What factors explain the current arctic albedo and its future change?

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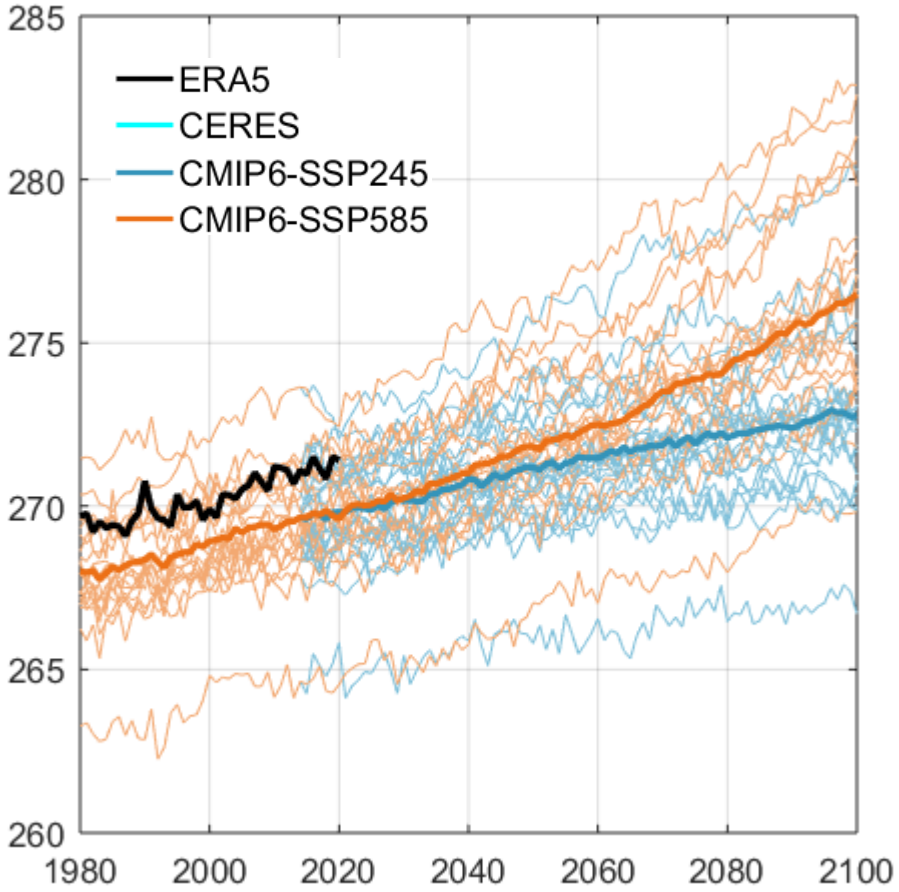
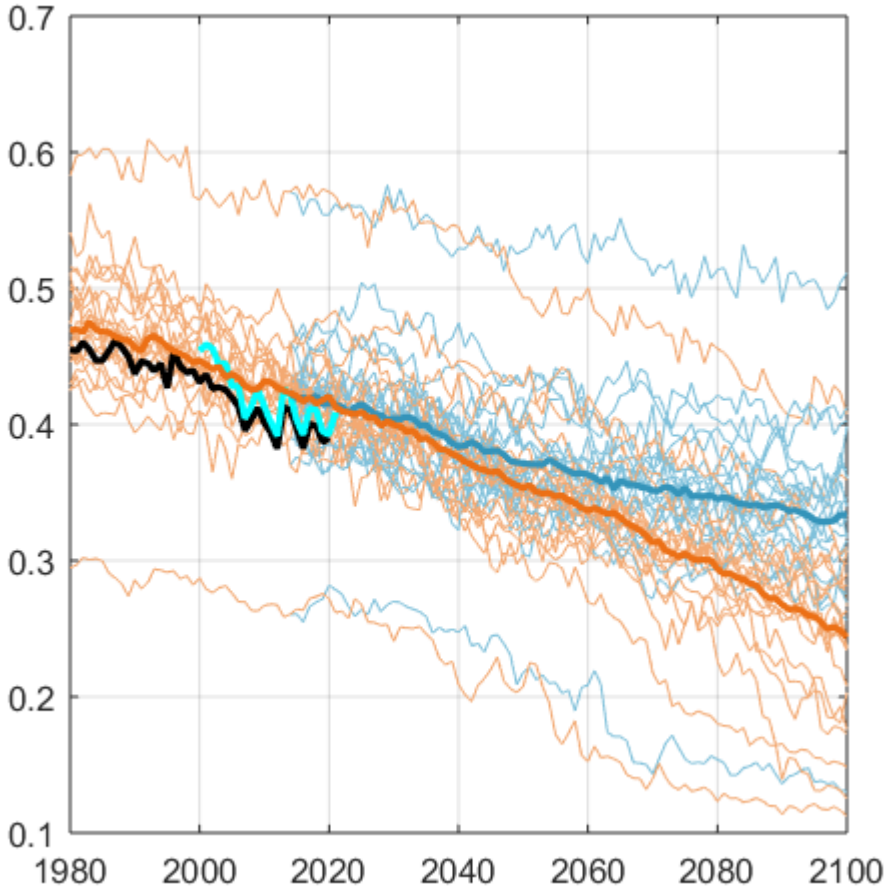
Arctic undergoes rapid warming associated with surface albedo decrease

Surface temperature (K)



year

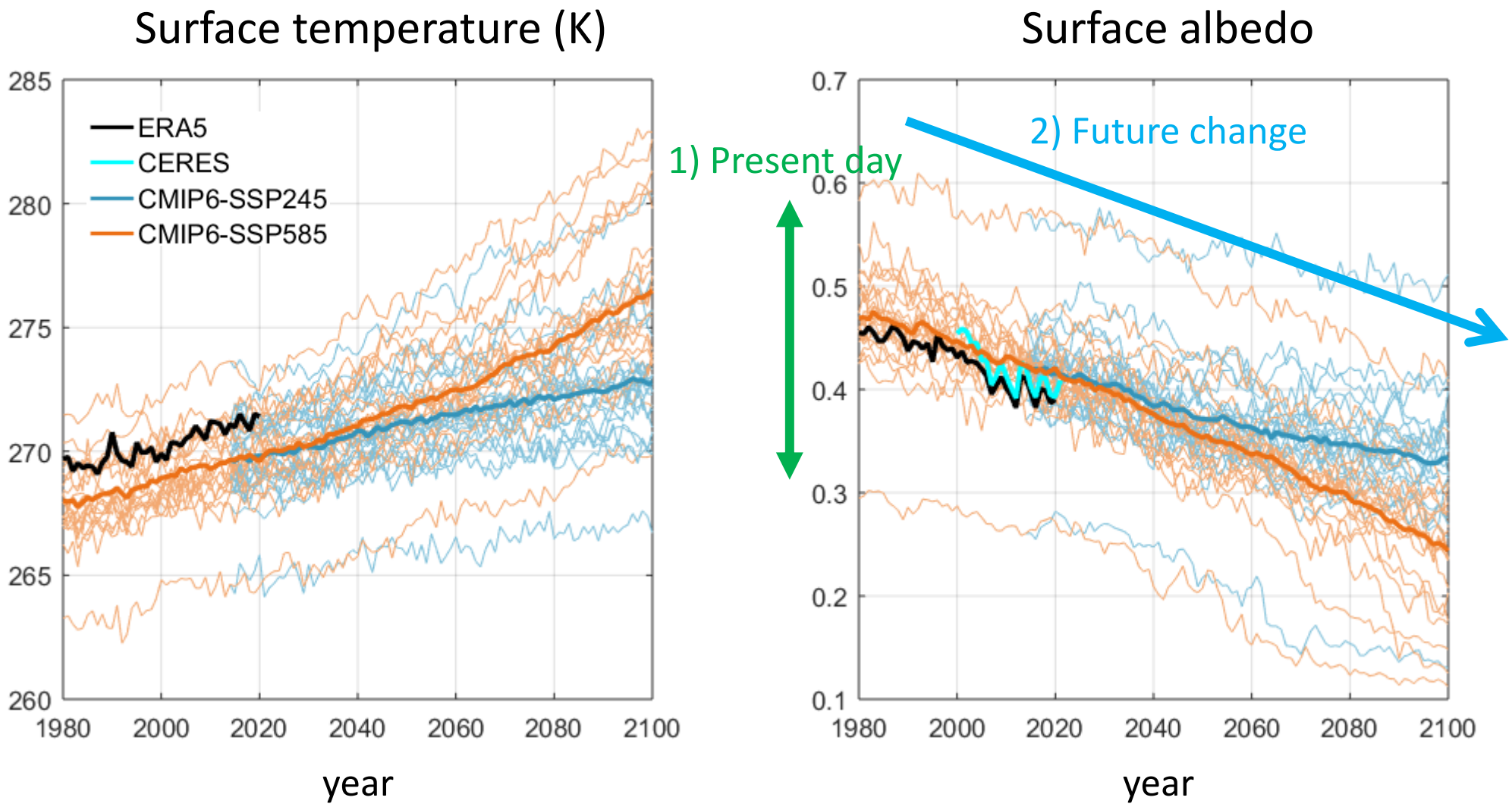
Surface albedo



year

T and α are averaged over the Arctic Ocean domain during the sunlit season

Arctic undergoes rapid warming associated with surface albedo decrease



T and α 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

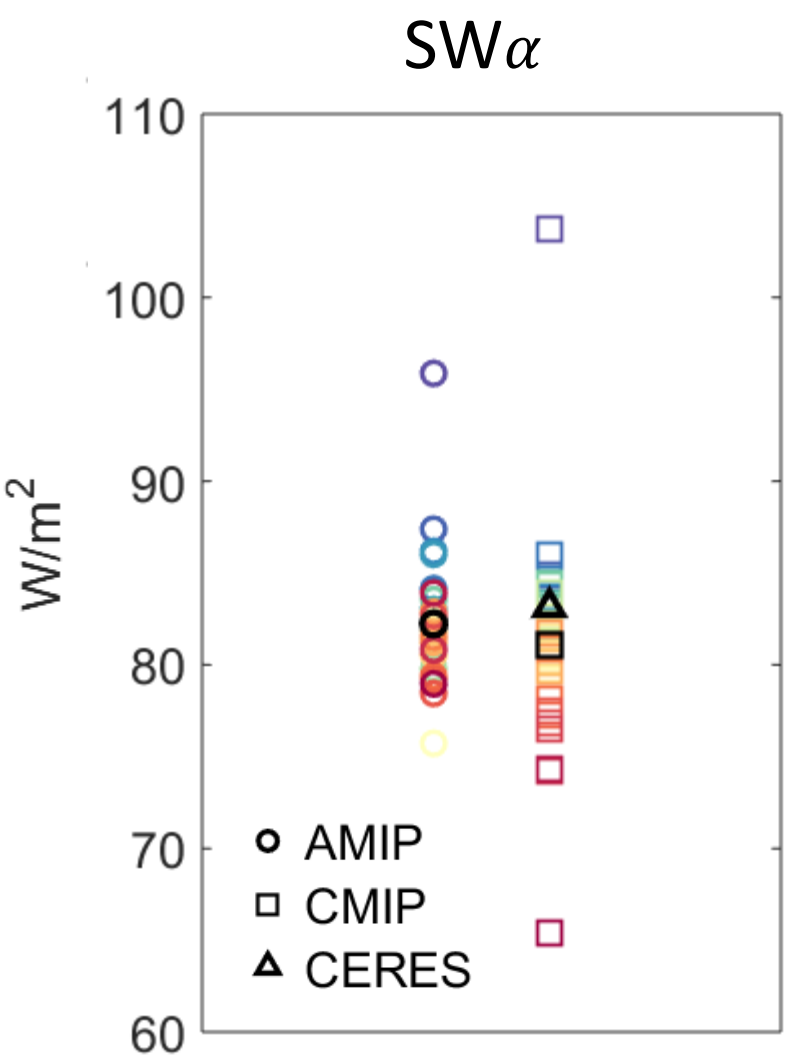
- AMIP 32 models: historical run, 1980-2014 (SST & SIC fixed)
- CMIP 32 models: historical run, SSP245/585 1980-2100 (Full coupled models)
- CERES EBAF Ed4.1 product : 2001-2021
- Hurrell SST/sea ice consistency criteria applied to merged HadISST & NCEP-0I2
- ERA5 reanalysis: 1980-2021

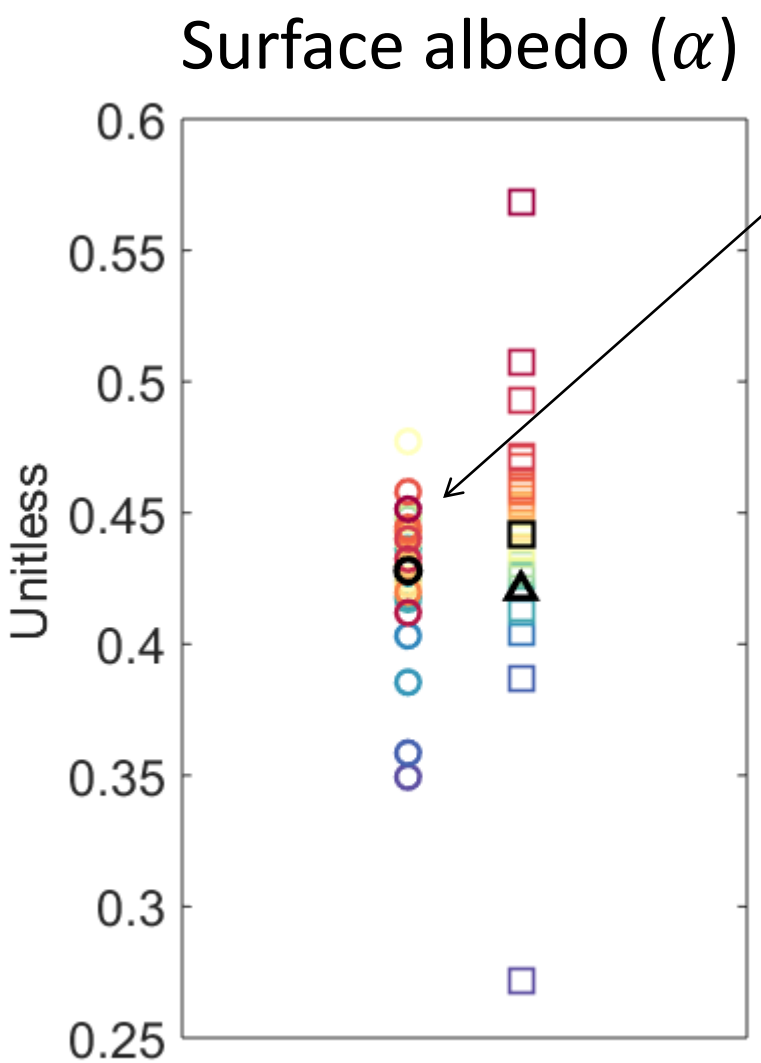
Surface albedo : $\alpha_s = \frac{F_{\uparrow}^{SFC}}{F_{\downarrow}^{SFC}}$

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





AMIP: prescribed SST & sea Ice concentration

0.1 $\Delta\alpha \rightarrow$ 17.5W/m² ΔSWα

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

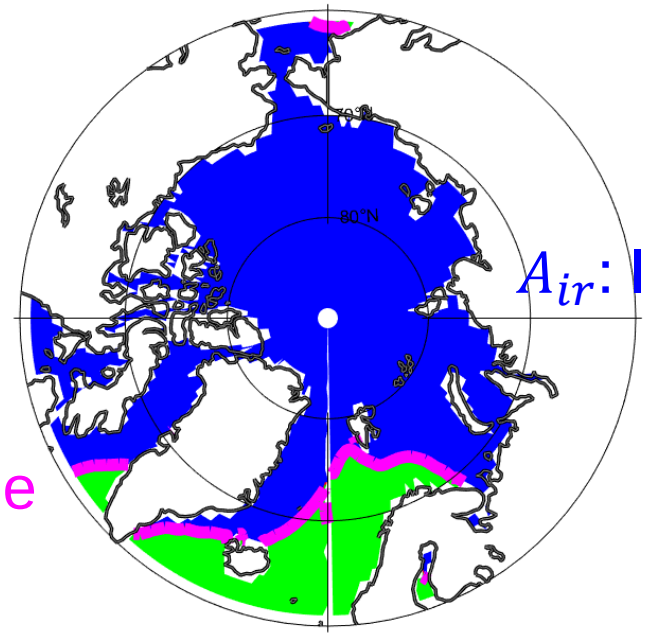
Sea ice concentration is not a main driver for spreads in surface albedo?

Breaking down albedo: a new definition for ice albedo difference and sea ice concentration difference

$$\alpha = \alpha_{ir} A_{ir} + \alpha_{or}(1 - A_{ir})$$

$$\alpha_{ir} = \alpha_{i_{ir}} c_{ir} + \alpha_{o_{ir}}(1 - c_{ir})$$

: ocean albedo is calculated by averaging the surface albedo where sea ice concentration is less than 15%



A_{ir}: Ice region

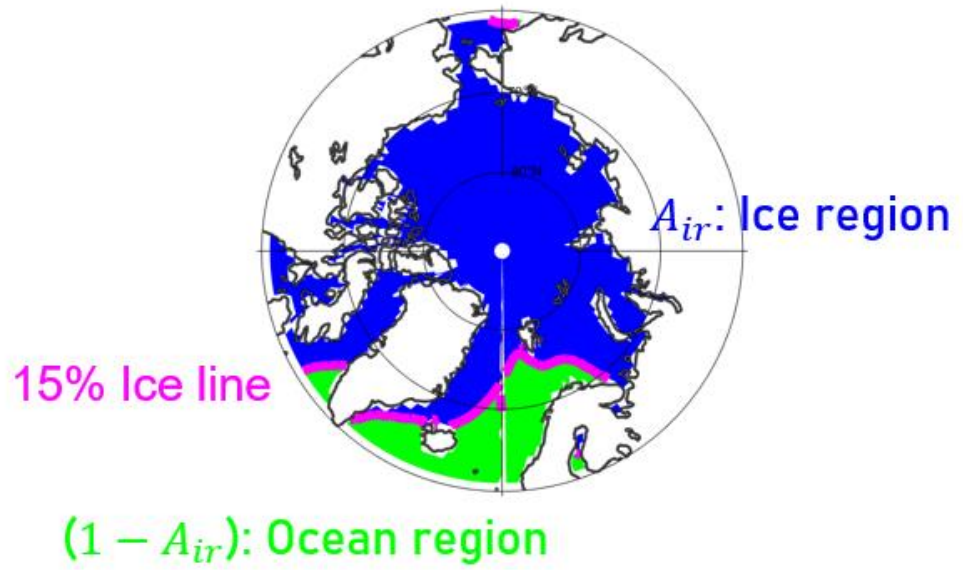
15% sea ice concentration line

$(1 - A_{ir})$: Ocean region

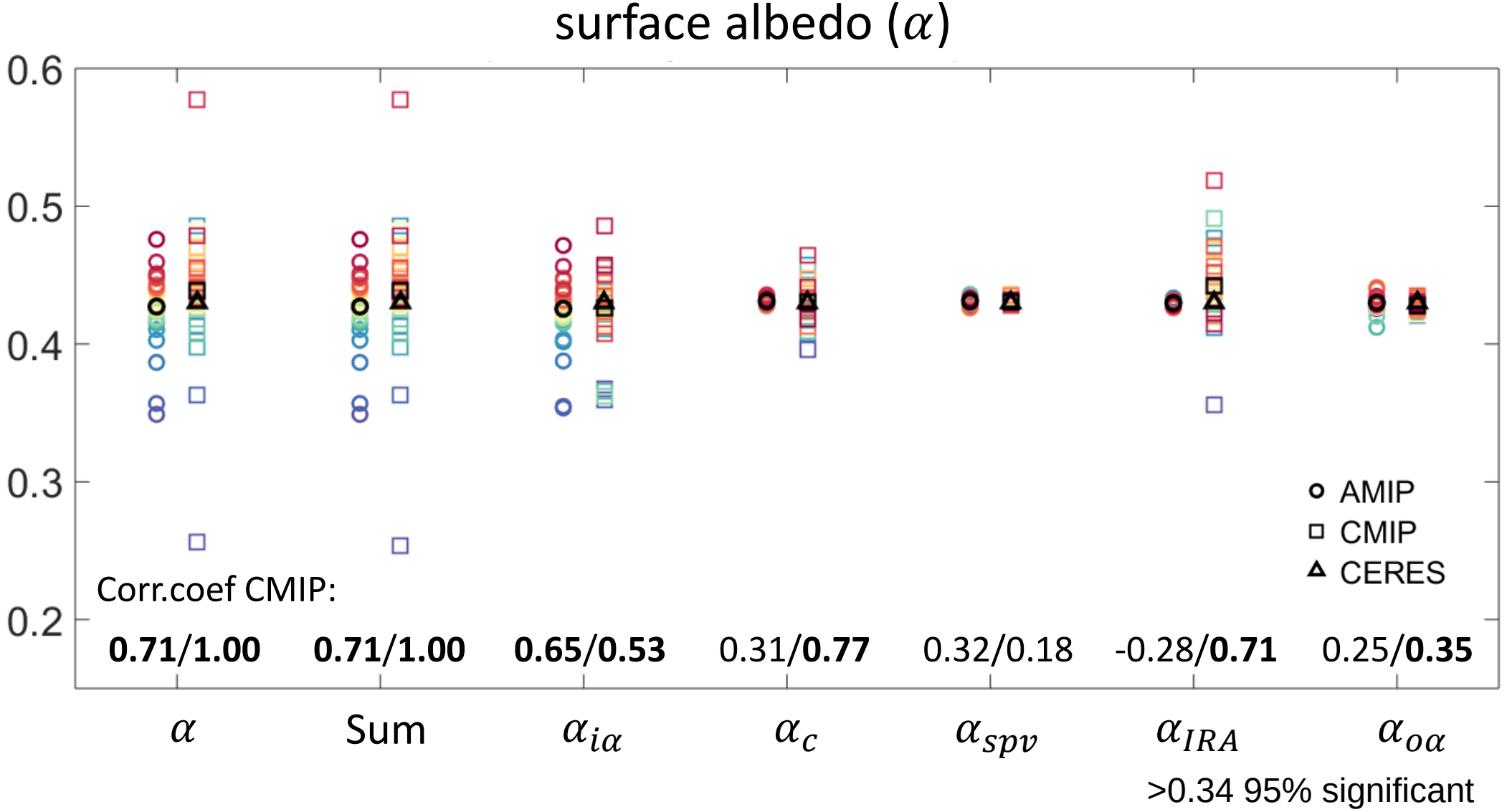
Breaking down albedo: a new definition for ice albedo difference and sea ice concentration difference

$$\delta\alpha = \delta\alpha_{i\alpha} + \delta\alpha_c + \delta\alpha_{spv} + \delta\alpha_{IRA} + \delta\alpha_{o\alpha}$$
$$\text{①} \quad \text{②} \quad \text{③} \quad \text{④} \quad \text{⑤}$$

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



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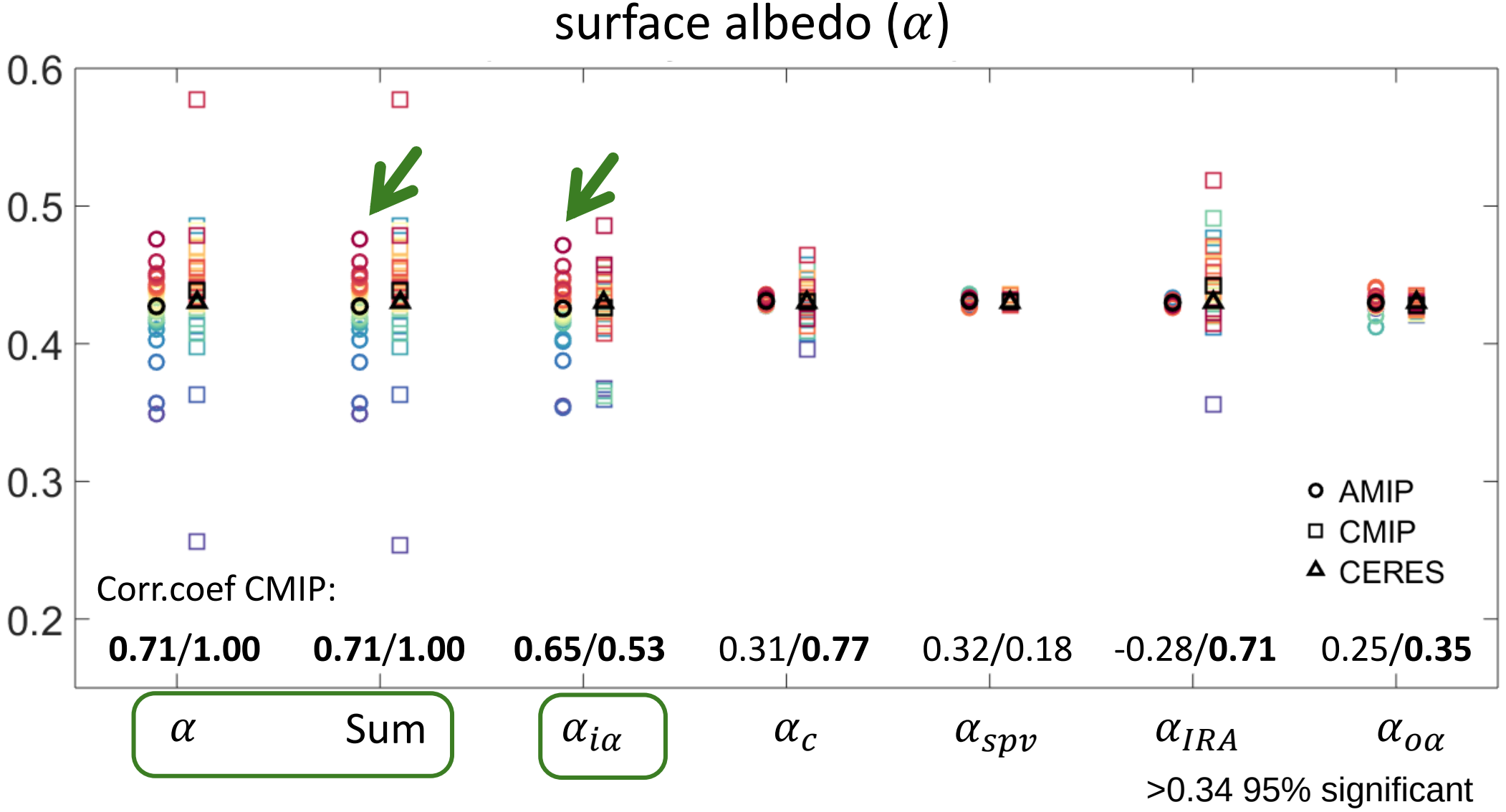

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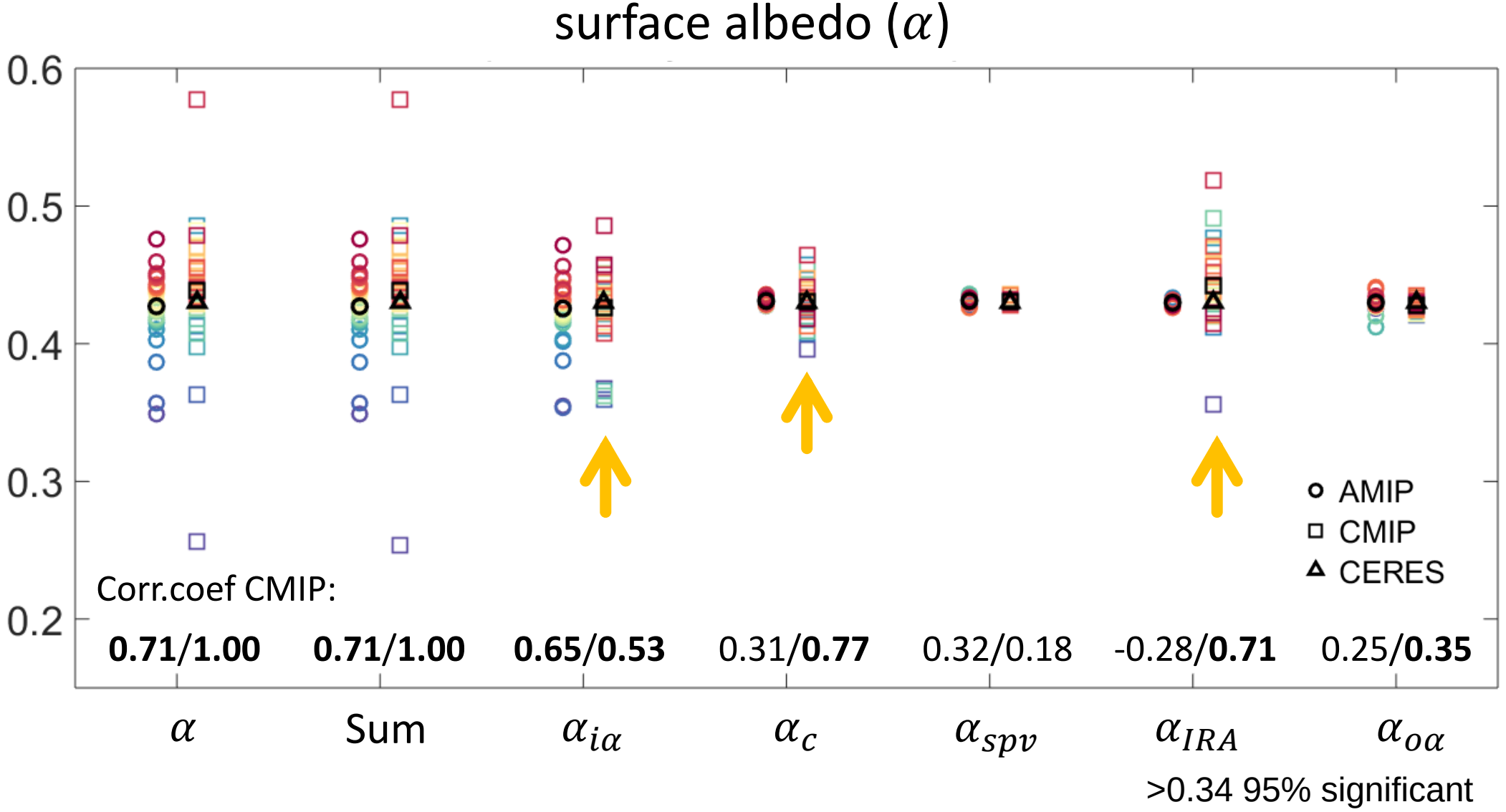
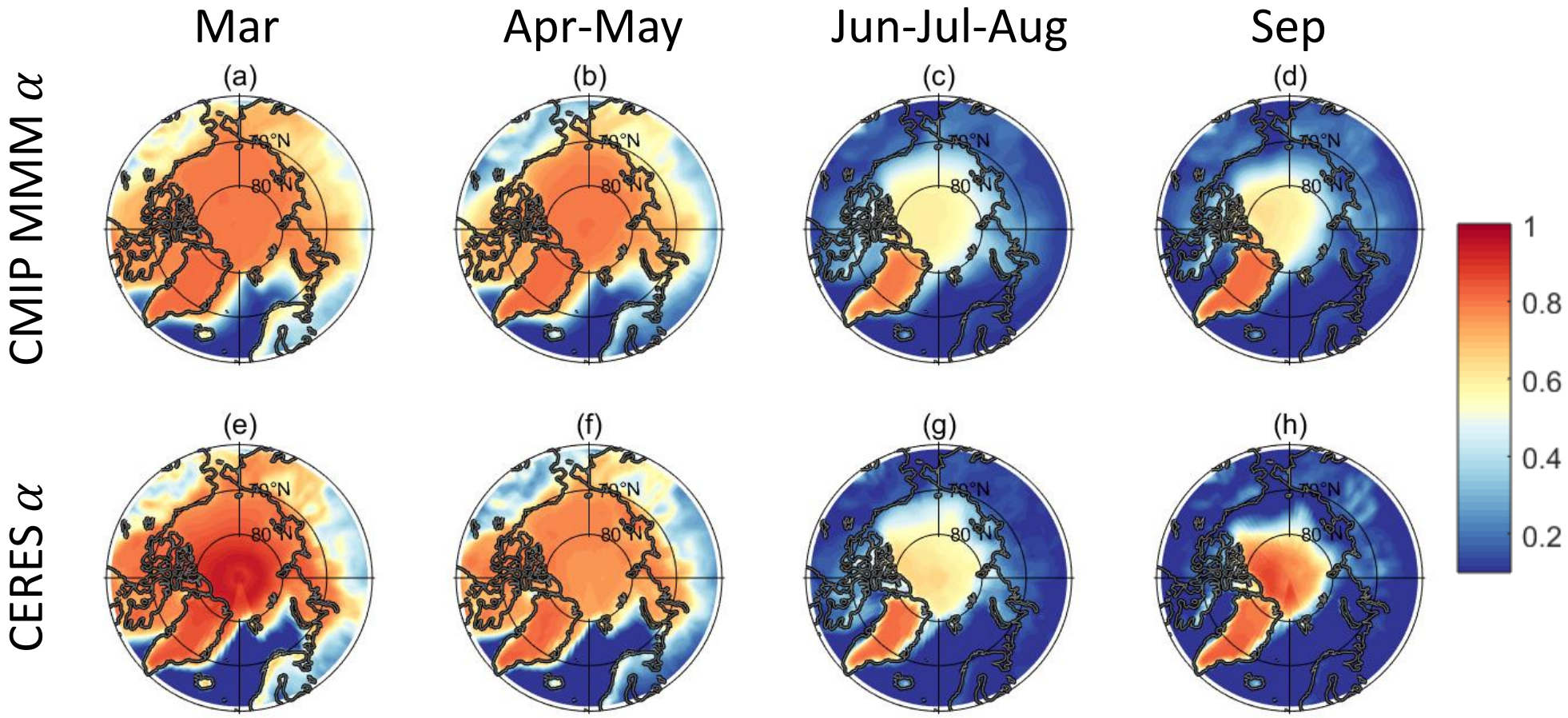


The seasonal and regional analysis exposes differences in surface albedo between CERES and CMIP models



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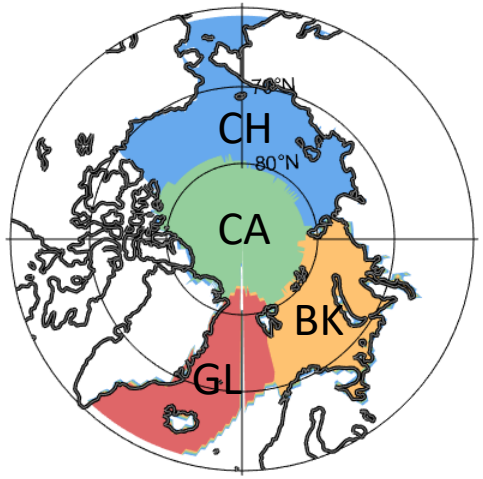
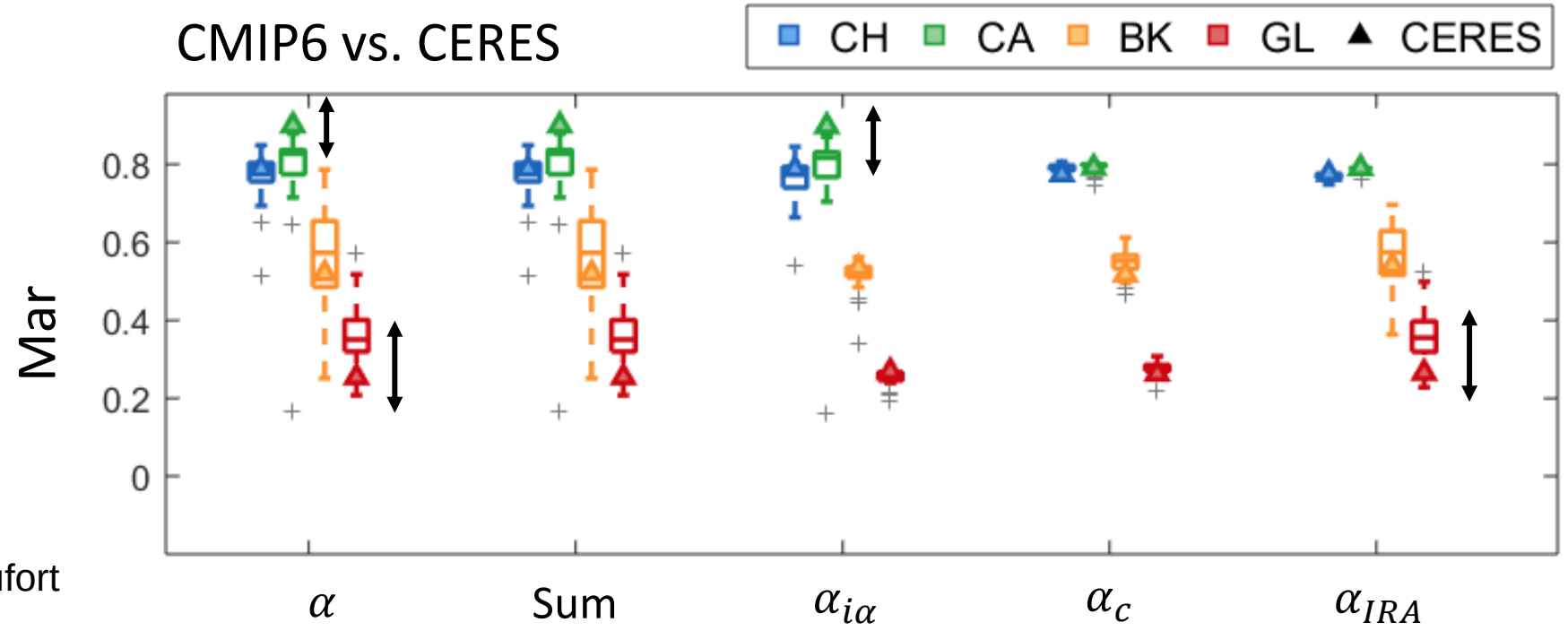


CH: East Siberian, Chukchi, & Beaufort
CA: Central Arctic
BK: Barents, Kara, & Laptev
GL: Greenland sea



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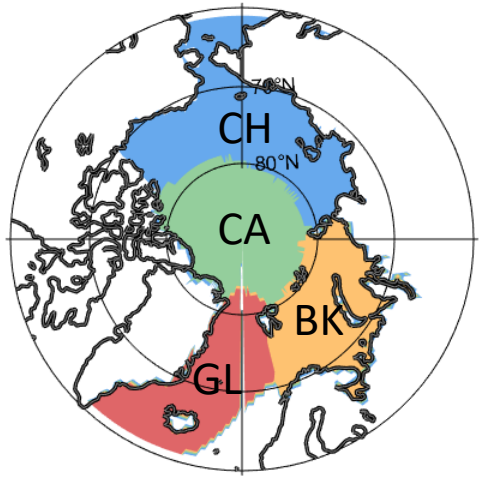

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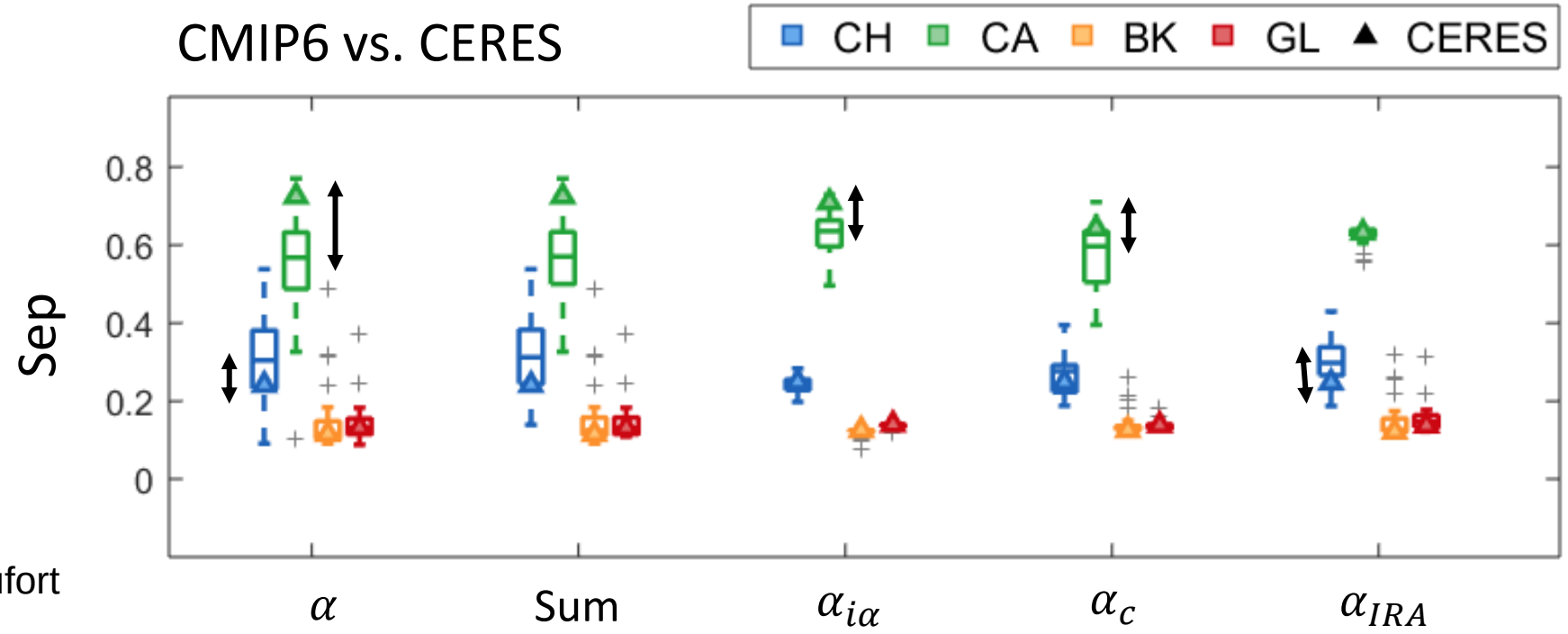
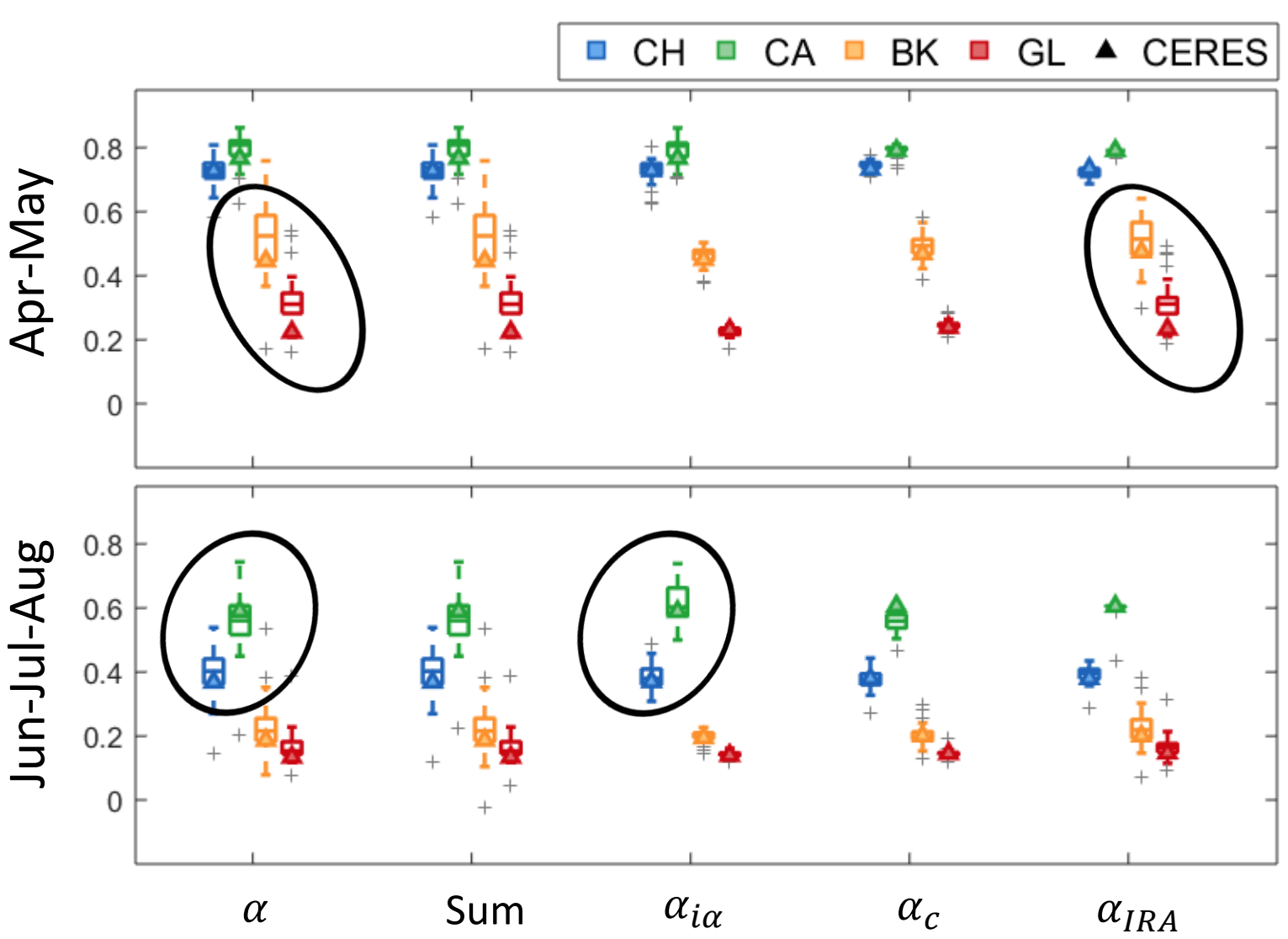


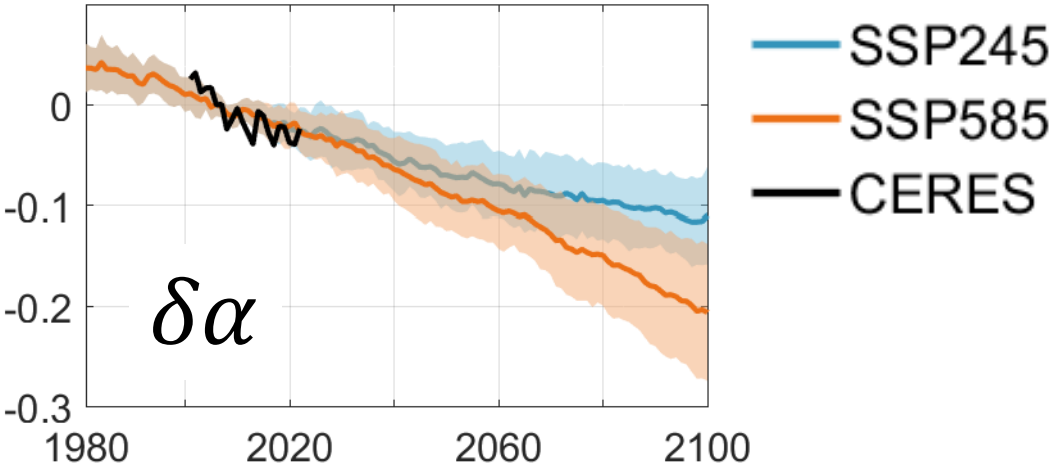
The large spread across CMIP models is significantly influenced by both **seasonal and spatial** variations



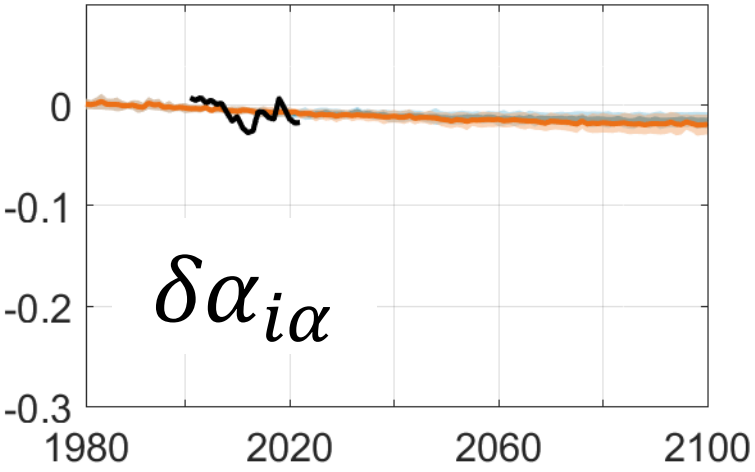
Early summer season:
Ice region term predominantly contributing to the albedo spread across the BK and GL

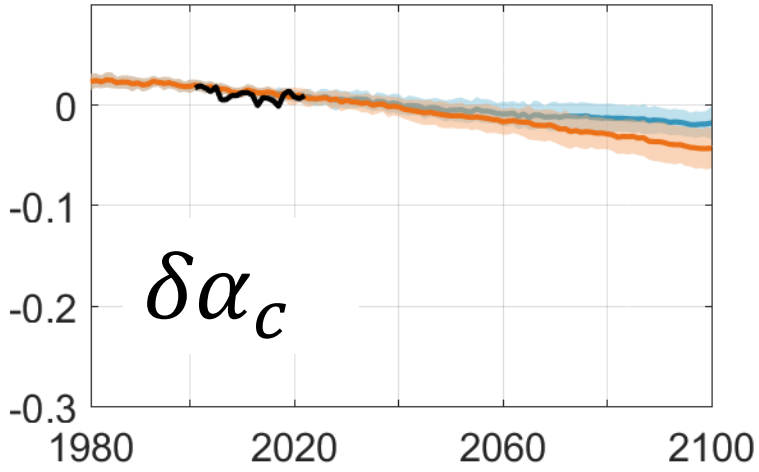
Late summer season:
Ice albedo term contributing to the albedo spread across the CH and CA

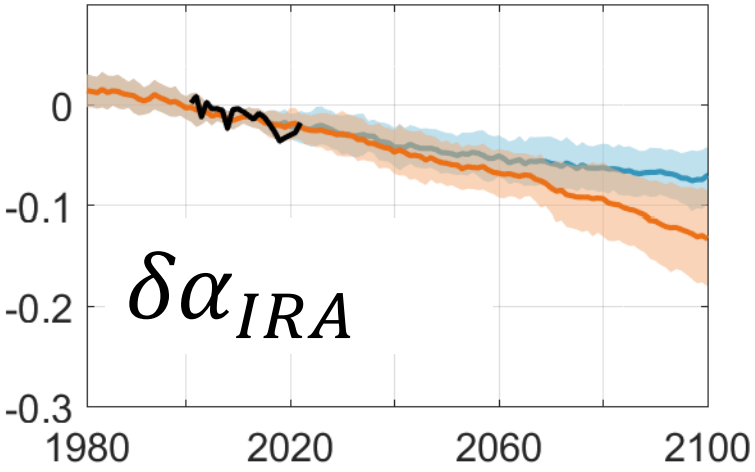
The temporal evolution of surface albedo changes closely follows the **ice region term**



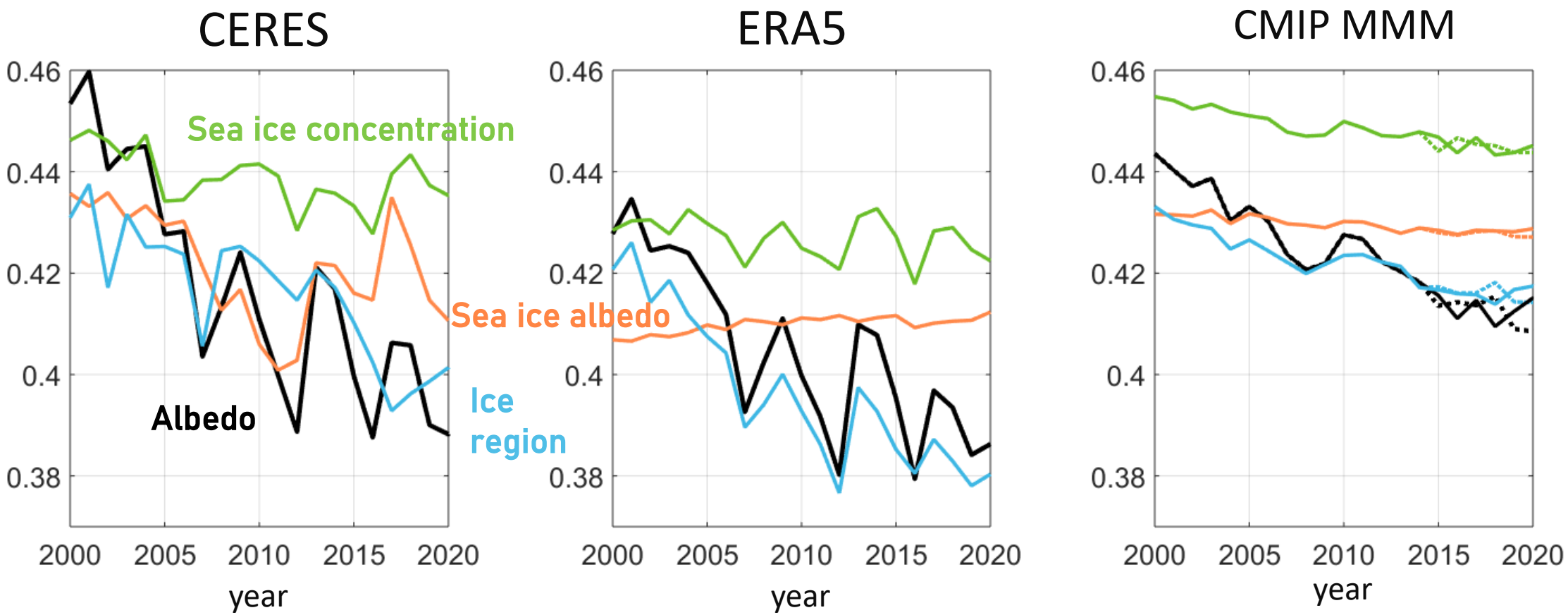
- CERES shows a sharp decline in trend until around 2010, with significant fluctuations affected by the sea ice albedo term
- Minimal variability of the sea ice albedo term in models compared to the considerable interannual variability and significant fluctuations in CERES.







Models fail to capture the **yearly fluctuations in the ice albedo** term as in the CERES data



Summary

- **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.