Clouds increasingly influence Arctic sea surface temperatures as carbon dioxide rises

Anne Sledd (NOAA/CIRES)
Jennifer E. Kay (University of Colorado, CIRES/ATOC)
Tristan L'Ecuyer (University of Wisconsin – Madison)
Mike Steele (Applied Physics Lab

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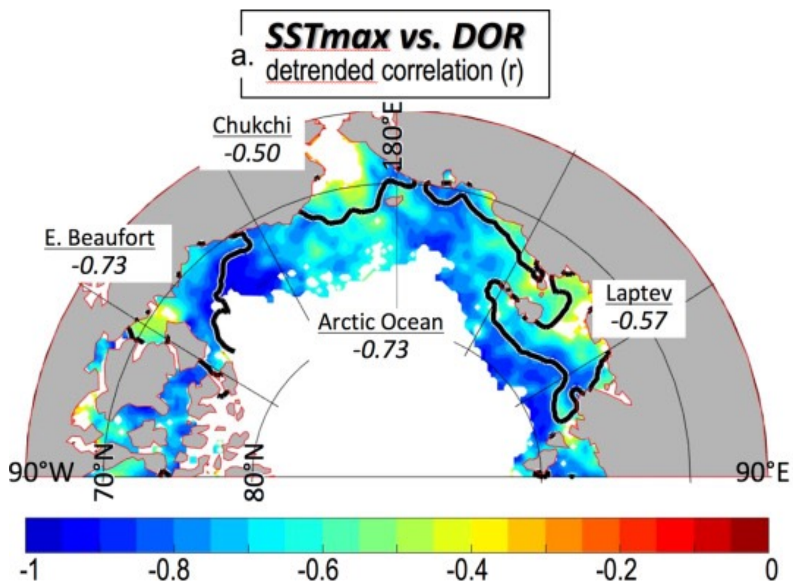
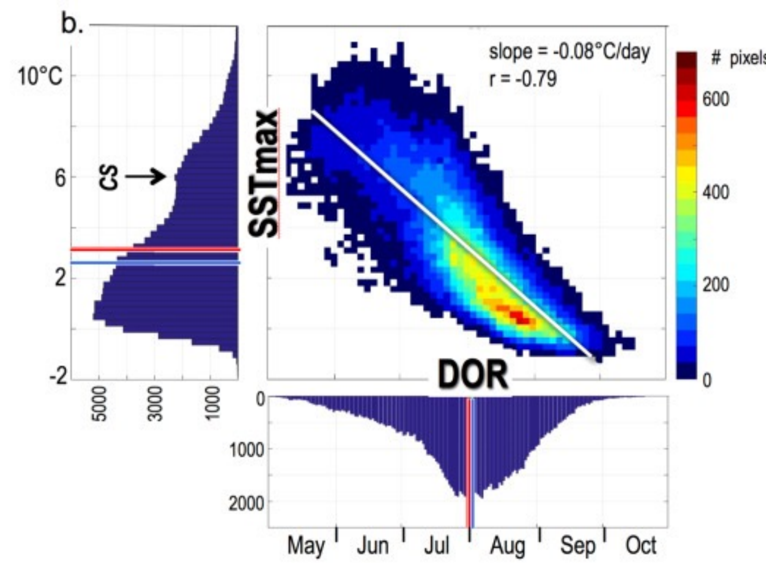
Contact: anne.sledd@noaa.gov

Motivation

- In a warmer world with more carbon dioxide, the Arctic has more open ocean for longer periods of time
- Observations show a larger maximum sea surface temperature (SSTmax) occurs with an earlier date of retreat (DOR)



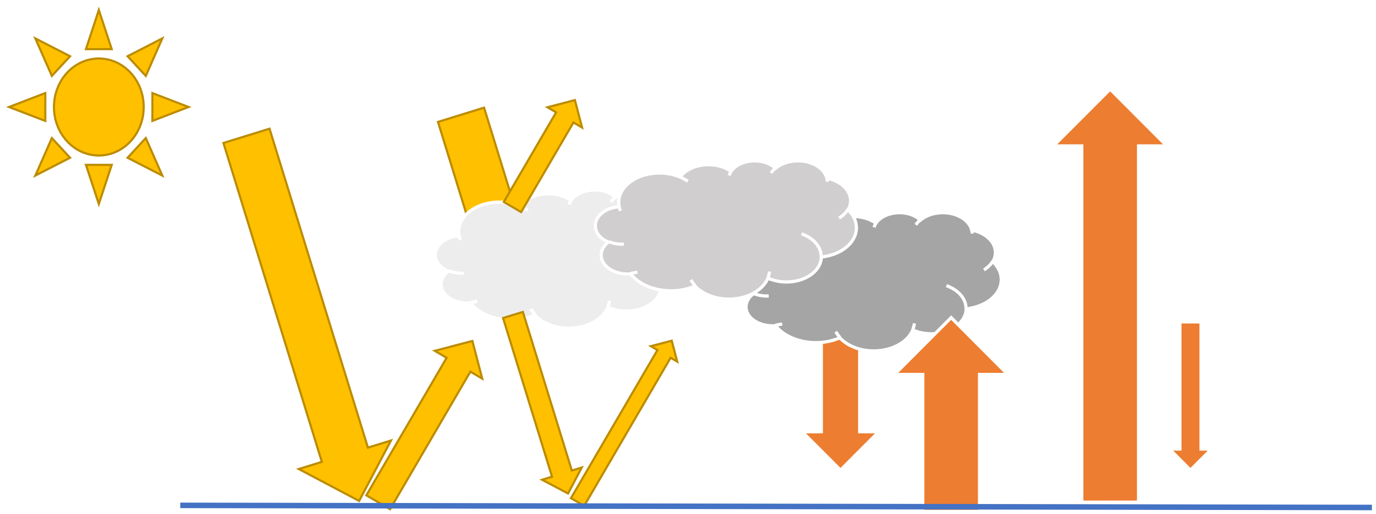


(Steele and Dickinson 2016)

Steele and Dickenson (2016) ignore clouds… So?

Clouds strongly influence radiative fluxes.

So… clouds could impact ocean heat gain during the melt season and thus, the maximum sea surface temperature



Research Questions

1) Do clouds affect ocean surface warming in the Arctic? If yes, is it through cloud longwave warming or shortwave cooling effects?
2) Do the impacts of clouds on seasonal surface warming change with a warming climate?

CESM2-CAM6 simulations

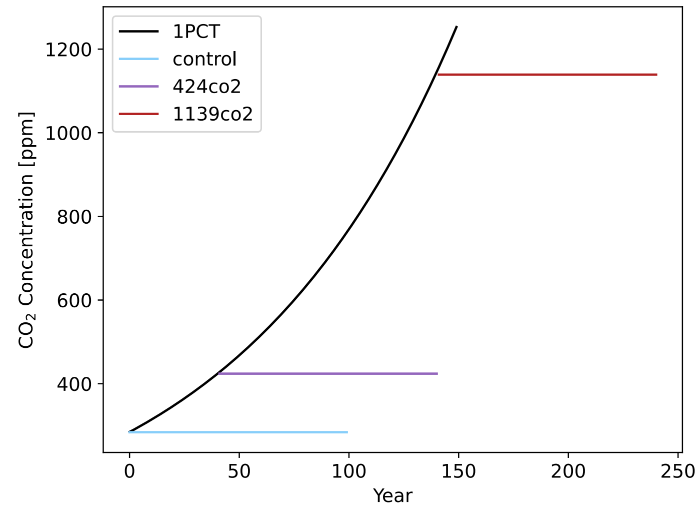
Three runs branched from CESM2 1PCT (1% increase in CO_2/year) run:

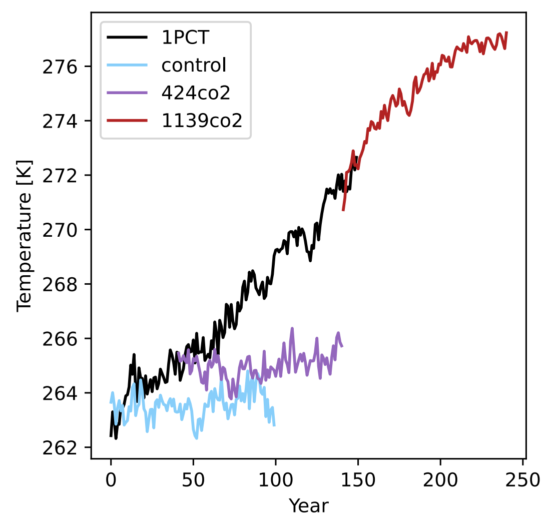
1) Pre-industrial – 287 ppm CO_2

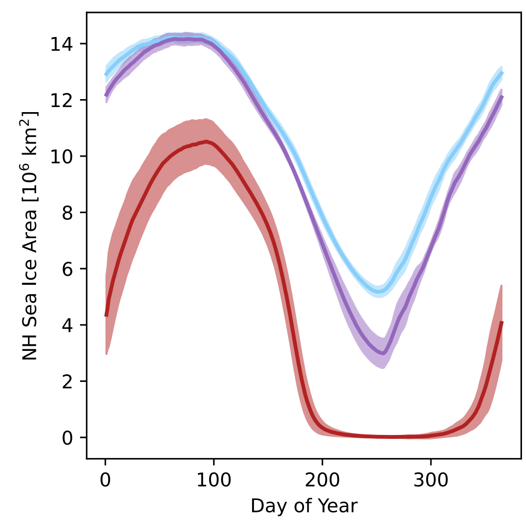
2) "present" - 424 ppm CO_2

3) 4x CO2 - 1139 ppm CO_2

- Each run 100 years long
- Runs are not in equilibrium but have increasingly warm and ice-free Arctic Oceans







Definitions: Melt Season vs. Heat Season

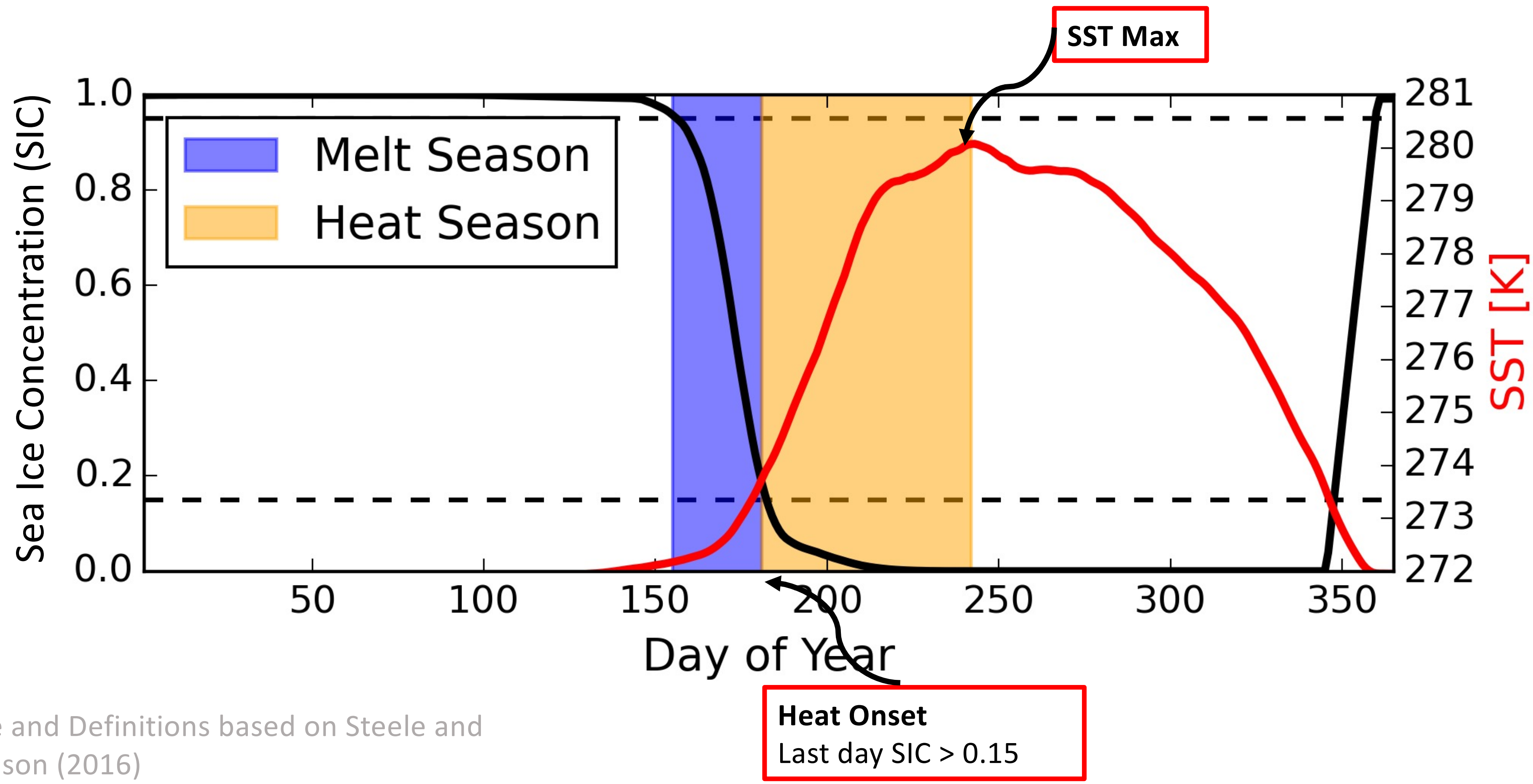
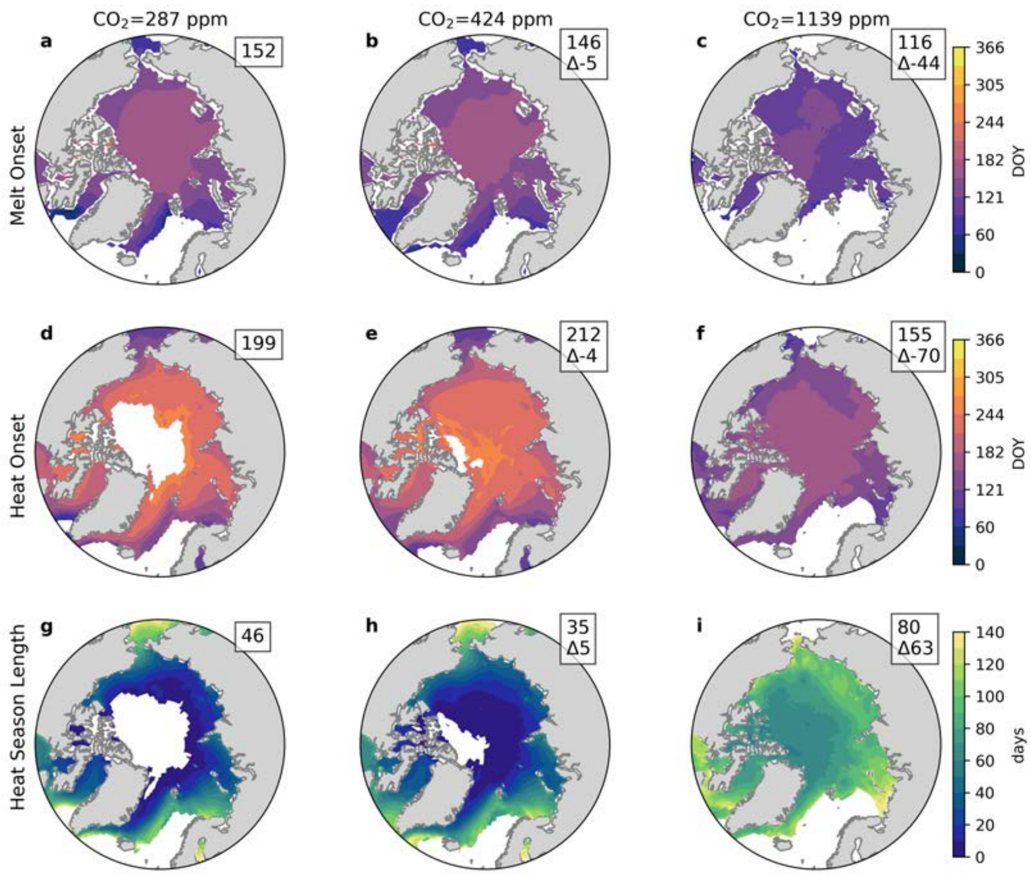


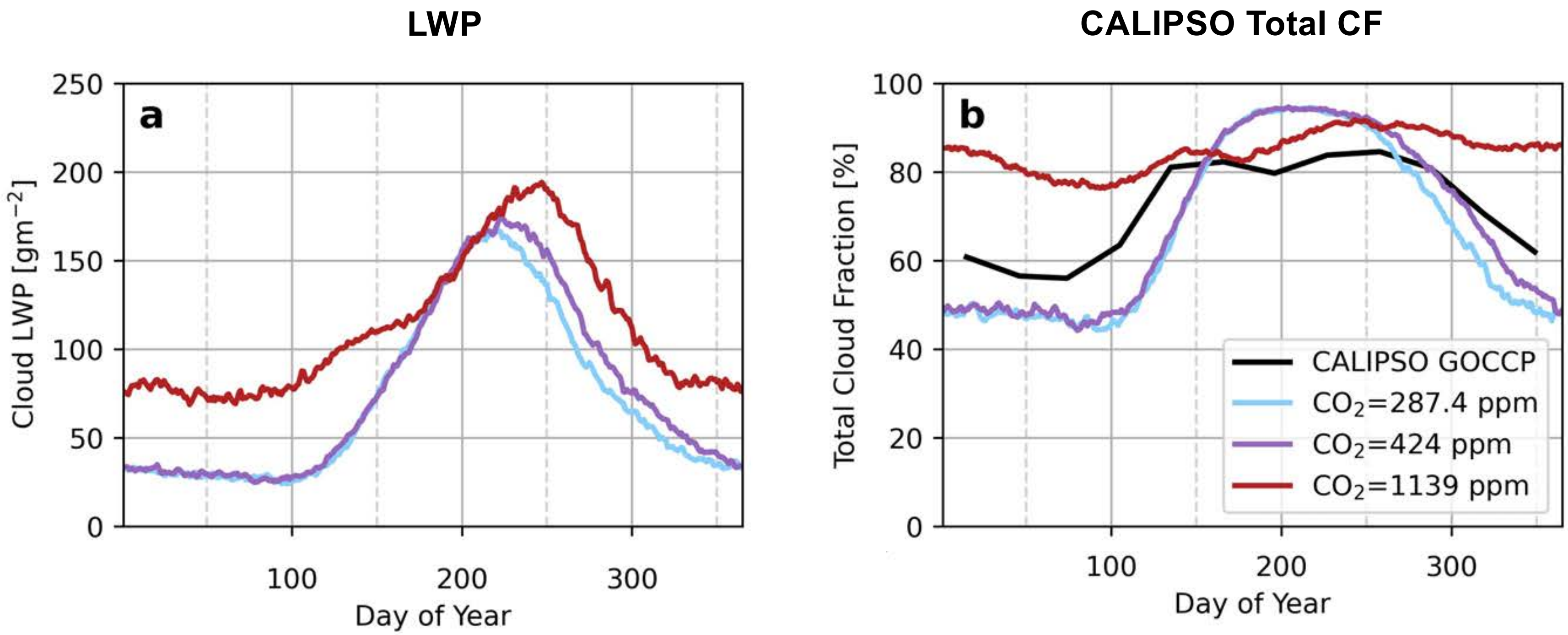
Figure and Definitions based on Steele and Dickinson (2016)

Under higher CO_2, Arctic sea ice melts earlier and *the ocean warms for longer (longer "heat season")*



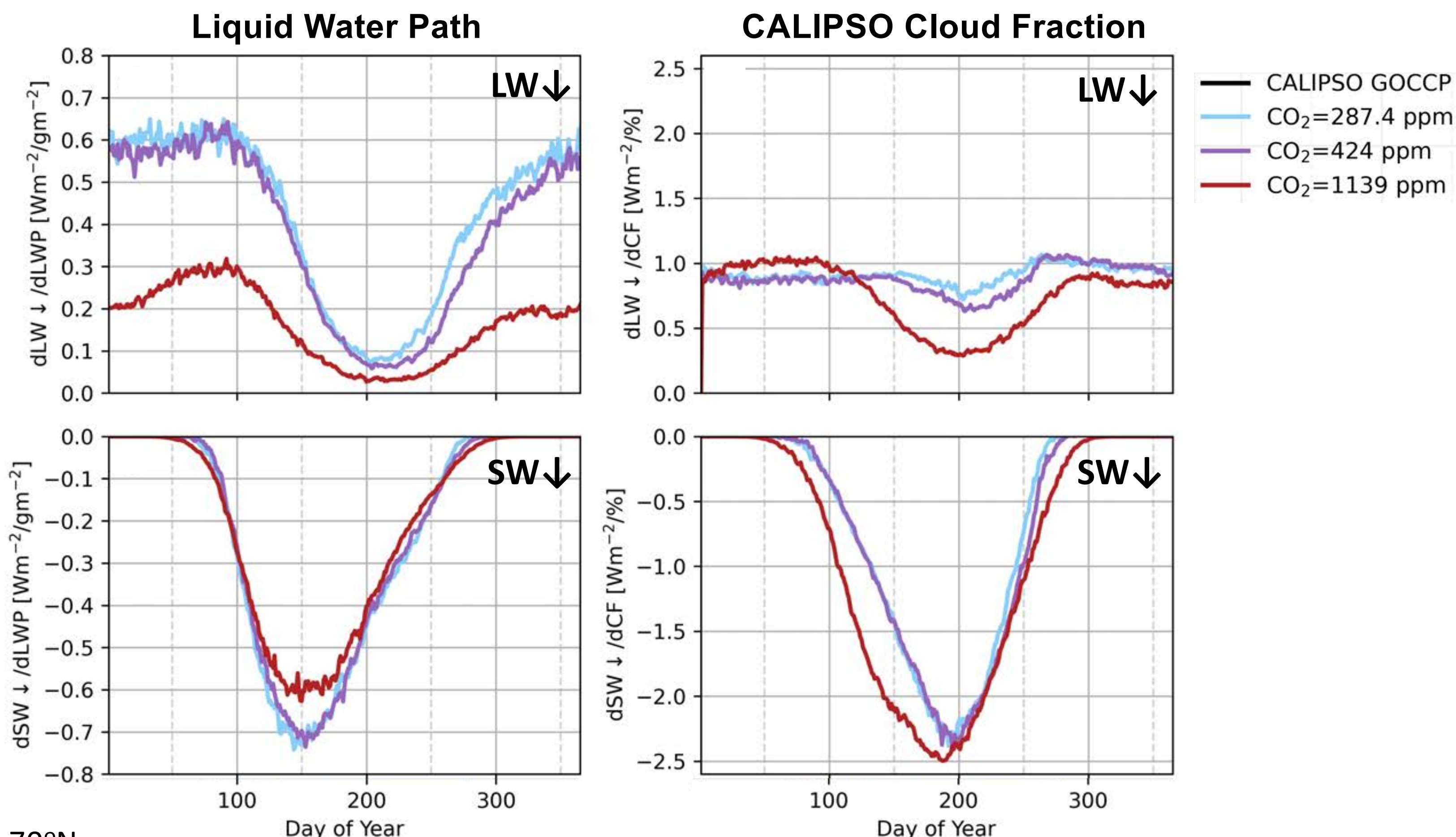
CO_2	Heat Season Length
287 ppm	Weeks in interior, Months at lower latitudes
424 ppm	Weeks to months
1139 ppm	Multiple months

What about clouds in CESM2?



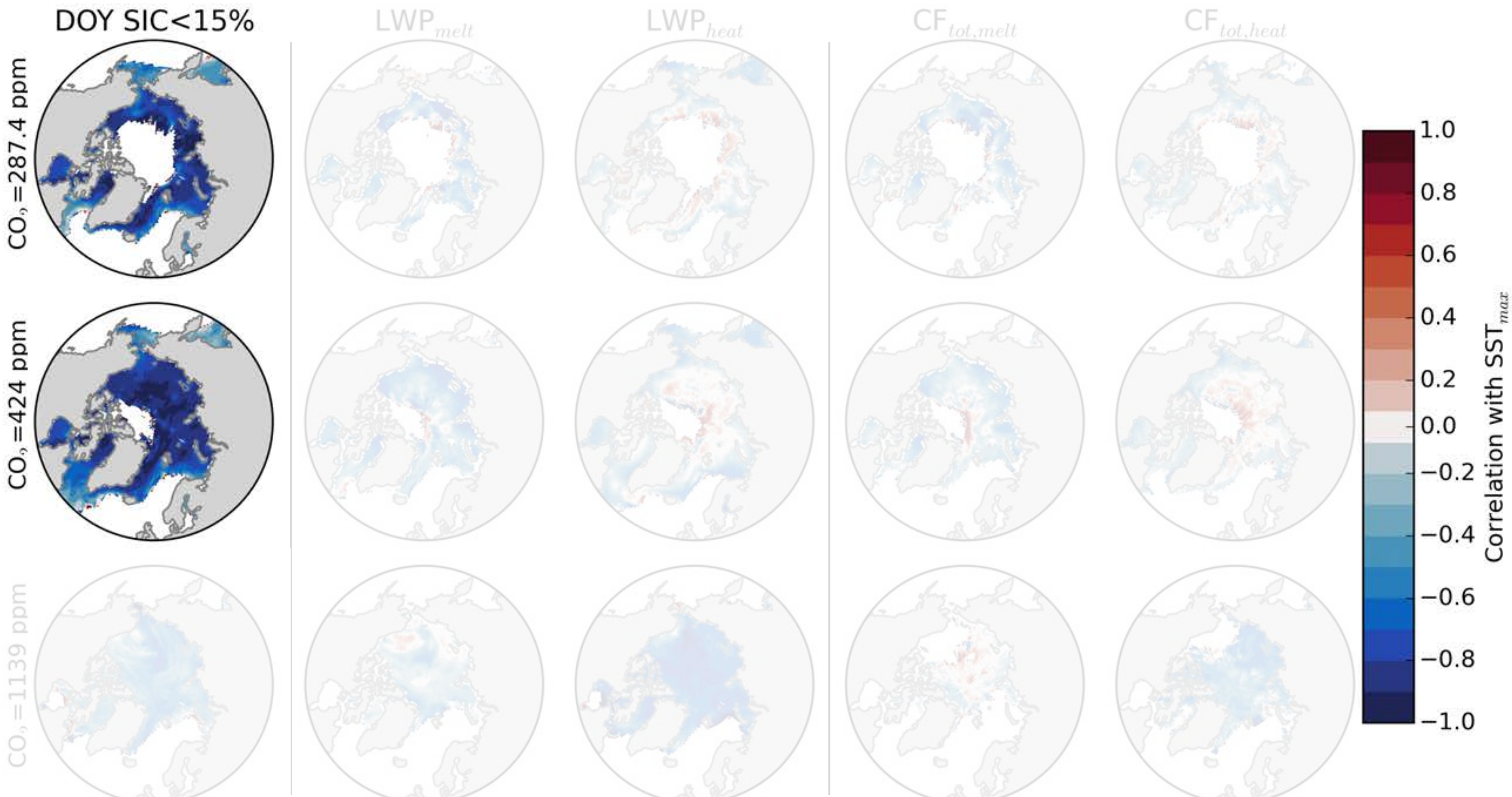
**Values for ocean grid cells >70^{o}N.*
See McIlhattan et al. 2020 for comparison of Arctic clouds in CESM1-CAM5 and CESM1-CAM6 (*[https://doi.org/10.1029/2020JD032521**](https://doi.org/10.1029/2020JD032521)**)**

Cloud influence on radiation varies with season and CO_2

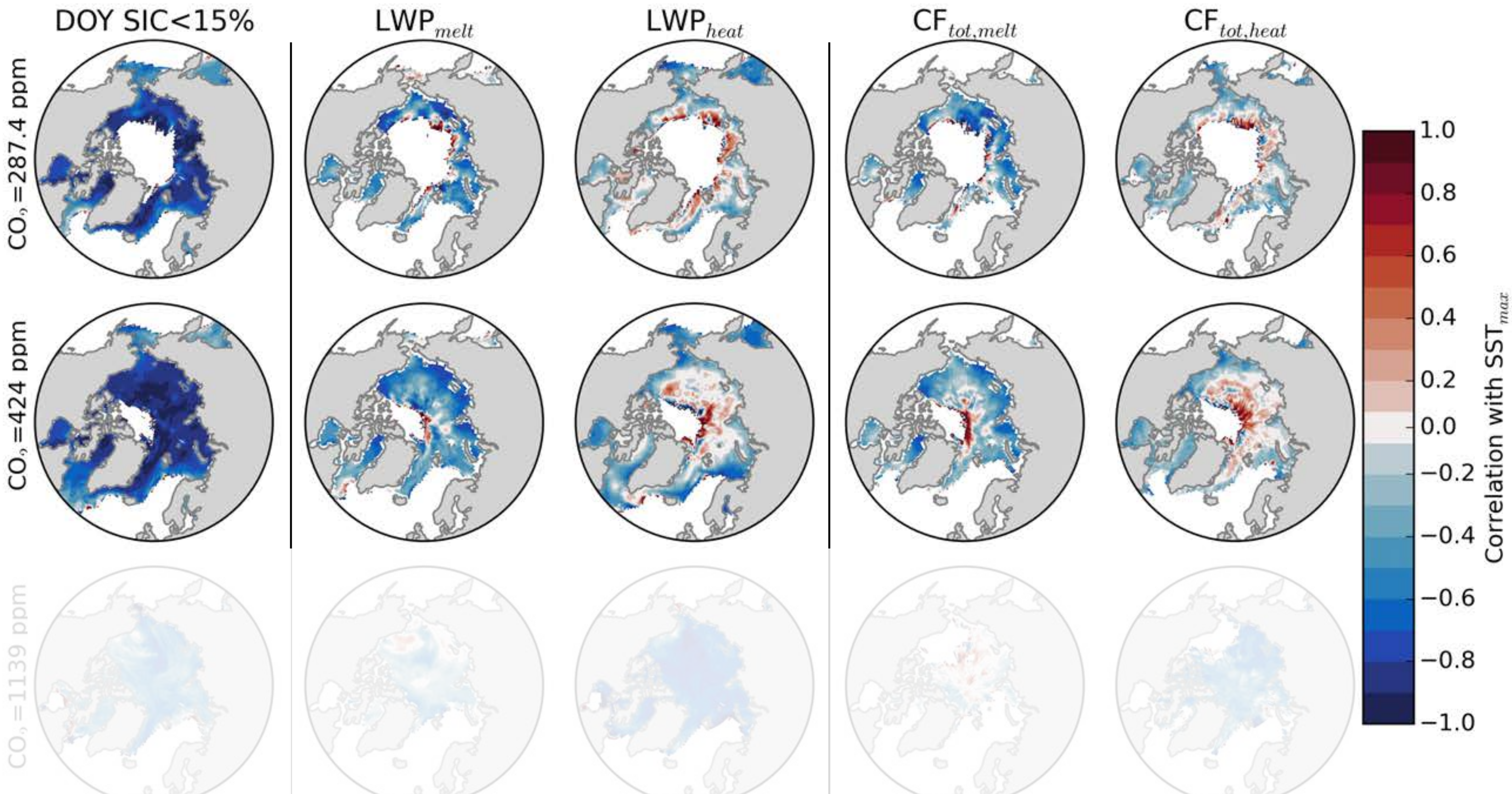


*ocean grid cells >70°N

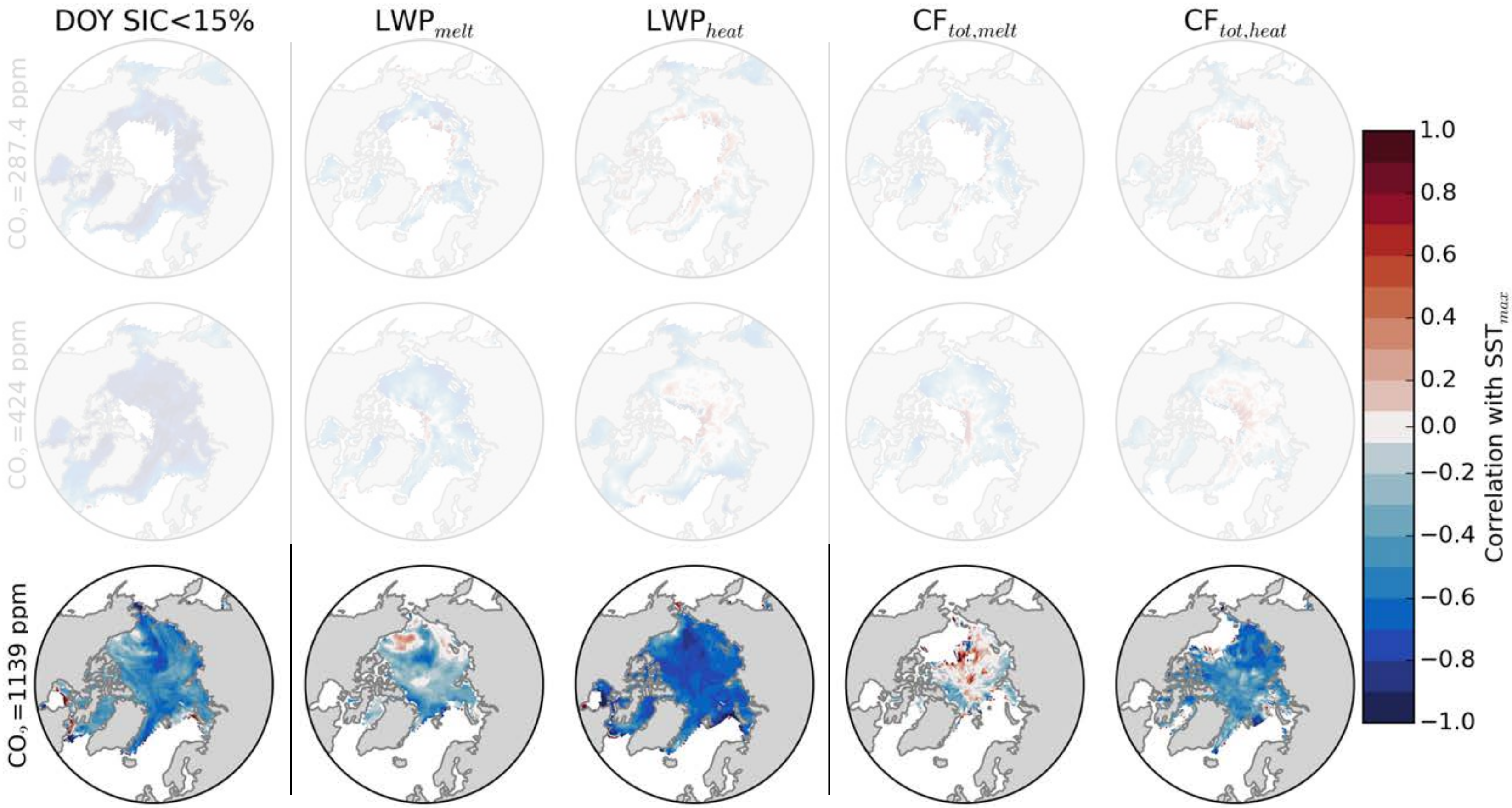
Results: At low CO_2, an early start of the heat season leads to higher maximum SST.



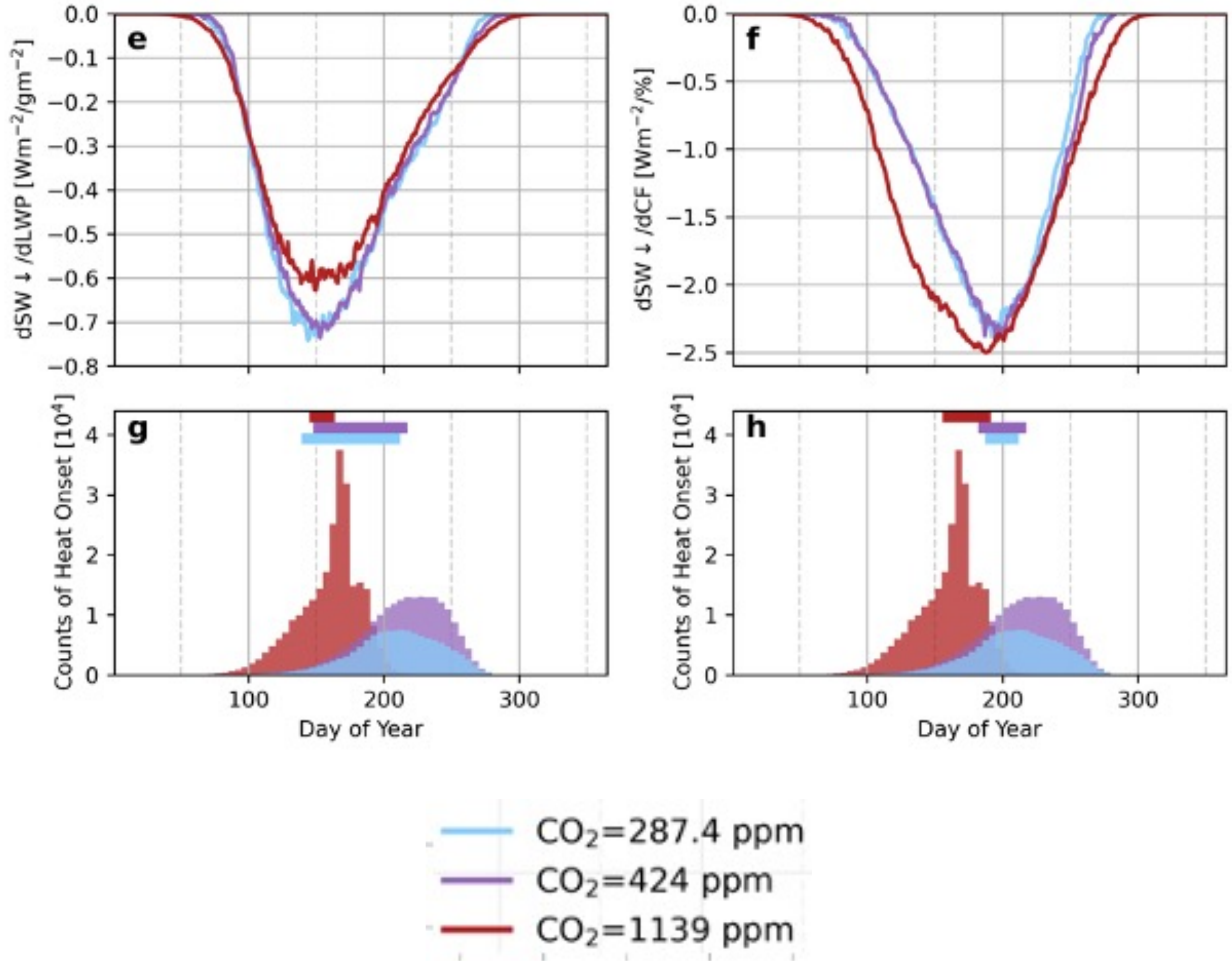
Results: At low CO_2, sea ice retreat timing (not clouds) is strongly correlated with maximum SST.



Results: As the heat season aligns with the June solstice, clouds increasingly explain maximum SST.

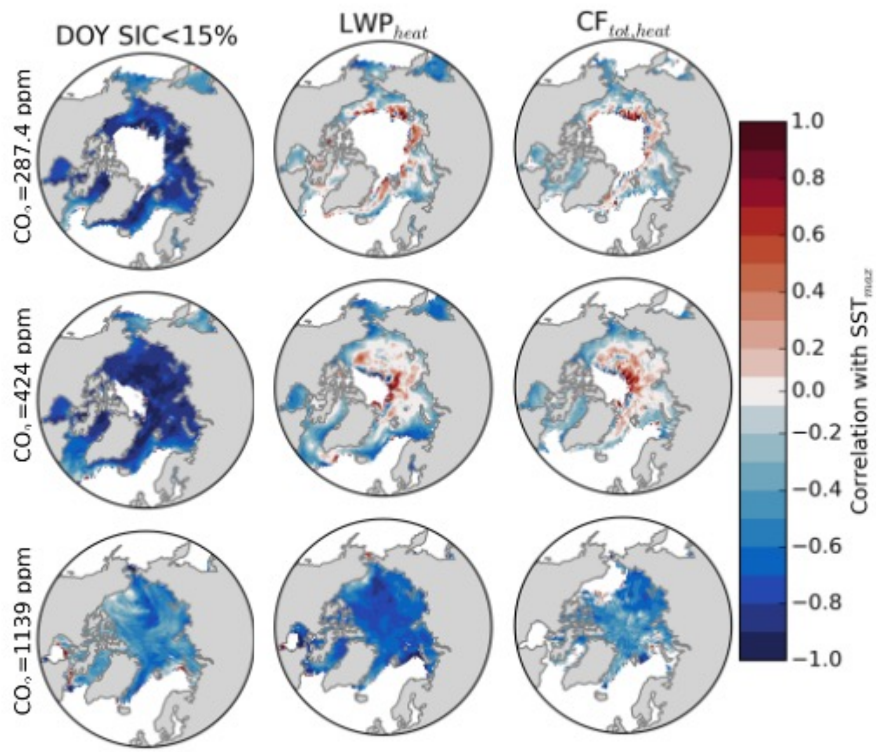


Results: *The alignment of heat season onset with the June solstice and the peak influence of clouds on shortwave fluxes optimized as CO2 increases…*



Summary – Sledd et al. (in prep)

- **With low CO2, sea ice retreat timing, not clouds, generally controls maximum annual Arctic SSTs.**
- **As CO_2 increases, sea ice retreats closer to the June solstice, and clouds increasingly explain more maximum SST variability.**
  - At high CO_2 levels, the *earlier* and *longer* heating season coincides with when the surface is most affected by shortwave cloud cooling
- **When the Arctic is seasonally ice-free, SST_{max} becomes 3x more sensitive to clouds.**



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