

Clouds and the cryosphere: A view of Arctic sea ice and cloud interactions from CALIPSO, CloudSAT, and CERES

Patrick C. Taylor

NASA Langley Research Center

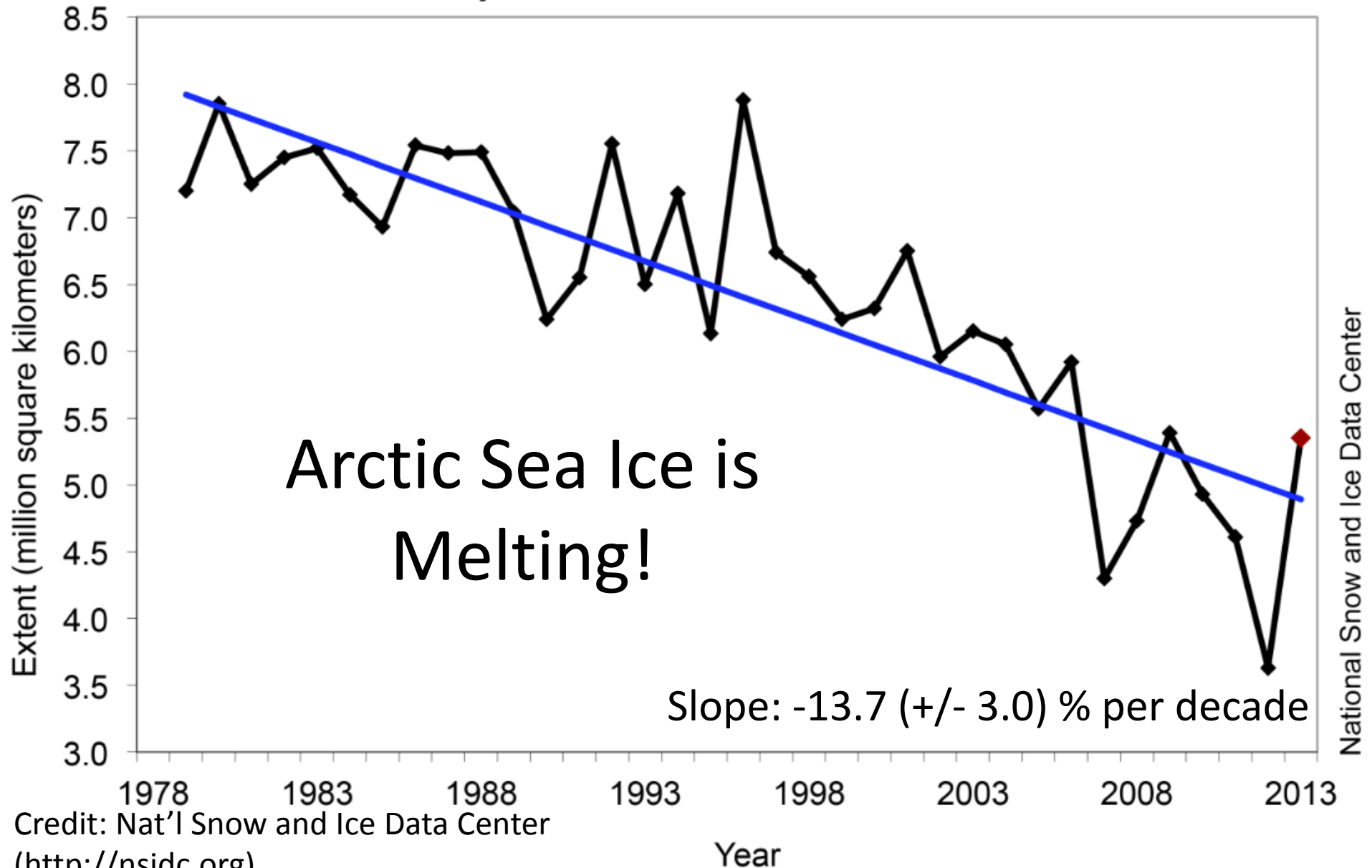
Climate Science Branch

16 December 2014

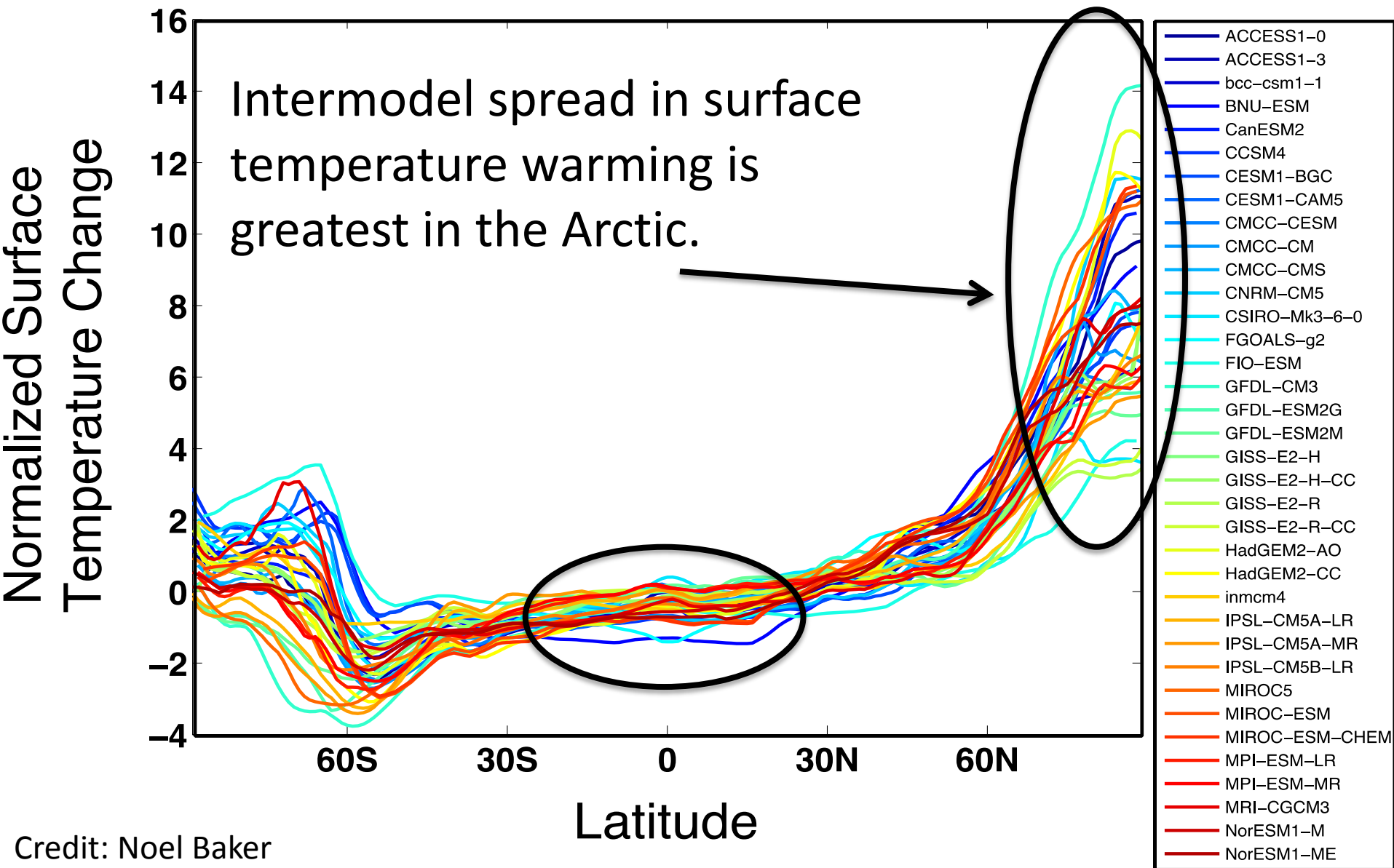
patrick.c.taylor@nasa.gov

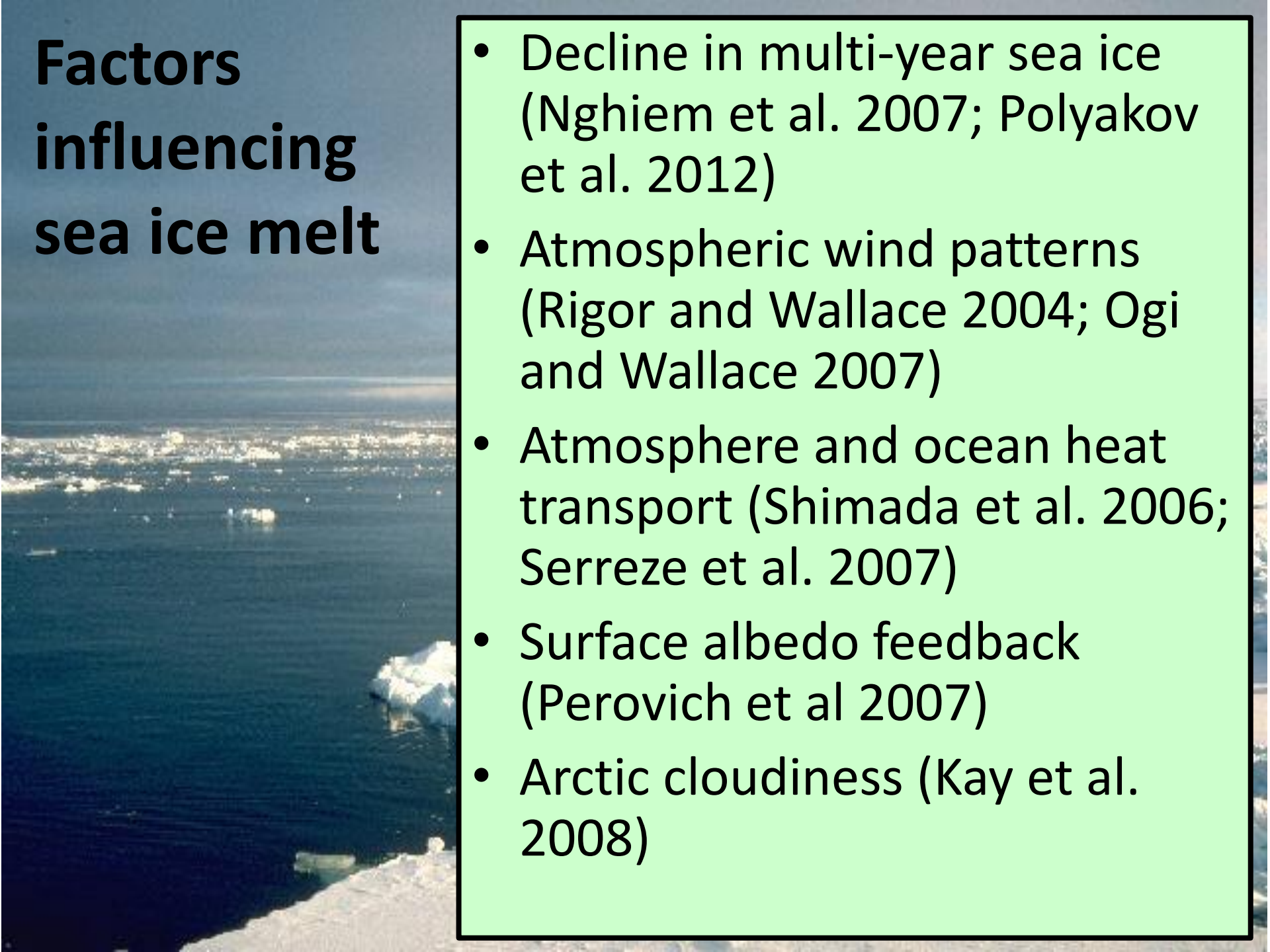
Acknowledgements: Seiji Kato, Kuan-Man
Xu, Noel Baker, and Ming Cai

Average Monthly Arctic Sea Ice Extent September 1979 - 2013



Zonal mean Surface Temperature Response (1% per year CO₂ increase)

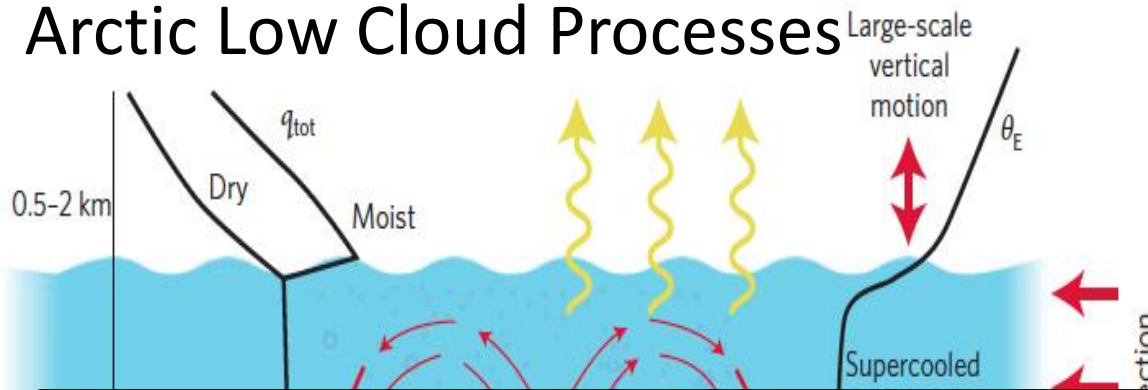


A photograph of a sea ice melt, showing a dark blue ocean with scattered white ice floes and a distant shoreline under a clear sky.

Factors influencing sea ice melt

- Decline in multi-year sea ice (Nghiem et al. 2007; Polyakov et al. 2012)
- Atmospheric wind patterns (Rigor and Wallace 2004; Ogi and Wallace 2007)
- Atmosphere and ocean heat transport (Shimada et al. 2006; Serreze et al. 2007)
- Surface albedo feedback (Perovich et al 2007)
- Arctic cloudiness (Kay et al. 2008)

Arctic Low Cloud Processes



Radiative Cooling

- Drives buoyant production of turbulence
- Forces direct condensation within inversion layer
- Requires minimum amount of cloud liquid water

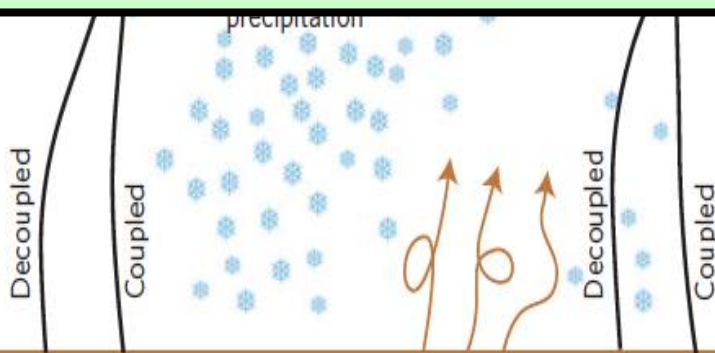
Microphysics

- Liquid forms in updrafts and sometimes within the

Science Questions:

How do clouds respond to changes in sea ice?

What is the surface radiative forcing due to sea ice-cloud interactions?



Surface Layer

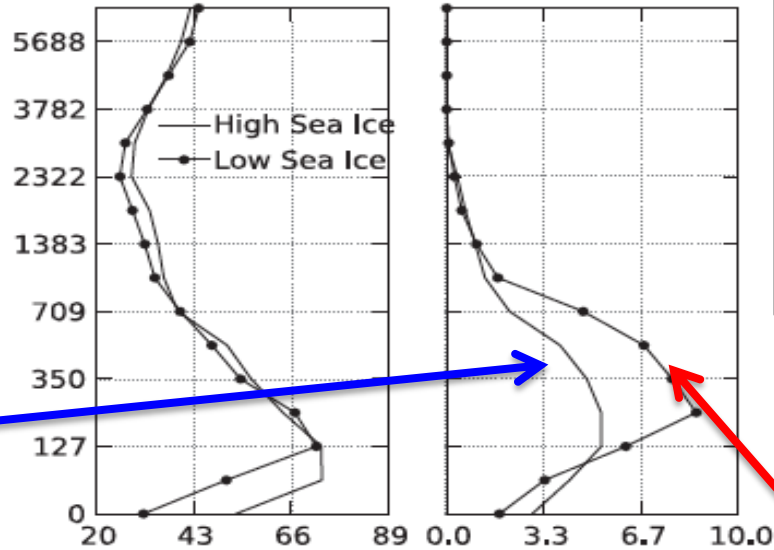
- Turbulence and q contributions can be weak or strong
- Sink of atmospheric moisture due to ice precipitation
- Surface type (ocean, ice, land) influences interaction with cloud

The influence of the surface type on the cloud properties implies an interaction between clouds and sea ice that may significantly influence Arctic climate change.

Morrison et al. (2012;
Nature Geoscience)

Sea ice-Cloud Interaction: Some Modeling Evidence

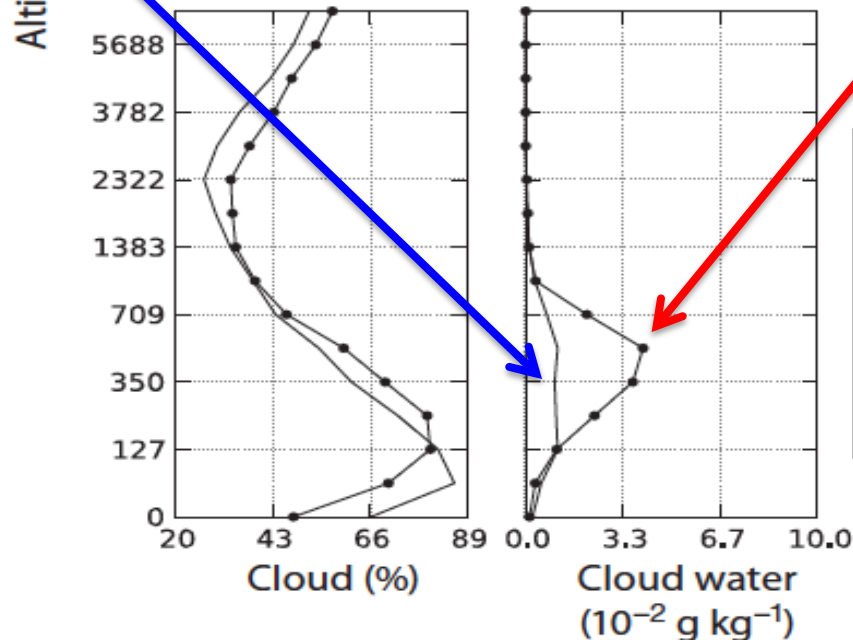
September



Cloud base and LWC are higher in Cloud Resolving Model simulations with anomalously low sea ice.

Barton and Veron (2012)

October



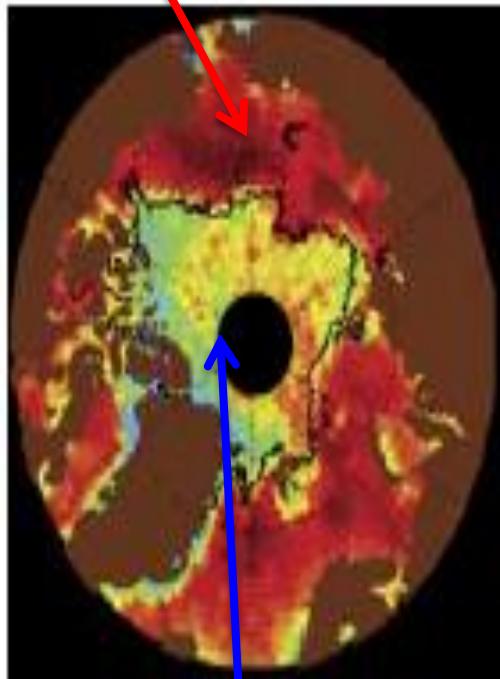
Surface radiative forcing due to sea ice-cloud interactions is only important during Oct. because SW and LW CRF offset in Sept.

Sea ice-Cloud Interaction: Some Observational Evidence

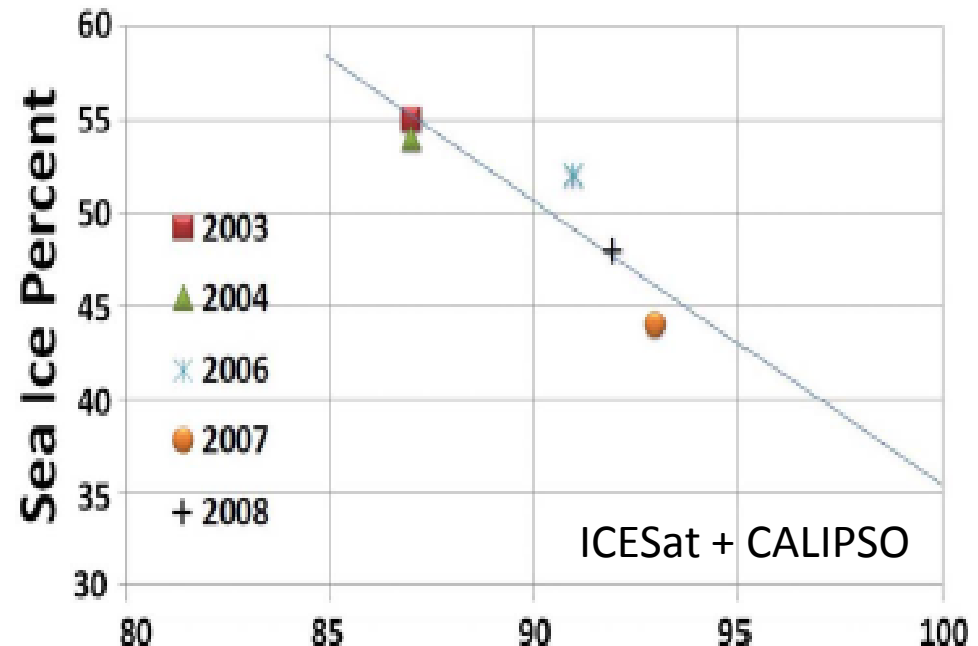
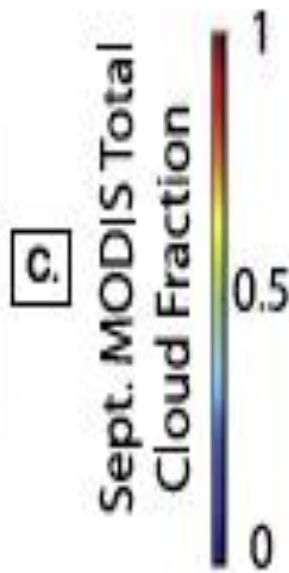
Significant correlation between cloud fraction and the sea ice extent in AUTUMN: larger cloud fraction over open water and lower cloud fraction over ice.

Larger cloud fraction over ocean

Kay and Gettelman (2009)



Sept. 2008

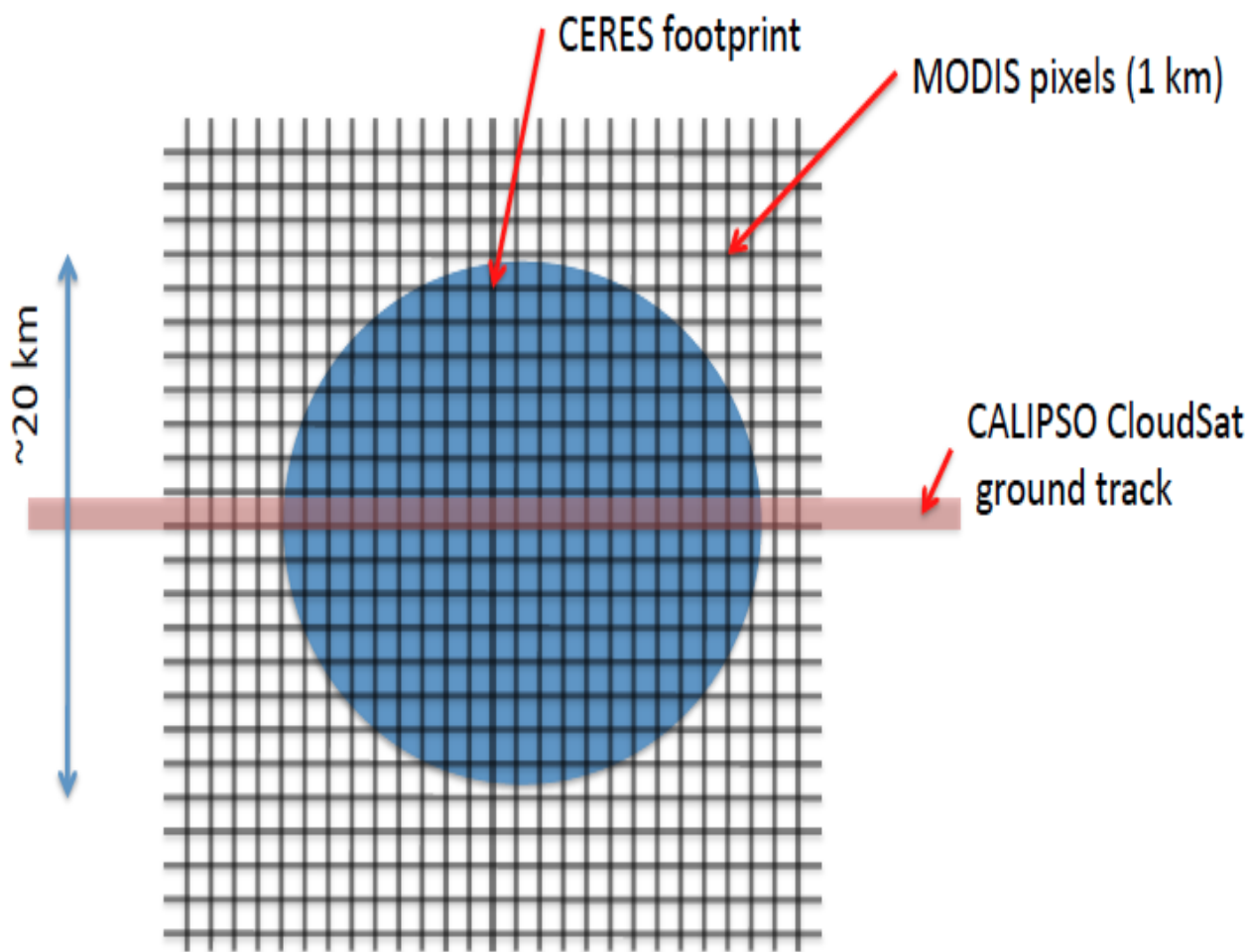


Palm et al. (2010) Cloud Percent

Lower cloud fraction over sea ice

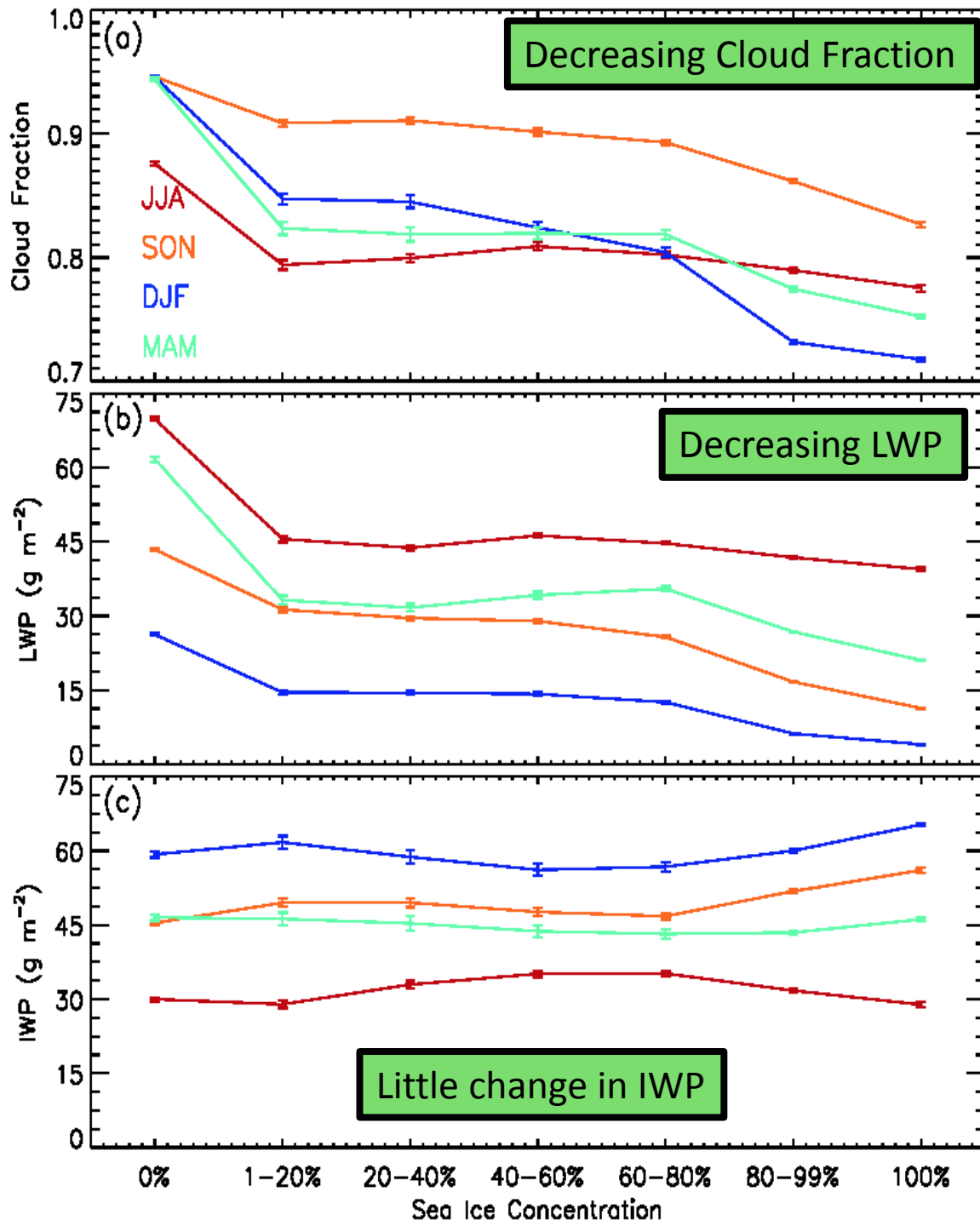
No relationship during summer because the atmosphere and surface tend to be decoupled.

CALIPSO-CloudSAT-CERES MODIS (C3M) Merged Data Product (Kato et al. 2010)



Data contains footprint averaged

- 1. Merged CALIPSO-CloudSAT vertical cloud property profiles (cloud fraction, LWC, IWC)**
- 2. Computed vertical radiative flux profiles computed with CALIPSO and CloudSat derived cloud properties**
- 3. Sea ice concentration (SSM/I)**



Sensitivity of column integrated cloud properties to sea ice concentration

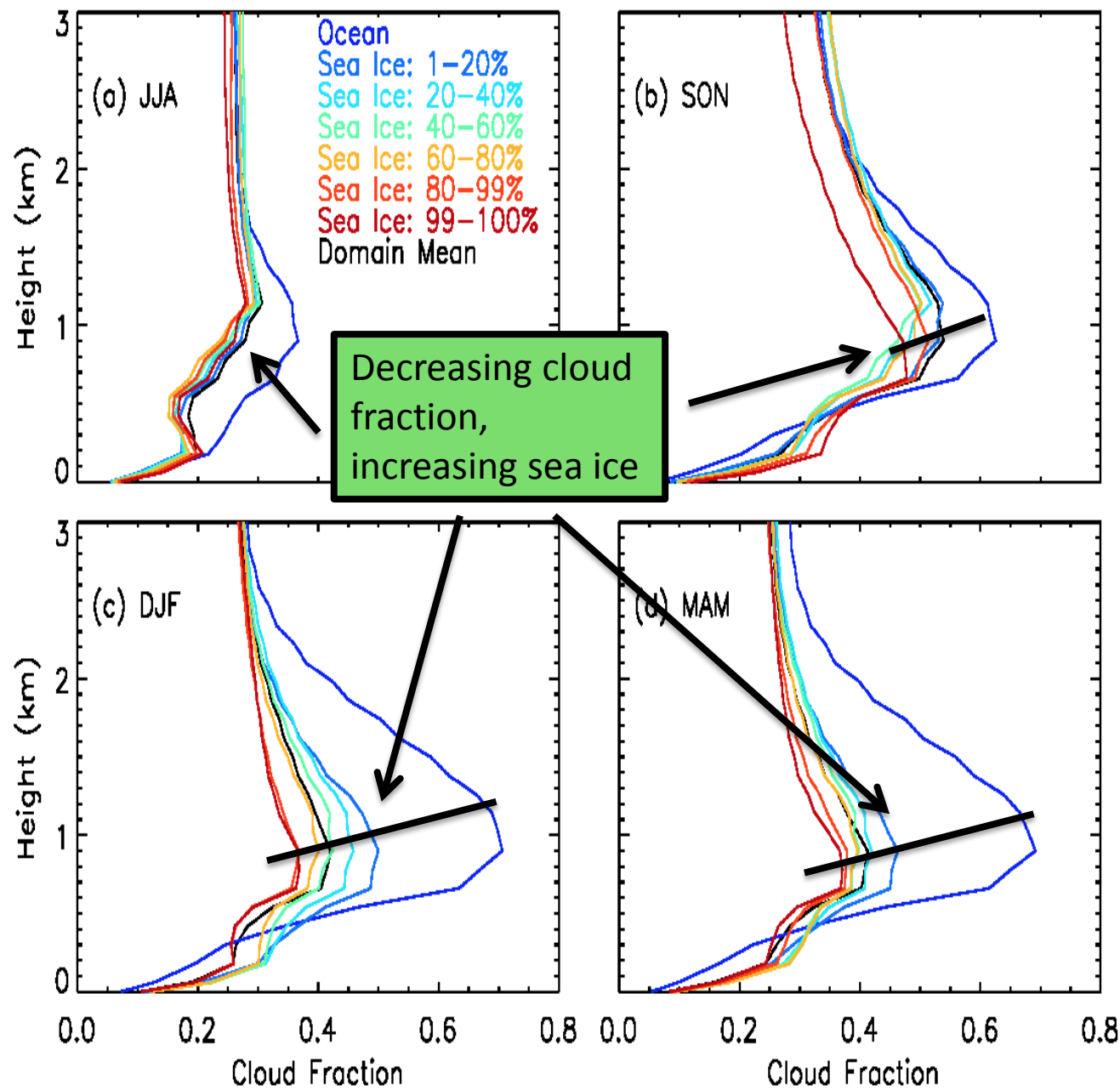
Cloud fraction and LWP are smaller in footprints with larger sea ice concentration.

The sign of the relationship is consistent across seasons, but vary in magnitude.

Sensitivity of cloud fraction vertical profile to sea ice concentration

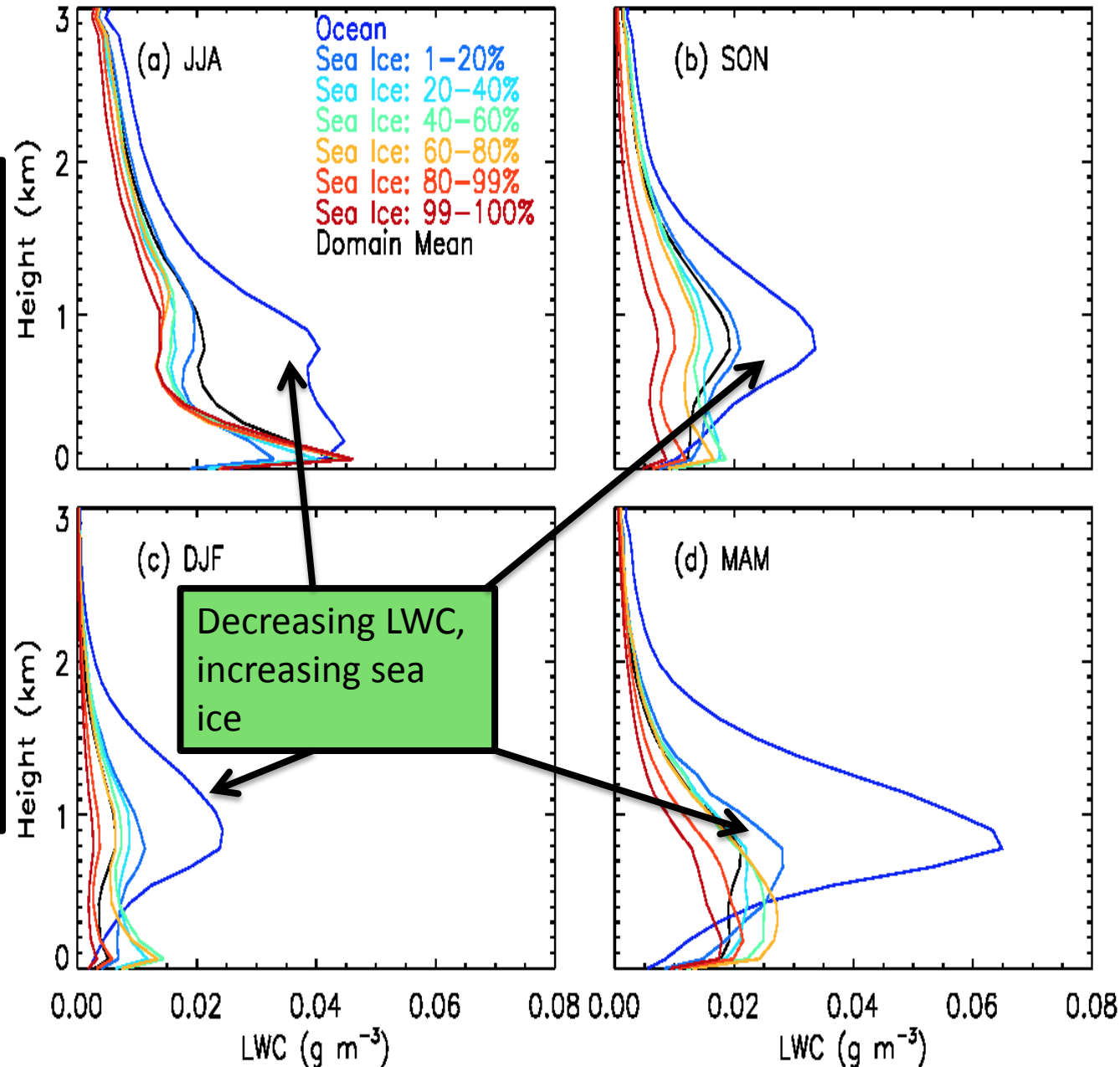
Maximum cloud fraction decreases in magnitude and height with increasing footprint average sea ice concentration.

JJA is unique.



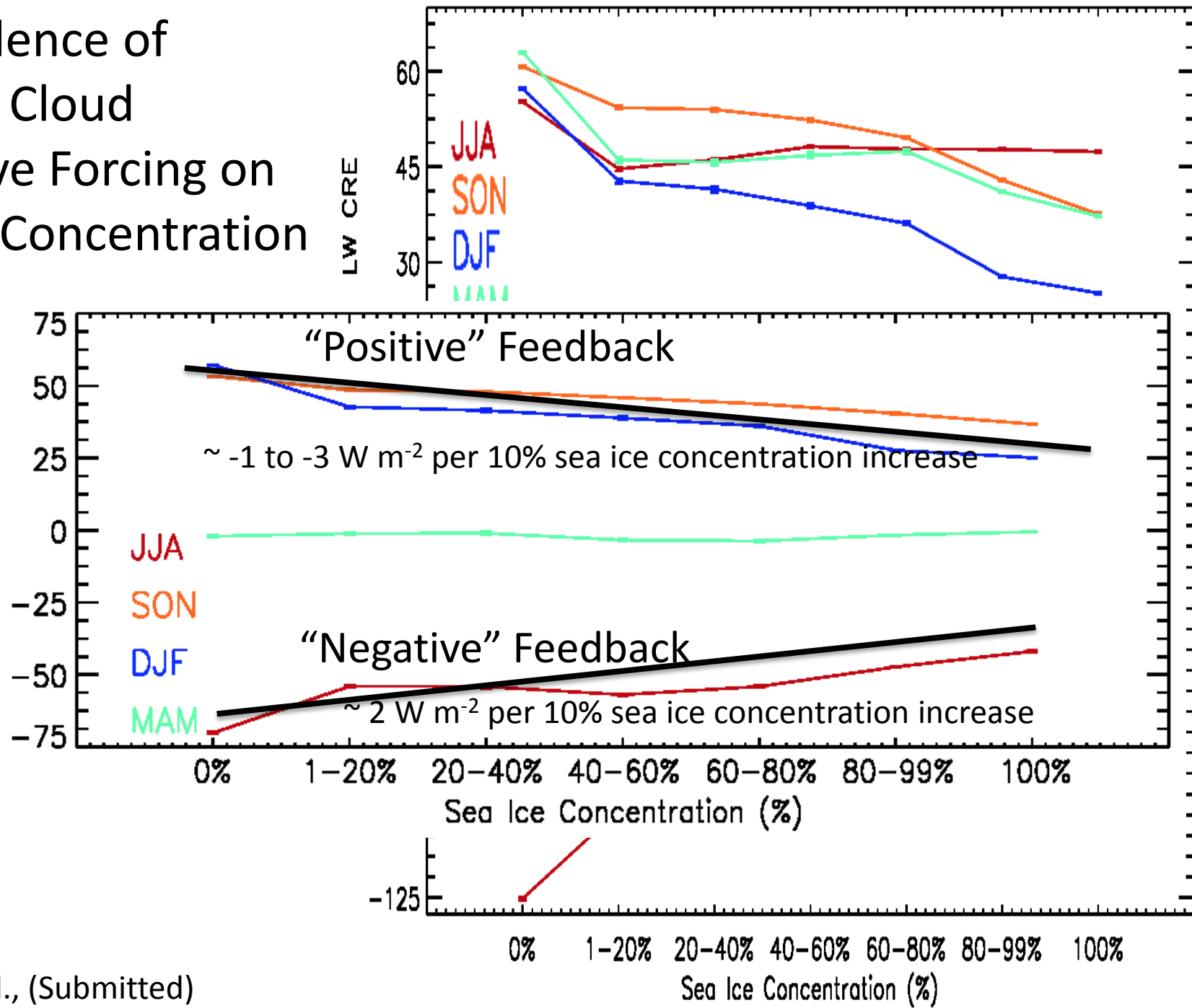
Sensitivity of the liquid water content (LWC) vertical profile to sea ice concentration

Level of maximum LWC decreases in magnitude and height with increasing sea ice concentration.



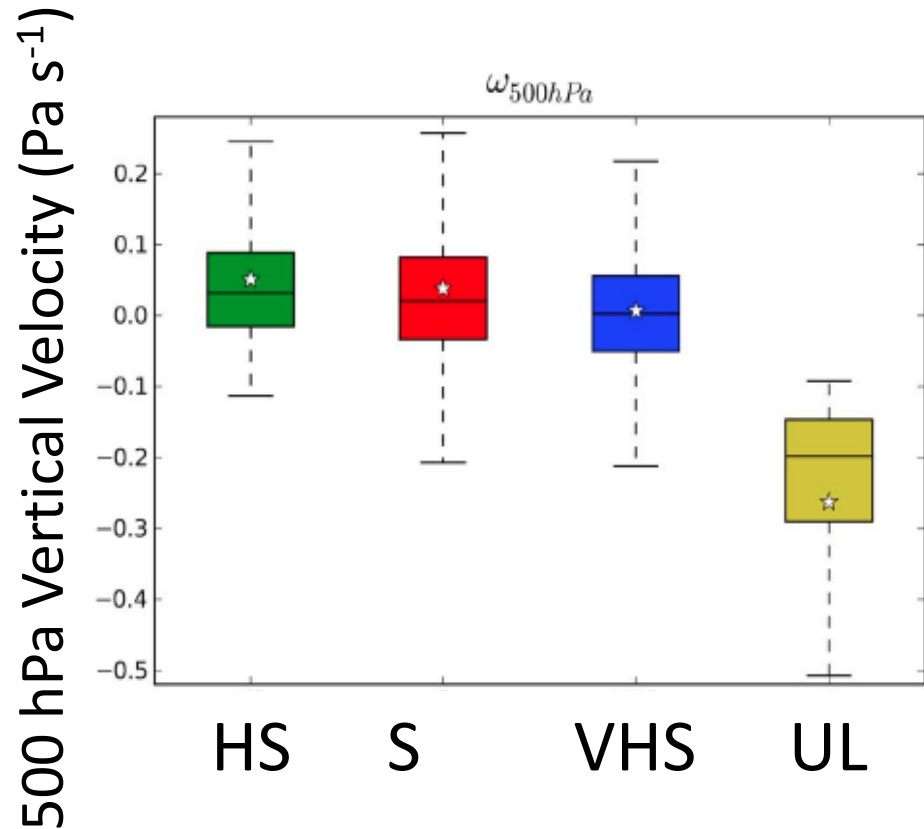
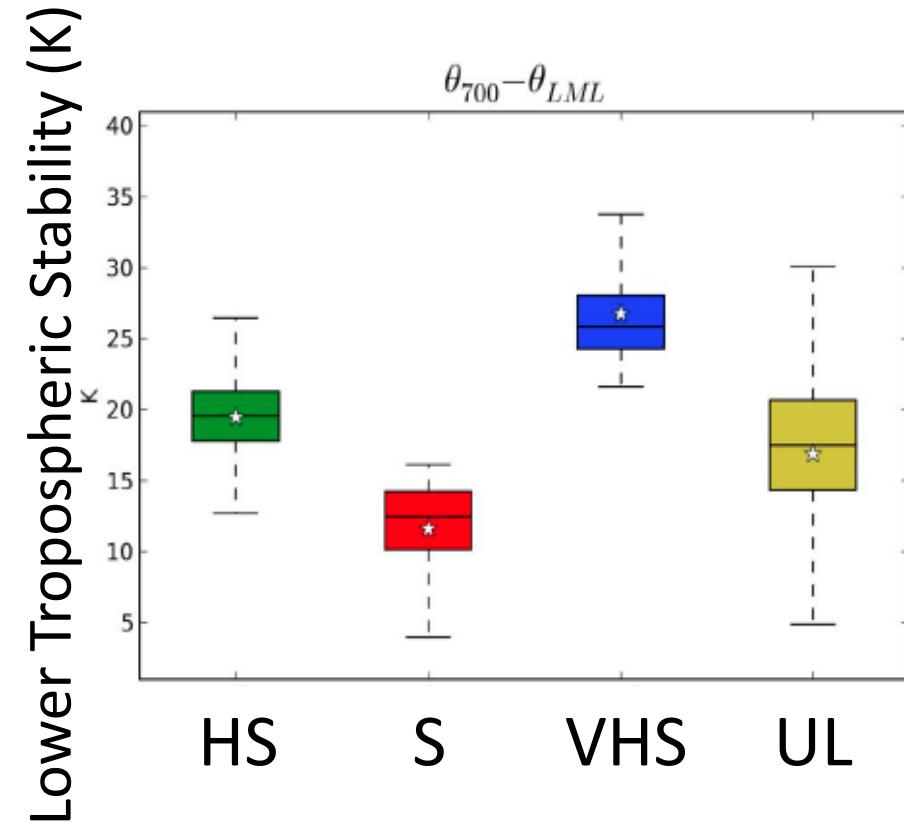
Dependence of Surface Cloud Radiative Forcing on Sea Ice Concentration

Magnitude of the radiative dependence on season



Dependence of sea ice-cloud
interaction on atmospheric state

Atmospheric State Regimes (Barton et al. 2012)

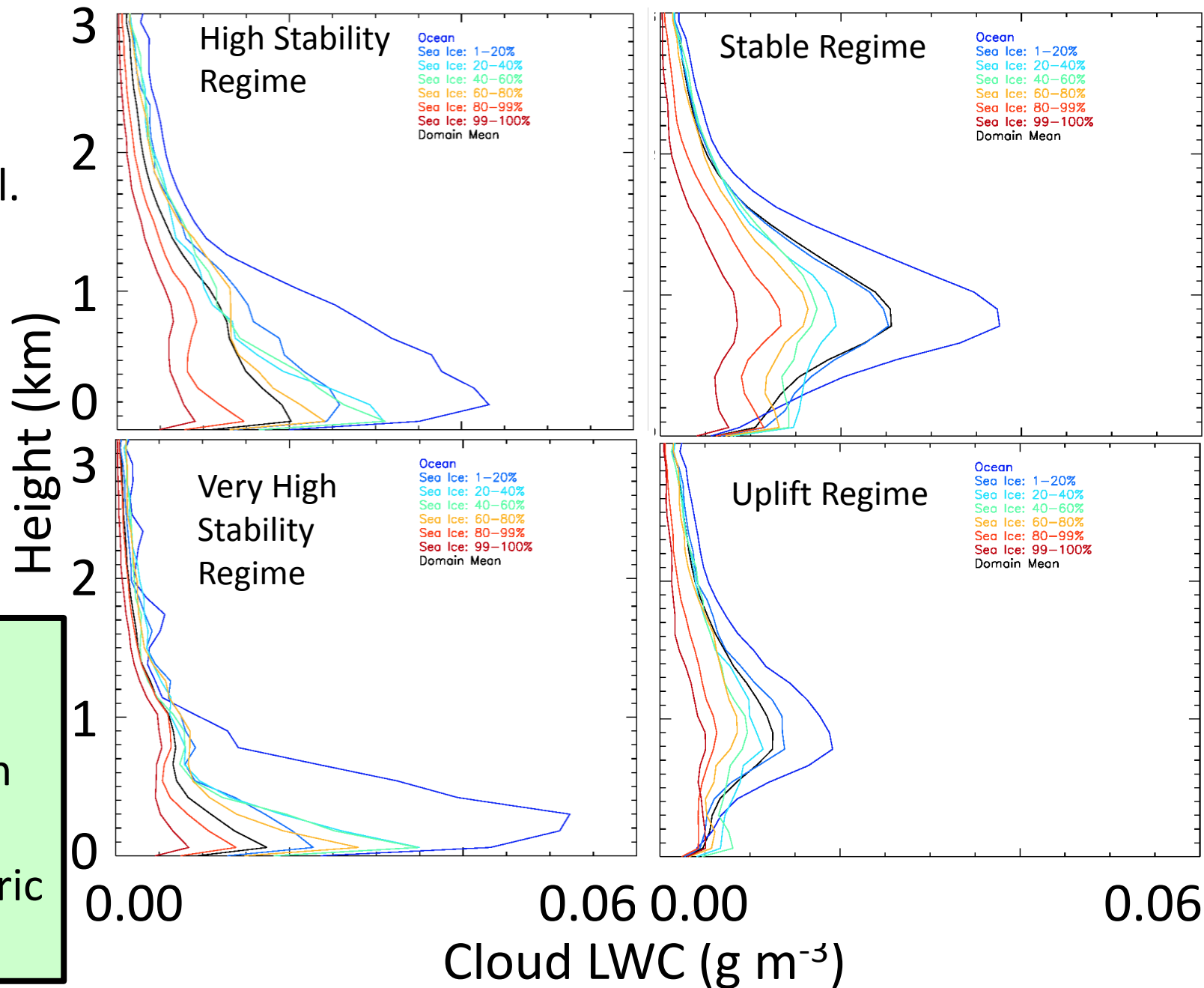


Atmospheric state regimes determined using K-means cluster analysis.

High Stability (HS): $15 \text{ K} < \text{LTS} < 25 \text{ K}$
Stable (S): $\text{LTS} < 15 \text{ K}$
Very High Stability (VHS): $\text{LTS} > 25 \text{ K}$
Uplift (UL): $\omega_{500} < -0.1 \text{ Pa s}^{-1}$

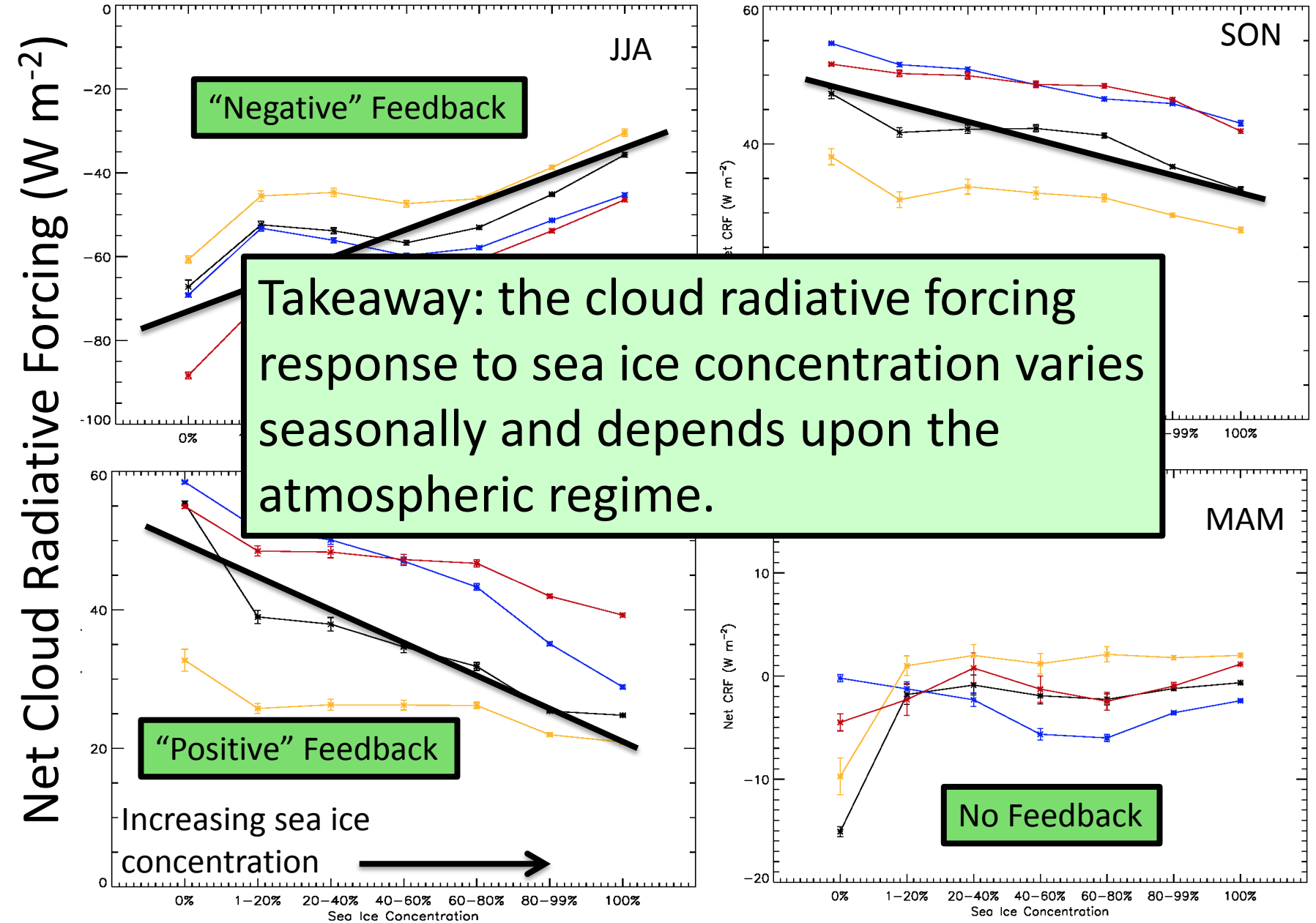
Sensitivity of LWC to sea ice concentration by atmospheric regime

(SON)
Taylor et al.
(In prep.)



Sea ice-cloud interaction varies by atmospheric regime.

Surface radiative forcing of sea ice-cloud interaction



Implications

Takeaway 1: Through a summer negative interaction and a winter positive interaction sea ice-cloud interactions buffer seasonal sea ice loss.

Takeaway 2: Arctic low cloud fraction and LWC are expected to increase in a warmer future climate with less sea ice enhancing polar warming amplification.

The results imply two critical features for simulating Arctic climate change and sea ice-cloud interactions:

- (1) Distribution of atmospheric regimes must be properly simulated.
- (2) Characteristics of the marginal ice zone must be properly modeled

Uncertainties and observational needs

- Continued active remote sensing of clouds.
- A significant uncertainty in this analysis is the knowledge of Arctic atmospheric state.
- To understand the physical mechanisms behind the cloud response to sea ice observations of surface turbulent fluxes in the Arctic are necessary.

Thank you.