Influence of Arctic liquid clouds on surface energy fluxes

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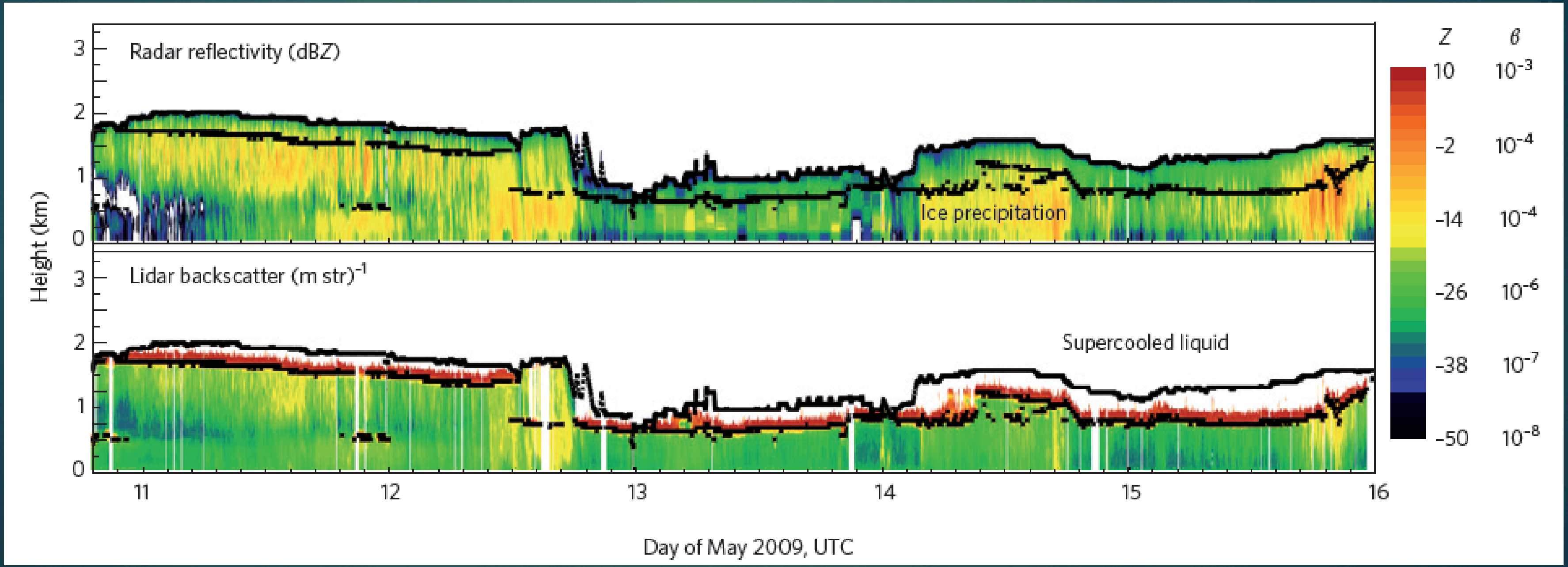
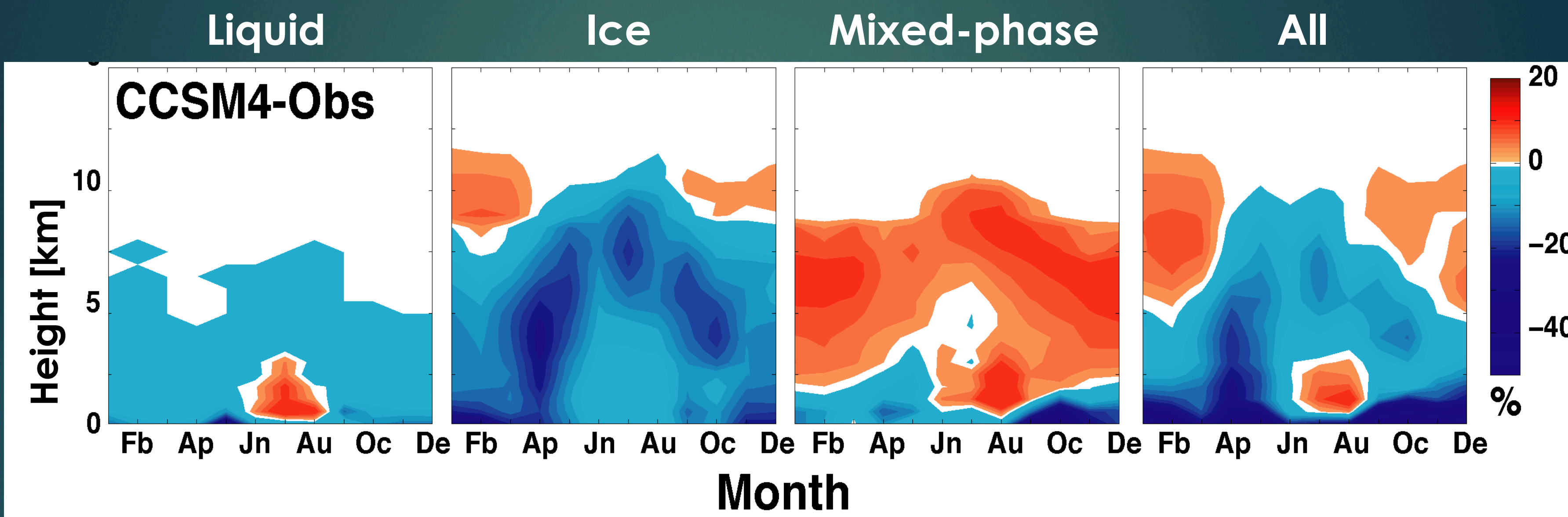
Arctic liquid clouds

- Strong driver of surface energy (implications for the cryosphere)
- High fractional occurrence (persistent)
- Potential sensitivities to changing climate (temperature, moisture)



Model Deficiencies



de Boer et al. 2012

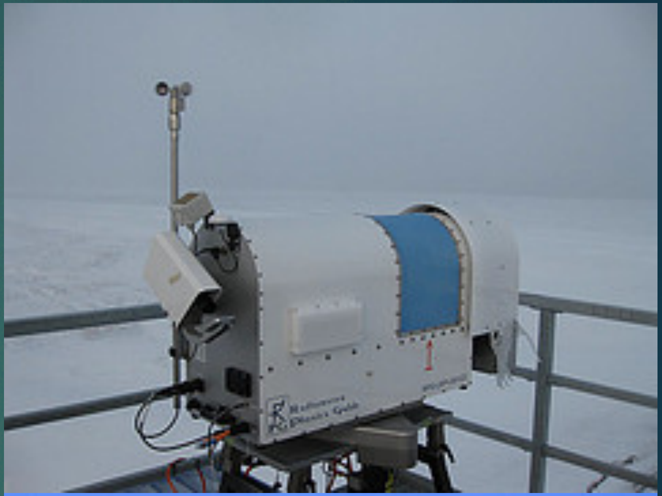
Models struggle with liquid
- Occurrence fraction
- Vertical distribution
- Condensed mass

These can have big implications

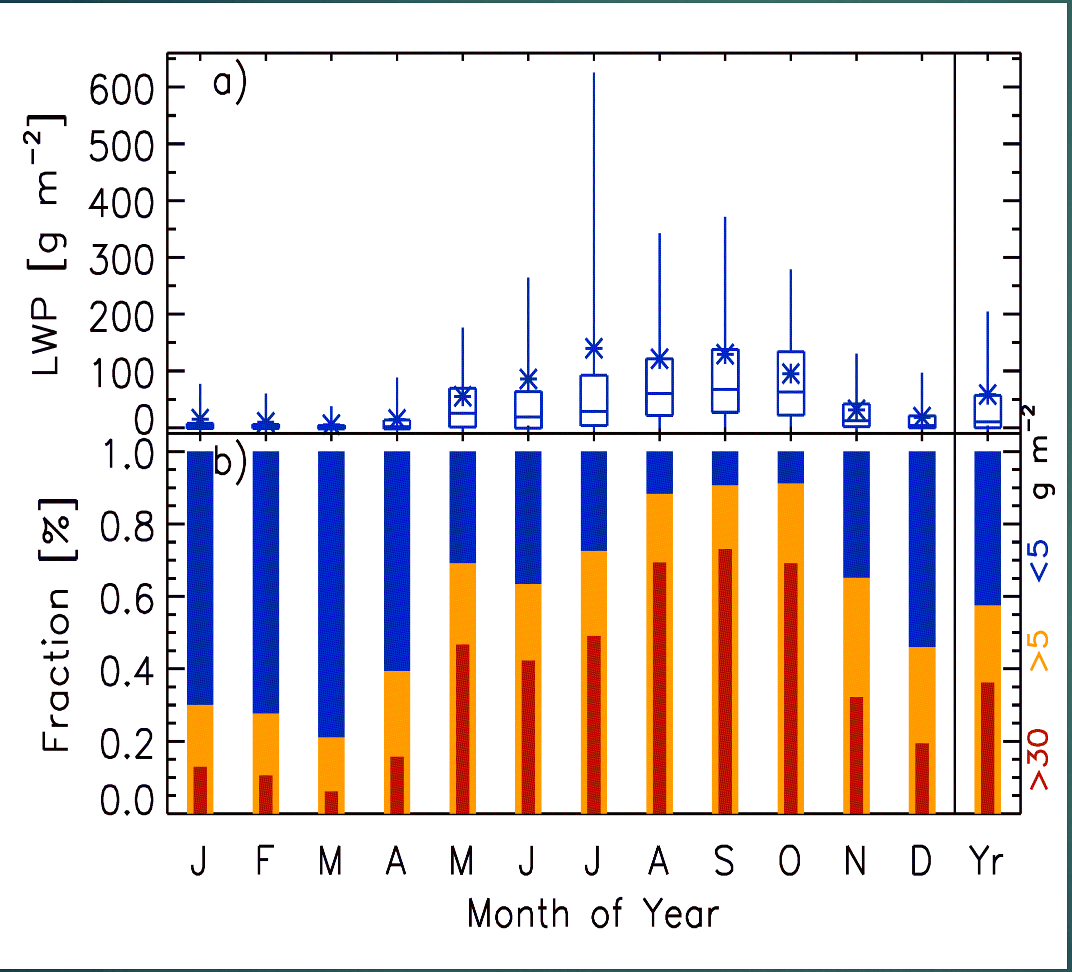
Observations

- DOE ARM site in Barrow, Alaska
- ~ 10-year data set
- Ground-based observations
- Cloud presence / liquid water path
- Surface radiation / turbulent fluxes (bulk turbulent fluxes)
- Sub-surface energy fluxes
- Method:
  - Examine monthly statistics
  - Compare fluxes when liquid present or not

$$F_{atm} = Q_{LW} + Q_{SW} + H_S + H_L$$



Liquid Occurrence

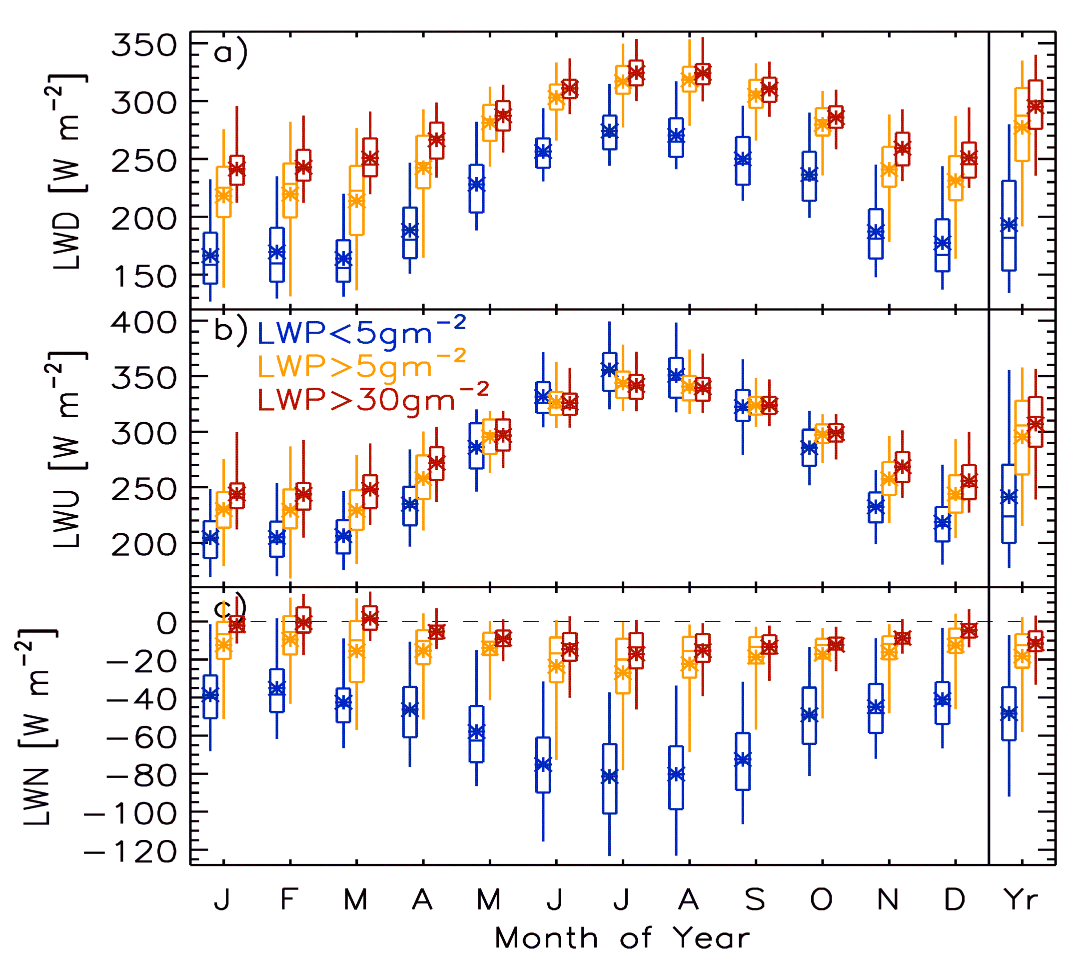


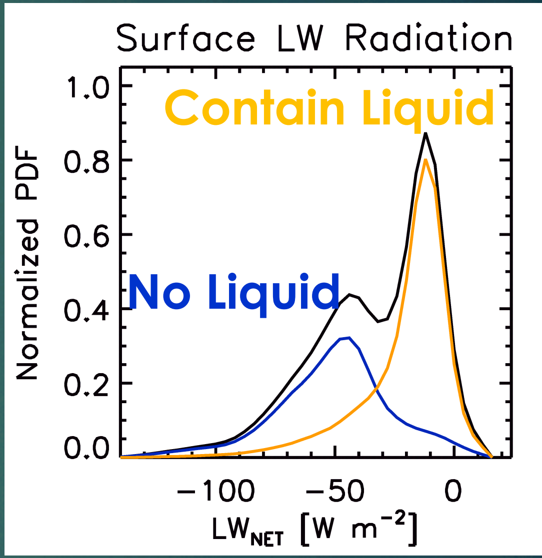
"No Liquid":
LWP < 5 g/m^2

"Liquid":
LWP > 5 g/m^2

"Opaque":
LWP > 30 g/m^2

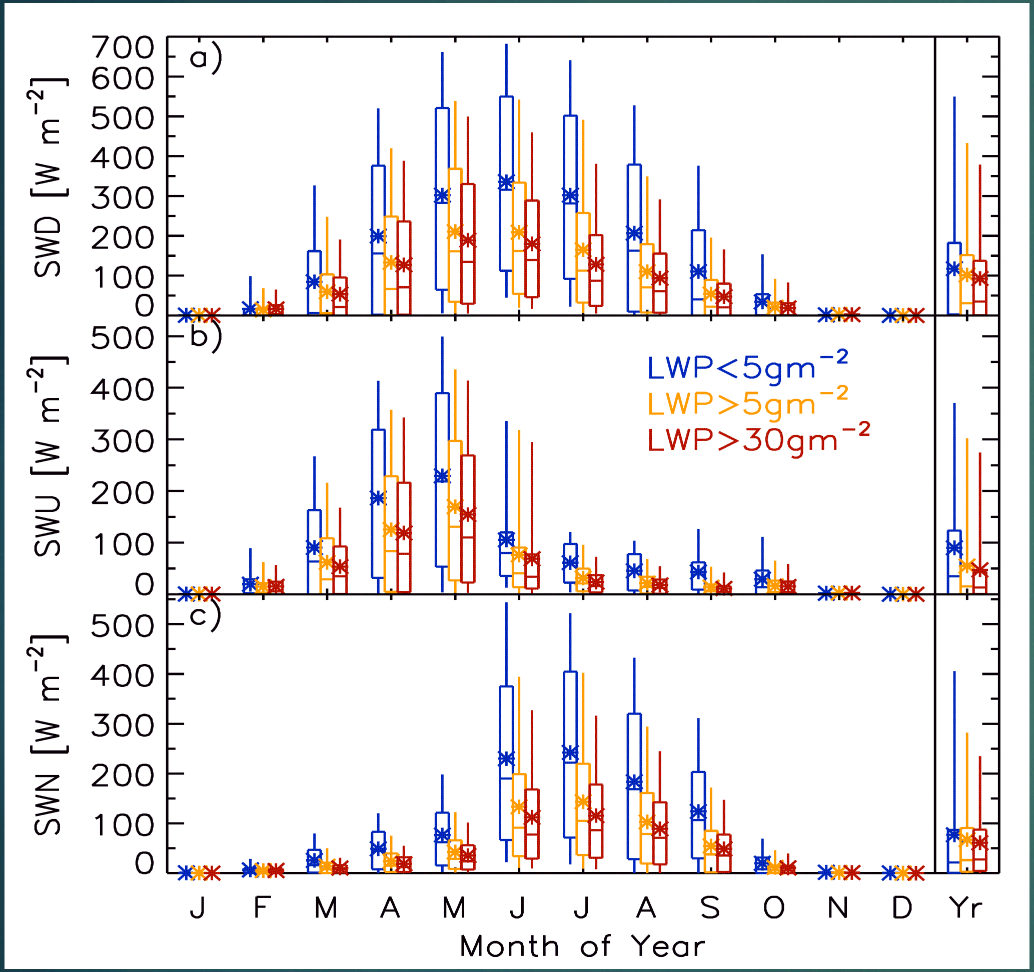
Longwave Radiation



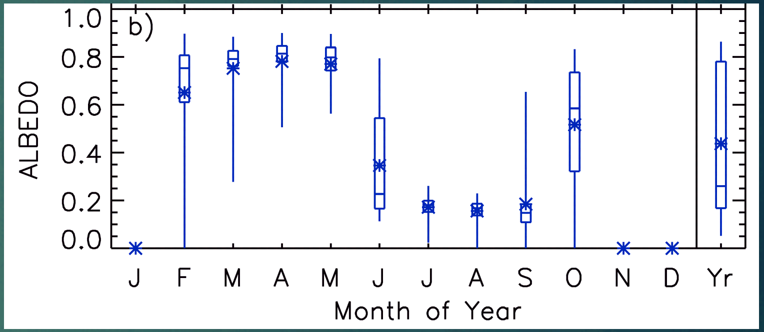


Liquid = less surface cooling to space

Shortwave Radiation

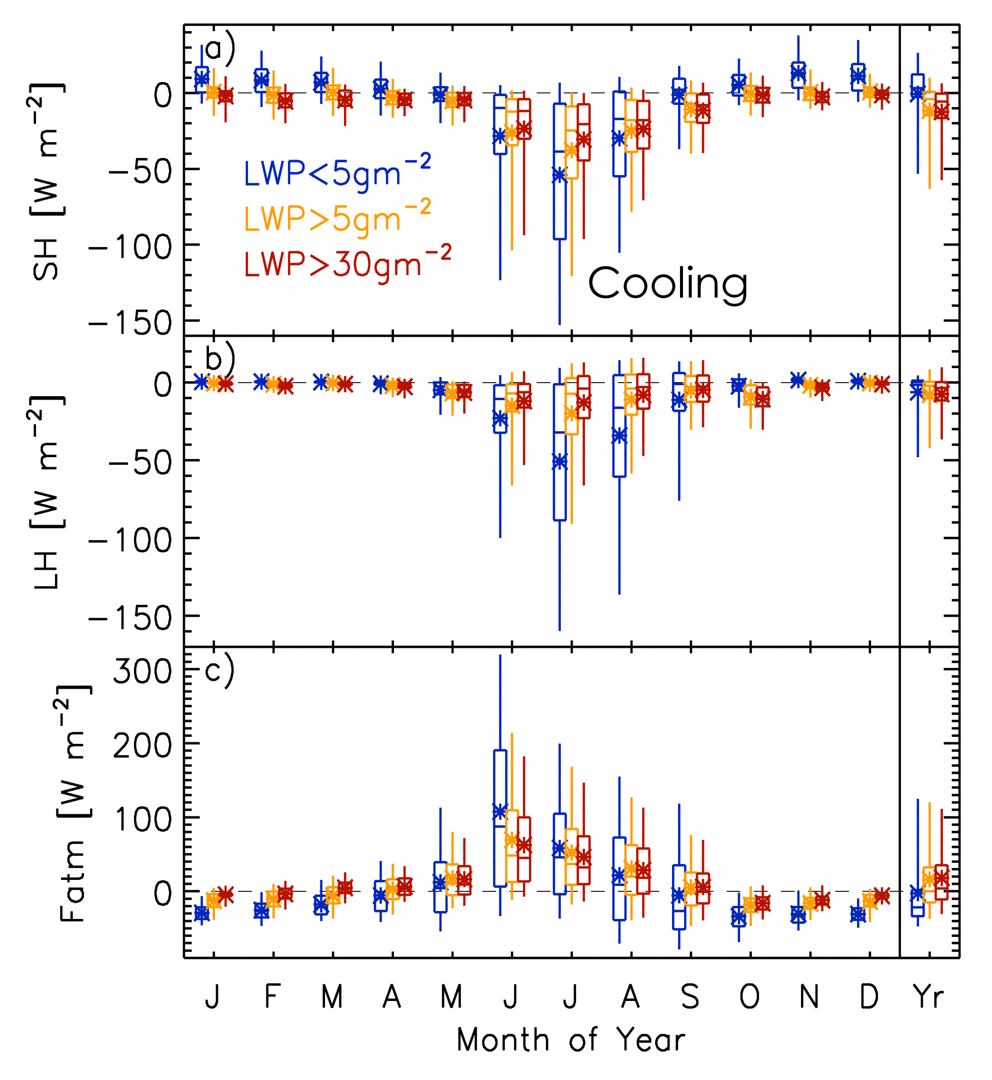


Surface albedo



Liquid = less surface warming from the sun

Turbulent and Total Atmos

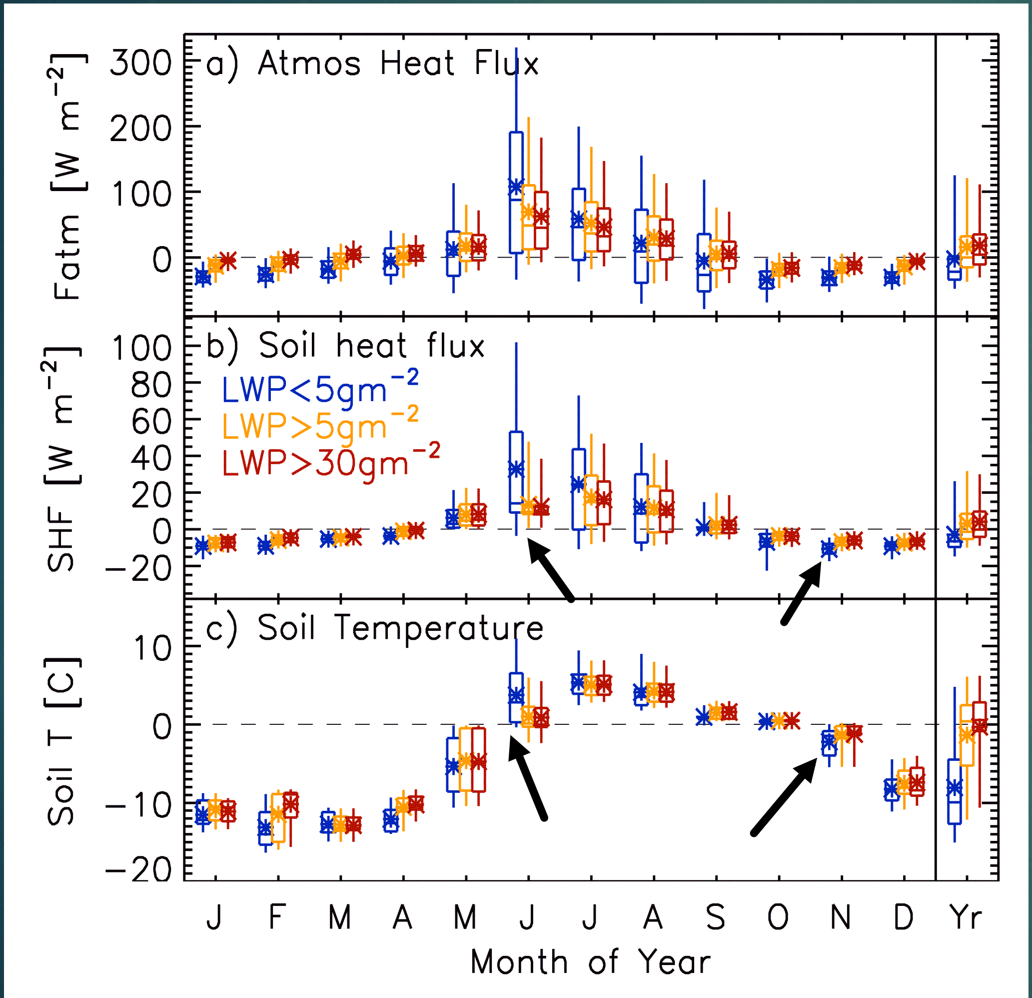


Liquid clouds diminish turbulent fluxes and the net atmospheric flux

Large warming in June:

- Snow melts => Large increase in SWN
- Surface-atmos structure takes time to adjust
- Surface turbulent cooling increase lags

Impact on sub-surface

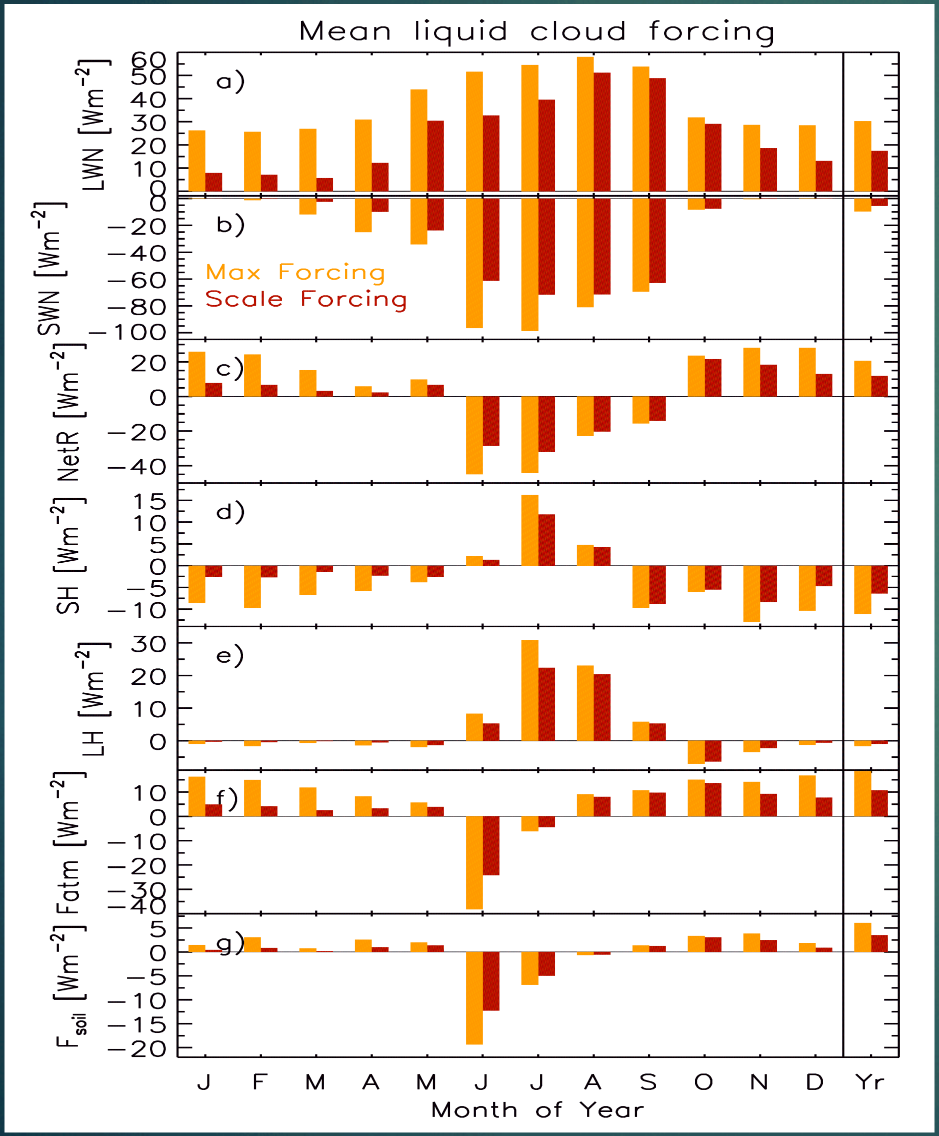


Atmospheric flux drives soil flux

Their difference leads to changes in soil temperature

June and fall transitions in soil T largely driven by "non-liquid" periods.

Liquid Forcing of Fluxes



LCF = Liquid Cloud Forcing

$LCF_{max} = (F_{noliq} - F_{liq})$

$LCF_{net} = LCF_{max}$ *Liq_fraction

- LCF_{LWN} peaks in fall due to occurrence of liquid clouds
- LCF_{SWN} peaks in summer due to snowmelt & sun cycle
- LCF_{RAD} negative for 4 mon
- LCF_{TURB} largely counteracts radiative forcing
- LCF_{ATM} negative only in June/ July
- LCF_{SOIL} follows LCF_{ATM}
- Liquid slows summer soil warming and winter soil cooling

Conclusions and Future

- Arctic liquid clouds are frequent, even in winter
- Cloud radiative effects drive responses in the system with implications for soil/permafrost
- Clouds cool the soil in June and July

- What role does spatial heterogeneity play?
- Do cloud dynamics/mixing matter?
- What is the net effect on permafrost?
- How will liquid clouds change in the future?