Radiative effect of clouds at Ny-Ålesund, Svalbard, as inferred from ground-based remote sensing observations

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1) Outline

- Clouds strongly impact the available energy at the surface, at the top of the atmosphere as well as its vertical distribution within the atmosphere.
- Cloud radiative effect (CRE), i.e. the difference between the all-sky and clear-sky fluxes, strongly depend on the cloud macrophysical (e.g. frequency of occurrence, cloud vertical distribution) and microphysical (e.g. phase, water content, hydrometeor size distribution) properties.

Question: What is the radiative effect of clouds at the Arctic site Ny-Ålesund?

→ for the first time, the impact of clouds on the shortwave (SW) and longwave (LW) fluxes is estimated for Ny-Ålesund exploiting more than 2 years (06/2016 -10/2018) of continuous vertical cloud measurements at the German-French research station AWIPEV

2) Methodology

Retrieval of cloud macro- and microphysical properties

- based on Cloudnet target classification (Fig. 1; $\Delta t = 30$ s, $\Delta z = 20$ m), retrieval of liquid and ice water content and effective radii (see Table 1)

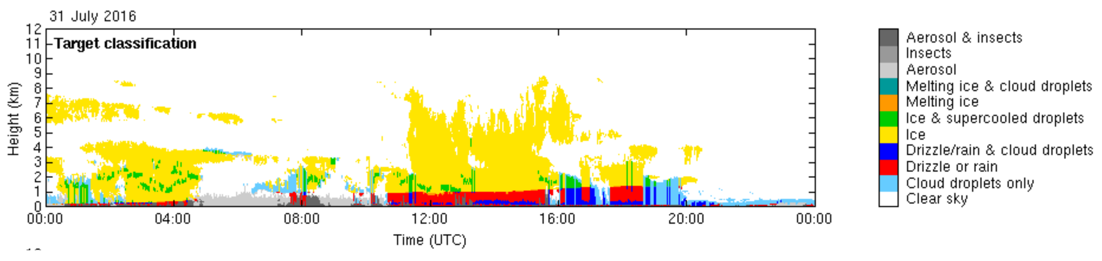

***Fig. 1**:* Example of Cloudnet target classification for 31 July 2016 at Ny-Ålesund.

***Table 1**:* Overview of applied cloud microphysical retrieval algorithms.

Cloud property	Retrieval method
liquid water content	**liquid only clouds**: Frisch et al. (1995) using radar reflectivity factor Z and liquid water path (LWP) from microwave radiometer; **mixed/multi-layer clouds**: scaled adiabatic LWC profile using LWP of MWR
liquid effective radius	**liquid only clouds**: Frisch et al. (2002) using Z and MWR LWP; **mixed/multi-layer clouds**: climatological value (5 µm)
ice water content	Hogan et al. (2006) using Z and temperature T
ice effective radius	Delanoë and Hogan (2010) using IWC and visible extinction coefficient α from Hogan et al. (2006); IWC and α are both functions of Z and T

Radiative transfer calculations with RRTMG

Thermodynamic profiles (GDAS model profiles + surface obs. combined with MWR IWV) | Retrieved cloud microphysical properties | Aerosol information (climatological AOD value from AERONET obs.; profile shape from lidar obs. at Ny-Ålesund; maritime clean aerosol) | Surface properties (albedo, surface temperature) from BSRN data

⇩ INPUT ⇩

Rapid Radiative Transfer Model RRTMG

⇩ OUTPUT ⇩

shortwave and longwave fluxes and heating rate profiles

RRTMG with clouds ⟷ impact of clouds ⟷ RRTMG without clouds

- **cloud radiative effect**

$$CRE = (SW\downarrow - SW\uparrow + LW\downarrow - LW\uparrow)_{all\ sky} - (SW\downarrow - SW\uparrow + LW\downarrow - LW\uparrow)_{clear}$$

3) Evaluation of simulated surface fluxes

- analysis period: 10 Jun 2016 - 5 Oct 2018
- 30-s radiative transfer calculations averaged over 10 min and compared to observations of the baseline surface radiation network (BSRN)
- reasonable agreement of simulated and observed surface downwelling fluxes (Fig. 2)
  - ➢ clear-sky: small bias and small interquartile range for both SW and LW surface fluxes
  - ➢ cloudy sky: small bias but larger interquartile range for SW fluxes due to 3-D effects, misclassification, uncertainties in cloud properties

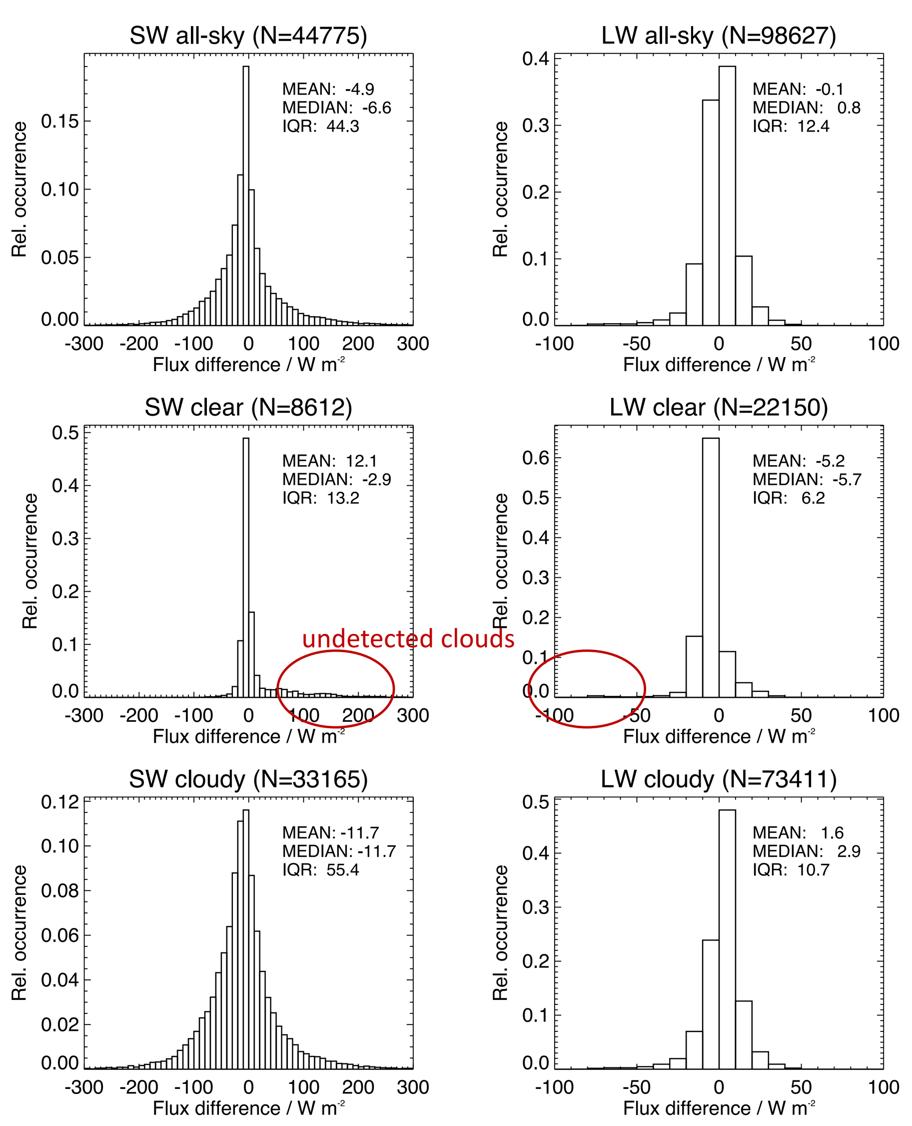

***Fig. 2**:* Histograms of simulated minus observed surface downwelling shortwave and longwave fluxes at Ny-Ålesund. Fluxes are averaged over 10 min. For clear (cloudy) subset, only 10-min intervals with all profiles being clear (cloudy) are considered.

4) Cloud properties and cloud radiative effect

Cloud properties and surface CRE

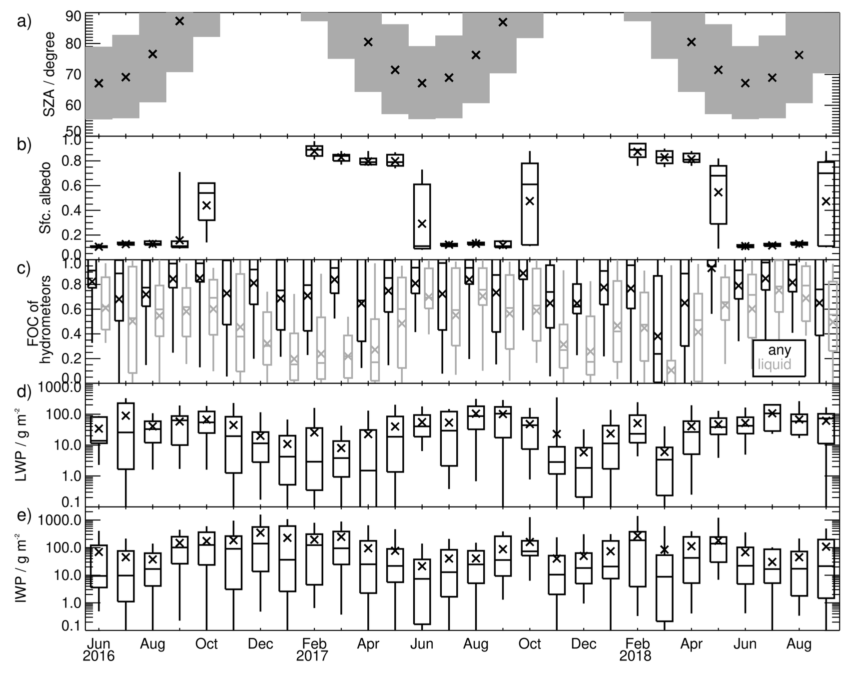

***Fig. 3**:* a) Range of daily minimum and maximum values of solar zenith angle (grey box) with mean monthly value indicated by an "x". Boxplots of daily mean values of b) solar surface albedo, c) frequency of occurrence (FOC) of any hydrometeors (black) and liquid droplets (grey) in atmospheric column, d) non-zero liquid water path (LWP) and e) non-zero ice water path (IWP).

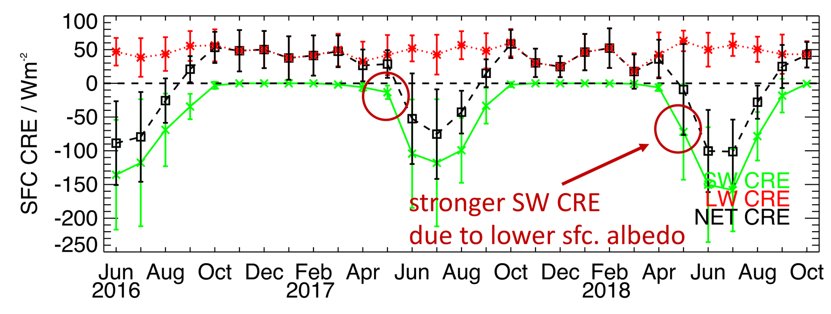

***Fig. 4**:* Monthly mean SW (green), LW (red), and NET (black) surface cloud radiative effect (CRE) at Ny-Ålesund calculated from the RRTMG simulations. Vertical bars indicate standard deviation of daily values.

- LW SFC CRE follows the seasonal cycle of FOC of liquid and LWP (Fig. 4)
- net SFC CRE positive from September to April/May and negative in JJA
- yearly averaged (2017) net SFC CRE is 12 Wm^{-2} → overall, clouds have a warming effect at the surface at Ny-Ålesund

Sensitivity of cloud radiative effect

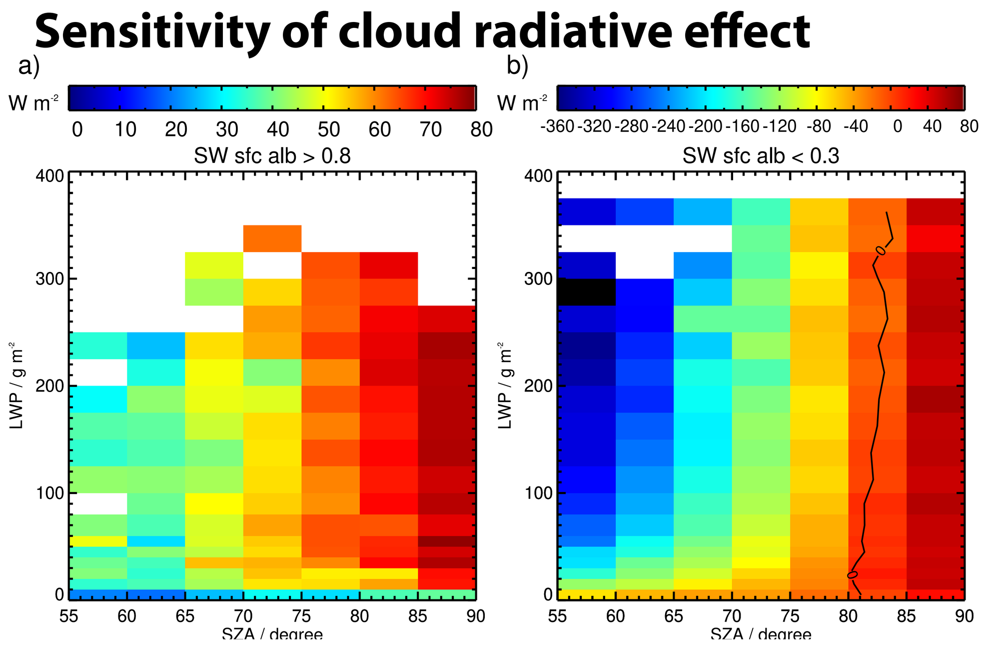

***Fig. 5**:* Net surface CRE as a function of LWP and SZA for a) surface albedo values > 0.8 and b) > 0.3. The analysis is based on hourly mean values. The 0 Wm^{-2} isoline is shown in b).

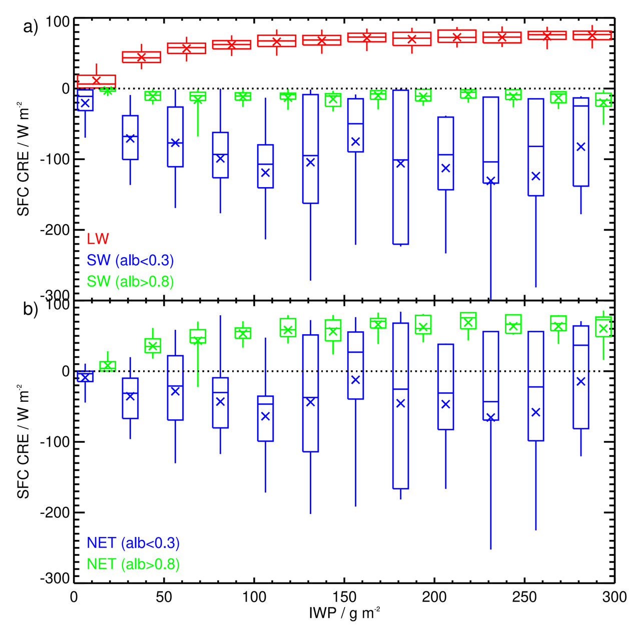

***Fig. 6**:* a) Longwave (red) and shortwave and b) net surface CRE as a function of IWP for cases with low (<5 gm^{-2}) LWP. The SW and NET CRE is calculated for SZA<90° and surface albedo <0.3 (blue) and > 0.8 (green), respectively. The analysis is based on hourly mean values.

- liquid containing-clouds: LW SFC CRE can be explained to a large extent by the LWP; SW and net surface CRE mainly depend on LWP, SZA and surface albedo (Fig. 5)
- ice clouds: asymptotic behavior of LW CRE(IWP) similar to liquid-containing clouds (Fig. 6); net CRE always positive for high surface albedo; for low surface albedo dependence on SZA and IWP with a warming effect only for SZA > 80°

Relative contribution of liquid and ice clouds to surface CRE

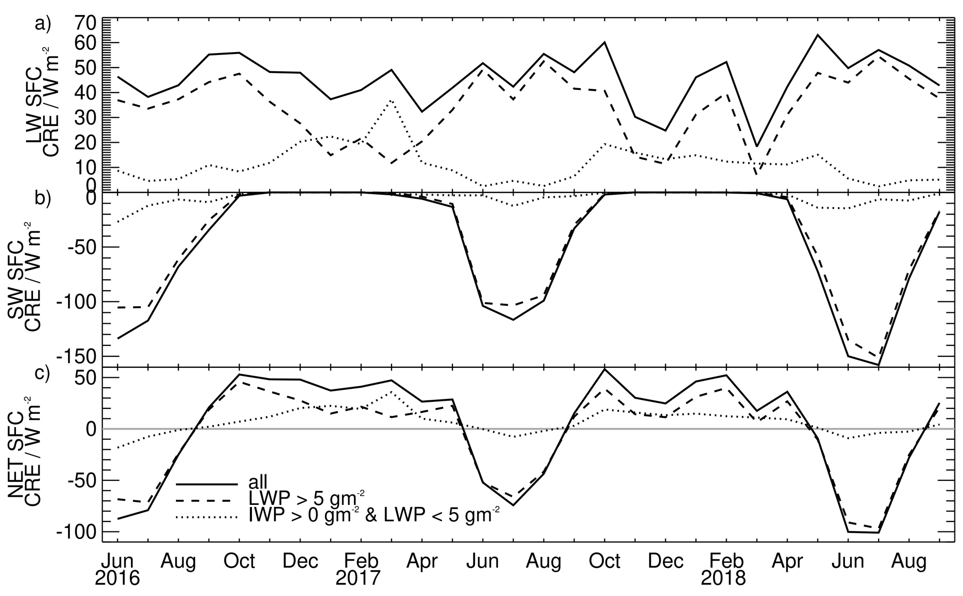

***Fig. 7**:* a) LW, b) SW and c) net monthly mean SFC CRE for all conditions (solid line), for cases with LWP>5 gm^{-2} (dashed line) and for cases with IWP>0 gm^{-2} and LWP<5 gm^{-2} (dotted line). The grey solid line in c) indicates the zero line.

- discriminating between "liquid" clouds with LWP > 5 gm^{-2} and "ice" clouds with IWP > 0 gm^{-2} and LWP < 5 gm^{-2}
- "ice" clouds can contribute up to 75% in the net SFC CRE during polar night (Fig. 7)
- winter: equal contribution of "liquid" and "ice" clouds to the monthly net SFC CRE
- summer: "liquid" clouds clearly dominate the signal and account for 70 to 98% of the net SFC CRE

5) Conclusions & Outlook

- For the first time, the cloud radiative effect has been characterized for the Arctic site Ny-Ålesund.
- Coming next: analysis of vertical redistribution of energy by clouds and how clouds impact the atmospheric heating rates at Ny-Ålesund
- cloud radar measurements will be continued at AWIPEV from summer 2019 onwards
  → expansion of time series by further years and analysis of interannual variability of CRE

References

Delanoë, J., and R. J. Hogan, Combined CloudSat-CALIPSO-MODIS retrievals of the properties of ice clouds, *Journal of Geophysical Research*, 115, D00H29, doi:10.1029/2009JD012346, 2010.

Frisch, A., C. Fairall, and J. Snider, Measurement of stratus cloud and drizzle parameters in ASTEX with a Kα-Band doppler radar and a microwave radiometer, *Journal of the Atmospheric Sciences*, 52, 2788–2799, 1995.

Frisch, A., M. Shupe, I. Djalalova, G. Feingold, and M. Poellot, The retrieval of stratus cloud droplet effective radius with cloud radars, *Journal of Atmospheric and Oceanic Technology*, 19, 835–842, 2002.

Hogan, R., M. Mittermaier, and A. Illingworth, The retrieval of ice water content from radar reflectivity factor and temperature and its use in evaluating a mesoscale model, *Journal of Geophysical Research*, 45, 301–317, 2006.

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