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E3SM-Arctic: A High-Resolution Coupled Model for Advancing Arctic Climate and System Interactions

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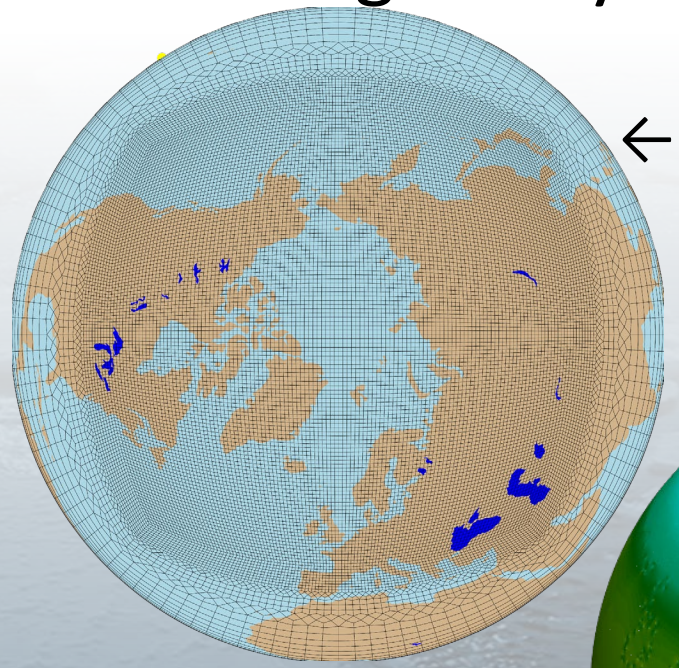
Introduction

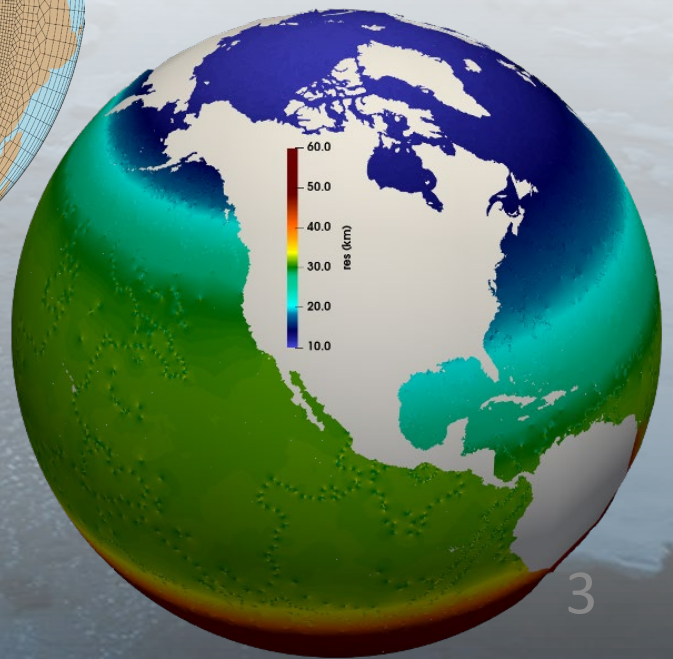
- **Science Focus:** Arctic Amplification and its attribution
- **Motivation:**
  - Arctic warming 2-4 times faster than the global mean.
  - Sea ice reduction, oceanic changes, and teleconnection mechanisms affecting global climate.
  - Importance of Earth System Models (ESMs) in simulating Arctic processes.

Model Overview

- **Model:** E3SM version 2.1 with Arctic Regionally Refined Meshes (RRM).
- **Finer resolution in the Arctic**
  - atmosphere 110 – 25 km
  - ocean/ice: 30 – 10 km
  - land: 165 – 25 km
  - river-routing: 0.5° – 0.125°



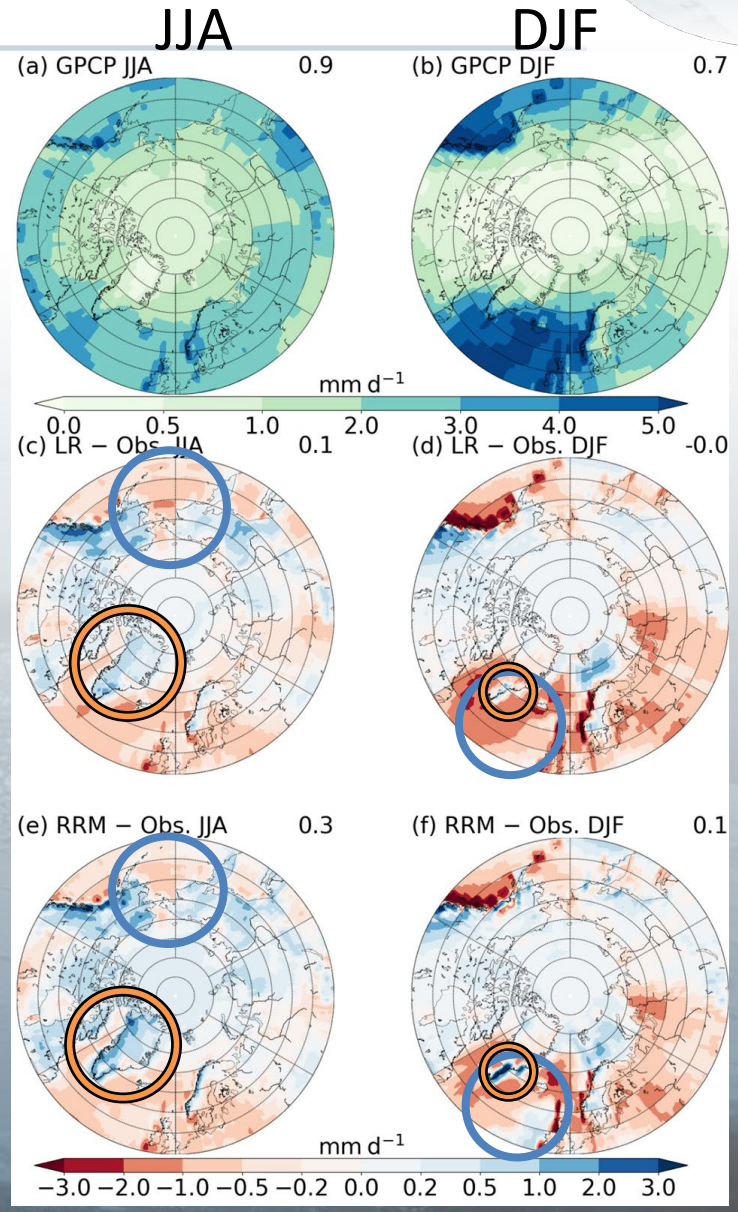
← Atmosphere/land mesh



Ocean/sea-ice mesh →

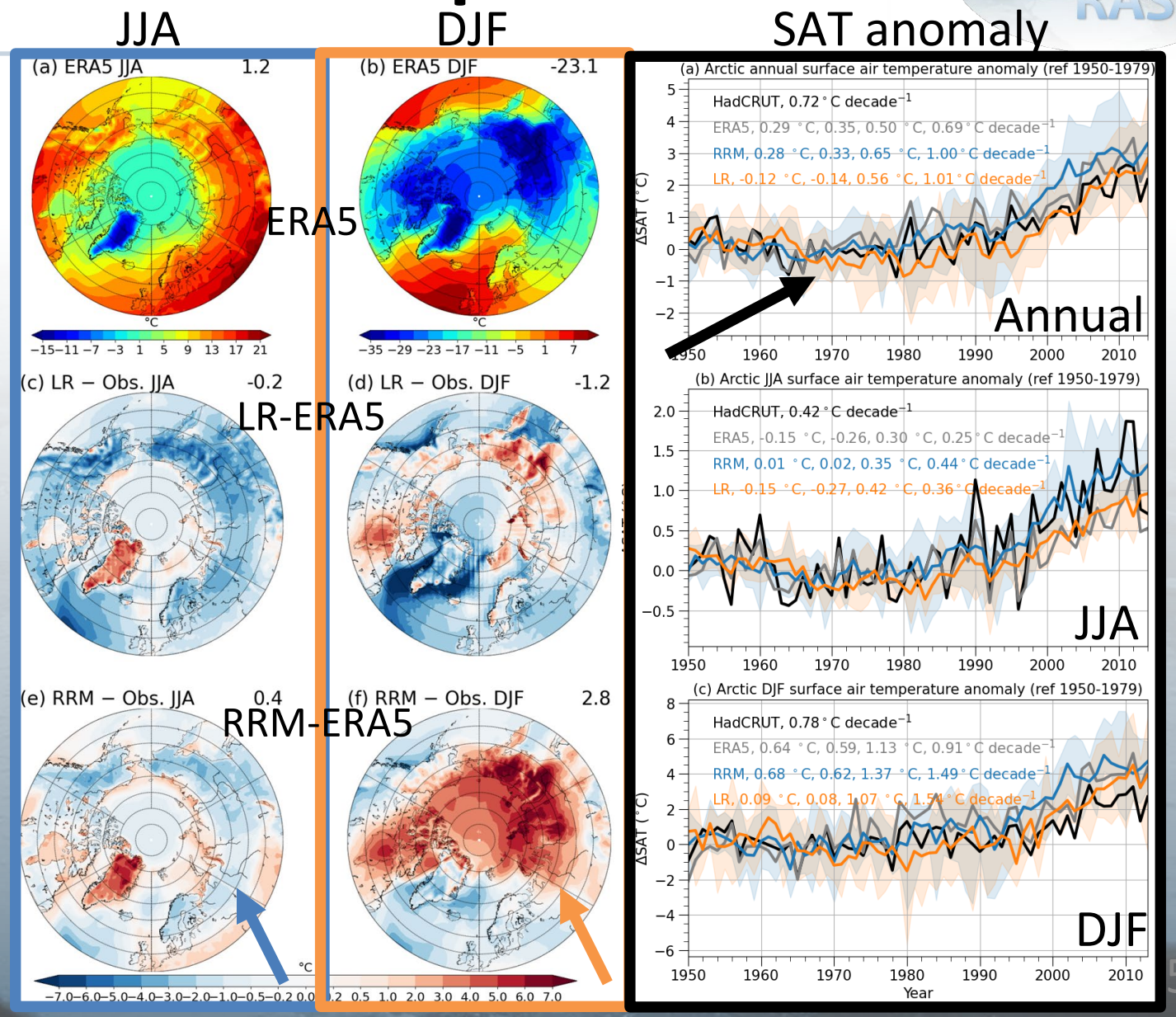
Better Seasonal Precipitation in RRM

- Improvement:
  - Reduced biases compared to LR in both summer and winter
- Degradation:
  - Overestimation of orographic precipitation over Greenland



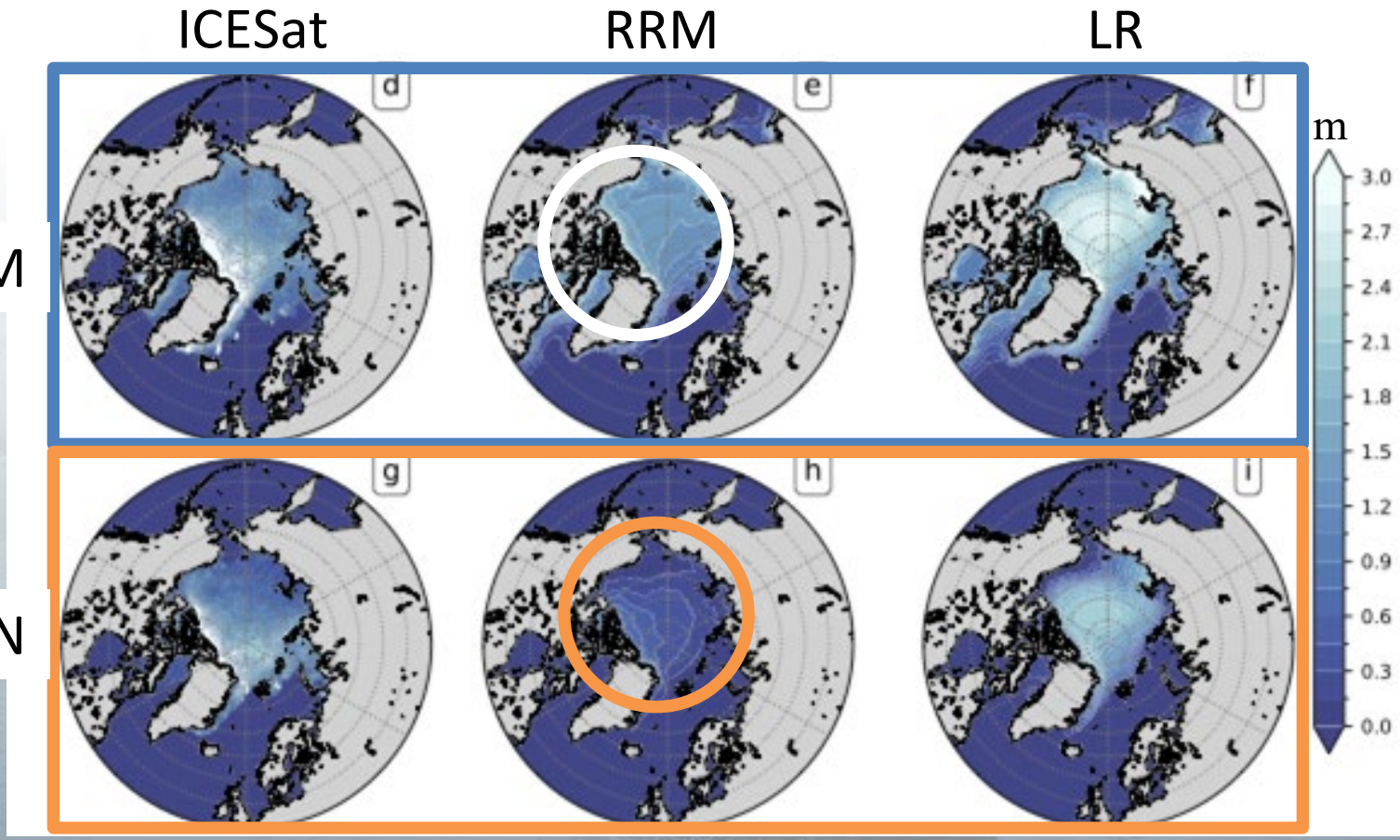
RRM Impact on Surface Air Temperature

- Reduced cold bias in summer.
- Increased winter warm bias.
- Consistent trends of Arctic SAT in both models, with RRM showing stronger warming.
- Warm winter bias linked to:
  - Thinner sea ice
  - Increased surface turbulent heat fluxes
  - Enhanced albedo feedback



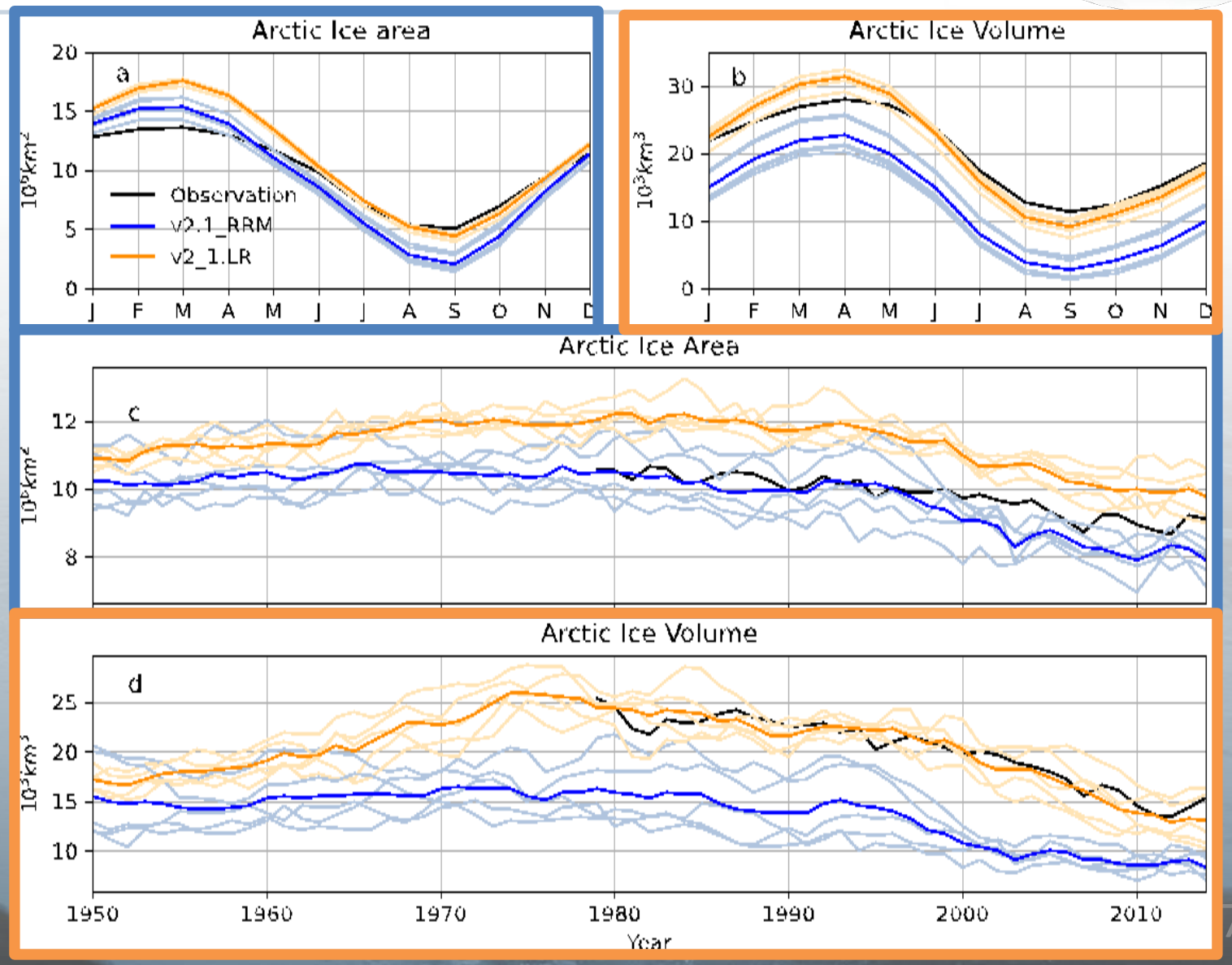
RRM Impact on Sea Ice

- RRM improves sea ice thickness distribution.
- RRM underestimates winter sea ice extent.
- Greater **albedo feedback** in RRM due to more open water



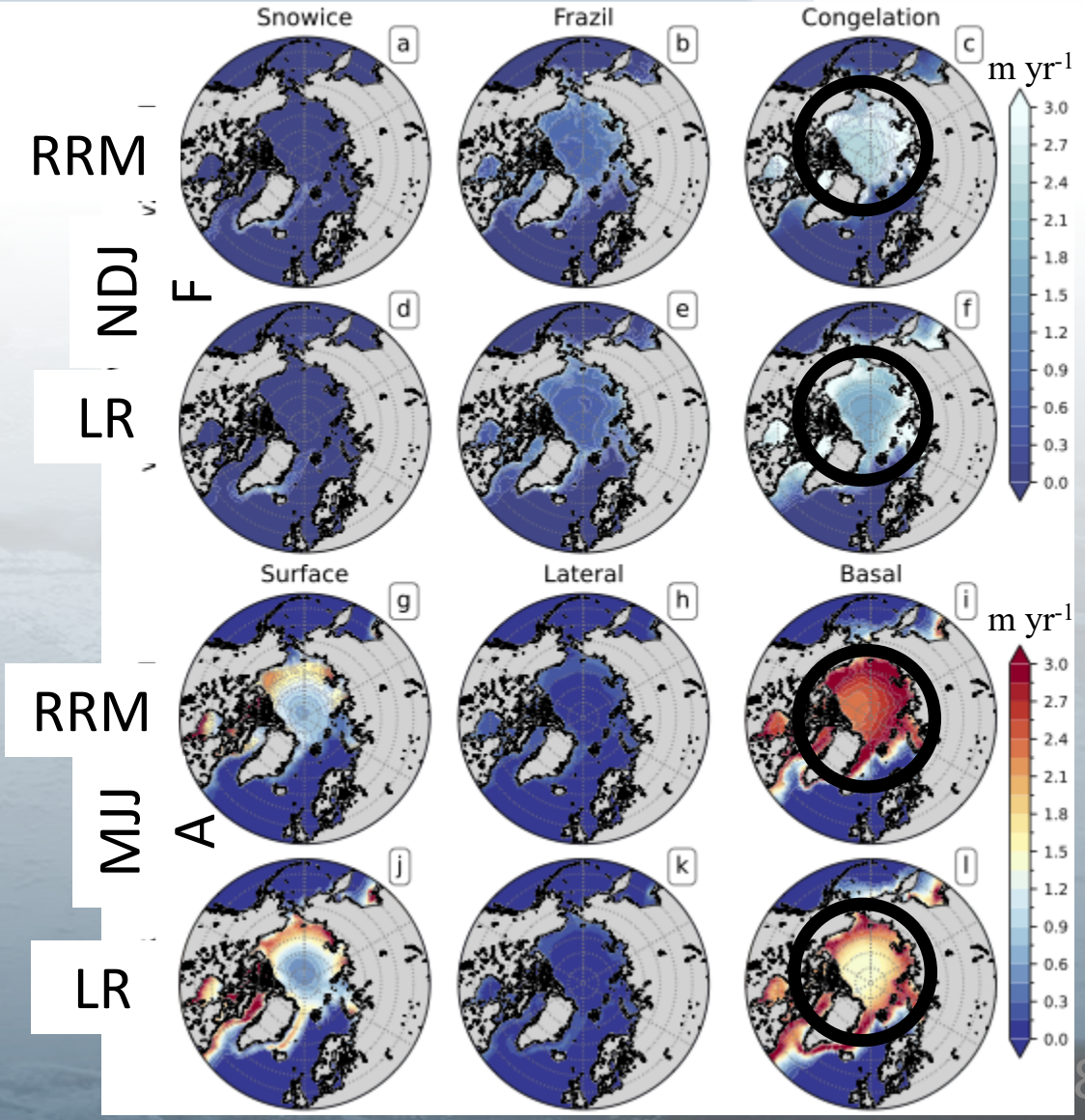
RRM Impact on Sea Ice

- RRM underestimates sea ice volume.
- LR overestimates the sea ice area in winter (more so than the RRM); RRM exhibits an enhanced seasonal cycle
- The larger sea ice extent in LR leads to smaller surface heat fluxes from the ocean and weaker SW and LW CRE than observed



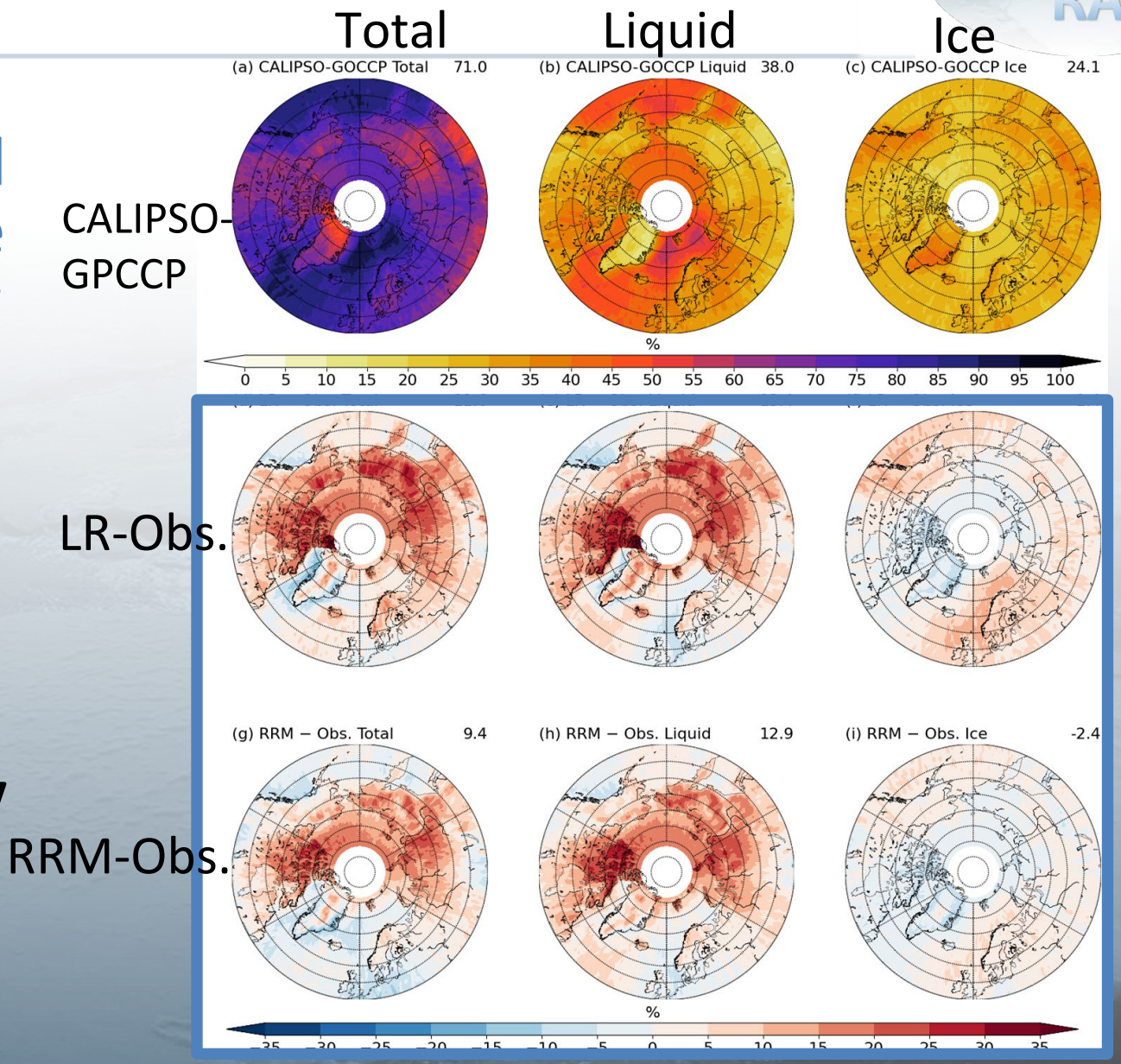
RRM Impact on Sea Ice Growth & Melt

- RRM grows more ice in winter but also melts more ice in summer.
- Growth:
  More **congelation growth** in RRM due to thinner ice and less snow insulation.
- Melt: Warmer SSTs in RRM enhance **basal** melt.



Better Cloud Cover Simulations than LR

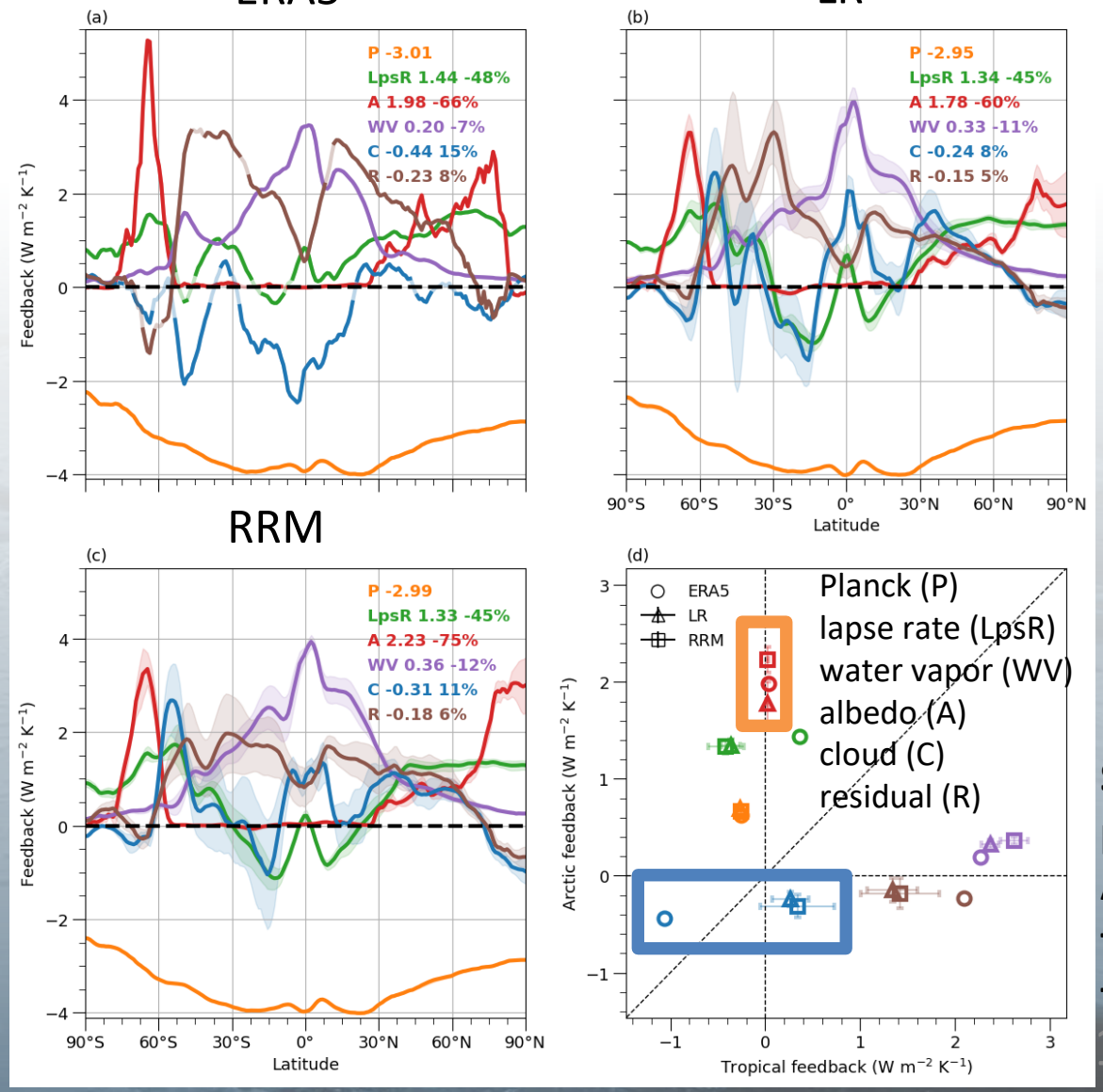
- Improved shortwave and longwave cloud radiative effects (CRE), influencing Arctic warming.
- Both LR and RRM show **negative cloud feedback** in the Arctic, with RRM exhibiting a more negative feedback than LR, **aligning more closely with ERA5**.



Radiative Feedbacks

- Radiative feedback patterns align with observed Arctic Amplification signals.
- RRM shows:
  - Stronger albedo feedback due to more open water
  - More negative cloud feedback, closer to ERA5

Zonal-mean radiative feedbacks, feedback terms (W m^{-2} K^{-1}) for 1980 – 2014

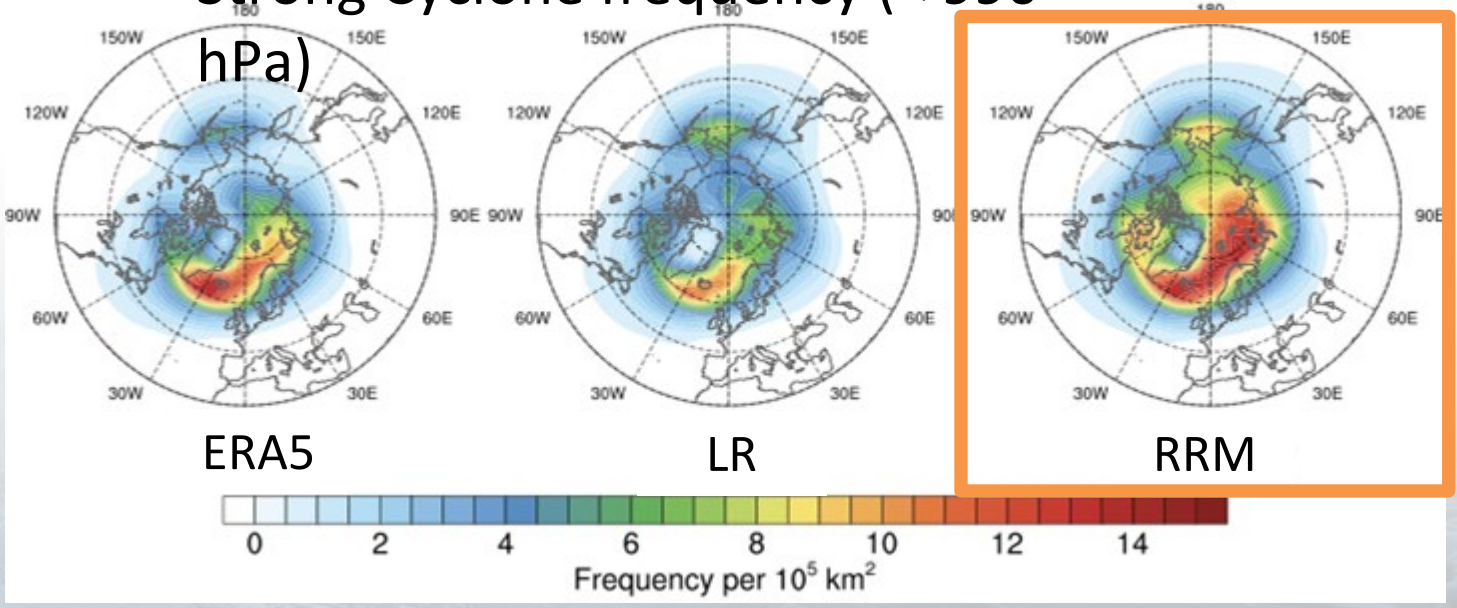


Scatter plot of Arctic V.S. tropical feedbacks

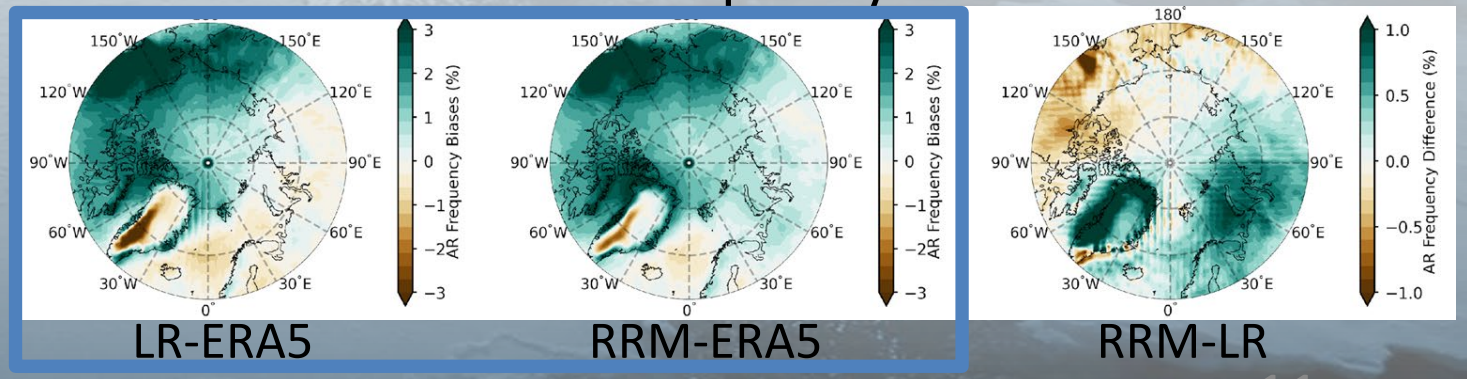
Synoptic Scale Features: Improved Cyclones and ARs

- Overestimation of strong cyclone frequency → Enhance air-sea exchange: wind-driven mixing, ice breakup, heat fluxes.
- Better representation of atmospheric river (AR) frequency and moisture transport

Strong Cyclone frequency (< 990 hPa)



AR frequency



Summary

- RRM improves simulations of key Arctic processes such as precipitation, clouds, and sea ice.
- Persistent warm bias in winter and biases in cyclone frequency.
- Plans to investigate the remaining biases in RRM:
  - Prescribed SST/SIC
  - Cloud clocking
  - Slab ocean model

Huo et al. E3SM-Arctic: Regionally Refined Coupled Model for Advanced Understanding of Arctic Systems Interactions. *ESS Open Archive*. September 27, 2024.