Langley Research Center

# The Process of Amplified Arctic Warming: Influence on Arctic-Mid Latitude Connection in Climate Models?

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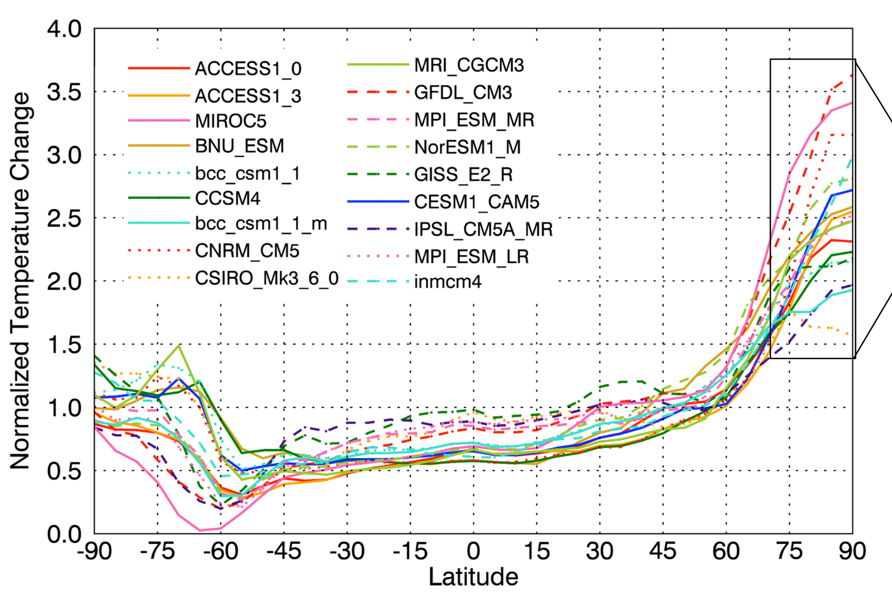
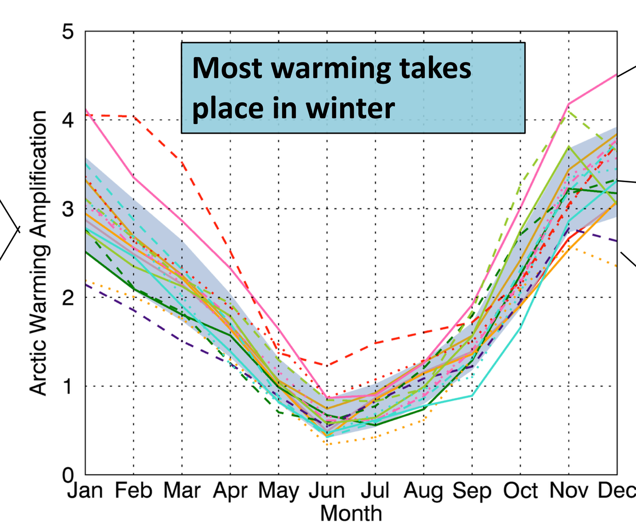
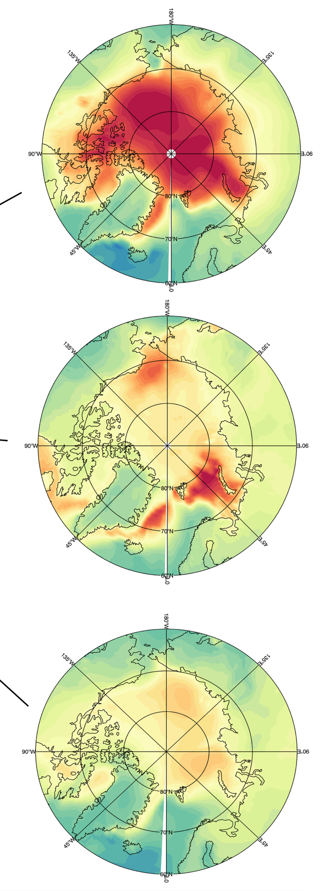
## 1. Introduction and Motivation

Goal: Identify process contributions to the CMIP5 inter-model spread in Arctic Amplification, because the manner in which a model warms is expected to influence the connections between the Arctic and the Mid-latitudes.



The degree of warming, its causes, and its spatial distribution will have a potentially significant influence on the pathways through which Arctic changes influence mid-latitude weather extremes, seasonal predictability, and climate.

Different spatial temperature response => Different Arctic circulation response

## 2. Methodology: Calculating Individual Feedback Partial Temperature Contributions using the surface energy budget equation.

Surface energy budget: $Q = (1-\alpha)SW\downarrow + LW\downarrow - \sigma T_s^4 - (S+L)$

This surface energy budget perspective (Lu and Cai 2009) allows us to isolate the individual contributions to PWA.

| FEEDBACK | PTC | ANNUAL MEAN (K) |
|---|---|---|
| Surface Albedo Feedback (SAF) | $\frac{-(\Delta\alpha)(\overline{S\downarrow} + \Delta S\downarrow)}{4\sigma T_s^3}$ | 1.97 ± 1.2 |
| Cloud Forcing (CRE) | $\frac{(1-\alpha)\Delta S\downarrow_{CLD} + \Delta F\downarrow_{CLD})}{4\sigma T_s^3}$ | 6.61 ± 1.6 |
| non-SAF shortwave clear-sky feedbacks | $\frac{(1-\alpha)\Delta S\downarrow_{CLR}}{4\sigma T_s^3}$ | -0.5 ± 0.41 |
| Longwave clear-sky feedbacks | $\frac{\Delta F\downarrow_{CLR}}{4\sigma T_s^3}$ | 7.12 ± 1.2 |
| Change in ocean heat storage (HSTOR) | $\frac{-\Delta Q}{4\sigma T_s^3}$ | -6.37 ± 1.6 |
| Change in latent and sensible heat fluxes | $\frac{-\Delta(S+L)}{4\sigma T_s^3}$ | -1.4 ± 0.71 |

**How to interpret:**

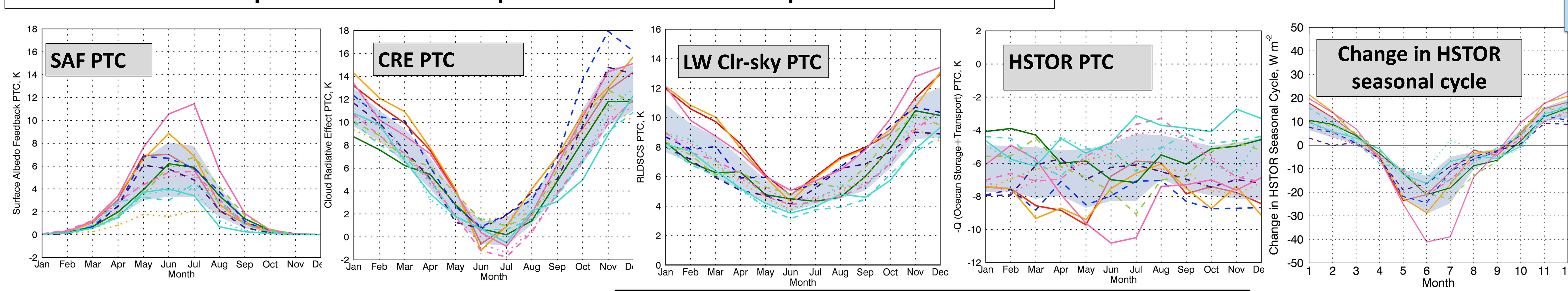
PTCs represent the contribution of each feedback to the total Arctic temperature change from present-day to 2100

Total annual mean Arctic $\Delta T_s$ by year 2100 is **7.43 K**

Results compared to analysis in Lu and Cai (2009) using CMIP3

The annual mean perspective illustrates that the two strongest warming contributions to the surface are change in the downwelling clear-sky longwave surface flux and cloud radiative effect whereas ocean heat storage is the largest "cooling" response.

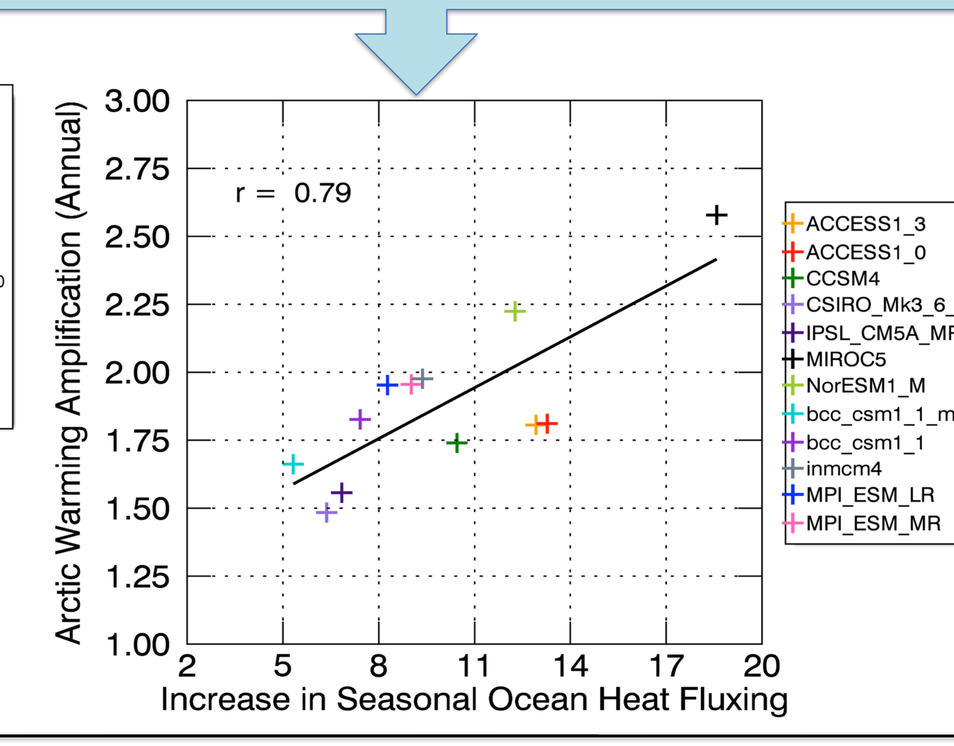
## 3. Results: Relationships between Arctic Amplification and Partial Temperature Contributions




Figures above illustrate the annual cycle of the partial temperature contributions by individual feedbacks to Arctic surface warming.

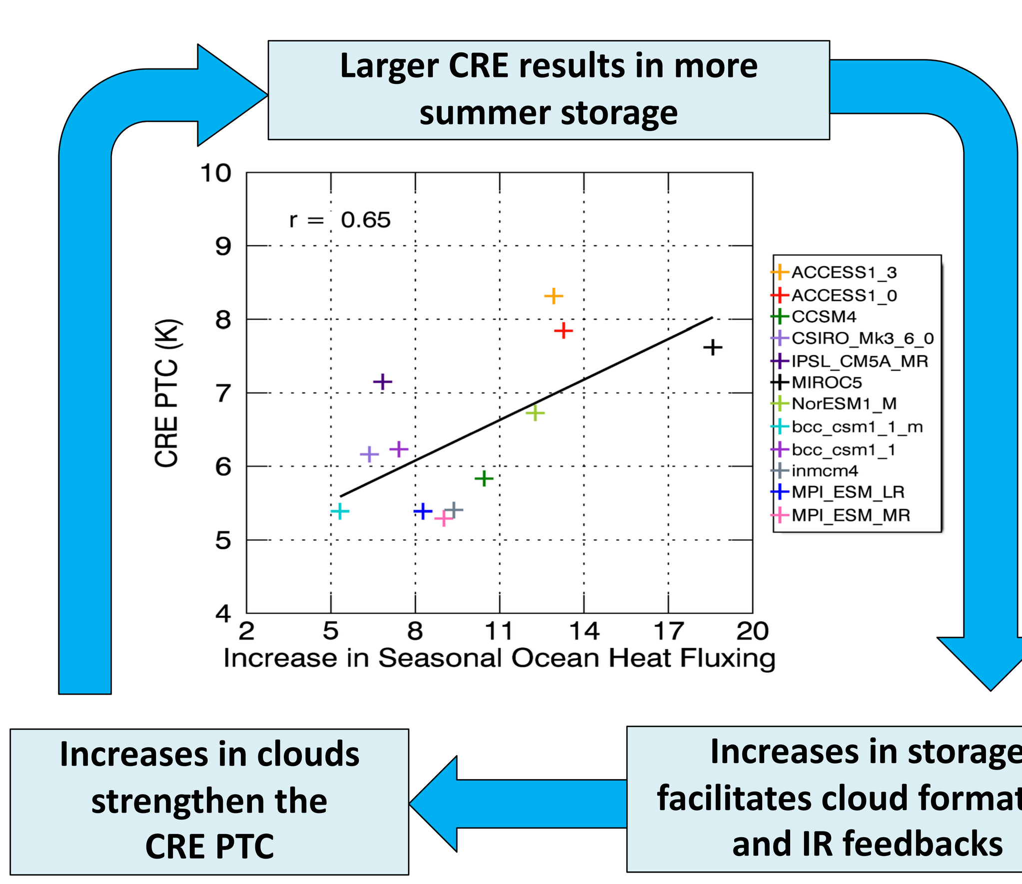
Each of the partial temperature contributions exhibit a robust annual cycle.

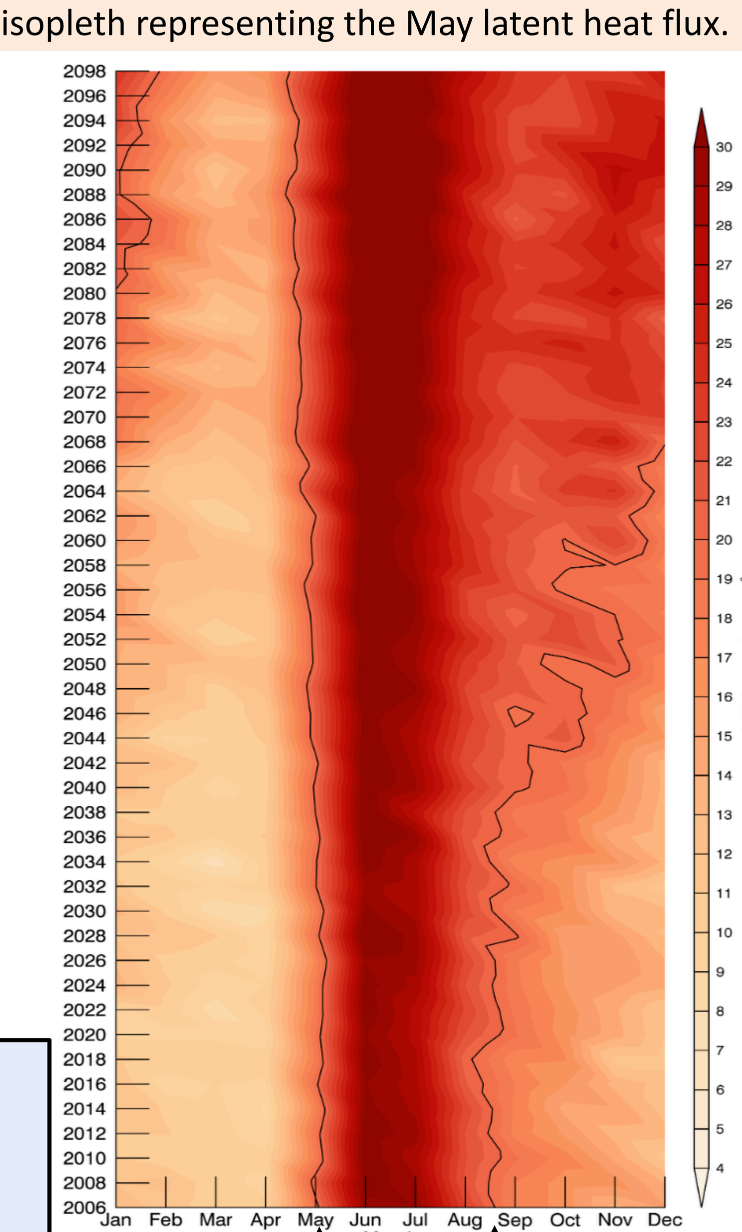
The increase in the seasonal cycling of ocean heat content is found to correlate with model Arctic Amplification (r = 0.79)




## 4. What does the Arctic do this the extra energy?

Figure below illustrates the time series of latent heat flux for a single CMIP5 climate model. The black line marks the isopleth representing the May latent heat flux.




By the end the of the century, it takes nearly all of winter for the surface latent heat flux to reach it's May "pre-melt season" value.

Takeaway: This cycle creates a 'memory' in the Arctic system of a warming event. While all heat gained during summer is released during winter, the thinning ice allows other feedback processes to interfere with the ability of model to lose energy to space.

## 5. Conclusions

- Largest contributions to the Arctic warming are from the downwelling clear-sky longwave surface flux and cloud radiative effect, both larger than the surface albedo feedback.
- Overwhelmingly, ocean heat storage is the largest contributor to slowing Arctic warming.
- The characteristics of the surface energy budget annual cycle response to increased $CO_2$ are critical to the spatial pattern and overall Arctic amplification.
- Clouds are found to play a very interesting role.
- The relationship between clouds and the seasonal fluxing of ocean heat storage suggests a feedback cycle of PWA (larger summer ocean heat storage => increases fall cloudiness => strengthening surface warming from clouds => thinner/less extension winter sea ice formation)
- The spatial contributions of this feedback loop likely influence the atmospheric circulation response and the connection between the Arctic and Mid-latitude weather and climate.
- Seasonality of the warming likely plays an important role in the connectivity between the Arctic and the mid-latitudes, because fall and winter is the time of year when the connection is strongest.

Takeaway: The processes represented in this surface energy budget decomposition control how the Arctic handles the extra energy it is currently receiving. Understanding how the Arctic climate systems deals with this extra energy is critical for unraveling the Arctic-Mid Latitude connection. At the heart, interactions between Arctic clouds, lower tropospheric stability, seasonal ocean heat storage, and the atmospheric circulation hold the key. Further investigation of the physics controlling these interactions in climate models, specifically understanding the influence of cloud microphysics and boundary layer mixing, hold promise for progress.