Langley Research Center

Interactions between sea ice, clouds, and the Arctic Circulation

Patrick C. Taylor[1], Seiji Kato[1], Kuan-man Xu[1], and Ming Cai[2]

[1] NASA Langley Research Center, Hampton, VA 23681 [2] Florida State University Tallahassee, FL

1. Introduction and Motivation

Goal: To quantify the covariation between Arctic clouds and sea ice using instantaneous footprint observations of cloud properties from CloudSAT and CALIPSO.

•The observed rapid Arctic surface temperature warming [Chylek et al., 2009] and sea ice melt (Stroeve et al. 2007) are evidence of a significant change in the Arctic surface climate.

•Arctic sea ice decline is a symptom and a driver of Arctic climate change (e.g., Holland and Bitz 2003).

•Observations and modeling studies suggest that low clouds respond to variations in Arctic sea ice extent (Pinto 1998; Kay and Gettelman 2009; Kay et al. 2010; Palm et al. 2010; Barton and Veron 2012).

•Reducing the significant uncertainty in the magnitude and sign of the Arctic cloud response to the changing Arctic sea ice cover is necessary for understanding the present and future Arctic climate (e.g., Curry et al. 1996).

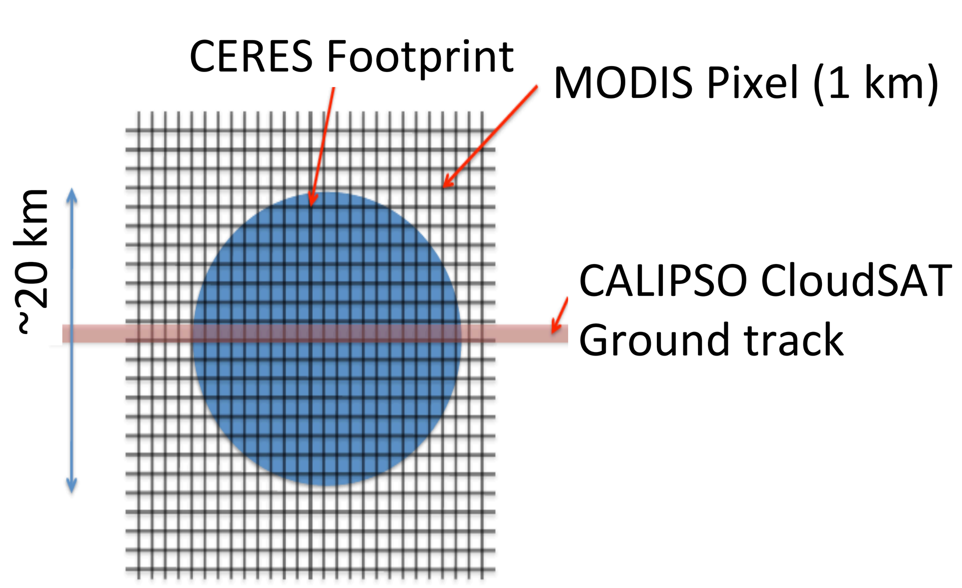
2. CALIPSO-CloudSAT-CERES-MODIS (C3M) data

•C3M (Kato et al. 2010) is a merged data product that placed CALIPSO, CloudSAT, CERES, and MODIS data onto a common 20 km footprint.

•C3M data is available from July 2006 through June 2010 at the NASA Langley ASDC: http://eosweb.larc.nasa.gov/

Dataset 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)**



3. Methodology: Defining Atmospheric State Regimes

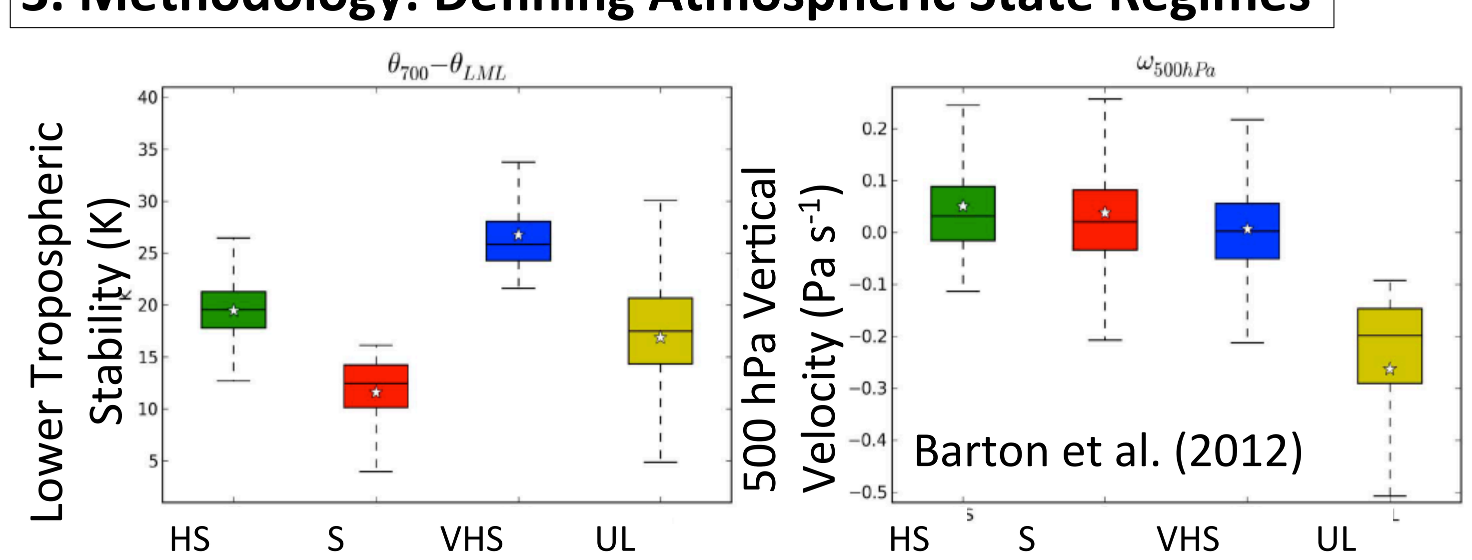
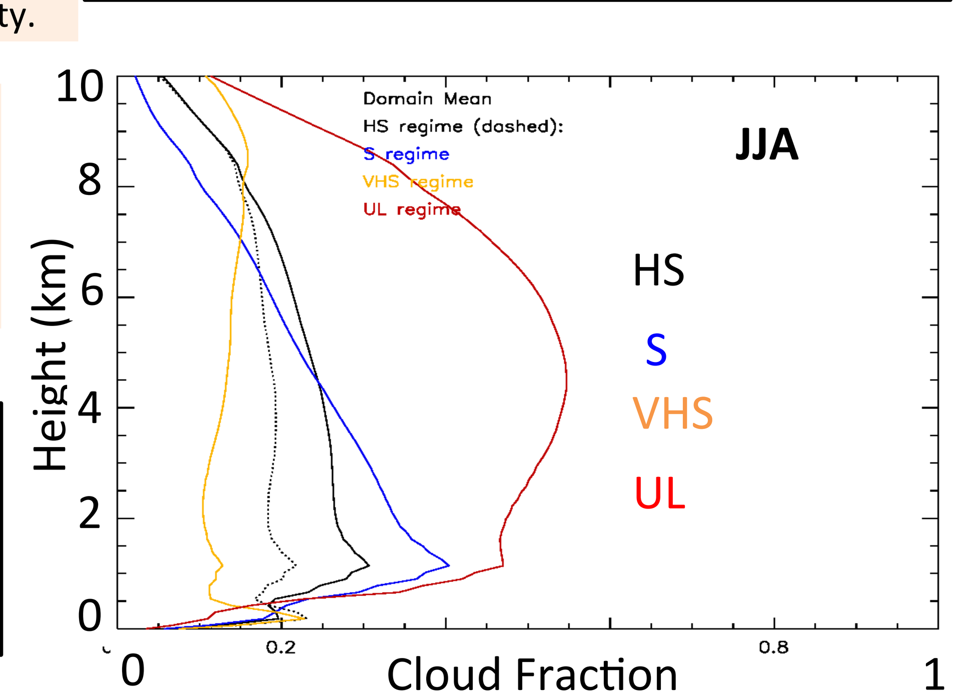


Figure above shows results of a K-means cluster analysis separating the Arctic atmosphere into 4 unique states using lower tropospheric stability (LTS) and 500 hPa vertical velocity.

- To first order, cloud properties are controlled by the dynamic and thermodynamic state of the atmosphere. **Therefore, to isolate the true covariance between Arctic low clouds and sea ice, the data are first separated into unique atmospheric state regimes**
- Atmospheric state regimes are determined using K-means cluster analysis.

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

Figure to the right shows the mean cloud fraction profile within each of the four atmospheric state regimes during the Arctic summer: June-July-August (JJA)



- The vertical distribution of cloud fraction is dependent upon the atmospheric state regime.
- Total cloud fraction and the level of maximum cloud fraction become smaller at Lower tropospheric stability increases.

4a. Results: Sensitivity of Column Integrated Cloud Properties to Sea Ice Concentration

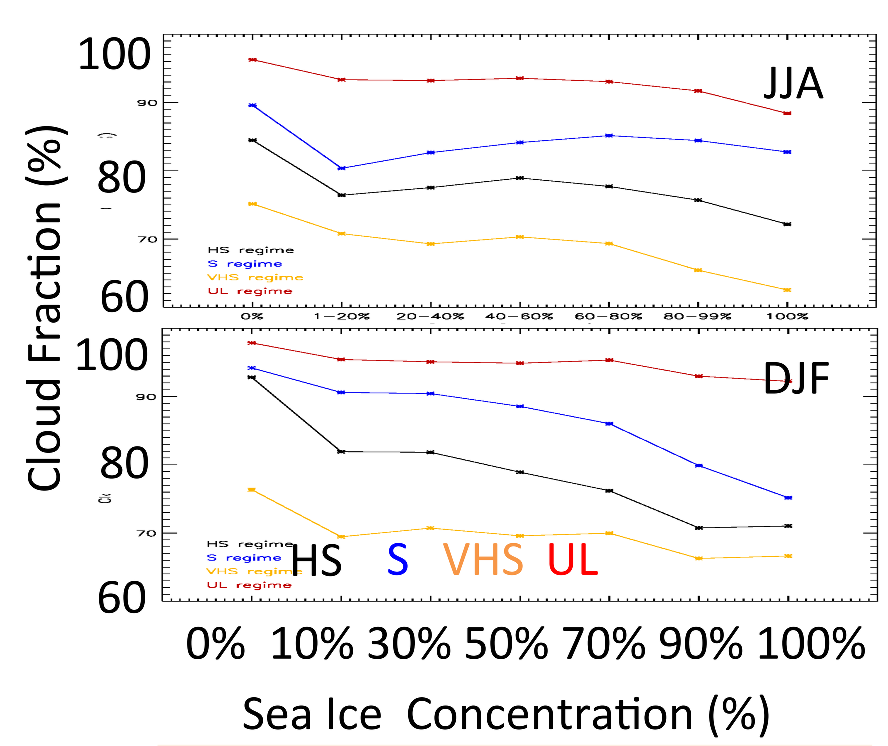
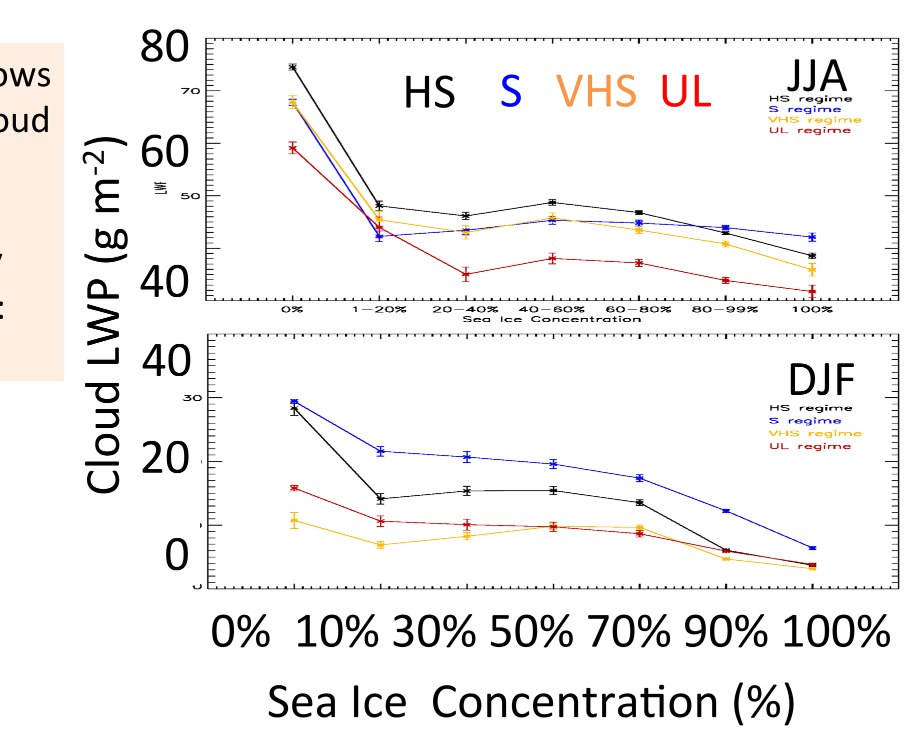


Figure above shows footprint averaged cloud fraction composited by atmospheric state regime and binned by sea ice concentration: 20% wide bins.

- The variation of cloud fraction with sea ice concentration depends upon both atmospheric state regime as well as season.
- The sensitivity of cloud fraction on sea ice concentration is larger in DJF under the HS regime.

- The variation of cloud LWP with sea ice concentration also depends upon both atmospheric state regime as well as season.
- **Overall, cloud LWP decreases with increasing sea ice concentration.**
- The dependence of LWP on sea ice concentration is qualitatively similar within each atmospheric regime and season

Figure to the right shows footprint averaged cloud LWP composited by atmospheric state regime and binned by sea ice concentration: 20% wide bins.



4b. Sensitivity of Cloud Property Vertical Profiles to Sea Ice Concentration

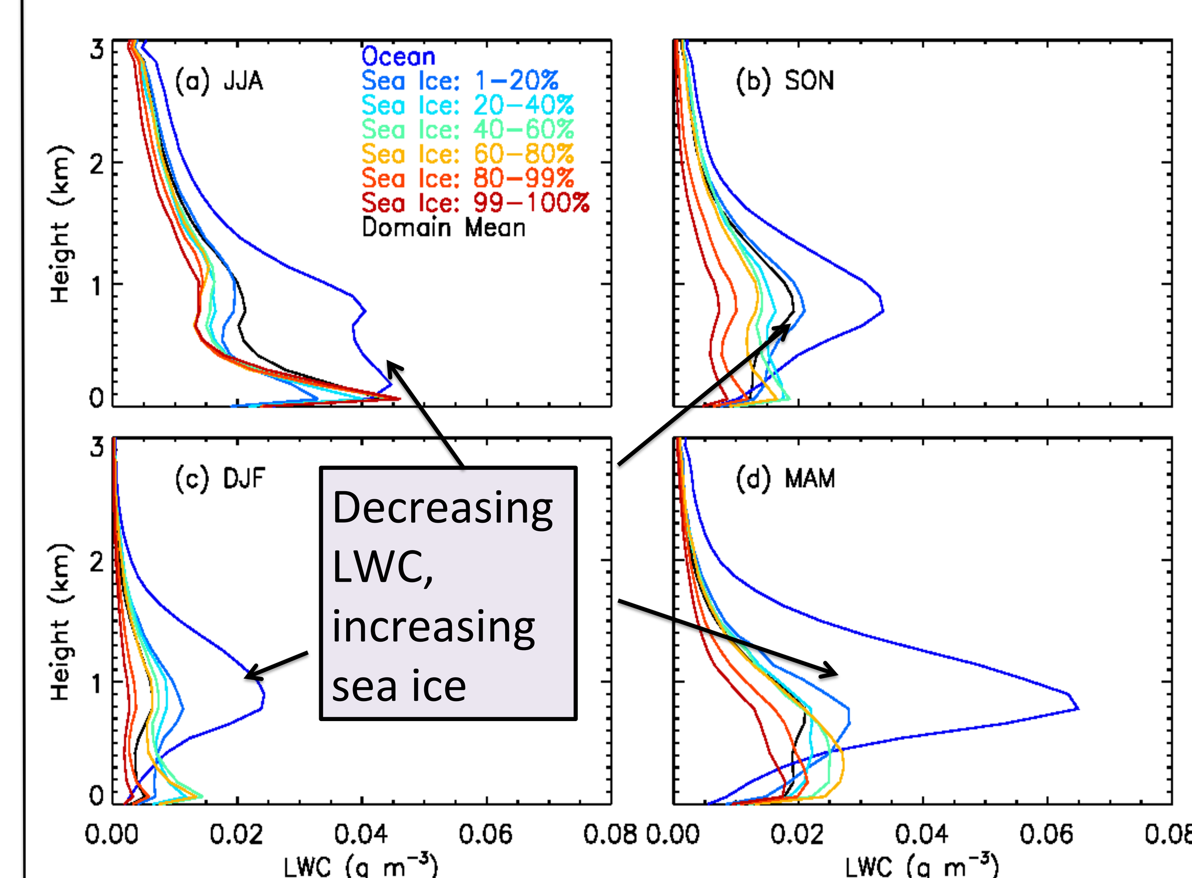


Figure above shows footprint averaged cloud LWC vertical profiles composited binned only by sea ice concentration: 20% wide bins.

- The level of maximum LWC moves closer to the surface with increasing sea ice concentration.

4c. Sensitivity of the Surface Cloud Forcing (CRF) to Sea Ice Concentration

- In JJA, the covariation of the net CRF with sea ice concentration indicates a negative feedback between clouds and sea ice.

Less Ice => Surface Cooling by clouds => More ice

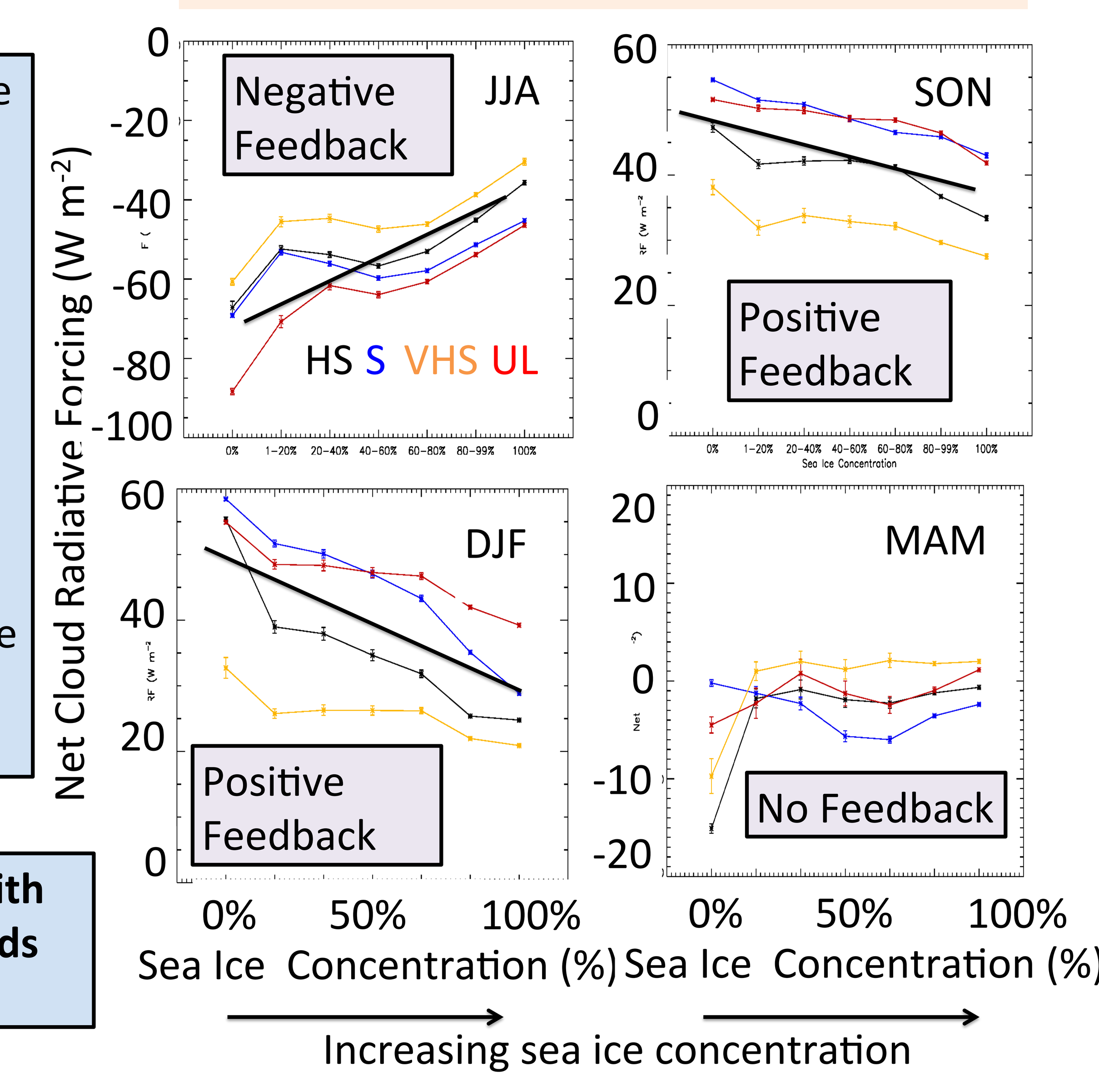
- In SON and DJF, the covariation of the net CRF with sea ice concentration indicates a positive feedback.

More Ice => Surface Warming by clouds => More ice

- No feedback is found in MAM

Takeaway: The cloud radiative forcing variation with sea ice concentration varies seasonally and depends upon the atmospheric state regime.

Figure below shows the net cloud radiative forcing composited by atmospheric state regime and binned by sea ice concentration: 20% wide bins.



5. Conclusions

•In summary, an instantaneous satellite footprint (process) level analysis has identified a statistically significant covariation between Arctic low cloud fraction and liquid water content and sea ice concentration in all seasons.

•Sea ice-cloud interactions buffer seasonal sea ice loss by limiting melting and accelerating freezing.

•Applying these relationships to a future climate with less sea ice suggests that low clouds in the Arctic should become more frequent and contain more liquid water.

•The results imply two critical features for simulation Arctic climate changes and sea ice-cloud interaction:

(1) Distribution of atmospheric regimes must be properly simulated

(2) Characteristics of the marginal ice zone must be properly modeled