Alaskan clouds in a pan-Arctic context

Synthesizing Knowledge from Ground-based Observations

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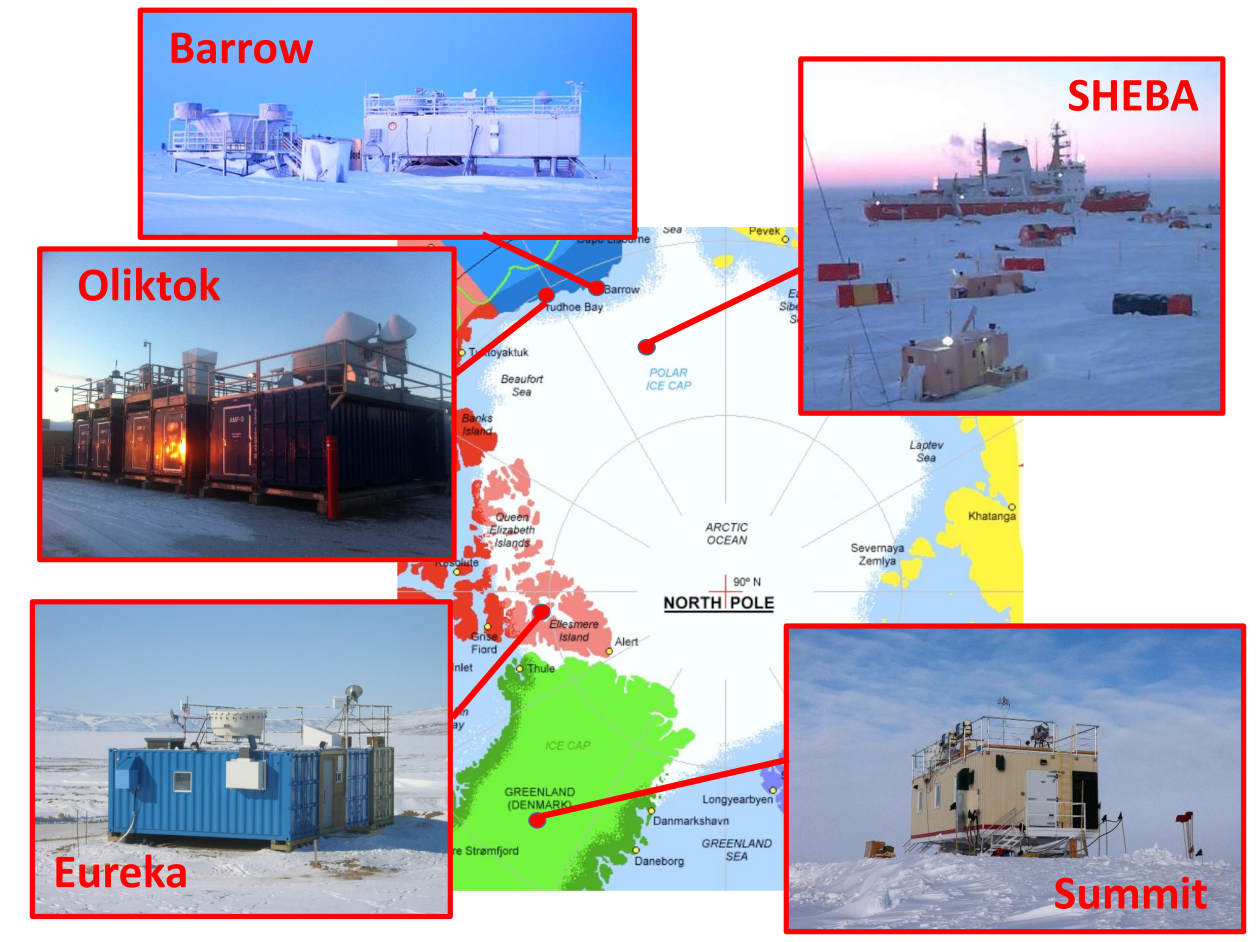
Question: How consistent are cloud processes across the Arctic?

1) Observations & Observatories



Five observatories across the Arctic have a consistent set of ground-based cloud instruments.

Data Sources

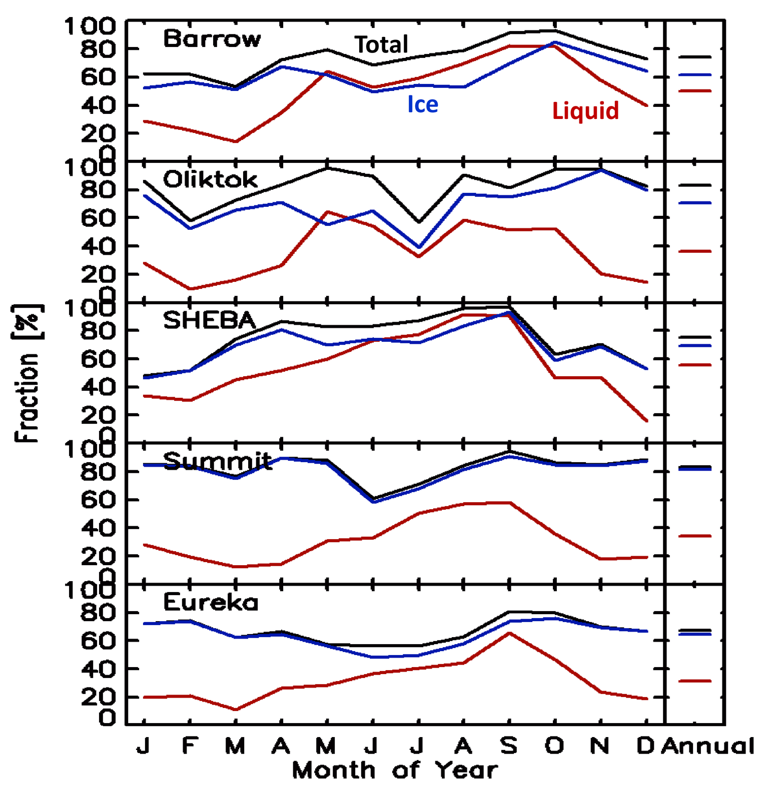
Cloud Phase – Radar, lidar, MWR, radiosonde (Shupe 2007)
Liquid Water Path – MWR (Turner et al. 2007)
Ice Water Path – Radar (Shupe et al. 2005)
Thermodynamics – Radiosonde
Cloud Radiative Effect – Broadband radiation

Note: Oliktok Point observations are adversely impacted by low-level radar artifacts; these lead to some false cloud identification.

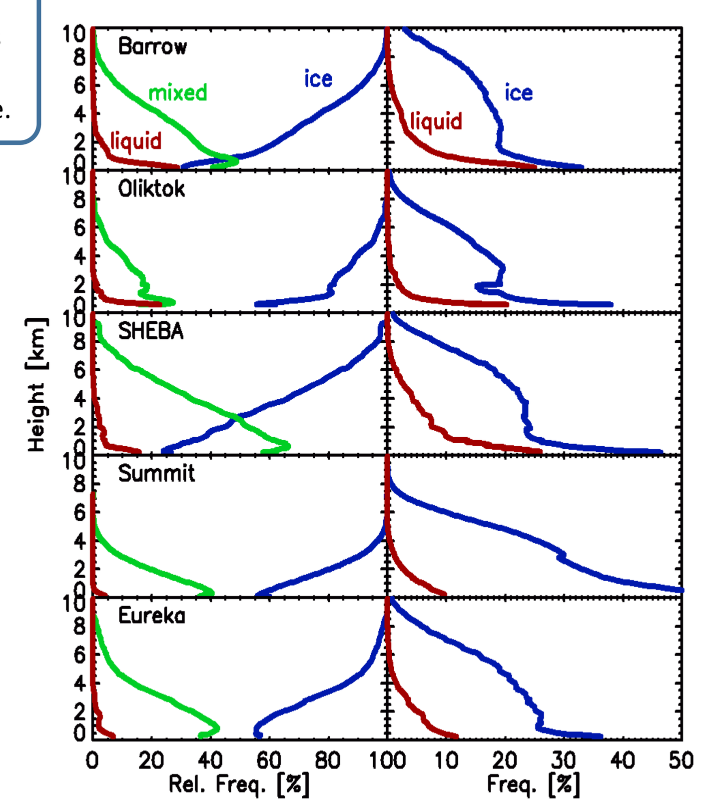
2) Phase Occurrence

Method

- Multi-sensor phase classification (Shupe 2007)
- Mixed-phase = Layer with liquid+ice OR liquid over ice
- When a panel includes only "ice" and "liquid," this refers to liquid or ice in any type of cloud.
- Temperature statistics within 1 hr of a radiosonde profile.



Monthly fractional occurrence of all clouds (black), ice in any cloud (blue) and liquid in any cloud (red)



[Left] Profiles of annual total relative fraction of ice (blue), mixed-phase (green), and liquid (red) clouds. [Right] Profiles of annual occurrence fraction of ice (blue) and liquid (red) in any cloud

Key Results

Barrow, Oliktok, SHEBA are similar due to proximity and meteorological similarity (some data limitations for Oliktok).

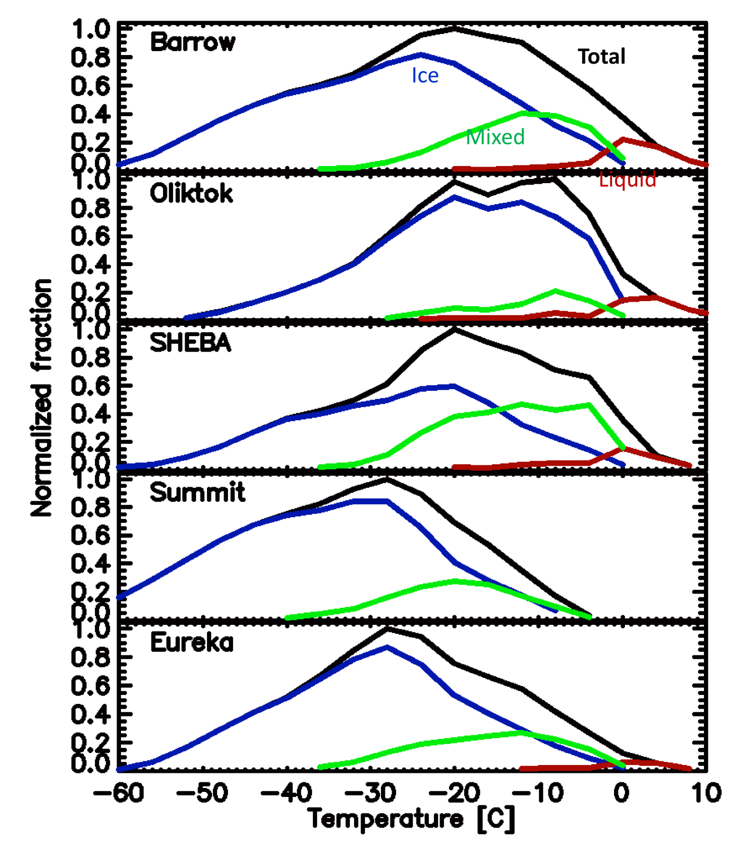
- Liquid occurs 50-60% of time
- Liquid occurs >20% of time below 1 km
- Liquid-only clouds occur, in part due to temperatures > 0C

Eureka is somewhat colder and Summit is the coldest (and both are relatively dry), causing significant differences in phase occurrence.

- Liquid occurs 30-35% of the time
- Liquid occurs <10% of time below 1 km
- Few liquid-only clouds occur

Similar occurrence fractions for different cloud types as a function of temperature at all sites, when taking the range of temperatures into consideration.

Annual distributions of cloud type as a function of temperature for all (black), ice (blue), mixed-phase (green) and liquid (red) clouds.



Conclusion

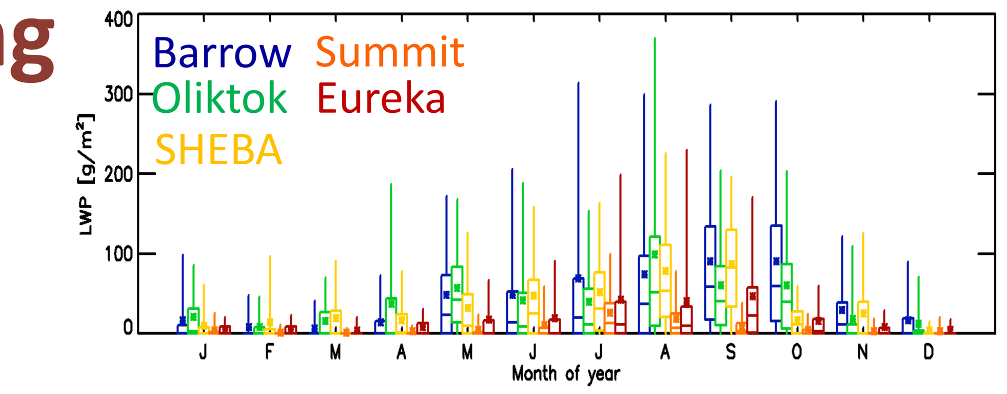
General pan-Arctic consistency in cloud phase occurrence; differences are primarily driven by differences in meteorology (primarily temperature).

3) Phase Partitioning

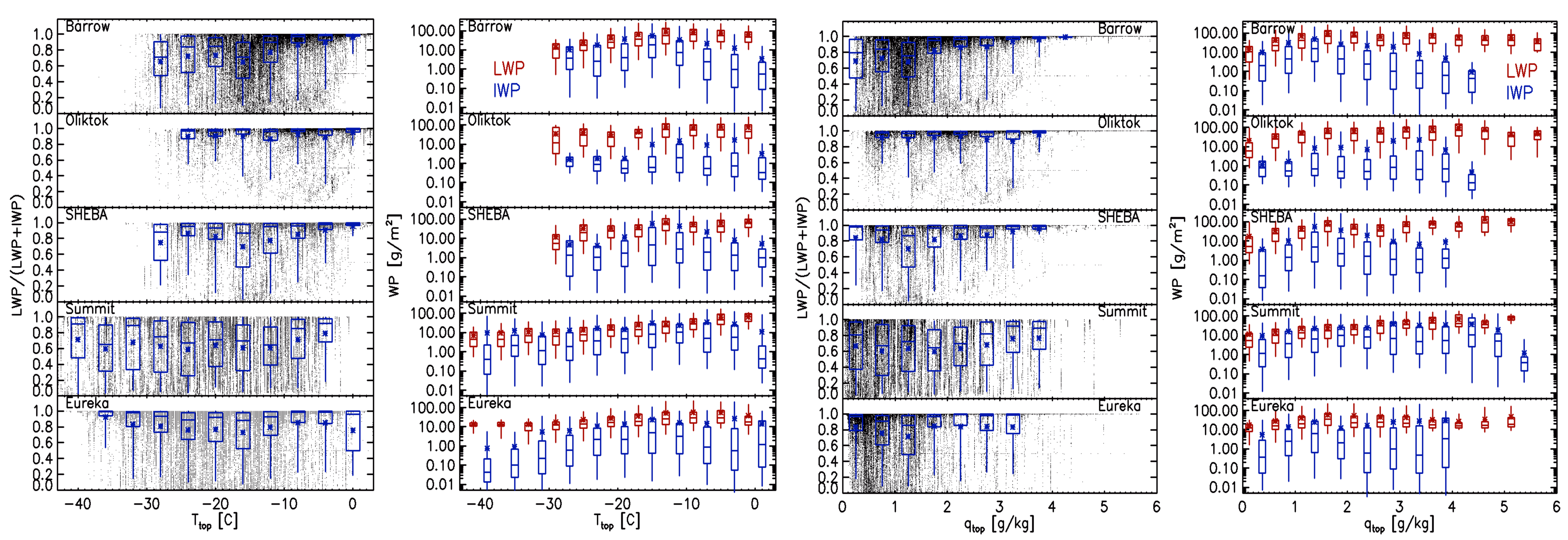
Method

- ShupeTurner microphysics retrieval (Shupe et al. 2015) applied to MMCR, MWR, depol lidar, radiosondes.
- Temperature (T) and specific humidity (q) from radiosondes
- Analysis conducted for periods within 1 hr of radiosonde
- Only considering clouds below 3 km containing liquid

Annual cycle of cloud liquid water path statistics from MWR.



Phase partitioning (LWP/TWP) and mass (LWP, IWP) as a function of cloud top temperature (left 2 panels) and cloud top specific humidity (right 2 panels) for five Arctic atmospheric observatories



Key Results

Similar to phase occurrence, the amount of LWP is highest at Barrow, Oliktok, and SHEBA; lower at Eureka; and lowest at Summit.

T and q are generally poor constraints on phase partitioning for clouds below 3 km

LWP increases with T until about -15C and with q until about 1.5 g/kg before the statistics level out.

IWP increases with T until about -15C and with q until about 1.5 g/kg and then decreases at higher values.

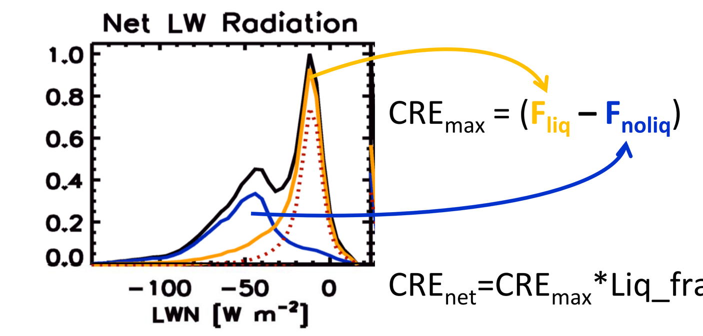
Summit, and to some degree Eureka, do not follow the same pattern, showing continually increasing LWP and IWP up to higher values of T and q.

Conclusion

1) At all sites, most clouds containing liquid water are liquid dominant at any T and/or q, with somewhat lower liquid fractions at Summit.
2) Condensed cloud mass (LWP and IWP) and phase partitioning are not cleanly constrained by T and/or q at any site >> further constraints are needed (aerosols, vertical motions).

4) Liquid Cloud Radiative Effects (CRE)

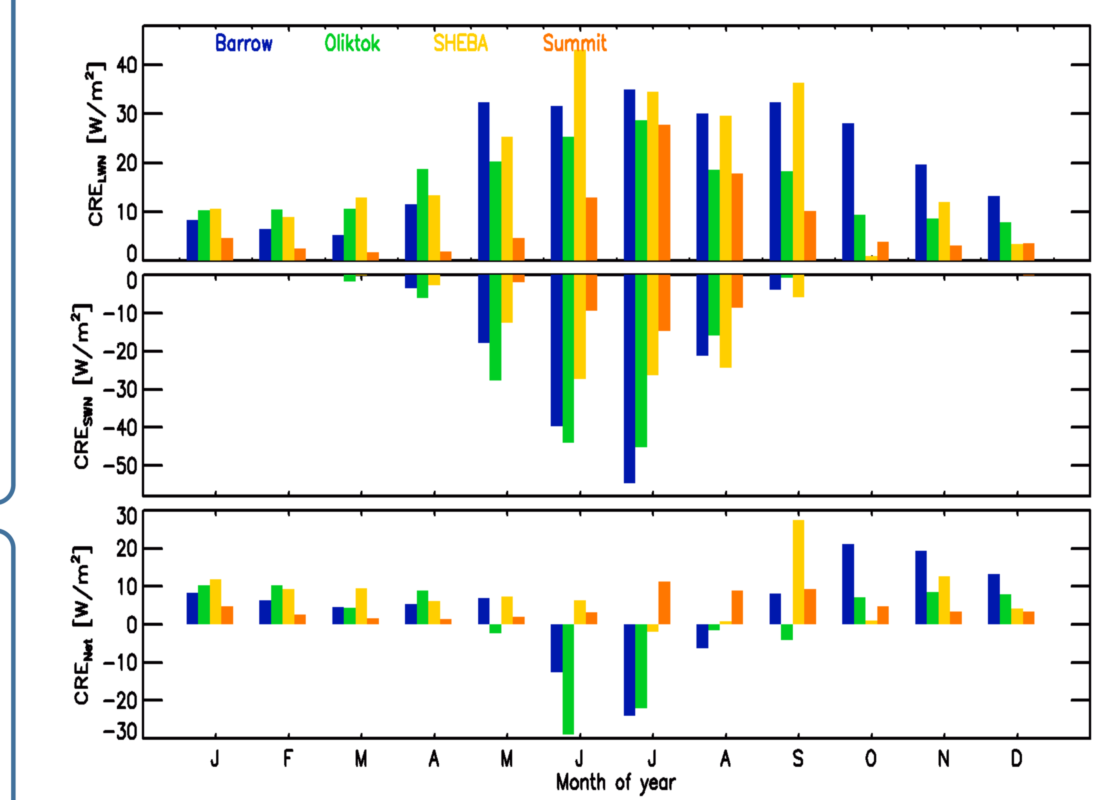
Method



Measurement-based CRE. Mean difference for a given radiation parameter between clouds that contain liquid water (LWP > 5 g/m2) and those that do not, multiplied by the fractional occurrence of liquid-containing clouds.

Eureka not included due to lack of upwelling radiation.

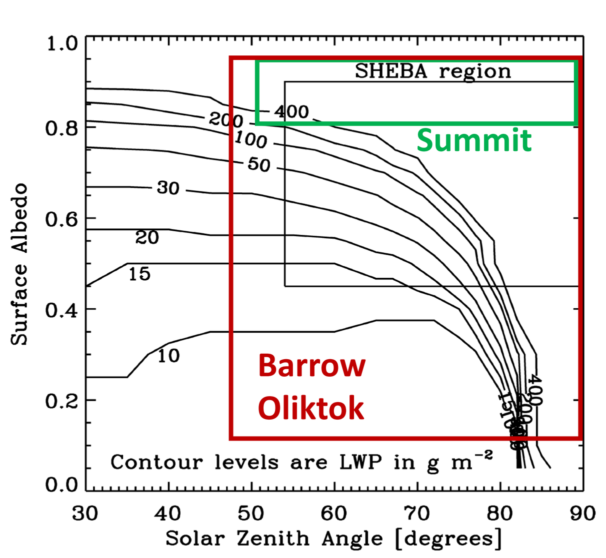
CRE from liquid-containing clouds for LW radiation (top), SW radiation (middle), and net radiation (bottom) for four different atmospheric observatories



Key Results

- CRE_LW annual variability is largely driven by the annual variability in LWP at a given site, modulated by BL structure (i.e., temperature gradient)
- CRE_SW annual variability is driven by the solar and albedo cycles.
- CRE_Net shows warming year round at all sites except for those sites where surface albedo decreases below ~0.6.

5) Explaining CRF with a simple model



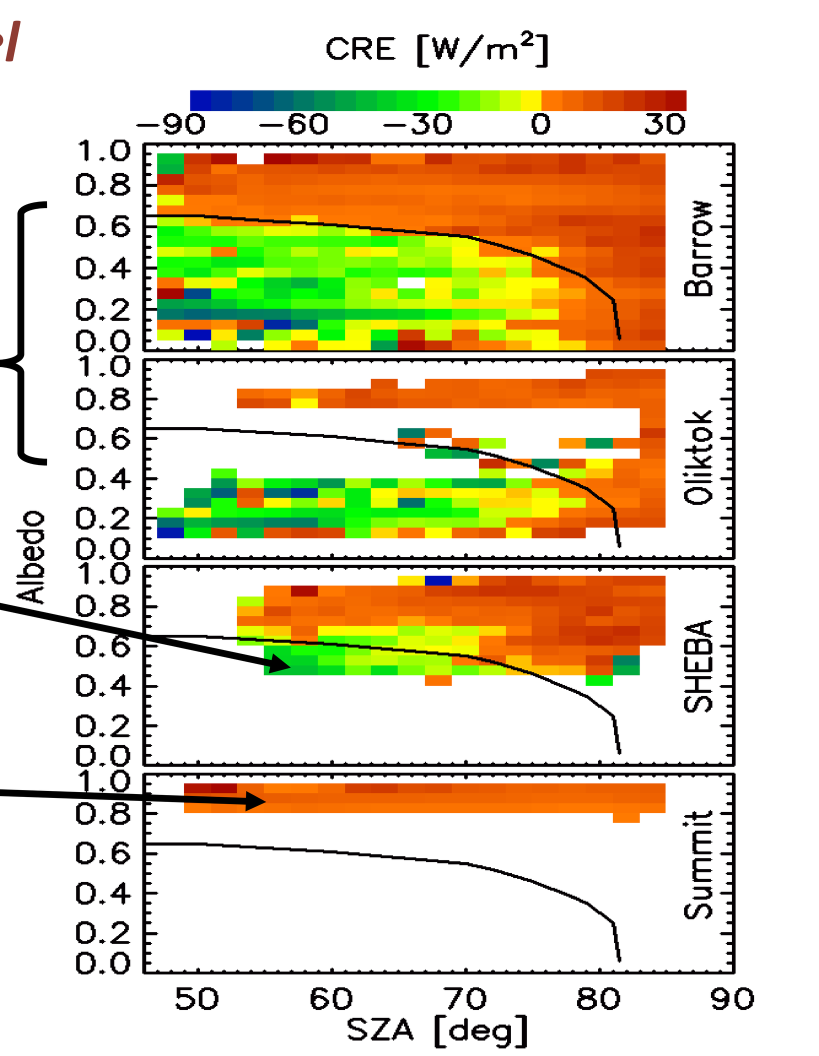
Contours show LWP at which CRE transitions from a surface warming to cooling effect, as a function of sun angle and surface albedo. Based on a simple model for cloud radiative forcing where cloud optical depth is parameterized based on LWP only (Shupe and Intrieri 2004). Different sites occupy different portions of the phase space.

General: For low surface albedo (most of the Earth) clouds cool the surface at day and warm the surface at night.

Over land: Snow largely determines the sign of cloud radiative effect.
Snow present = Surface warming
Snow absent = Surface cooling

Over sea ice: Bare ice decreases albedo enough to support a surface cloud cooling effect, but only for the highest sun angles

Over an ice sheet: Cloud warming of the surface occurs under almost all conditions because surface albedo is consistently high. Cooling only occurs with highest LWP in mid-summer.



Mean net liquid-cloud CRE as a function of sun angle and surface albedo at 4 different sites. The curve for LWP=30 g/m2 (typical average LWP) from the plot to the left is included in each panel.

Conclusion

Pan-Arctic cloud radiative effects vary substantially across the Arctic but appear to follow a relatively simple model based on sun angle, surface albedo, and cloud liquid water path.