What factors explain the current arctic albedo and its future change?
Arctic undergoes rapid warming associated with surface albedo decrease

Surface temperature (K)

Surface albedo

T and $\alpha$ are averaged over the Arctic Ocean domain during the sunlit season
Arctic undergoes rapid warming associated with surface albedo decrease

Surface temperature (K) and surface albedo

1) Present day
2) Future change

T and \( \alpha \) are averaged over the Arctic Ocean domain during the sunlit season
A comparison of CERES Surface albedo in the Arctic with AMIP and CMIP6 model output

- AMIP 32 models: historical run, 1980-2014 (SST & SIC fixed)
- CMIP 32 models: historical run, SSP245/585 1980-2100 (Full coupled models)
- CERES EBAF Ed4.1 product: 2001-2021
- Hurrell SST/sea ice consistency criteria applied to merged HadISST & NCEP-0I2
- ERA5 reanalysis: 1980-2021

Surface albedo: \( \alpha_s = \frac{F_{\uparrow}^{SFC}}{F_{\downarrow}^{SFC}} \)

averaged over 65°N, sunlight season (Mar through Sep)
What is the controlling factor that explains model differences in present-day surface albedo?

*Present-day: 2001-2021

\[ 0.1 \Delta \alpha \rightarrow 17.5 \text{W/m}^2 \Delta \text{SW} \alpha \]

Most inter-model spreads in CMIP models are comparable to those in AMIP simulations.

Sea ice concentration is not a main driver for spreads in surface albedo?
Breaking down albedo: a new definition for ice albedo difference and sea ice concentration difference

\[ \alpha = \alpha_{ir} A_{ir} + a_{or} (1 - A_{ir}) \]
\[ \alpha_{ir} = \alpha_{ir} c_{ir} + \alpha_{or} (1 - c_{ir}) \]

: ocean albedo is calculated by averaging the surface albedo where sea ice concentration is less than 15%
Breaking down albedo: a new definition for ice albedo difference and sea ice concentration difference

\[ \delta \alpha = \delta \alpha_{i\alpha} + \delta \alpha_c + \delta \alpha_{spv} + \delta \alpha_{IRA} + \delta \alpha_{o\alpha} \]

① Sea ice albedo in ice region
② Sea ice concentration in ice region
③ Albedo spatial variance term
④ Ice region term
⑤ Albedo in ocean region
Consideration of surface **ice albedo** is a key component in modeling spread of surface albedo.
Consideration of surface ice albedo is a key component in modeling spread of surface albedo.

surface albedo ($\alpha$)

Corr.coef CMIP:

- $0.71/1.00$
- $0.71/1.00$
- $0.65/0.53$
- $0.31/0.77$
- $0.32/0.18$
- $-0.28/0.71$
- $0.25/0.35$

Consideration of surface ice albedo is a key component in modeling spread of surface albedo.
Consideration of surface **ice albedo** is a key component in modeling spread of surface albedo.
The seasonal and regional analysis exposes differences in surface albedo between CERES and CMIP models.
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CH: East Siberian, Chukchi, & Beaufort
CA: Central Arctic
BK: Barents, Kara, & Laptev
GL: Greenland sea
The large spread across CMIP models is significantly influenced by both **seasonal and spatial** variations.

Early summer season: Ice region term predominantly contributing to the albedo spread across the BK and GL.

Late summer season: Ice albedo term contributing to the albedo spread across the CH and CA.
The temporal evolution of surface albedo changes closely follows the ice region term

- CERES shows a sharp decline in trend until around 2010, with significant fluctuations affected by the sea ice albedo term
- Minimal variability of the sea ice albedo term in models compared to the considerable interannual variability and significant fluctuations in CERES.
Models fail to capture the **yearly fluctuations in the ice albedo term** as in the CERES data.
Despite the model mean of Arctic surface albedo agreeing with CERES, the significant inter-model spread may be a primary factor contributing the variability observed in Arctic warming across different model simulations.

The seasonal and regional analysis exposes differences in surface albedo between CERES and CMIP models.

The Arctic albedo exhibits a significant inter-model spread, even when sea ice is held constant in AMIP simulations.

Our analysis with a new albedo decomposition revealed that not only the ice fraction difference but the variance in ice albedo has a substantial effect on the model spread in albedo.

Time series data from historical and SSP scenarios indicates that sea ice albedo and concentration remain relatively unchanged in response to global warming, while the ice region term decreases significantly over time.

Between 2000-2021, CERES data indicates larger variability in the ice albedo term compared to the models. This suggest that CMIP models might not fully capture the variability in ice albedo, suggesting the potential for greater variability in the near future than current model projections.