ACLAUD (May–June, 2017)
  - AISA Eagle/Hawk
  - MiRAC (Microwave radiometer + radar)
  - AMALI (Lidar)
  - SMART albedometer (spectral solar irradiance)