Credit:
Mike Morton

Update on CESM2-CMIP5 simulations and their value for polar climate studies

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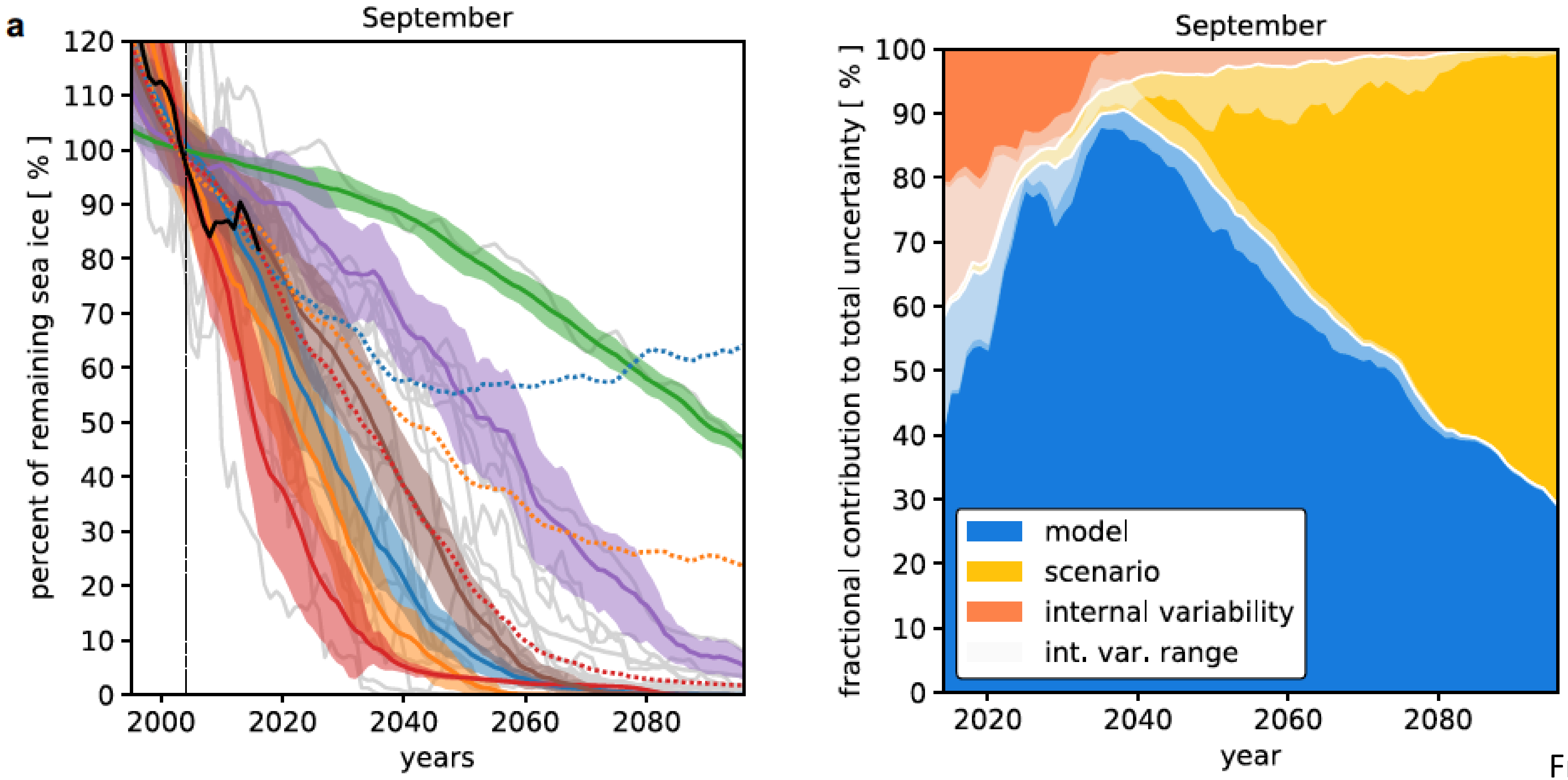
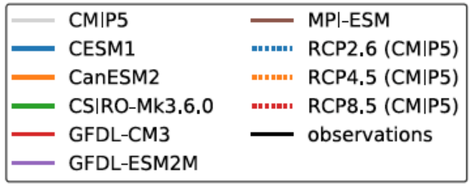
Uncertainty in climate projections

- Internal variability (chaotic system)
- Model structure (parameterizations, resolution, etc.)
- Scenario forcing (future GHGs, aerosols, etc.)

September Arctic Sea Ice Change

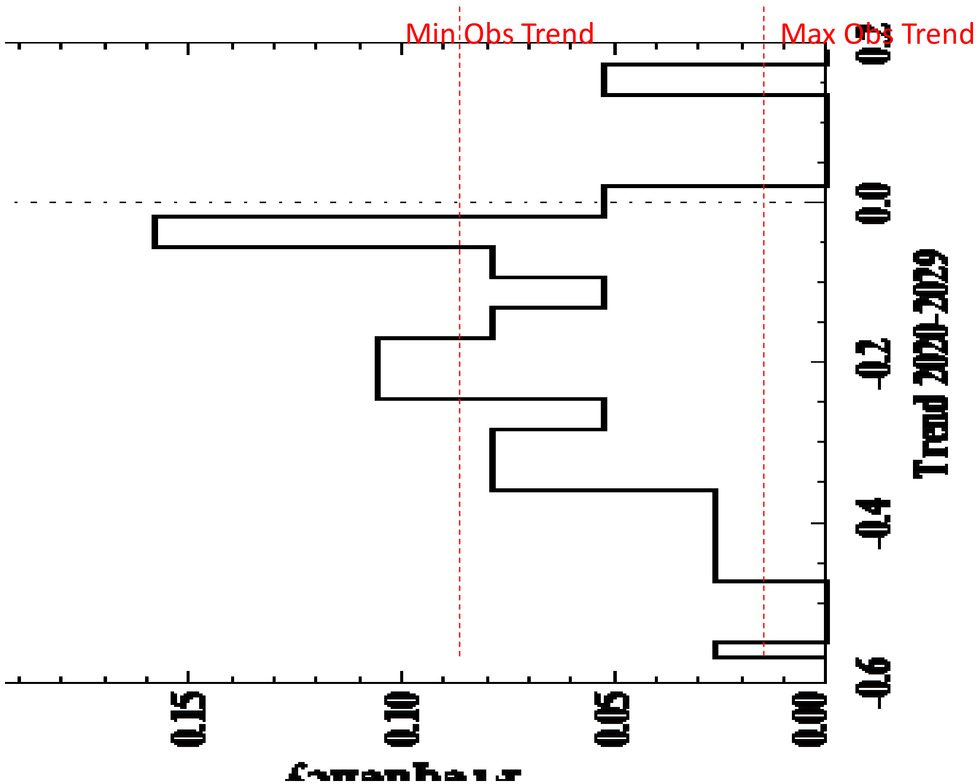




From Bonan, Lehner, Holland, 2021

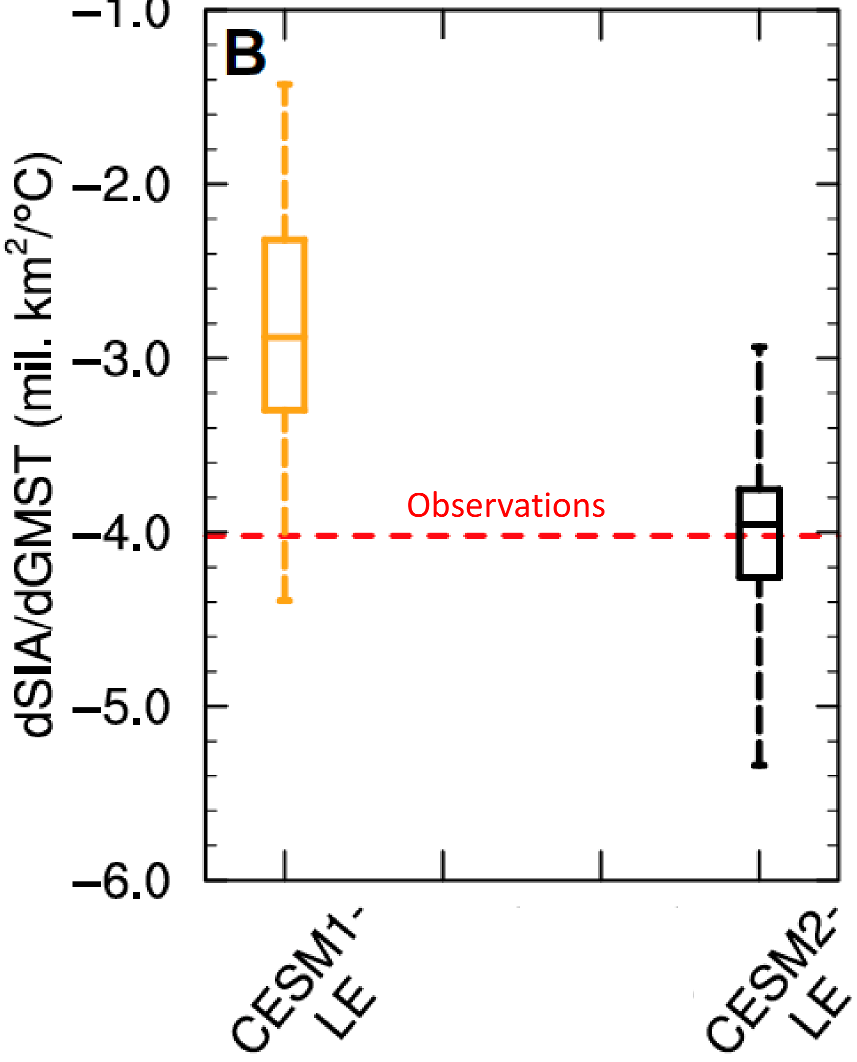
Sources of uncertainty in historical climate simulations

Importance of internal variability

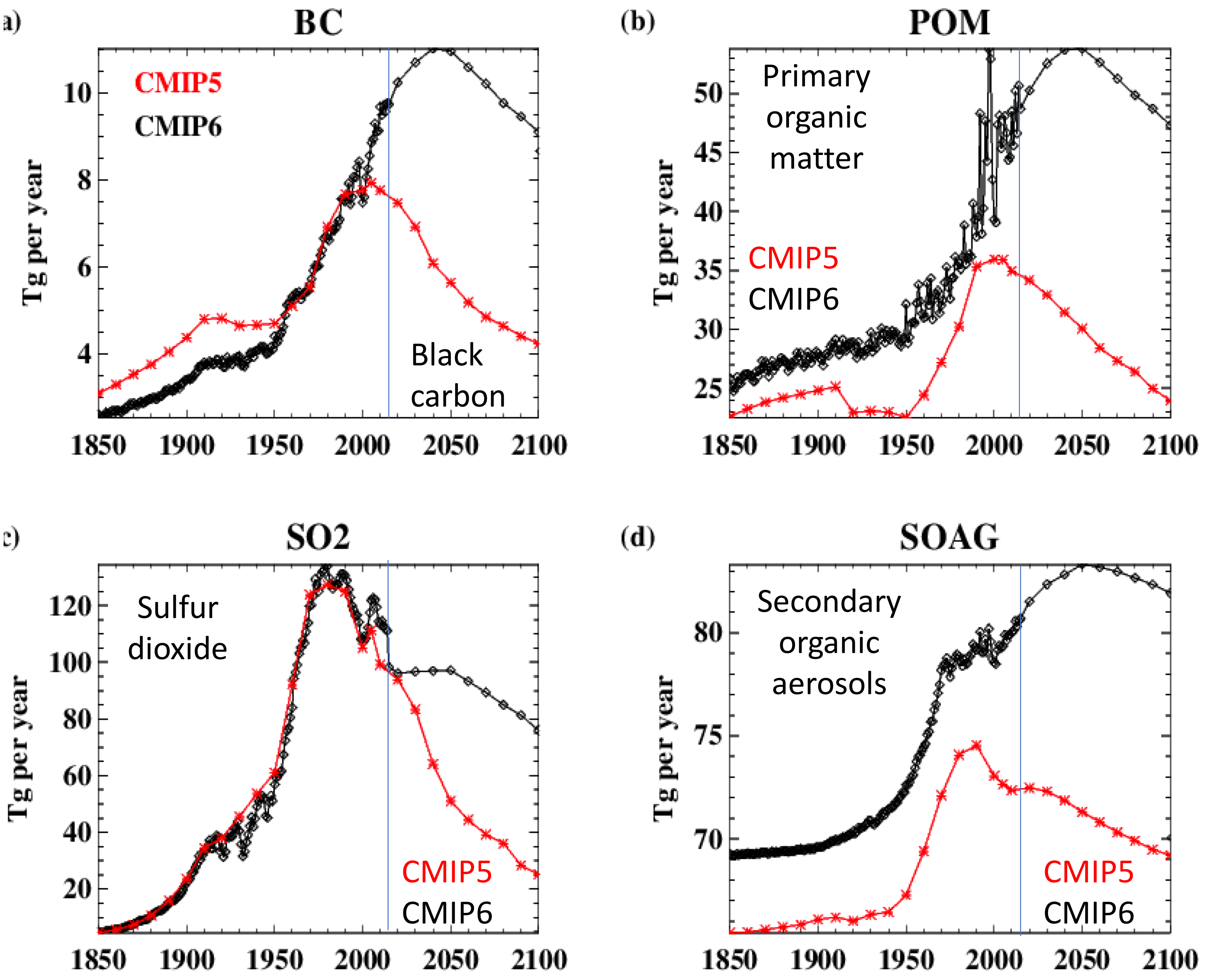


From the CESM1-LE

September NH Sea Ice Sensitivity
1979-2014



From: DeRepentigny et al 2022



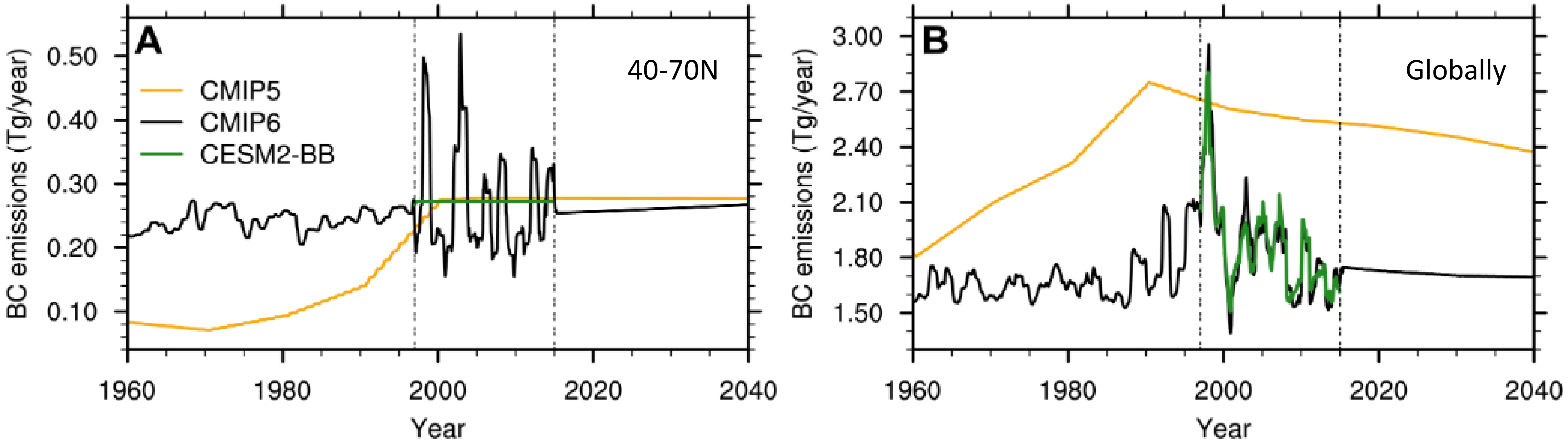
Less appreciated is the importance of historical forcing uncertainty

Anthropogenic aerosol and biomass burning emissions

Also true for volcanic emissions

From Holland et al., 2024

Biomass burning emissions



Both mean and variability of emissions are uncertain

Because of non-linear climate interactions, this can be important

From DeRepentigny et al., 2022

What is the influence of model structure and forcing uncertainty on historical Arctic change?

Focus on the forced climate signal (so ensemble means)

Done within the context of two models (CESM2 and CESM1)
And the uncertainty inherent in CMIP6 vs CMIP5 forcing

Exploring sources of climate simulation uncertainty

Experiments

- CESM1-LE, 40 members, run with CMIP5 forcings
- CESM2-LE, 50 members, run with CMIP6 forcings
- CESM2-CMIP5, 15 members, **new model but old (CMIP5) forcings**
- CESM2-LEsmbb, 50 members, run with CMIP6 forcings **but smoothed biomass burning emissions**

Differences between CESM2-LE and CESM1-LE are attributable to:

Model uncertainty = CESM2-CMIP5 – CESM1-LE

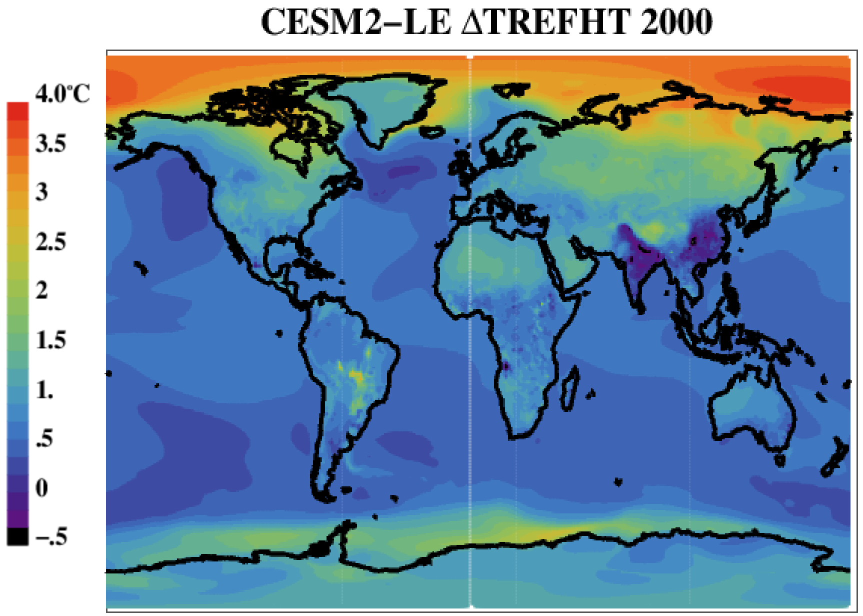
Forcing uncertainty = CESM2-LE – CESM2-CMIP5

Biomass Burning Forcing uncertainty = CESM2-LE – CESM2-LEsmbb

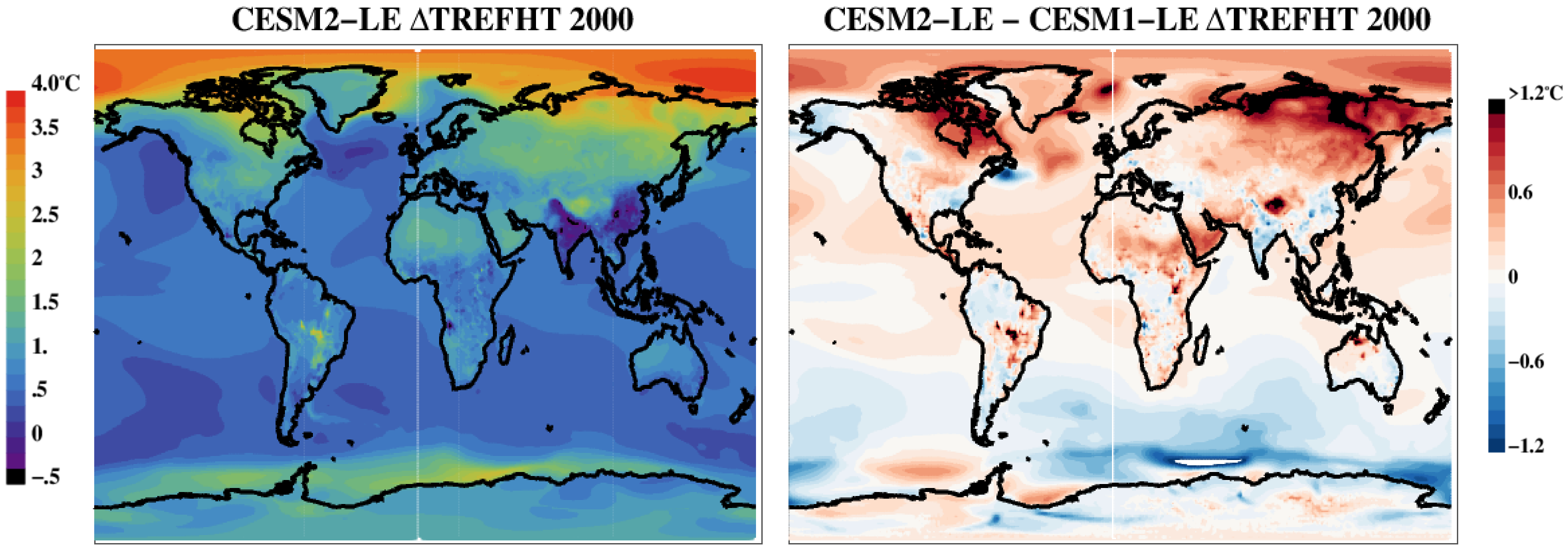
New simulations described in:

Holland, M. M., Hannay, C., Fasullo, J., Jahn, A., Kay, J. E., Mills, M., Simpson, I. R., Wieder, W., Lawrence, P., Kluzek, E., and Bailey, D.: New model ensemble reveals how forcing uncertainty and model structure alter climate simulated across CMIP generations of the Community Earth System Model, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2023-125, in review, 2023.

Air Temperature Change (2000-2020) Minus (1920-1940)



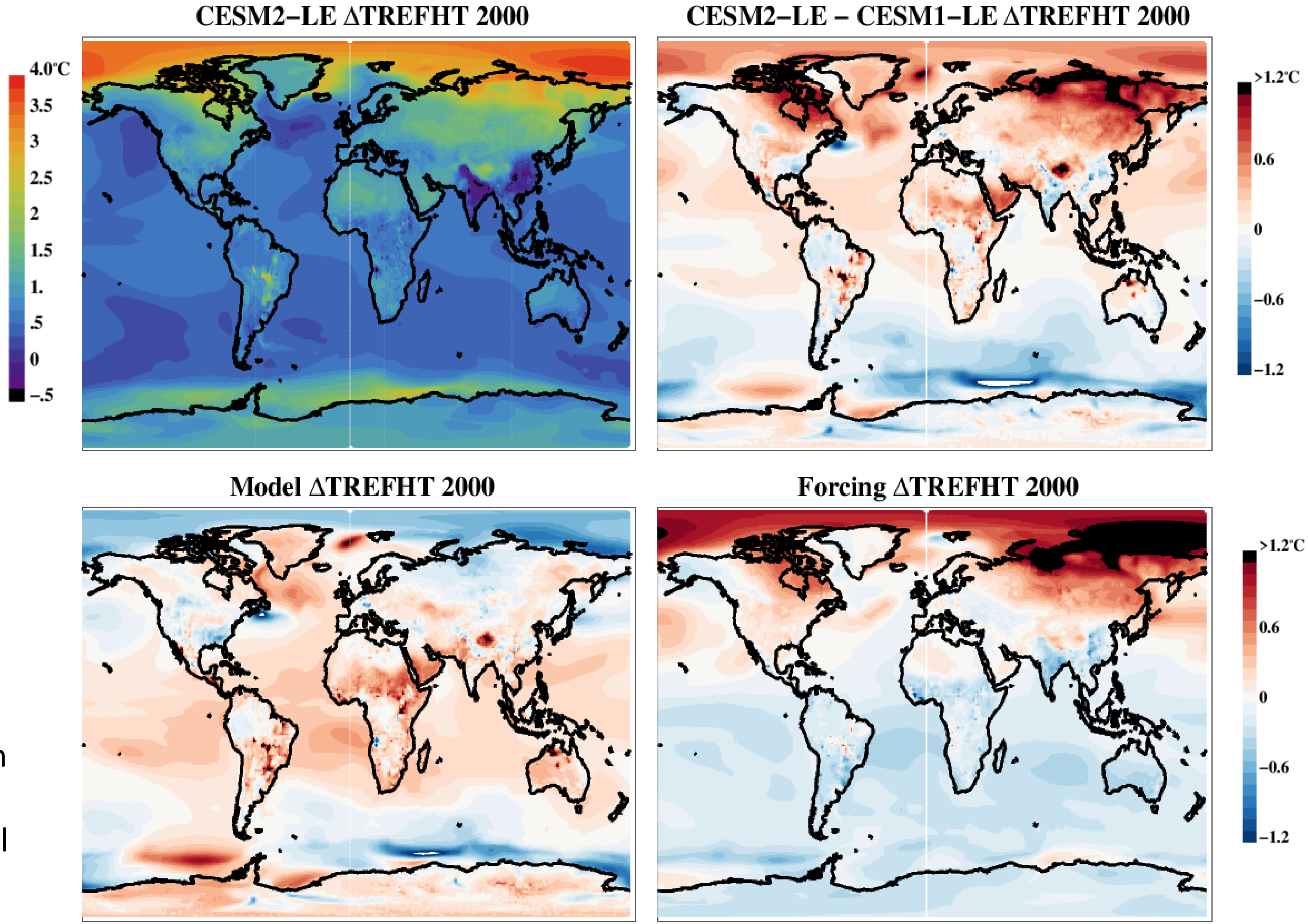
Air Temperature Change (2000-2020) Minus (1920-1940)



Relative to CESM1-LE, CESM2-LE simulates

- Increased warming in northern high latitudes
- Reduced warming in most of Southern Ocean

Air Temperature Change (2000-2020) Minus (1920-1940)

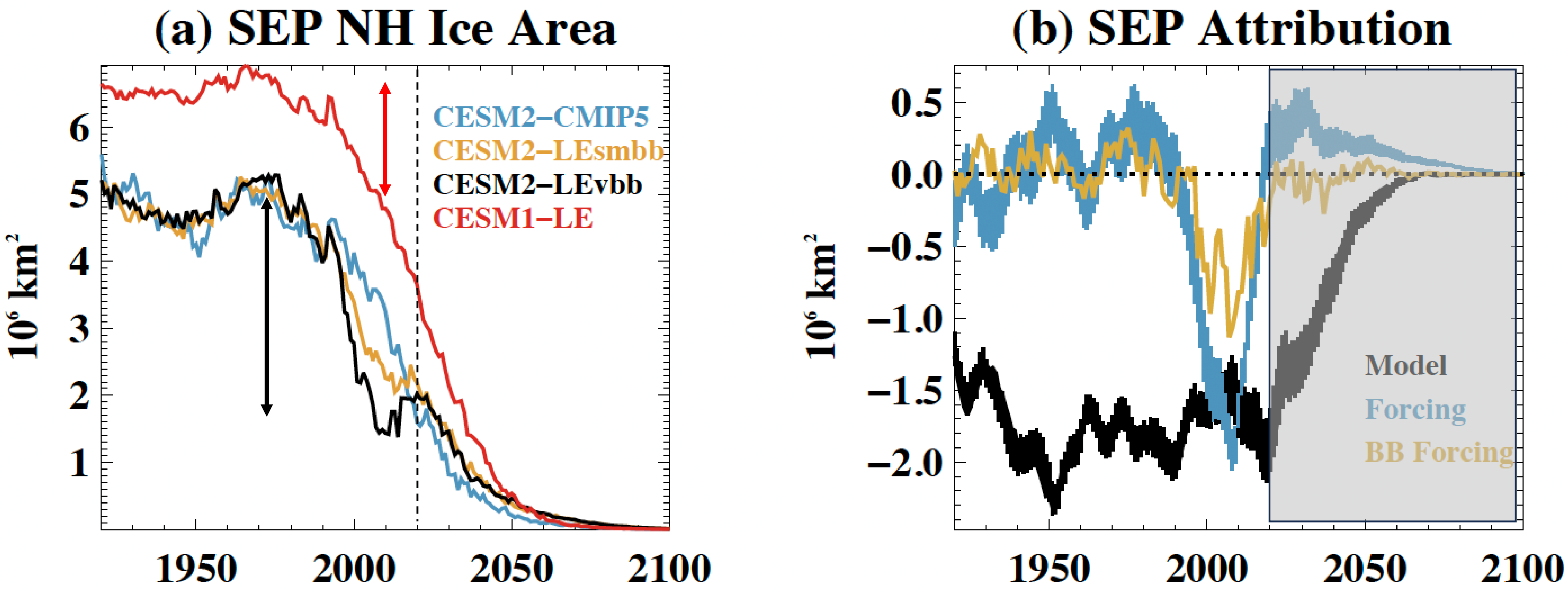


CESM2-LE has
- More Arctic warming
- Less S.Ocean warming

- Increased Arctic warming due to model forcing.
- Counteracted by model structure.

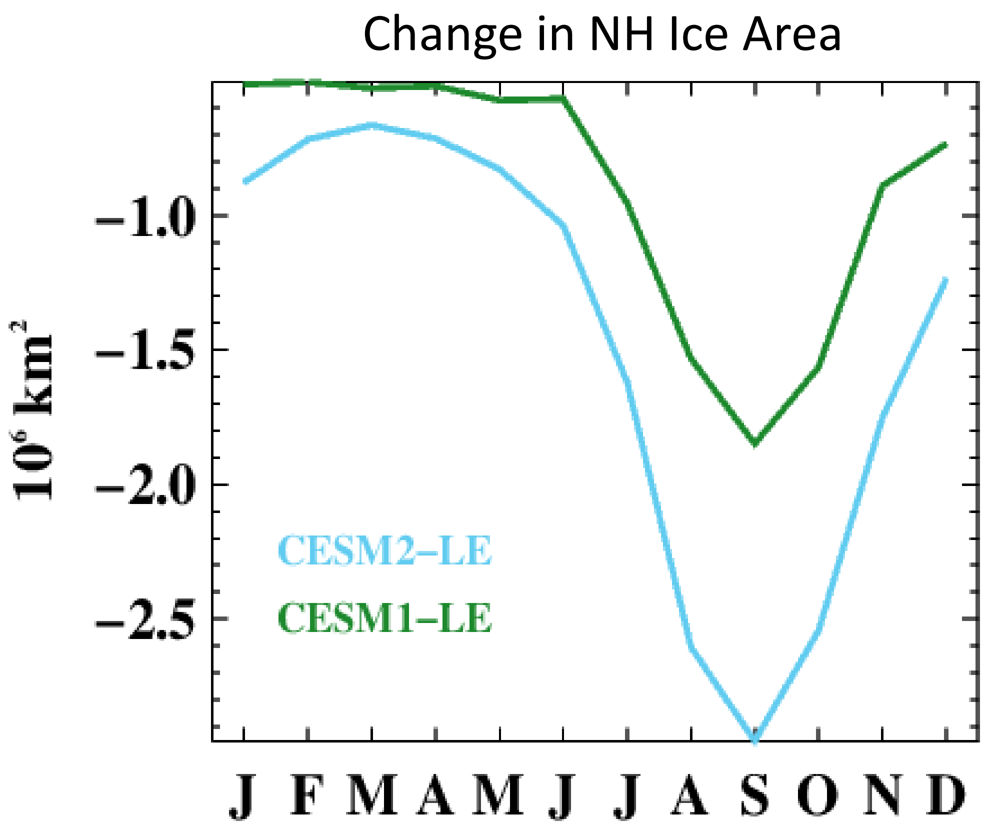
- Reduced Southern Ocean warming due mostly to model structure

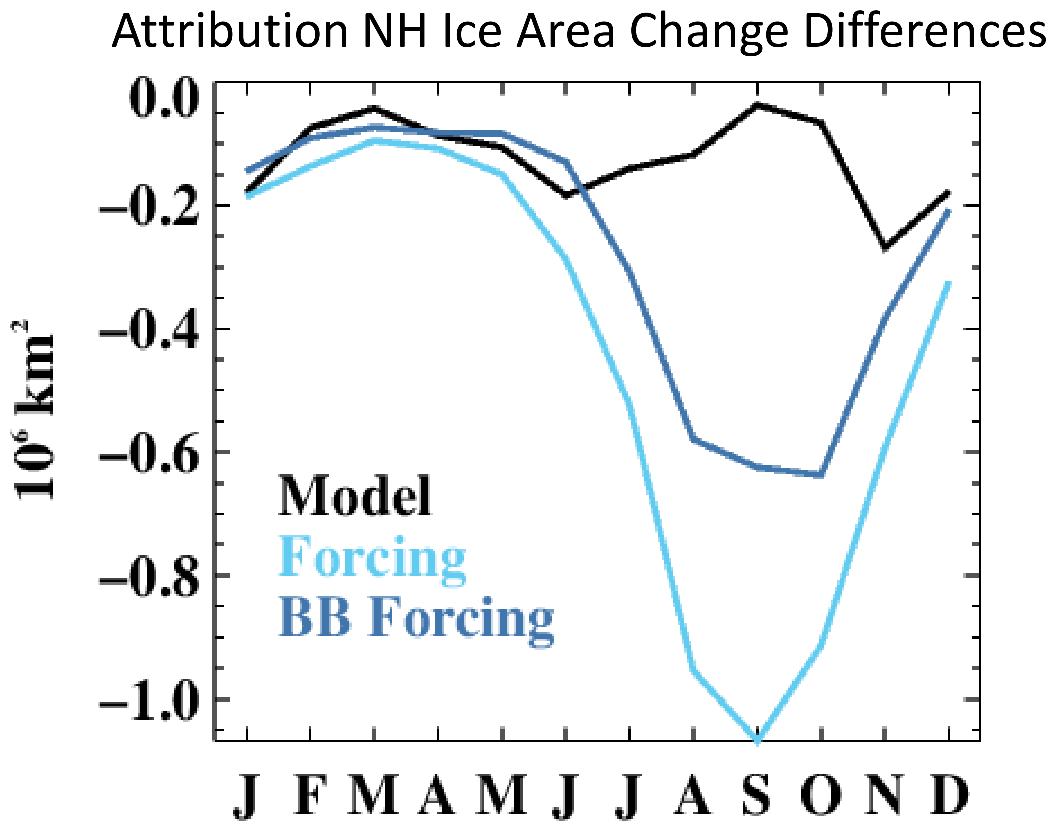
Arctic Sea Ice Loss



- CESM2-LE has lower historical ice cover as a result of model structure
- By 2020, CESM2-LE has larger ice loss than CESM1-LE (consistent with more warming)
- The larger ice loss is due to CMIP6 vs CMIP5 forcing differences, with BB forcing responsible for about half the total forcing signal

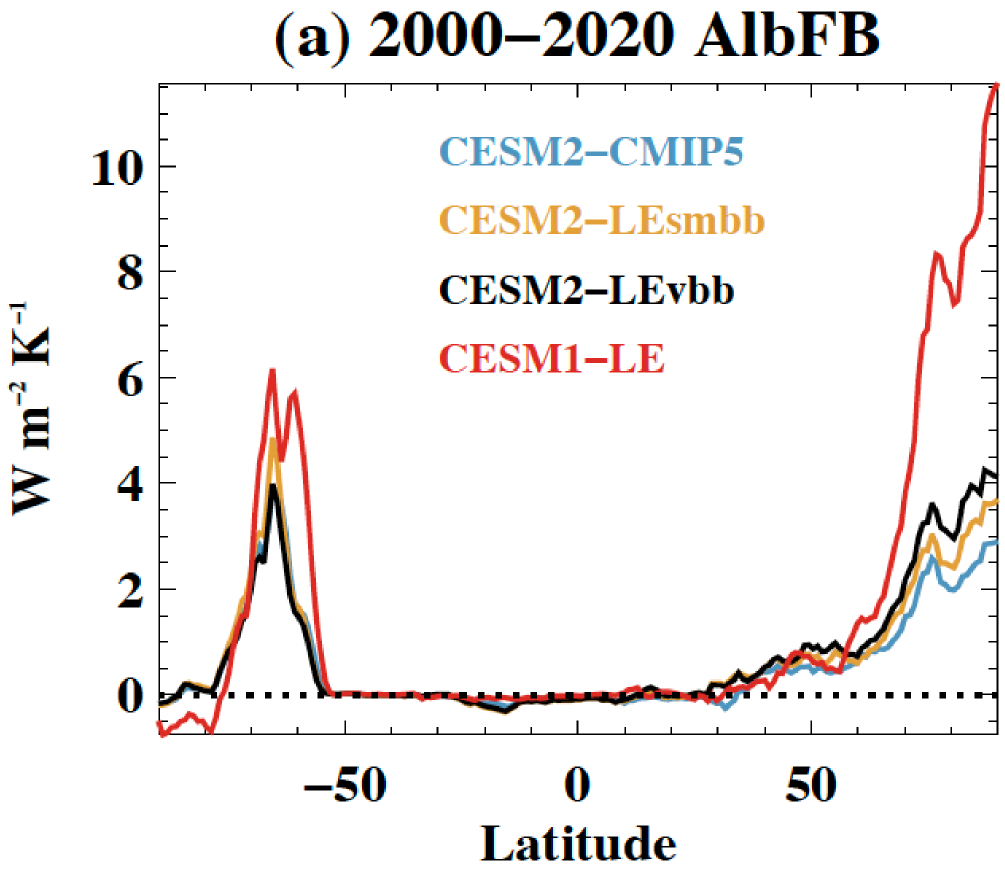
Monthly Ice Area Loss 2000-2020

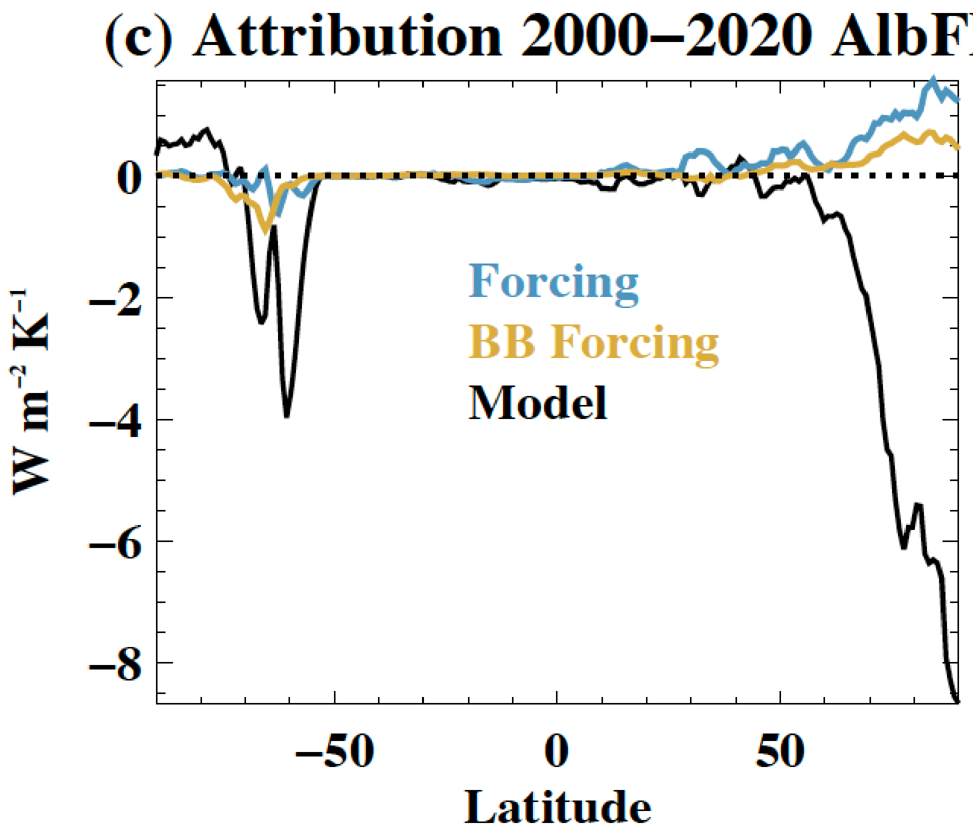




- CESM2-LE has larger ice loss than CESM1-LE throughout the year (consistent with more warming)
- This is largely driven by forcing uncertainty (CMIP6 forcing drives stronger ice loss)
- Larger ice area loss should drive a stronger positive albedo feedback

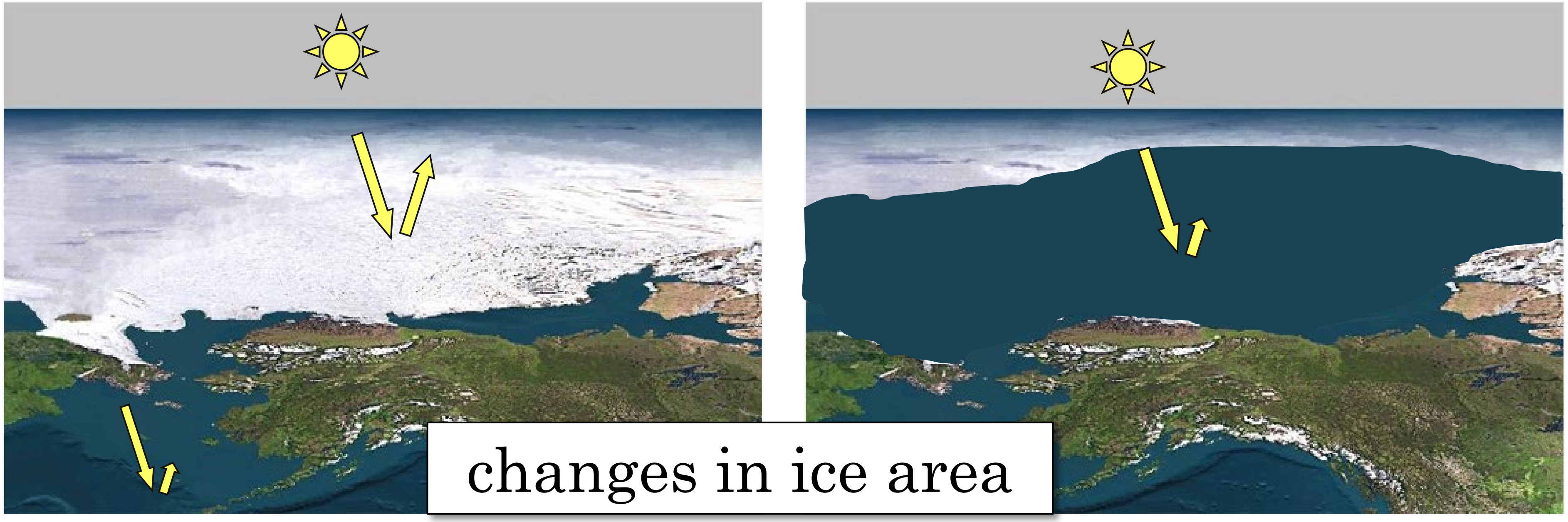
2000-2020 Surface Albedo Feedback

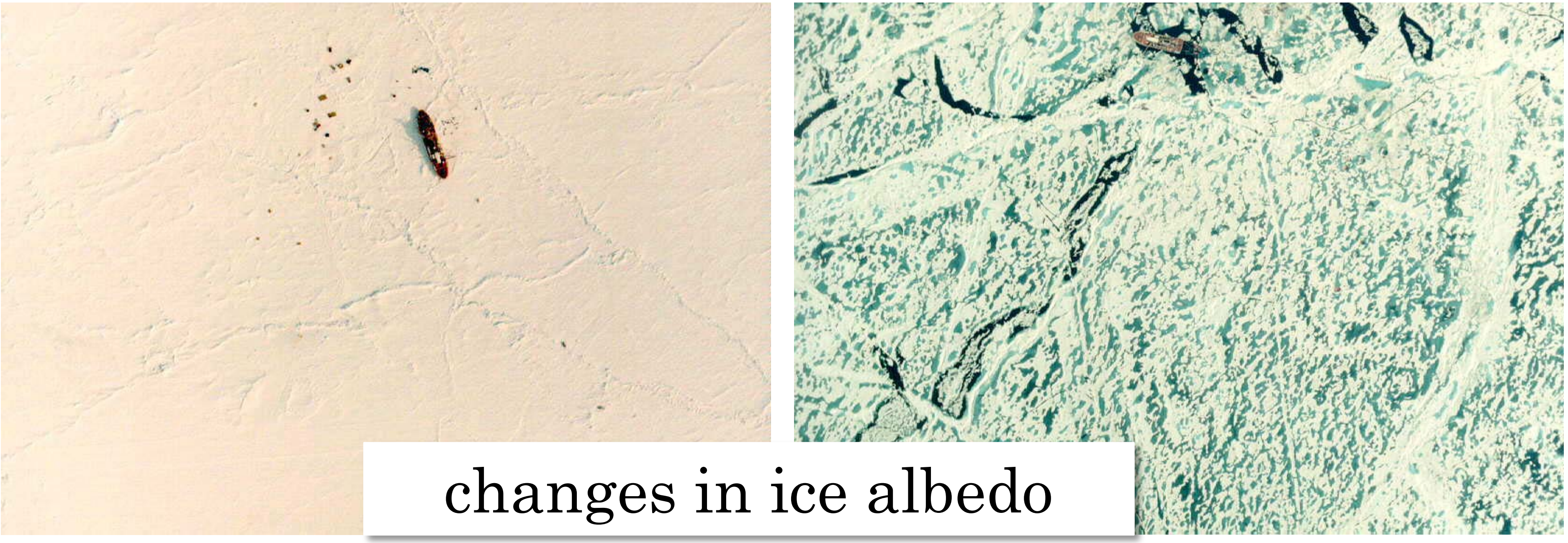




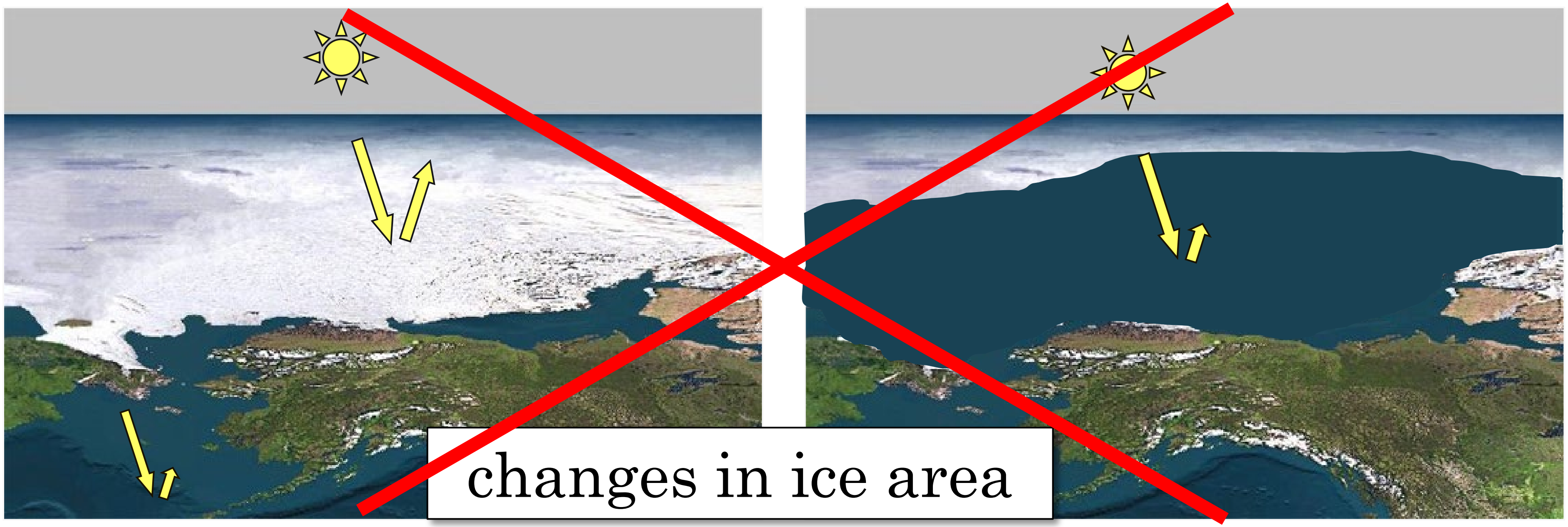
- **CESM2-LE** has a much weaker albedo feedback than **CESM1-LE** in the Arctic due to model structure (even with more September ice loss)
- Forcing drives stronger CESM2-LE albedo feedback (consistent with its influence on more warming, ice loss)

What controls the surface albedo response?

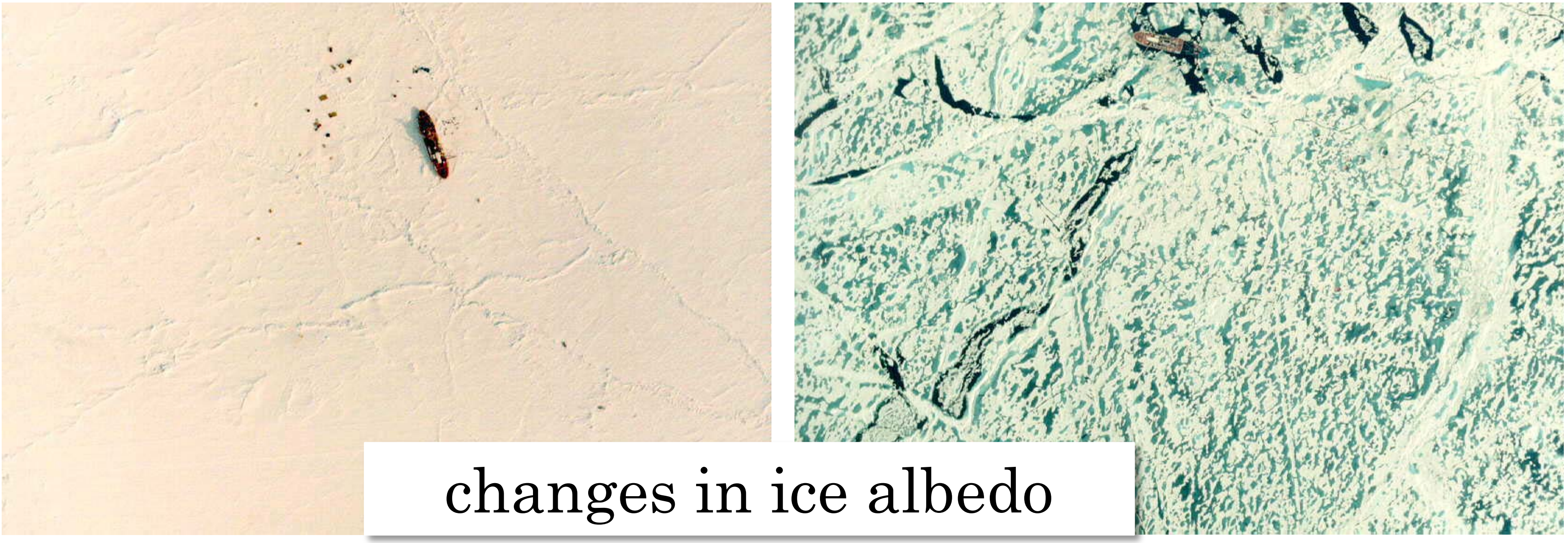




What controls the surface albedo response?

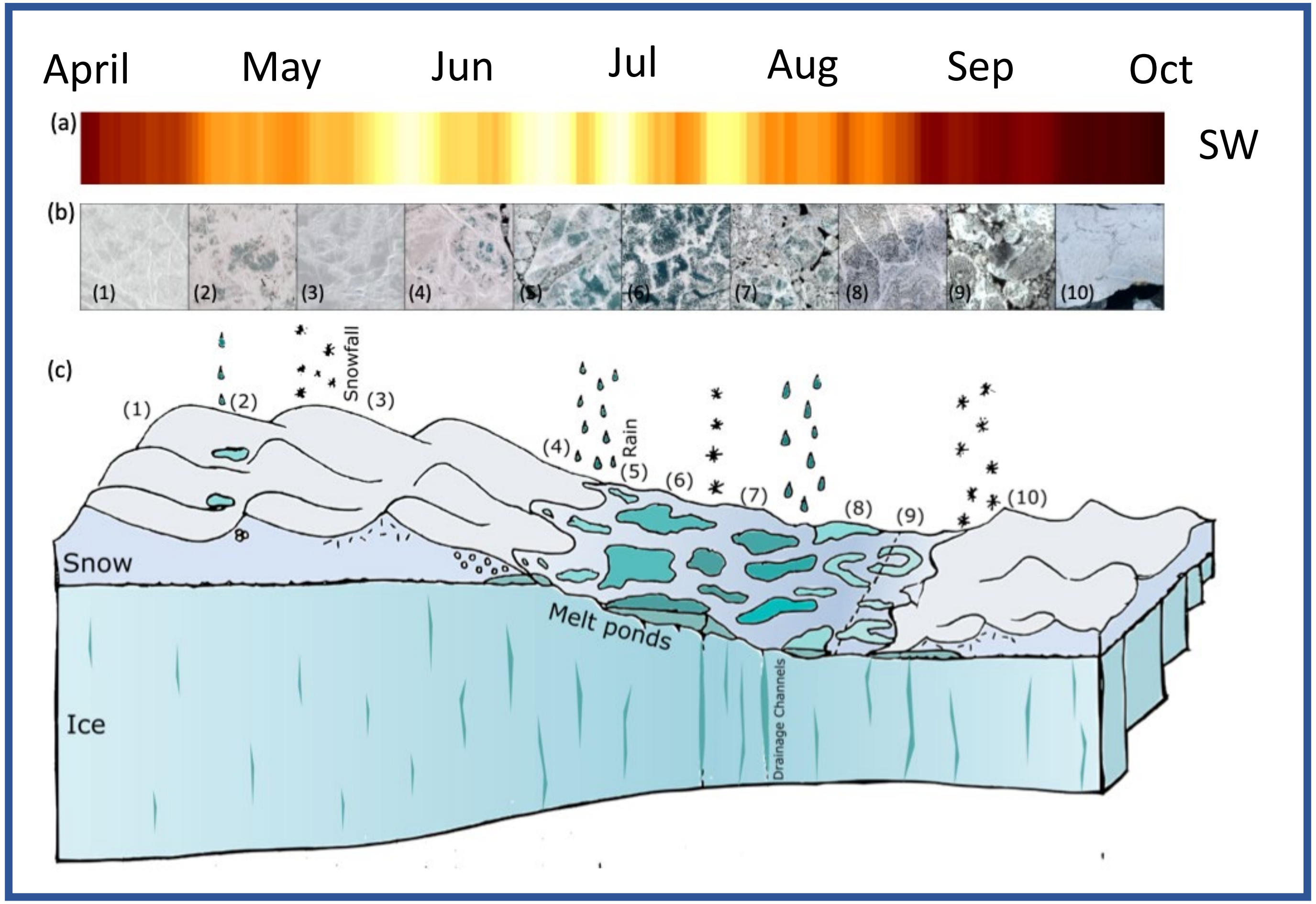


changes in ice area



changes in ice albedo

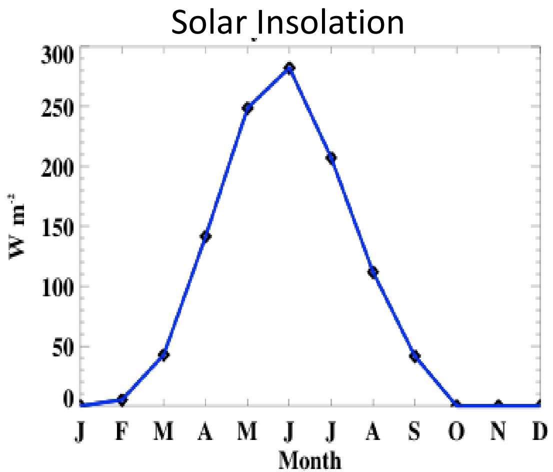
Factors affecting ice albedo evolution



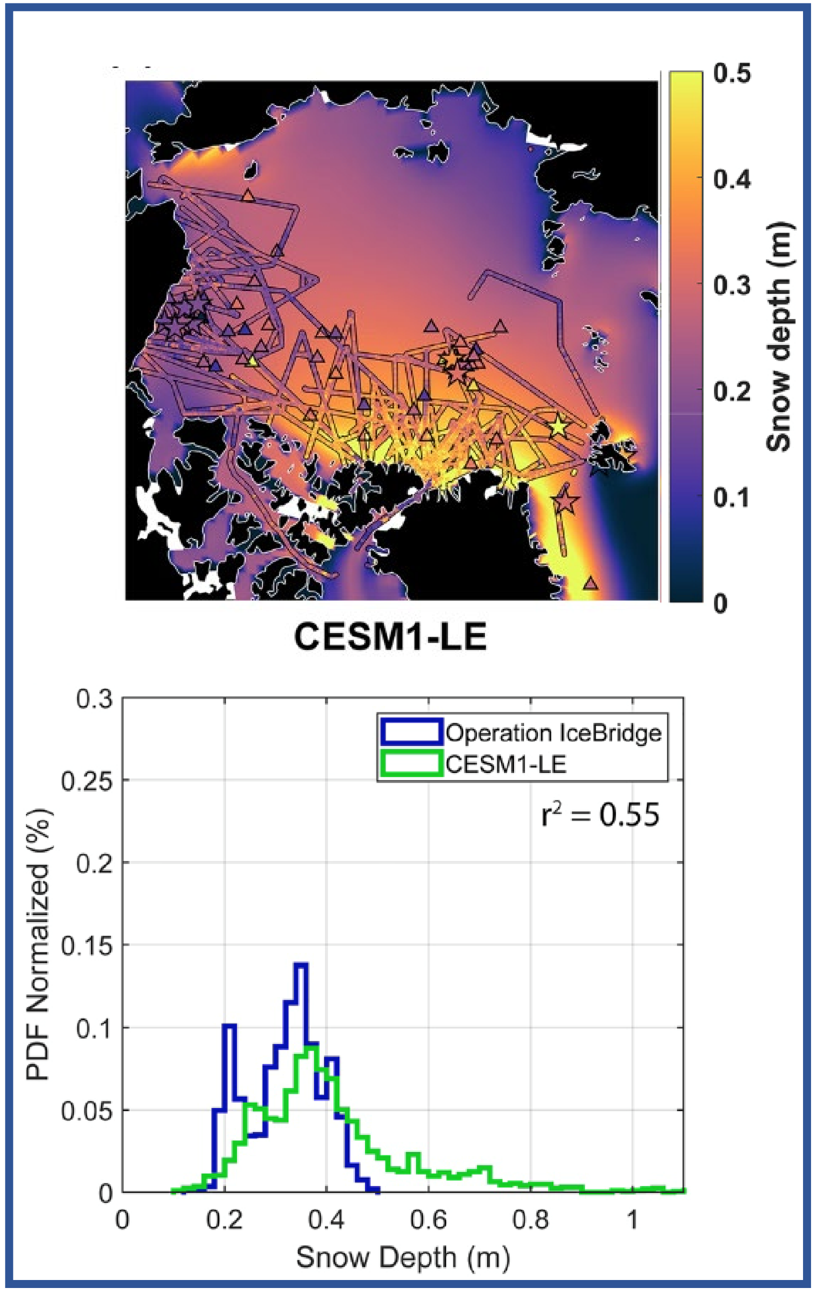
Importance of

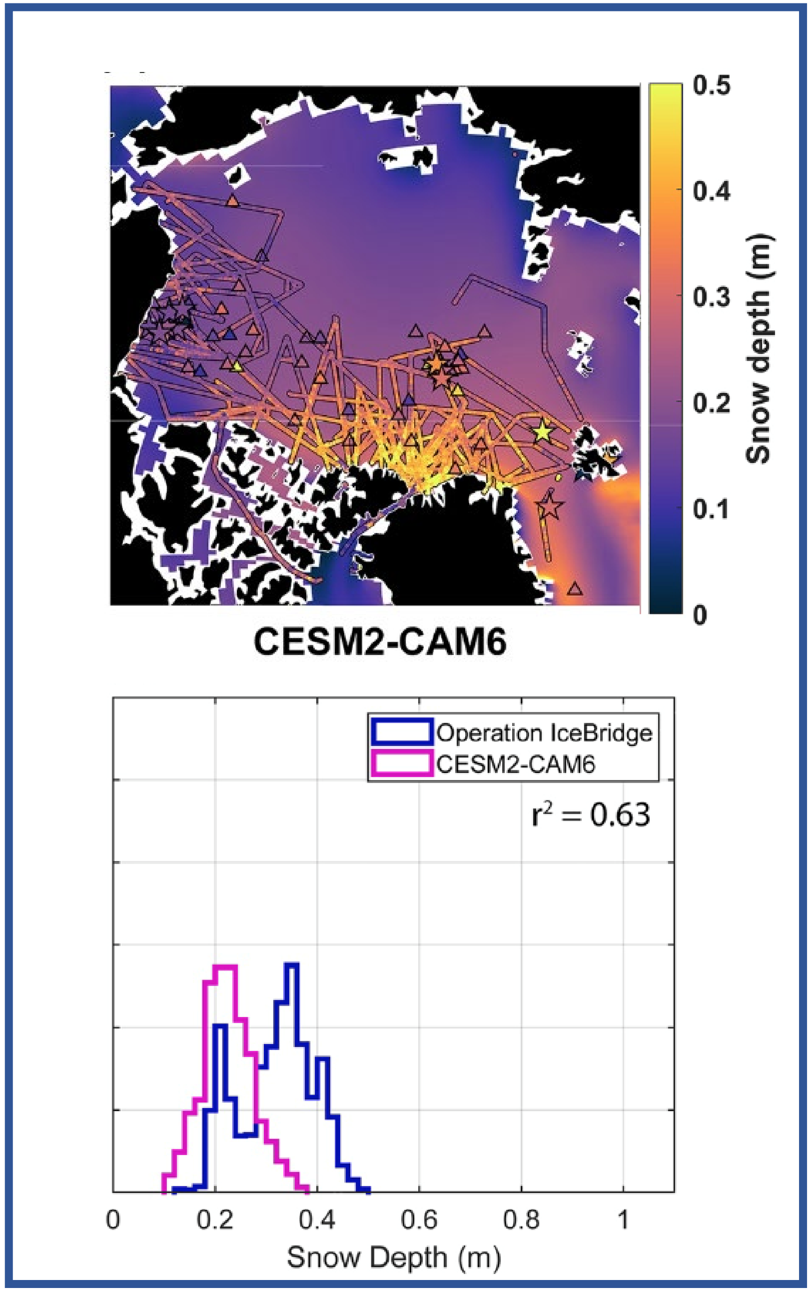
- **Snow**, its thickness, distribution, fractional coverage
- **Episodic rain/snowfall events** and their impacts
- **Ponding**, its evolution, fractional coverage, depth, and optical properties

- Timing is everything



Importance of snow climatology





CESM2-LE has thinner snow and a longer snow-free season than CESM1-LE

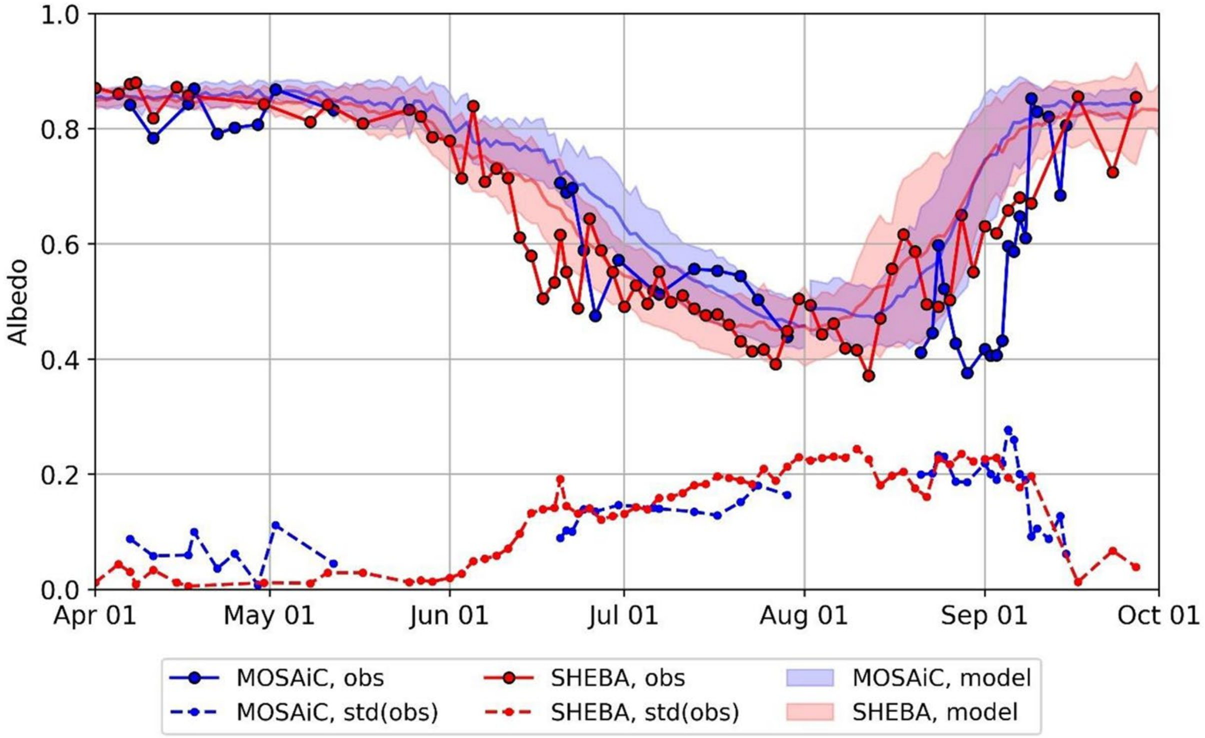
CESM1-LE and CESM2-LE bracket observations in their snow distributions

Less snow results in lower surface albedo

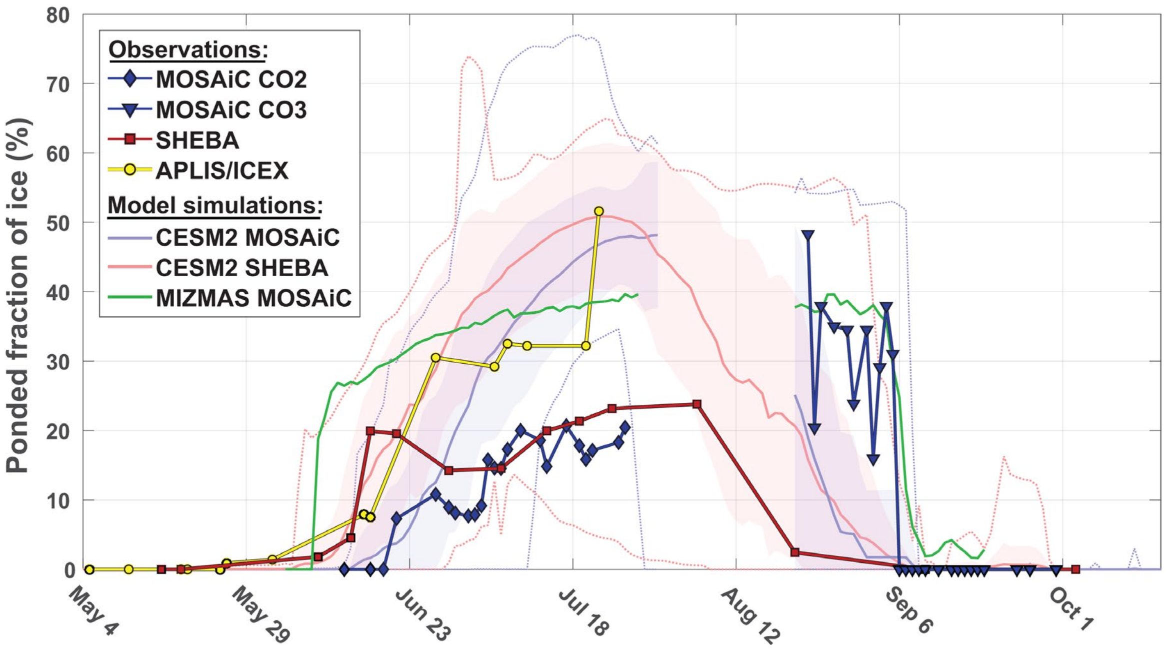
A lower initial albedo leads to less capacity for albedo change and weaker feedback

From Webster et al., 2021

Even when we simulate a "good" albedo, we may do so for the wrong reasons



From Light et al., 2022



From Webster et al., 2022

- CESM2-LE albedo evolution generally compares well to observations
  - However, it does so with too many ponds, which are too bright

Summary

- Historical forcing uncertainty is sizable and complicates the comparison of simulations across CMIP generations and with observations
- In CESM2-LE, CMIP6 forcing drives increased early 21st century Arctic warming and ice loss
- In CESM2-LE, the surface albedo feedback is weaker despite larger ice area loss
- This highlights the importance of the simulation of ice surface properties
- Analysis of CESM2 and CESM1 simulations suggest the importance of (and a need for improvement in and **diagnostics** for):
  - Snow climatology – thickness and extent
  - Episodic snowfall events?
  - Pond fractional coverage and optical properties
  - Provides a motivation for our discussion
- **Many other potentially useful simulations** are also available: single forcing large ensemble, high resolution runs (0.1^o ocean, 0.25^o atmosphere – iHESP runs), prediction (SMYLE) ensembles, etc.

PCWG Discussion

- Diagnostics
- Experiments
- Future Modeling Needs

Credit:
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Questions?