How Sea Ice Shapes the Seasonal Arctic Warming Pattern

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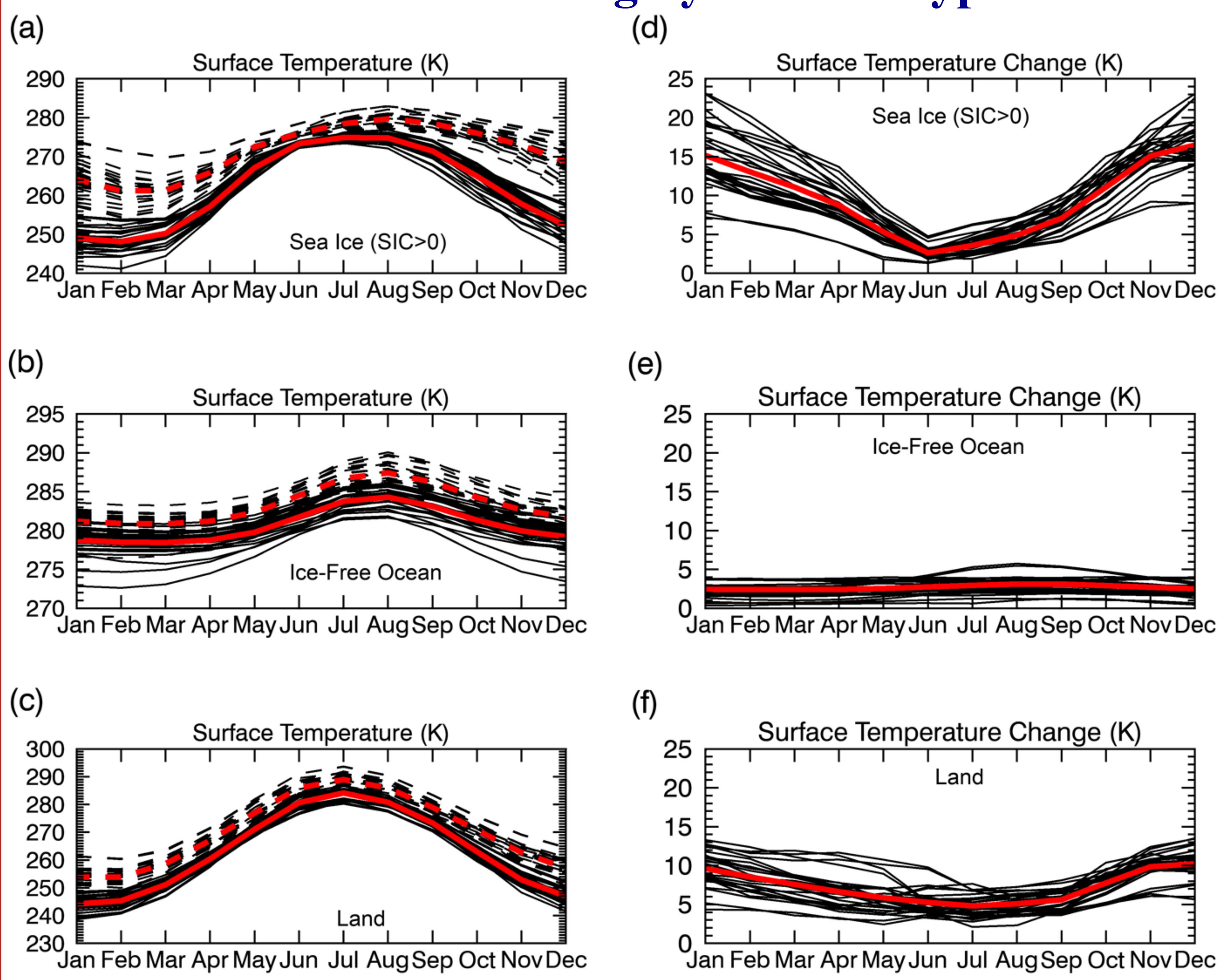
1. Background

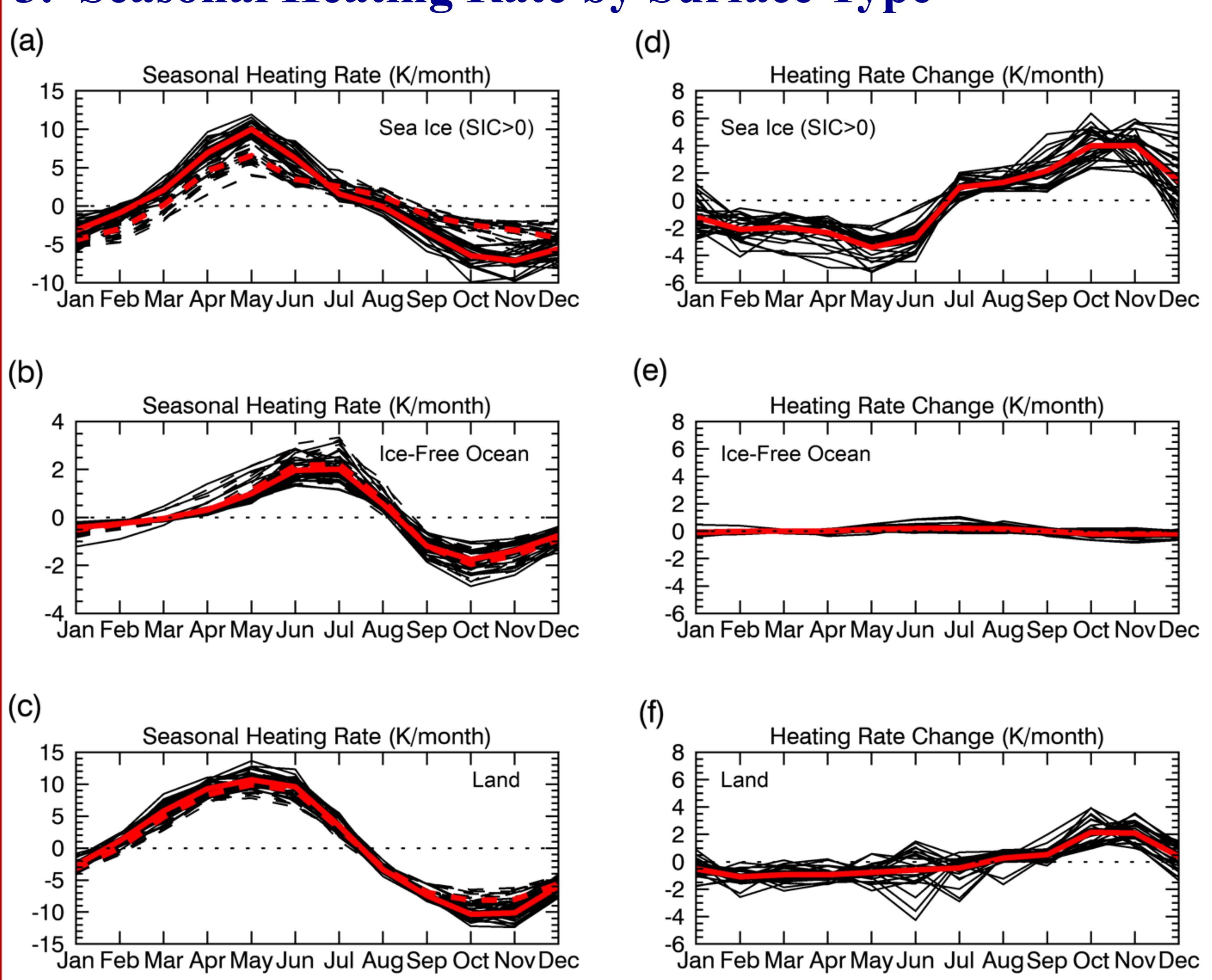
- Arctic Amplification is robustly strongest in winter and weakest in summer.
- Arctic amplification is normally analyzed through the lens of energy flux changes with relatively little attention paid to the thermal inertia properties of the surface and its change.
- The themal inertia of ocean is much greater than sea ice due to a greater specific heat capacity and mixed layer depth.
- Sea ice loss substantially changes the thermal inertia of the Arctic surface.
- This study analyzes how sea ice loss, by changing the thermal inertia of the surface and surface energy fluxes, shapes the seasonal Arctic warming pattern and explains the intermodel spread.

2. Seasonal Arctic Warming by Surface Type



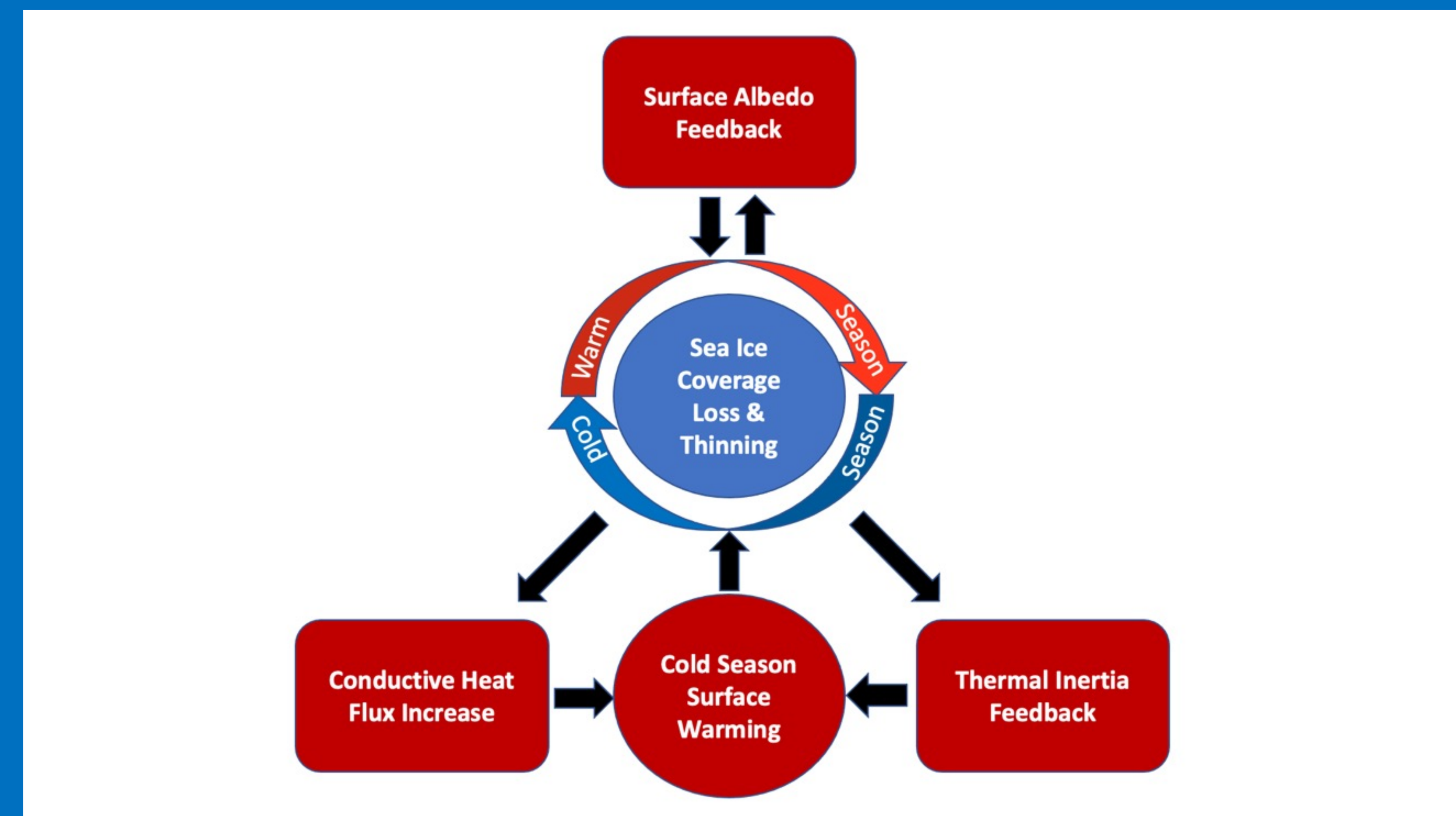
Black lines are individual CMIP5 models, while red lines are the ensemble means. Solid is for the historical simulations, while dashed is for the projected RCP8.5 scenario.

3. Seasonal Heating Rate by Surface Type



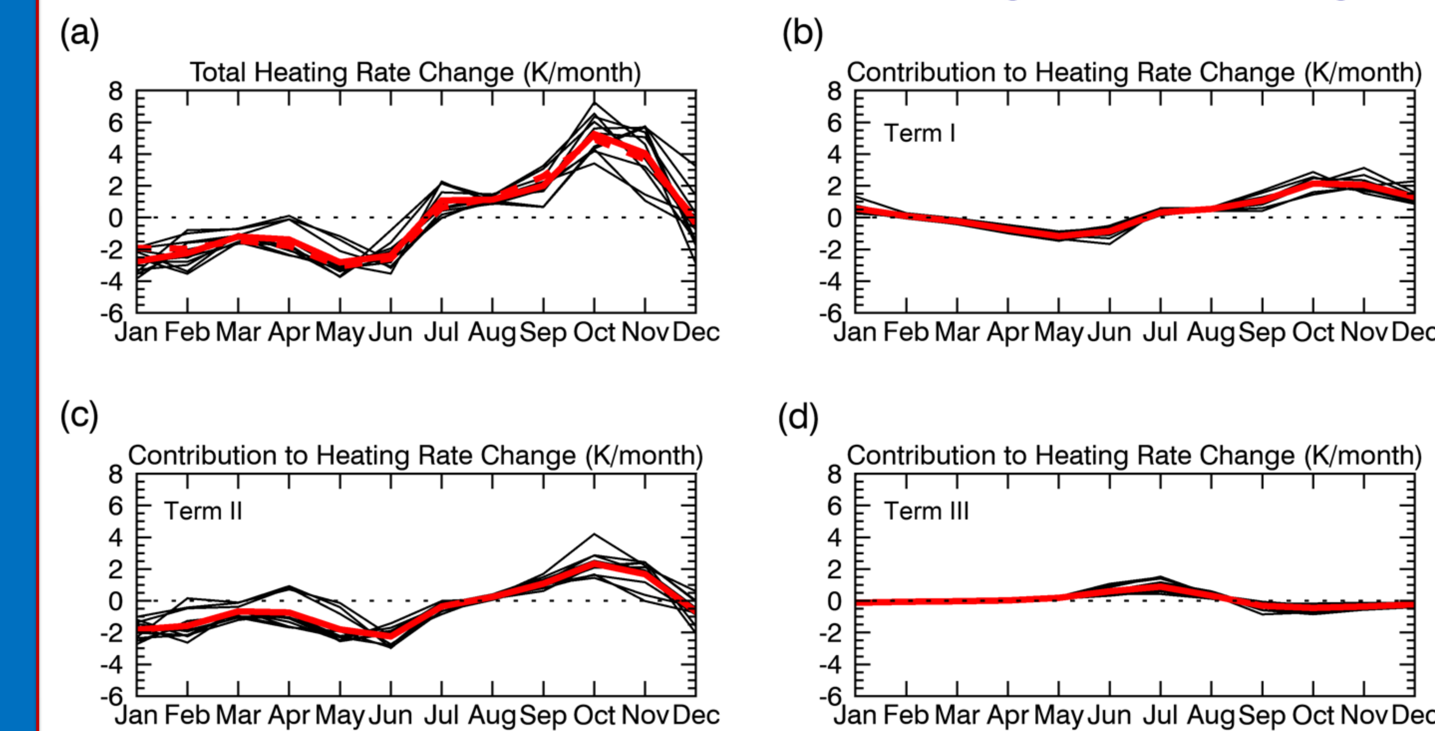
For Sea Ice: Cooling from summer to winter Slows, and Warming from winter to summer Slows.

Sea ice loss shapes the seasonal Arctic warming pattern through the interaction of the SAF, the increasing thermal inertia of the surface and the greater conductive heat flux reaching the ice surface from the ocean below. The thermal inertia of the surface, in particular, explains the warming minimum in summer and maximum in winter, while also serving as a limiting factor to the warming over Arctic seas.



- For a given forcing, larger (smaller) thermal inertia implies smaller (larger) warming.
- Ocean thermal inertia > sea ice thermal inertia
- Greater SW absorption (SAF) by ocean surface, due to sea ice loss, causes weak summer warming due to large thermal inertia, but greater oceanic heat content causes greater sea ice loss.
- Drop in sea ice coverage means increase in thermal inertia, which slows the normal cooling that occurs from summer to winter, producing the winter warming maximum.
- Sea ice thinning allows greater conductive heat flux from the warmer ocean below to reach the sea ice surface, contributing to the warming.
- Increase in thermal inertia due to sea ice loss also slow the normal warming that occurs from winter to summer, reducing the warming from winter to summer.
- Energy going to sea ice melt also limits the warm season warming.
- Once sea ice is completely lost the large oceanic thermal inertia limits the warming that occurs over the Arctic ocean.
- Study published at https://doi.org/10.1088/2752-5295/ace20f Sejas, S. A. and P. C. Taylor, 2023: The role of sea ice in establishing the seasonal Arctic warming pattern. *Env Res: Climate*

4. Contributions to Seasonal Heating Rate Change

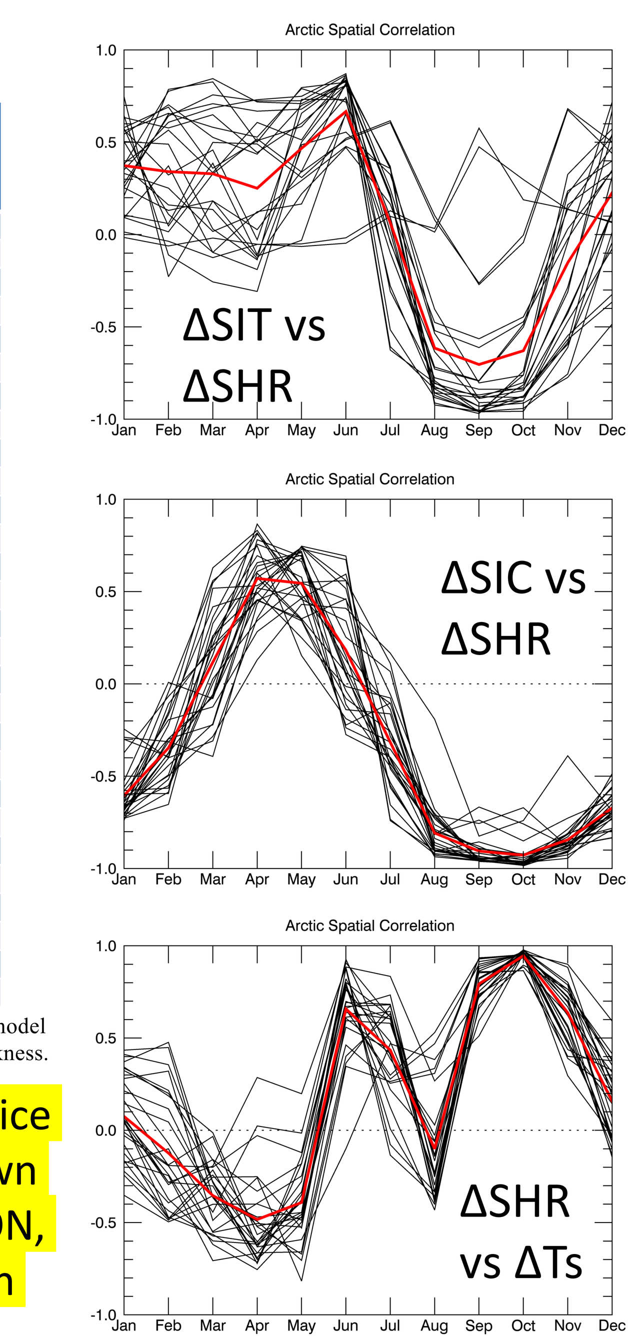


$$\Delta\left(\frac{\partial T_s}{\partial t}\right) \approx \left[\underbrace{\left(\frac{\partial T_{s,ice}}{\partial t}-\frac{\partial sst}{\partial t}\right)*\Delta SIC}_{I} + \underbrace{SIC*\Delta\left(\frac{\partial T_{s,ice}}{\partial t}\right)}_{II} + \underbrace{(1-SIC)*\Delta\left(\frac{\partial SST}{\partial t}\right)}_{III} + \underbrace{\left(T_{s,ice}-SST\right)*\Delta\left(\frac{\partial SIC}{\partial t}\right)}_{IV} + \underbrace{\frac{\partial SIC}{\partial t}*\Delta\left(T_{s,ice}-SST\right)}_{V}\right]$$

5. Spatial Correlations

Model	$\Delta\frac{\partial T_S}{\partial t}$ (SOND) vs ΔT_S (Max)	$\Delta\frac{\partial T_S}{\partial t}$ (SOND) vs ΔSIC (SOND)	$\Delta\frac{\partial T_S}{\partial t}$ (SON) vs $\Delta\frac{\partial T_{S,ice}}{\partial t}$ (SON)	$\Delta\frac{\partial T_{S,ice}}{\partial t}$ (SON) vs ΔTot_Thick (SON)	$\Delta\frac{\partial T_S}{\partial t}$ (SON) vs ΔTot_Thick (SON)
ACCESS1.0	0.90	-0.86	N/A	N/A	-0.79 (-0.81)
ACCESS1.3	0.91	-0.89	N/A	N/A	-0.87 (-0.87)
CCSM4	0.93	-0.95	0.97	-0.32 (-0.73)	-0.35 (-0.80)
CMCC-CESM	0.91	-0.66	0.12	0.47 (0.47)	-0.71 (-0.71)
CMCC-CMS	0.90	-0.83	0.24	0.17 (0.17)	-0.87 (-0.87)
CMCC-CM	0.89	-0.73	0.17	0.40 (0.39)	-0.78 (-0.79)
CNRM-CM5	0.92	-0.92	0.92	-0.72 (-0.72)	-0.81 (-0.82)
CanESM2	0.92	-0.97	0.98	-0.92 (-0.92)	-0.97 (-0.97)
GISS-E2-H-CC*	0.71	-0.78	N/A	N/A	0.34 (0.04)
GISS-E2-H*	0.76	-0.83	N/A	N/A	0.40 (0.13)
GISS-E2-R-CC*	0.80	-0.67	N/A	N/A	-0.21 (-0.21)
GISS-E2-R*	0.80	-0.70	N/A	N/A	-0.28 (-0.28)
HadGEM2-AO*	0.86	-0.44	N/A	N/A	-0.51 (-0.54)
HadGEM2-CC	0.92	-0.97	N/A	N/A	-0.82 (-0.86)
HadGEM2-ES	0.90	-0.96	N/A	N/A	-0.84 (-0.86)
IPSL-CM5A-LR*	0.92	-0.84	0.96	-0.67 (-0.68)	-0.74 (-0.74)
IPSL-CM5A-MR*	0.93	-0.83	0.98	-0.70 (-0.70)	-0.72 (-0.72)
IPSL-CM5B-LR*	0.84	-0.63	0.93	-0.53 (-0.55)	-0.65 (-0.68)
MIROC-ESM-CHEM	0.89	-0.97	N/A	N/A	-0.92 (-0.92)
MIROC-ESM	0.87	-0.97	N/A	N/A	-0.90 (-0.90)
MIROC5	0.92	-0.95	0.96	-0.80 (-0.81)	-0.87 (-0.89)
MPI-ESM-LR	0.87	-0.93	N/A	N/A	-0.89 (-0.89)
MPI-ESM-MR	0.90	-0.94	N/A	N/A	-0.92 (-0.92)
MRI-CGCM3	0.80	-0.59	0.93	-0.42 (-0.53)	-0.40 (-0.53)
MRI-ESM1	0.79	-0.61	0.95	-0.45 (-0.57)	-0.45 (-0.59)
NorESM1-ME	0.95	-0.86	0.96	-0.44 (-0.82)	-0.44 (-0.89)
NorESM1-M	0.96	-0.88	0.96	-0.43 (-0.80)	-0.46 (-0.87)
Ensemble Mean	0.88	-0.82	0.79	-0.38 (-0.49)	-0.61 (-0.70)

Values in parenthesis are for grid boxes with total thickness < 5m. * Indicates a model with no snow depth output, so total thickness is just indicative of the sea ice thickness.



Gridboxes with greater SIC loss and sea ice thinning tend to have a greater slowdown in seasonal cooling during SOND and SON, respectively, for nearly all models, which results in greater warming.

6. Inter-model Spread

Models with greater SW absorption during the warm season tend to have larger SIC loss and seasonal heating rate increase during SOND and a larger max warming in winter.