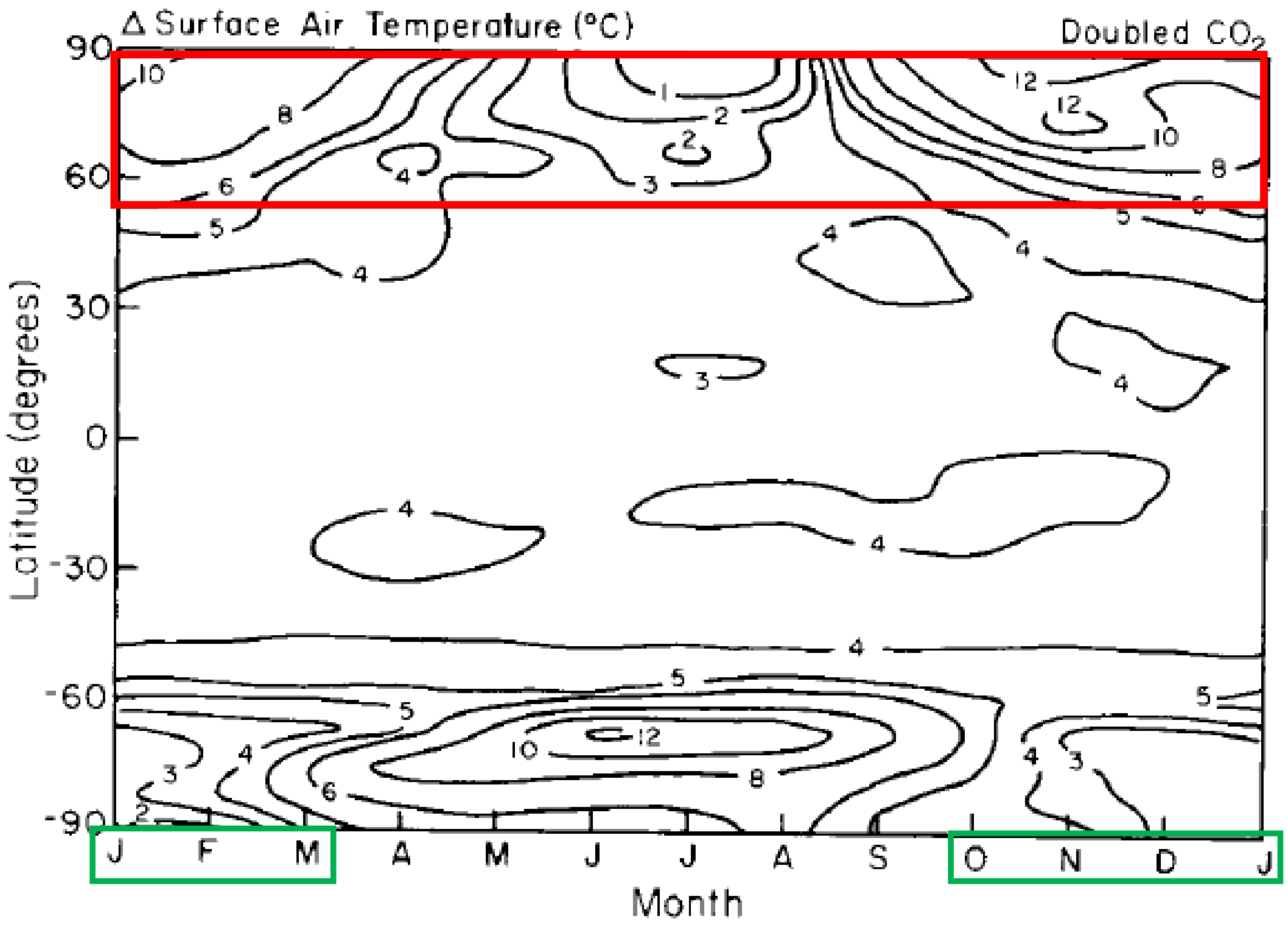
The Impact of Sea-Ice Loss on Arctic Climate Feedbacks and their Role for Arctic Amplification in CESM1 and ERA5

Matthew T. Jenkins and **Aiguo Dai**

University at Albany, State University of New York

27th Annual CESM Workshop
Climate Variability and Change Working Group Meeting
June 15, 2022

Overview of Arctic Amplification (AA)



Hansen et al. (1984)

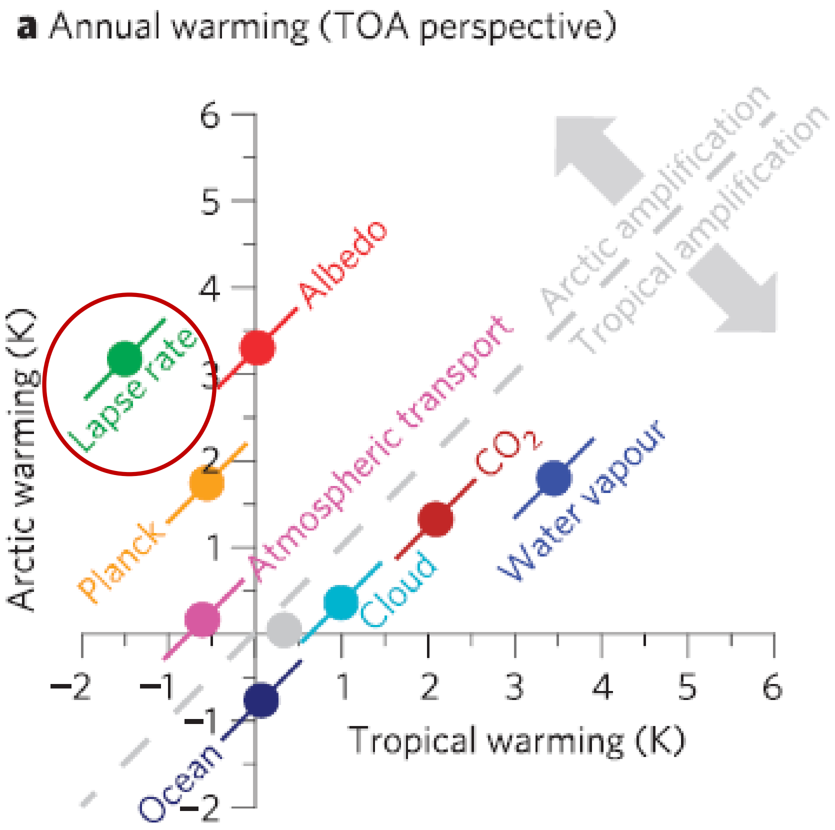
- AA recognized by early modeling studies with increased CO_2.
- Largest Arctic warming occurs in late autumn and early winter.
- Causes of AA are still debated.

Mechanisms for Arctic Amplification

- Sea-Ice Loss (Screen & Simmonds 2010; Boeke & Taylor 2018; Dai et al. 2019)
- Thermal inversions and Positive Lapse Rate Feedback (Bintanja et al. 2011; Pithan & Mauritsen 2014)
- Enhanced Poleward Energy Transport (Cai 2005; Gong et al. 2017)
- Downwelling surface longwave (LW) radiation (Burt et al. 2016)
- Other Processes

  - Sea-ice loss largely explains AA's **spatial** and **seasonal** patterns (e.g., Boeke & Taylor 2018; Dai et al. 2019)

Climate Feedbacks and AA in the CMIP5 4xCO_2 Runs



Pithan & Mauritsen (2014)

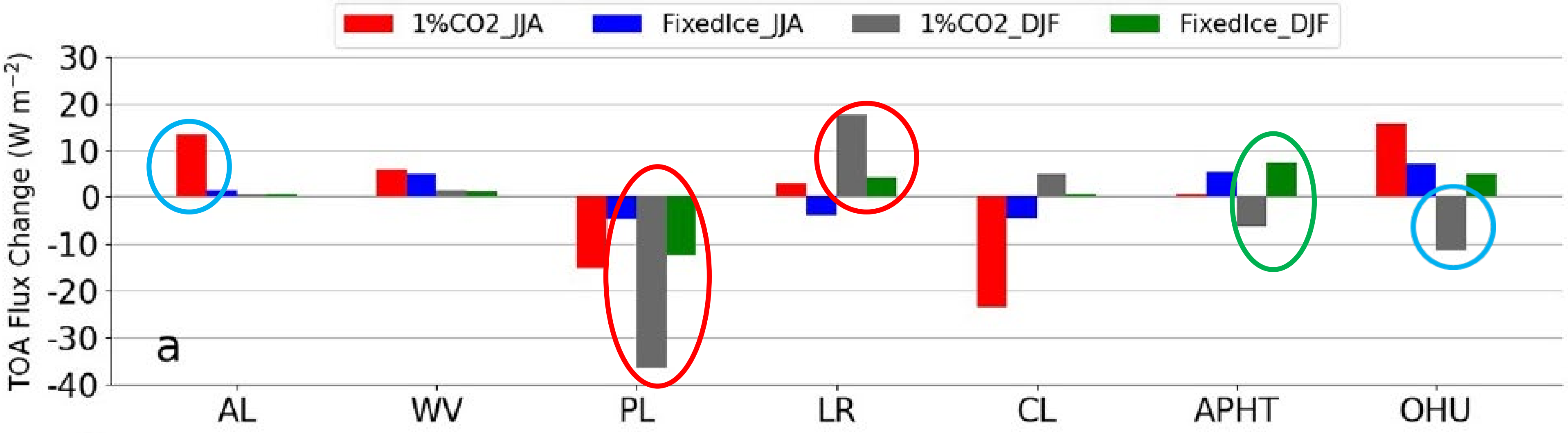
- Processes that induce greater warming in the **Arctic** contribute to AA.
- Processes that induce greater warming in the **lower latitudes** oppose AA.
- Lapse Rate Feedback warms the Arctic and cools the tropics.
  - Large lapse rate feedback attributed to high stability of Arctic atmosphere.

What is the impact of sea-ice loss on local Arctic climate feedbacks?

CESM1 Model Experiments

- CESM1 Experiments (run by Dai et al. 2019):
  - Standard 1%/yr increase in CO_2 run (1%CO_2)
    - Fully coupled, dynamic sea ice
  - Fixed sea-ice ice run (FixedIce)
    - Same as 1%CO_2 run, except effects of Arctic sea-ice loss are excluded.
    - **AA greatly reduced in FixedIce.**
  - Each simulation run for 235 years.
  - Years 131-150 compared to years 1-80 of a pre-industrial control run.
  - Feedbacks computed with radiative kernels (Pendergrass et al. 2018).

Sea-Ice Loss & Climate Feedbacks in CESM1



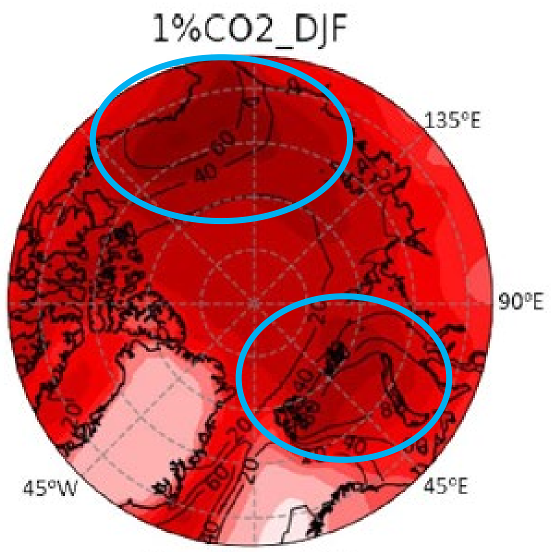
- Sea-ice loss enhances summer surface albedo feedback and winter oceanic heat release.
- Planck and lapse rate feedbacks greatly reduced without sea-ice loss.
- Winter atmospheric heat transport equatorward (across 67°N) with sea-ice loss.

AL - Surface Albedo Feedback; WV - Water Vapor Feedback; PL – Planck Feedback; LR – Lapse rate feedback
CL – Cloud Feedback; APHT – Atmospheric Poleward Heat Transport; OHU – Oceanic Heat Uptake

Jenkins & Dai (2021)

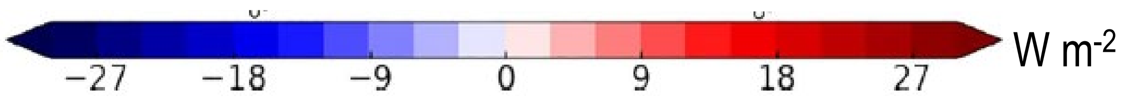
Lapse Rate Feedback & Sea-Ice Loss Spatial Patterns

- Shading – Lapse Rate Feedback (W m^{-2})
- Contours – Sea-Ice Loss (% multiplied by -1)



- Winter lapse rate feedback enhanced over areas with large sea-ice loss.

- Without sea-ice loss, the winter lapse rate feedback is reduced over the Arctic.
  (the atmosphere sees fixed sea ice in FixedIce)



Jenkins & Dai (2021)

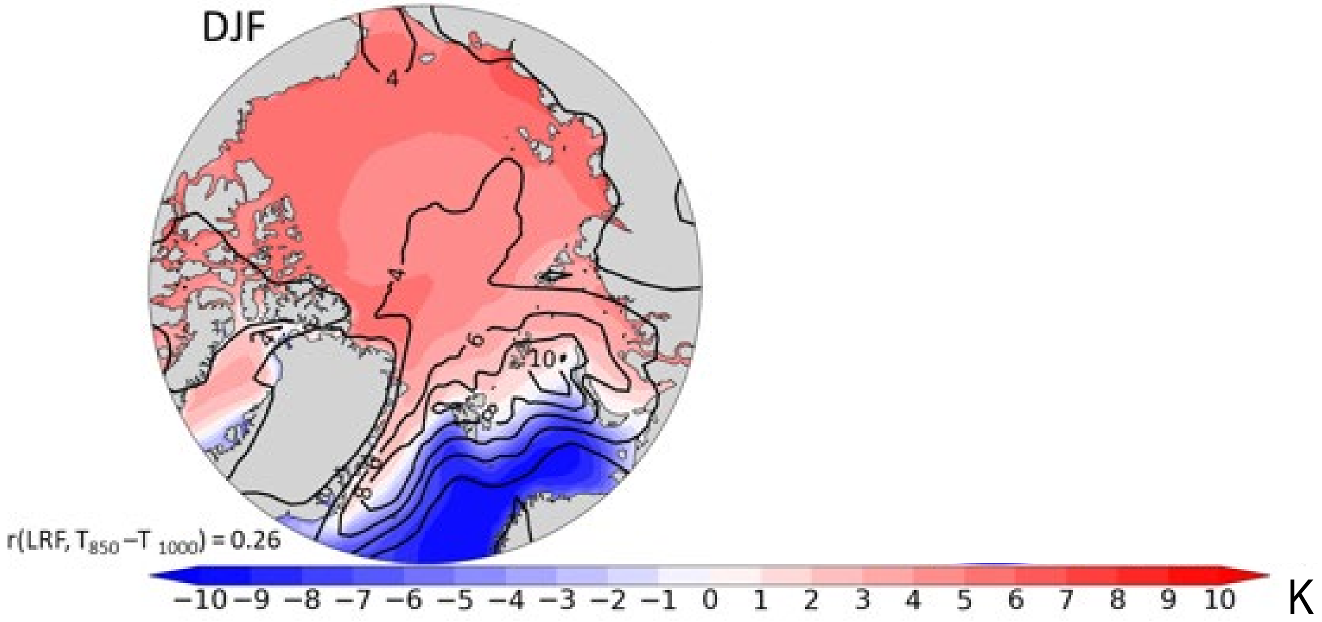
ERA5 Feedback Analysis

- Years 1990-2019 compared to years 1950-1979.
- Feedbacks computed with radiative kernels (Huang et al. 2017).

What are the spatial patterns of climate feedbacks in the Arctic?

Lapse Rate Feedback vs. Temperature Inversion

Winter



Unstable Conditions | Stable Conditions

Shading: 1950-1979 mean $T_{850\ hPa} - T_{1000\ hPa}$ (K)

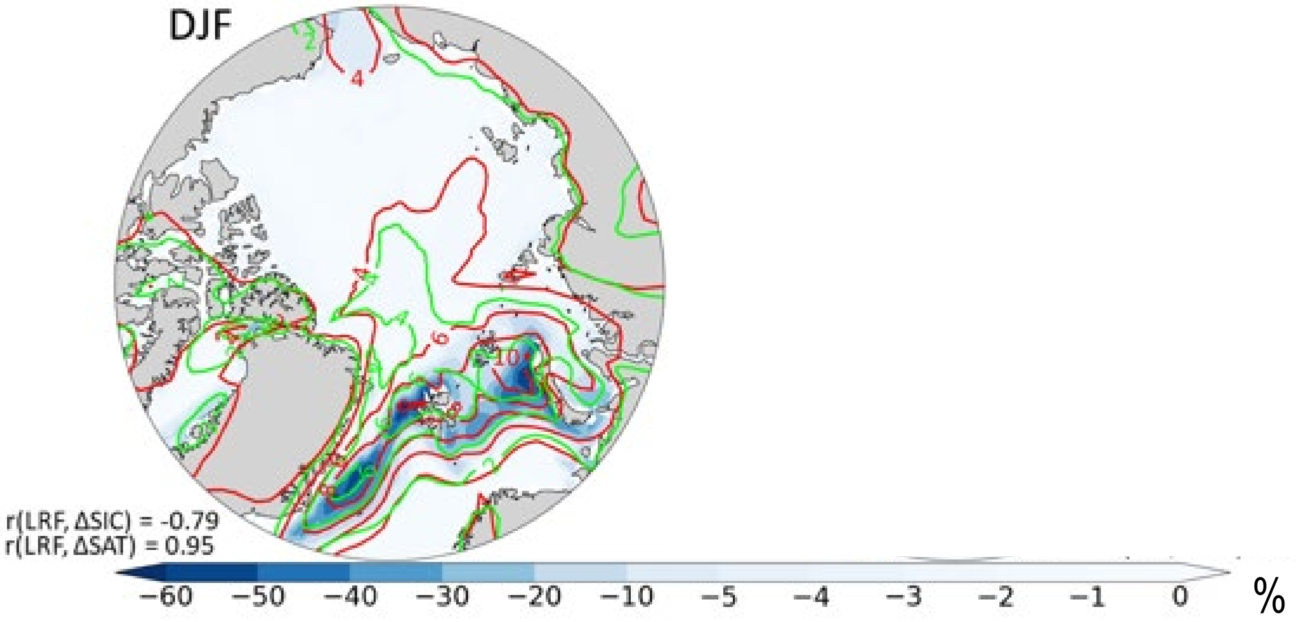
Contours: Lapse Rate Feedback (W m^{-2})

- Weak relationship in winter (**r = 0.26**)
- Moderate relationship in autumn (**r = 0.63**)

Jenkins & Dai (2022) *Submitted to GRL*

Lapse Rate Feedback vs. Sea-Ice Loss

Winter



Shading: Sea-Ice Loss (%)

Green Contours: ΔSAT (K)

Red Contours: Lapse Rate Feedback (W m^{-2})

- Lapse rate feedback closely related to autumn and winter ΔSAT and sea-ice loss.

Jenkins & Dai (2022) *Submitted to GRL*

Summary

- Summer surface albedo feedback and winter oceanic heat release are **reduced without sea-ice loss**.

- Winter lapse rate and Planck feedbacks are **reduced without sea-ice loss and oceanic heat release**.

- Winter lapse rate feedback closely follows spatial patterns of **sea-ice loss** and **surface warming**, but *not* the mean **temperature inversion**.

- Net atmospheric energy transport is **equatorward** with sea-ice loss and large AA.

Referenced Papers

Jenkins, M., & Dai, A. (2021). The impact of sea-ice loss on Arctic climate feedbacks and their role for Arctic amplification. *Geophys. Res. Lett.*, 48, e2021GL094599

Jenkins, M. T., & Dai, A. (2022). Arctic climate feedbacks in ERA5 reanalysis: Seasonal and spatial variations and the impact of sea-ice loss. *Geophys. Res. Lett.,* being revised.