Large Ensemble Analysis of Northern Hemisphere Snow Trends

Lawrence Mudryk & Paul Kushner
Department of Physics, University of Toronto

Chris Derksen
Environment Canada CRD

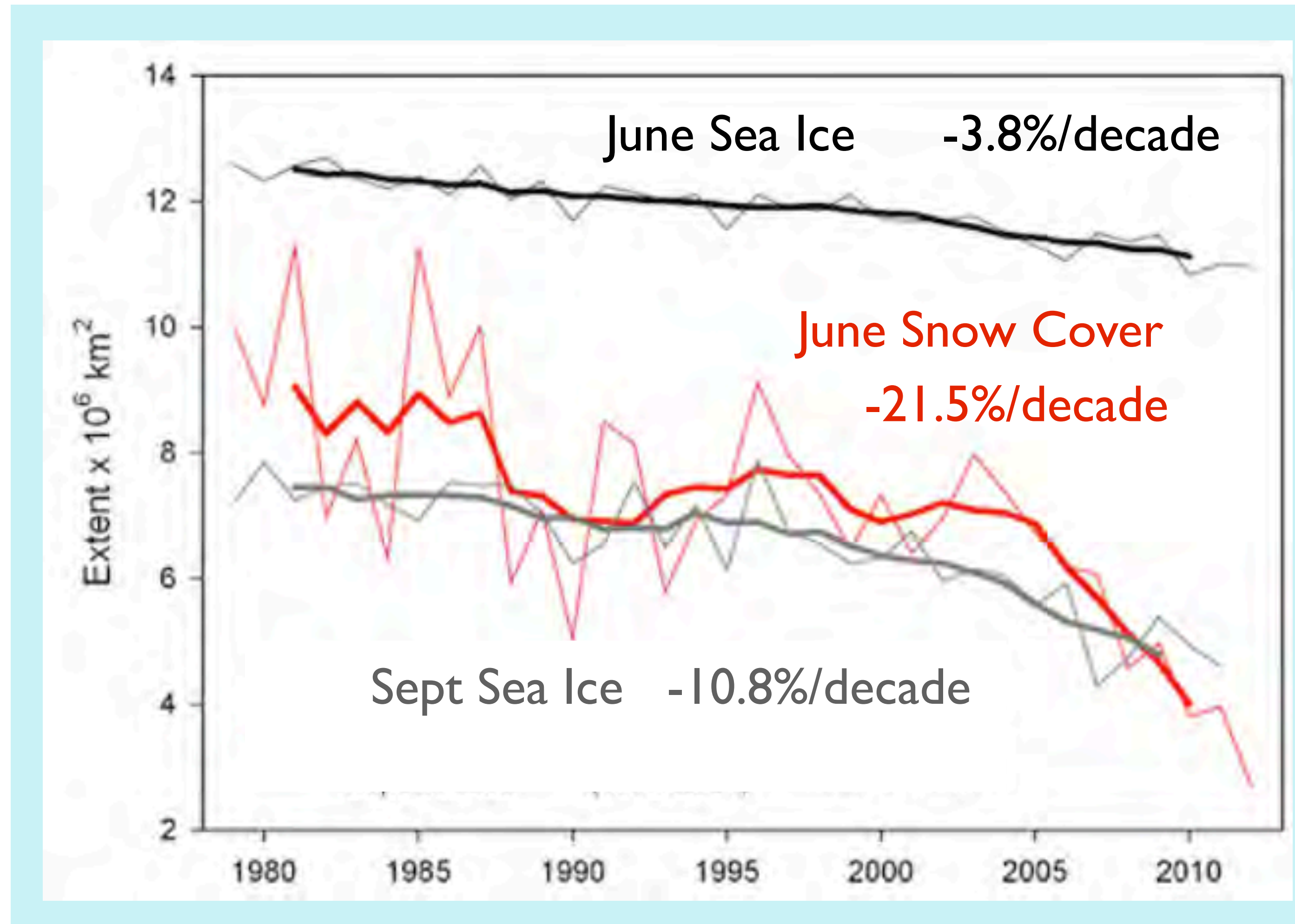
Mudryk et al., *Climate Dynamics*, in review

Introduction

Summertime snow is retreating faster than September sea ice. Springtime snow is also retreating rapidly.

- Can such changes be found in climate models and partitioned into anthropogenic and natural components?
- How are these trends related to trends in temperature, precipitation, circulation?

We use a large-ensemble methodology (e.g. Deser et al. 2010, 2012) from CCSM4 to interpret satellite era snow observations.



Derksen and Brown, 2012

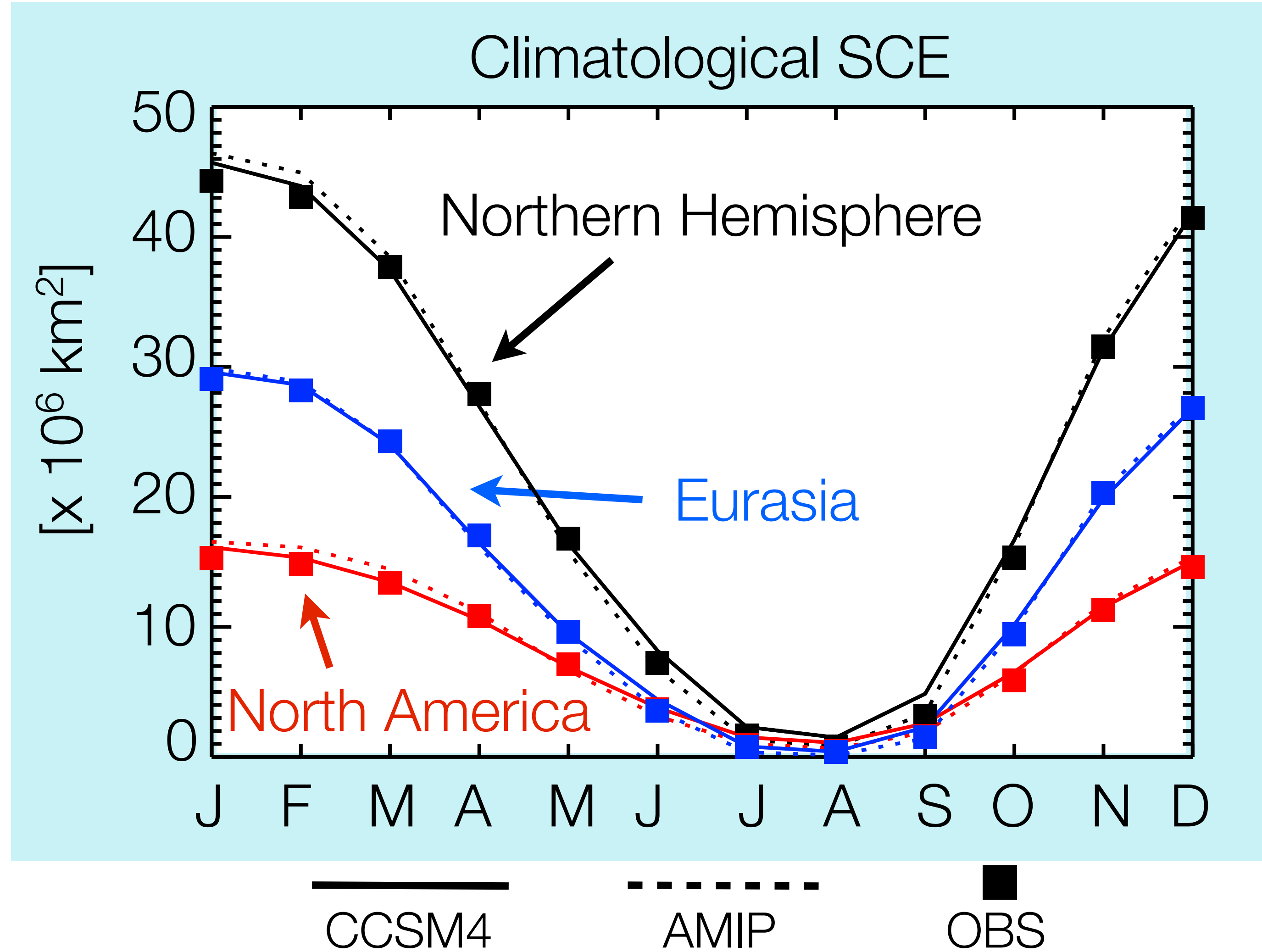
<table>
<tr><td rowspan="2">Models</td><td>CCSM4</td><td>• Coupled ocean-atmosphere
• 1981-2010</td><td rowspan="2">• 2 x 2.5 degree CAM4
• <code>historical</code> + <code>rcp45</code> extension after 2005
• 40 realizations, 1955 branch.</td></tr>
<tr><td>AMIP</td><td>• Observed ocean and sea ice
• 1981-2008</td></tr>
</table>

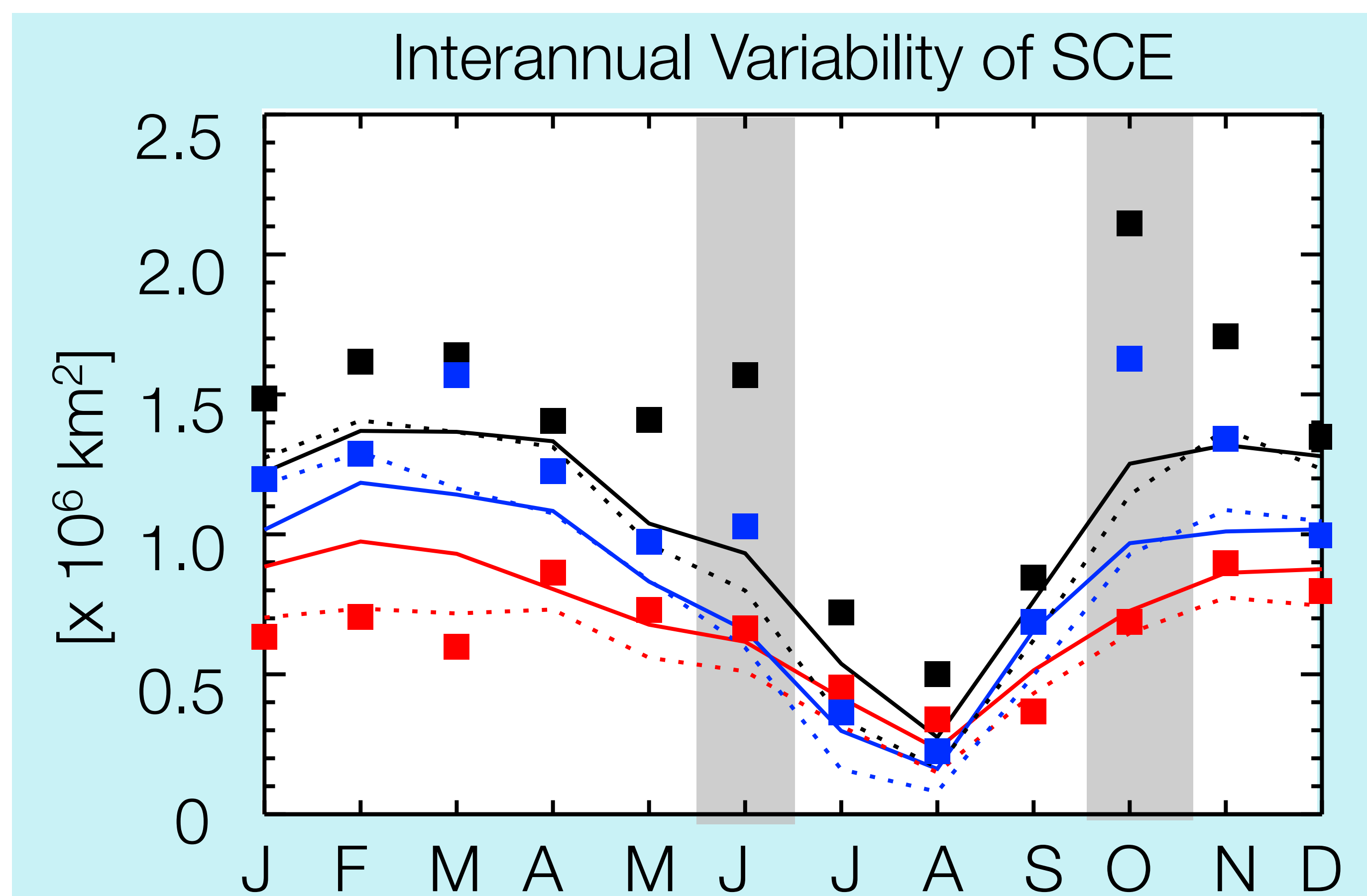
Models	CCSM4	• Coupled ocean-atmosphere • 1981-2010	• 2 x 2.5 degree CAM4 • `historical` + `rcp45` extension after 2005 • 40 realizations, 1955 branch.
	AMIP	• Observed ocean and sea ice • 1981-2008	

Obs	Snow cover fraction and extent (SCF and SCE)	• Rutgers/NOAA CDR 1981-2010 (Brown and Robinson 2011) • October CDR further analyzed by Brown and Derksen (2013)
	Land sfc temperature (Ts) and SST	Had CRU 4, Hurrell

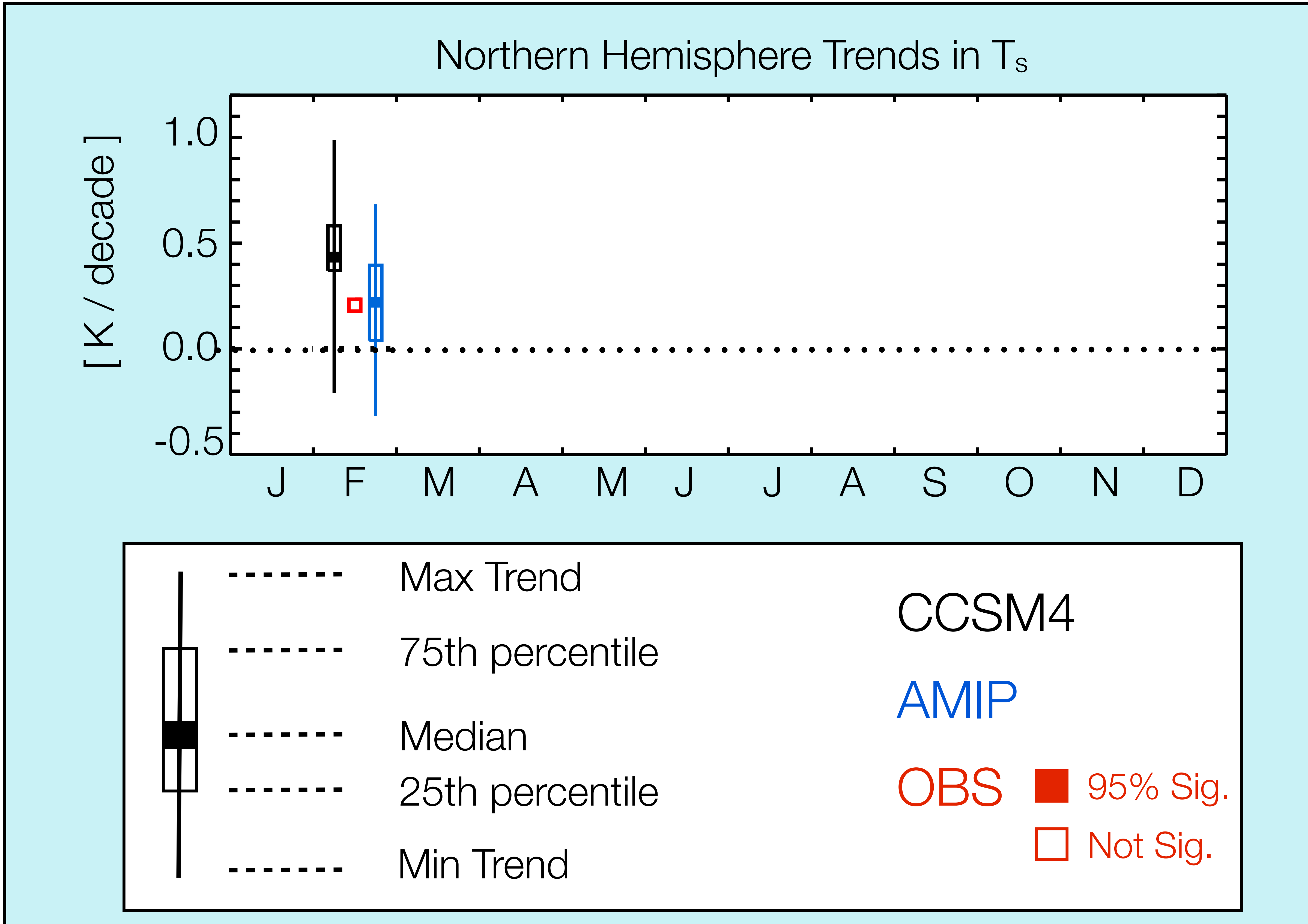
CCSM4 (2^0) Snow Simulation

- SCE seasonal cycle and variability generally well simulated (despite coarse resolution).
- SCE interannual variability too low in June and October (Arctic and SubArctic snow on/off).
- Coupling to ocean increases North American variability (not Eurasian variability).

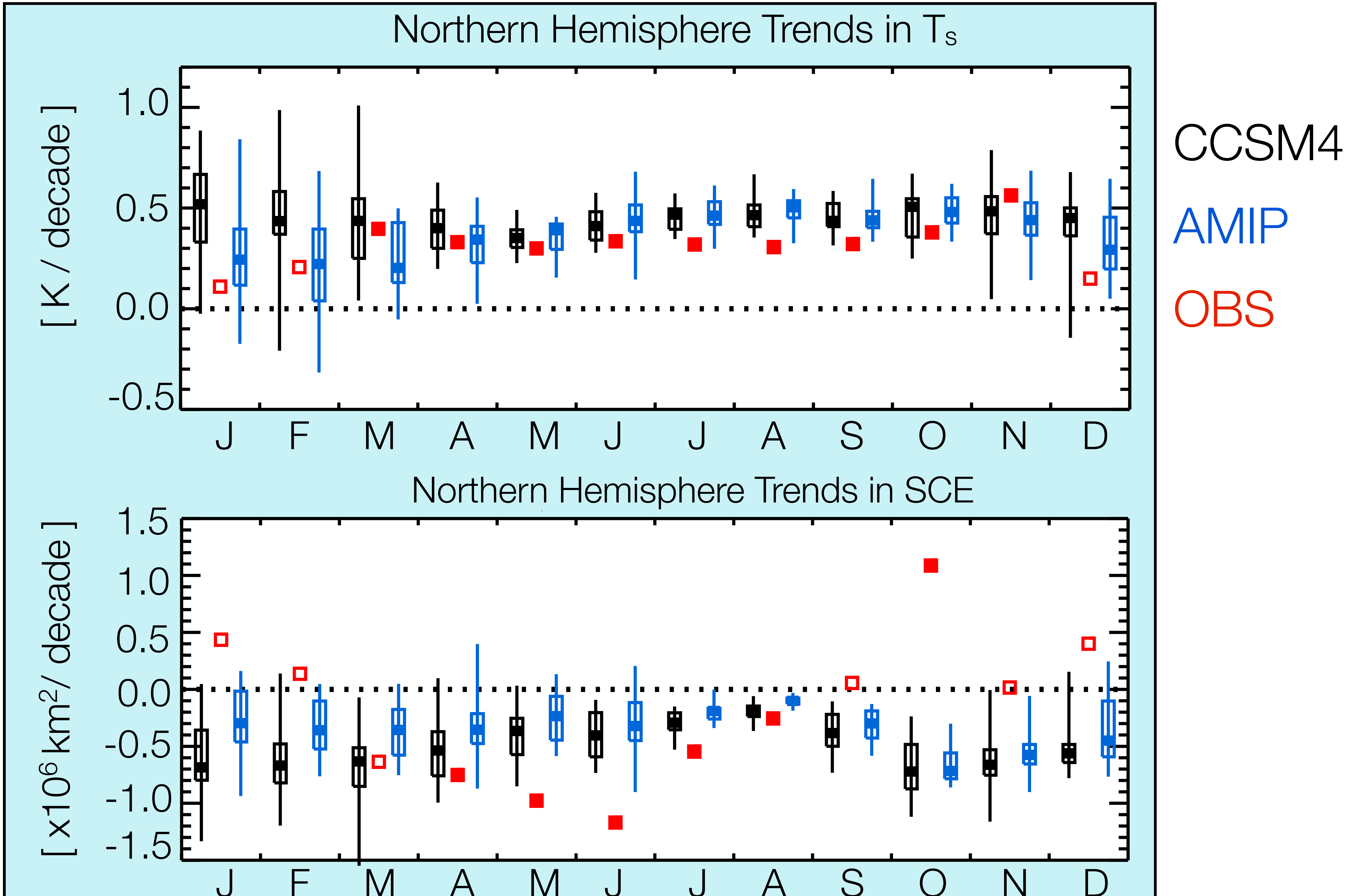




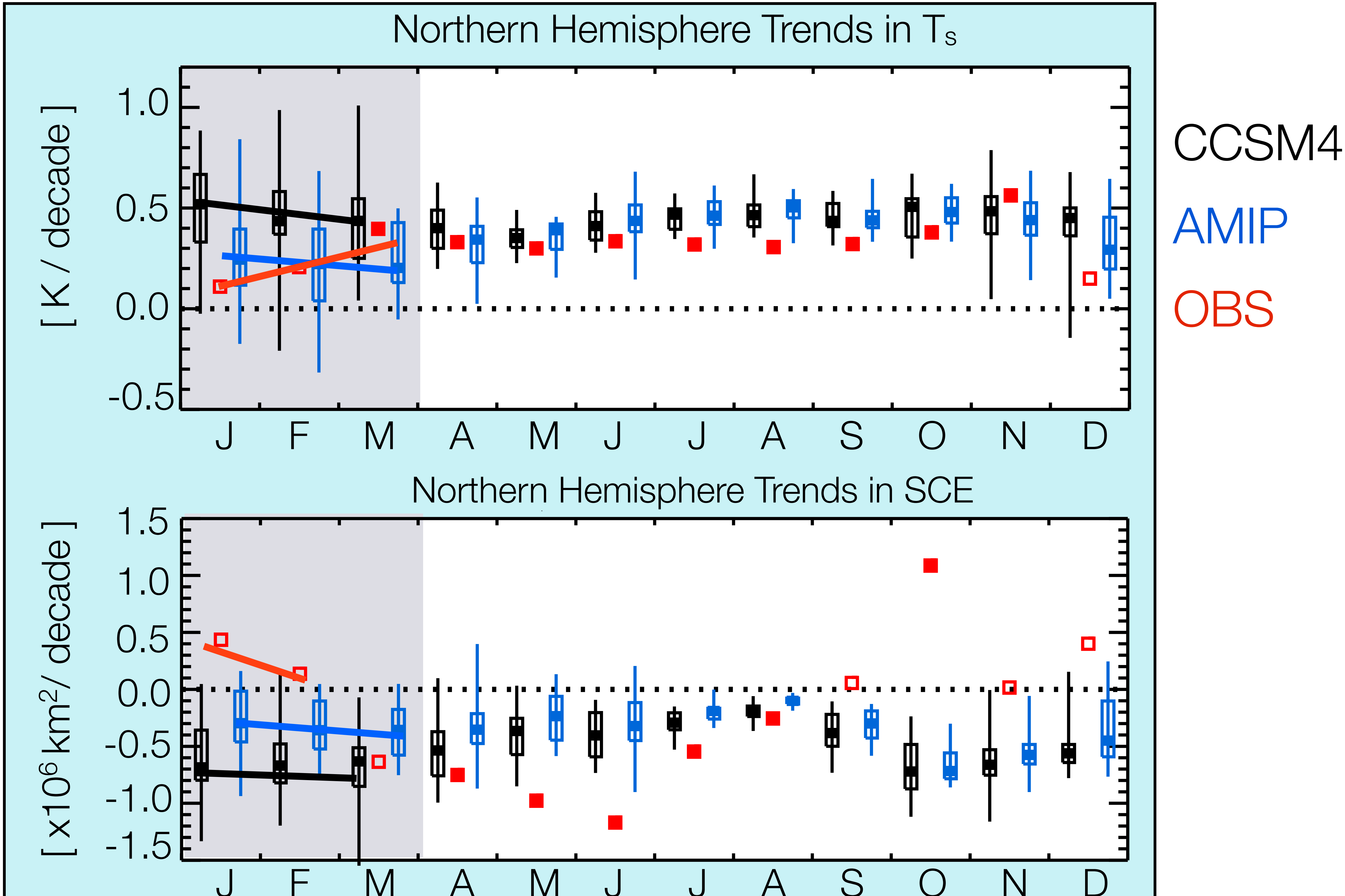
Model-Obs Comparison



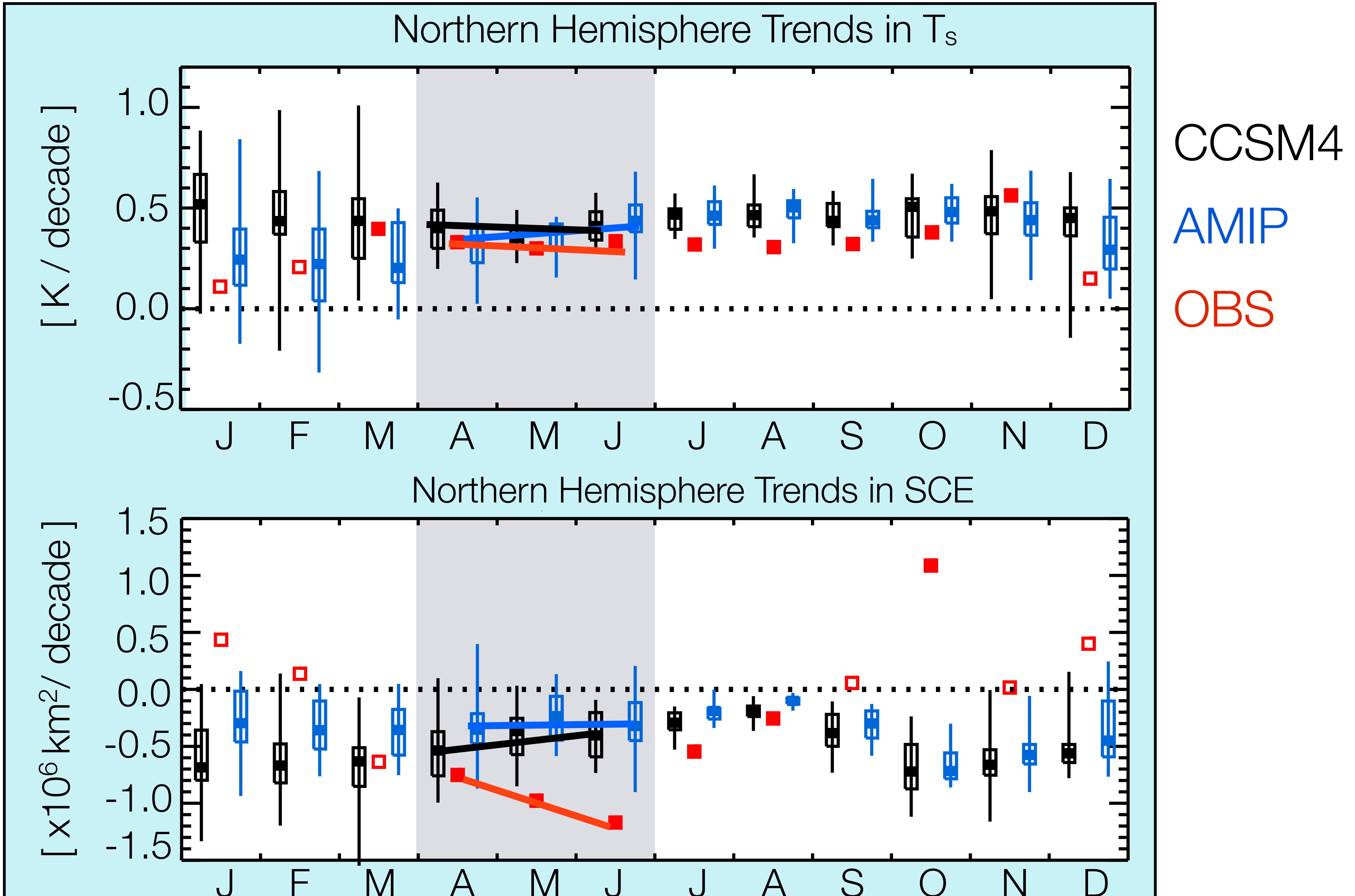
Northern Hemisphere SCE Trends



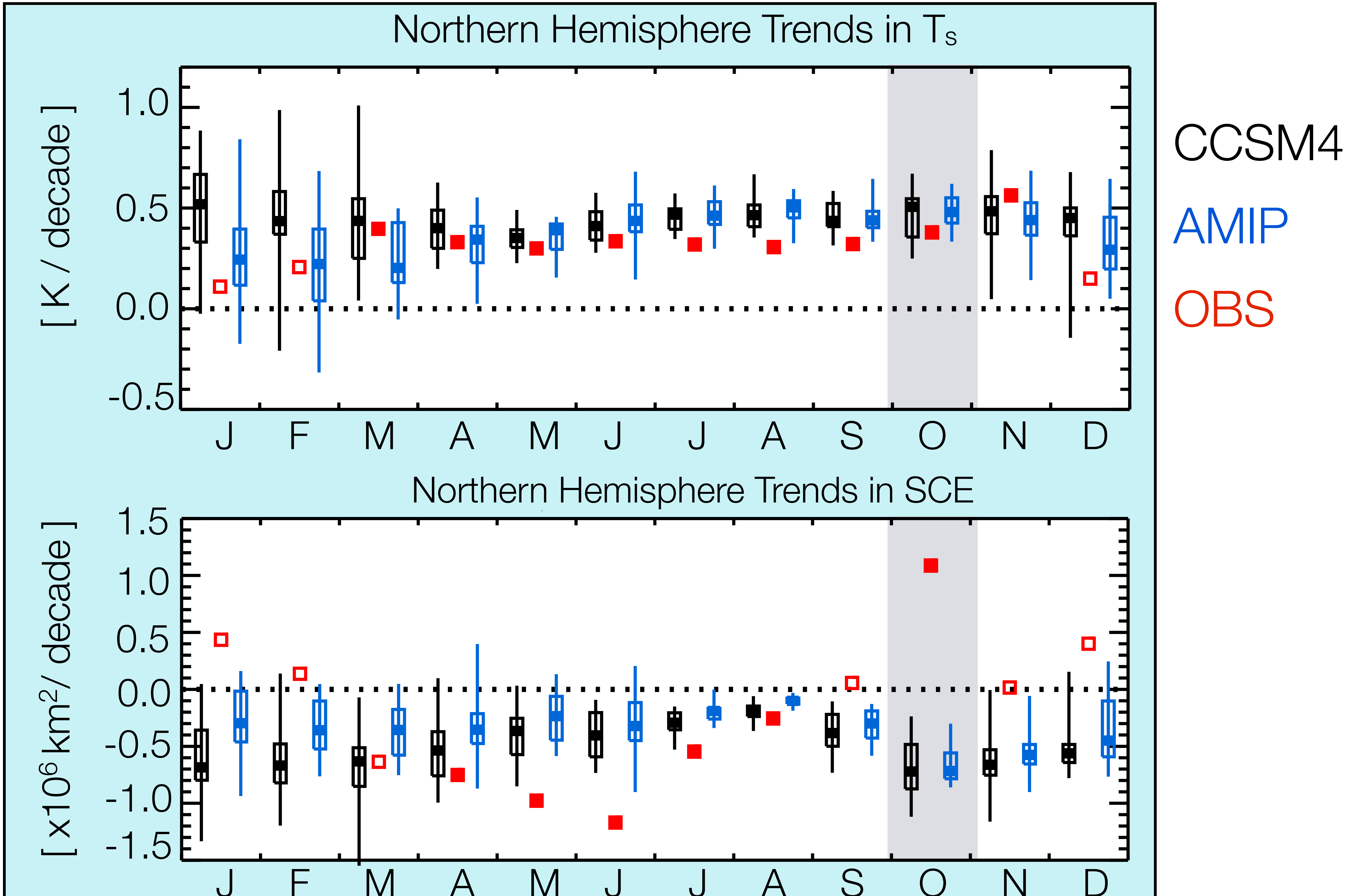
Northern Hemisphere SCE Trends



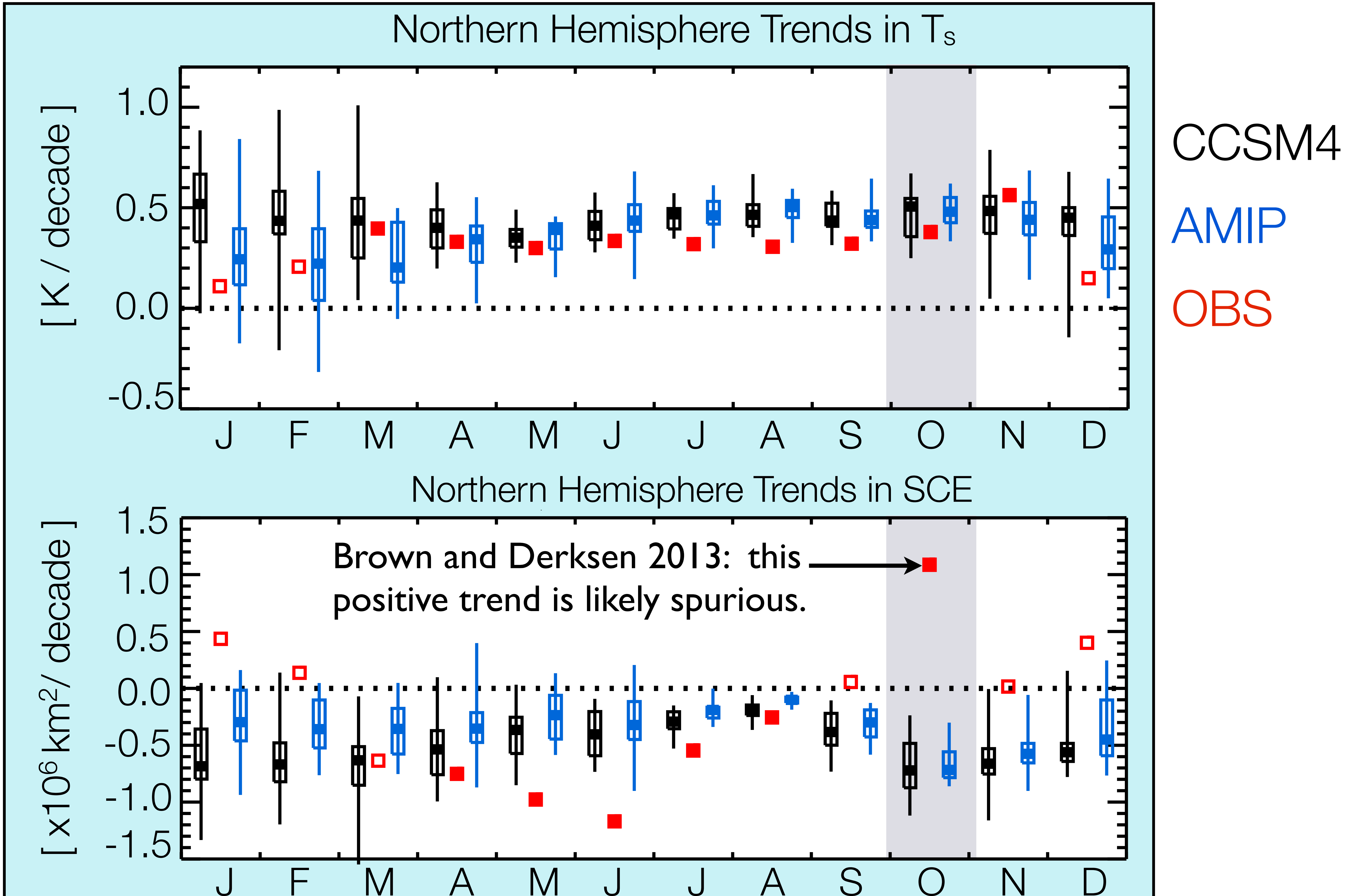
Northern Hemisphere SCE Trends



Northern Hemisphere SCE Trends



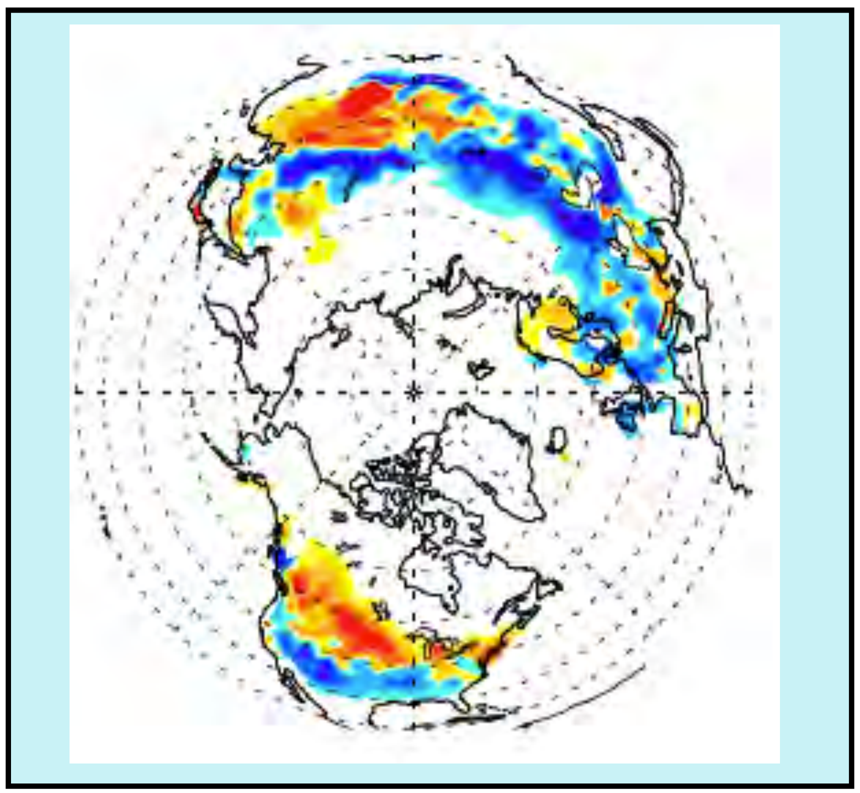
Northern Hemisphere SCE Trends

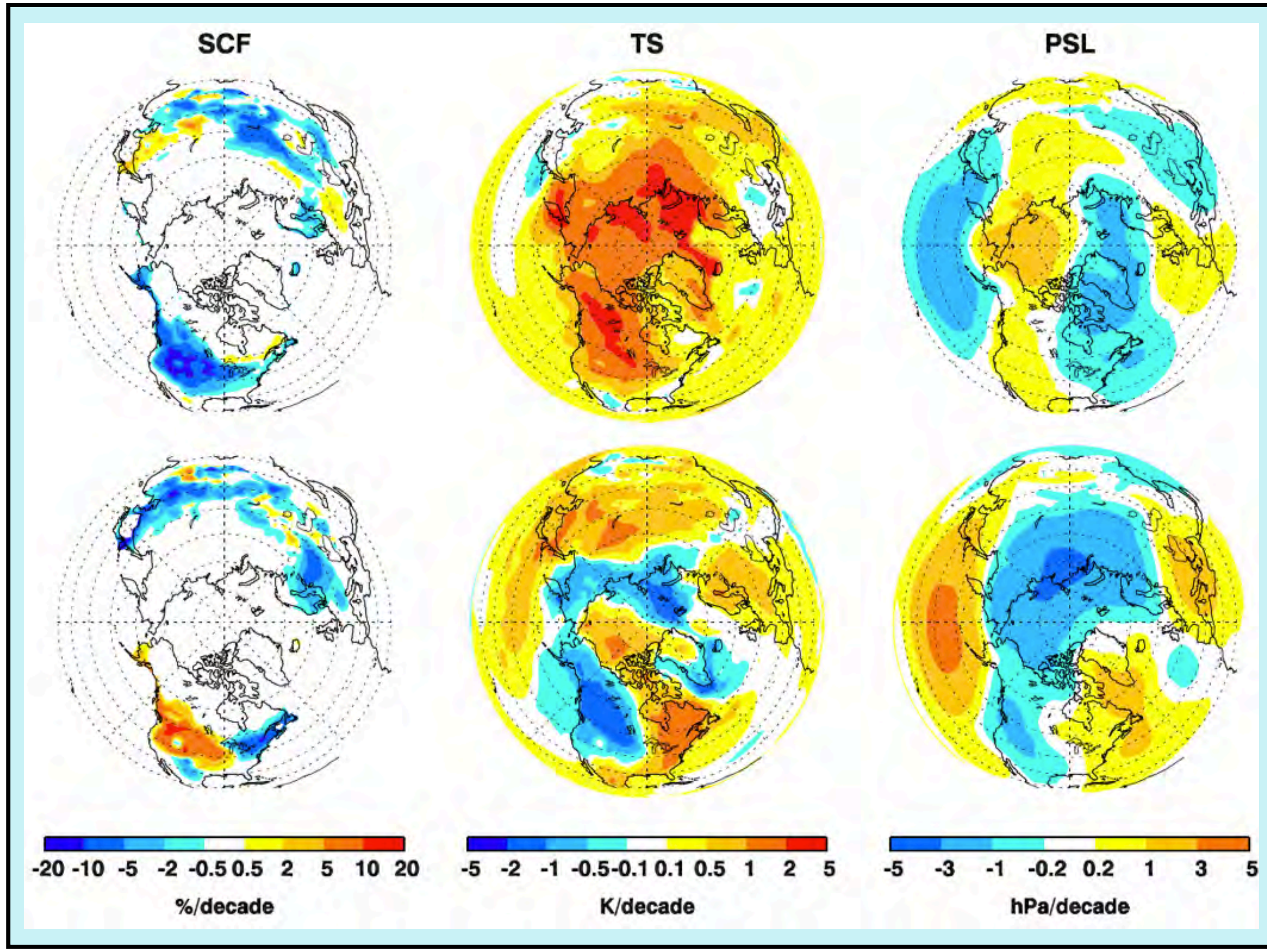


Patterns of Snow Trends

Trends in two CCSM4 realizations

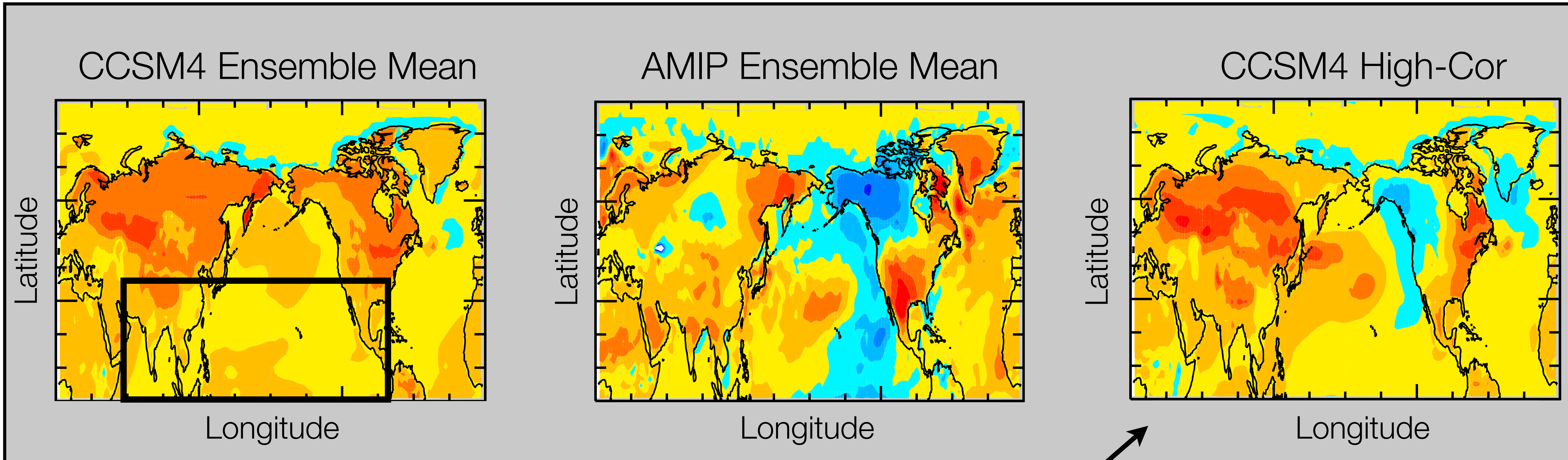
Obs SCF Trend JFM



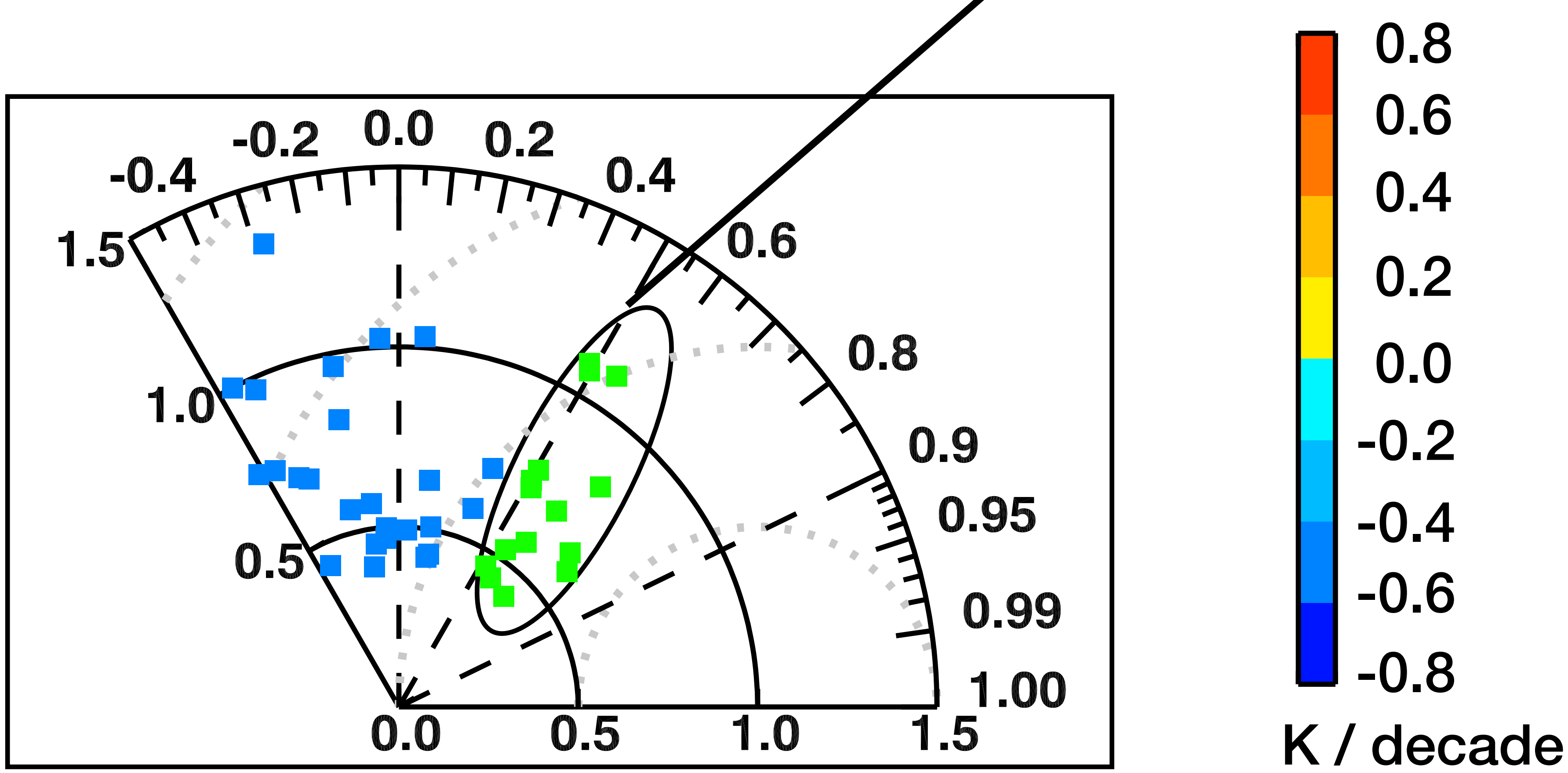


- Snow trend variability reflects thermal and circulation controls.
- We explore roles of SST and SLP predictors.

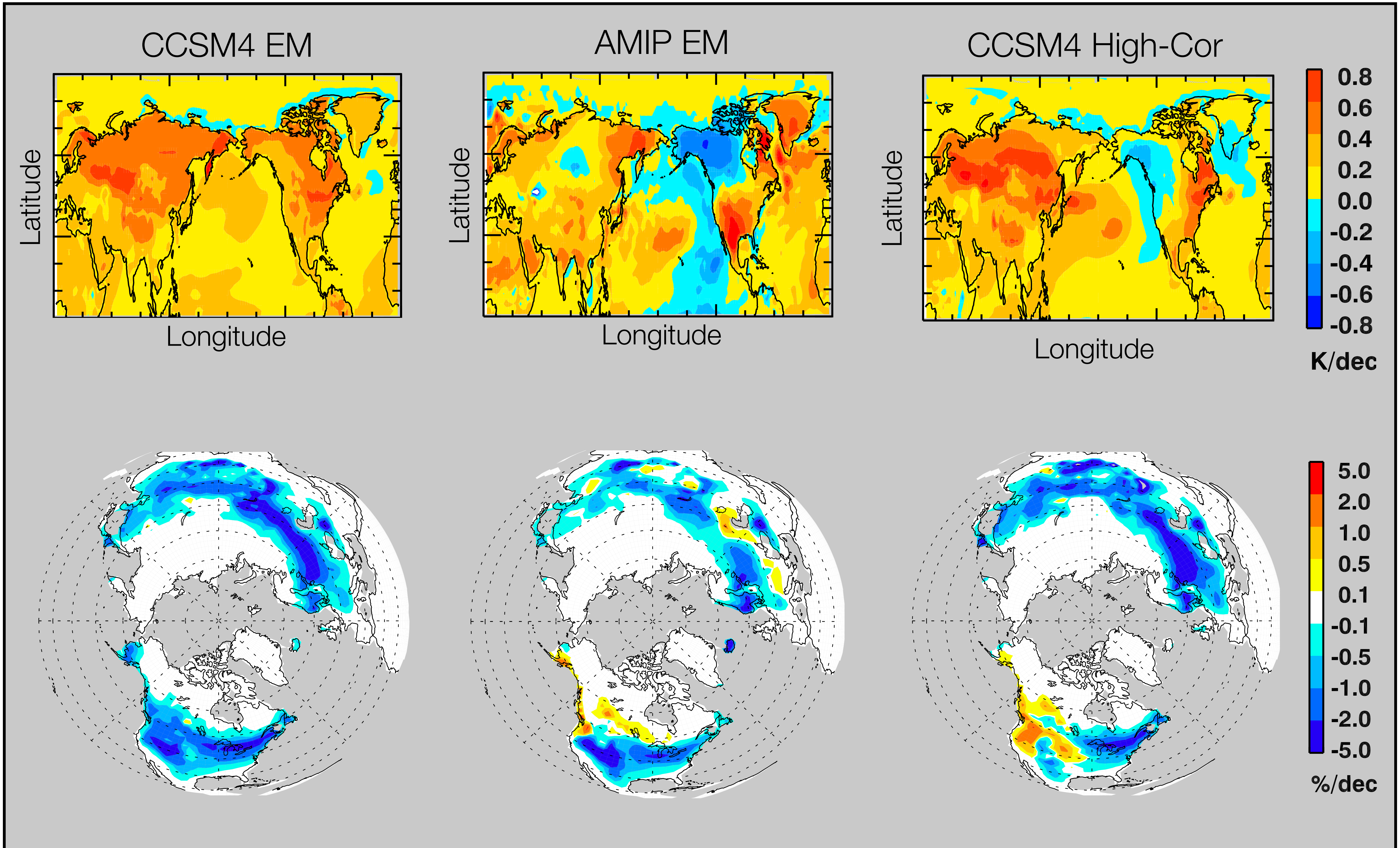
SST Influences



Select subset of CCSM4 ensemble whose trends in tropical/subtropical SST correlate with obs (see Shin and Sardeshmukh 2011).



SST Influences



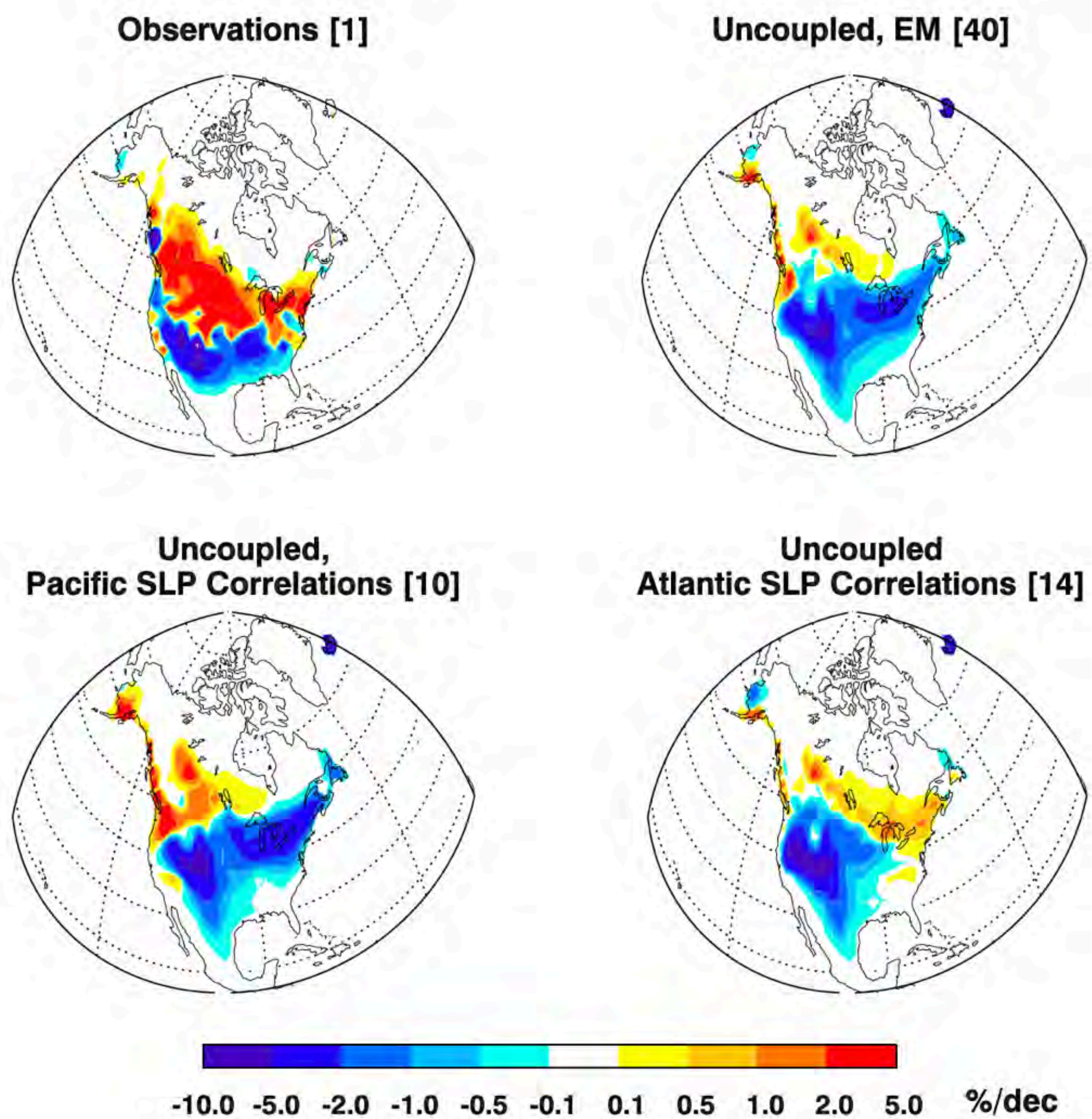
SLP Influences

Find AMIP simulations whose SLP trends match observed.

- Weaker Aleutian low goes with more snowcover over western North America
- Negative NAO trend goes with more snowcover over eastern North America

None of these regional trends in SLP or snow are very significant

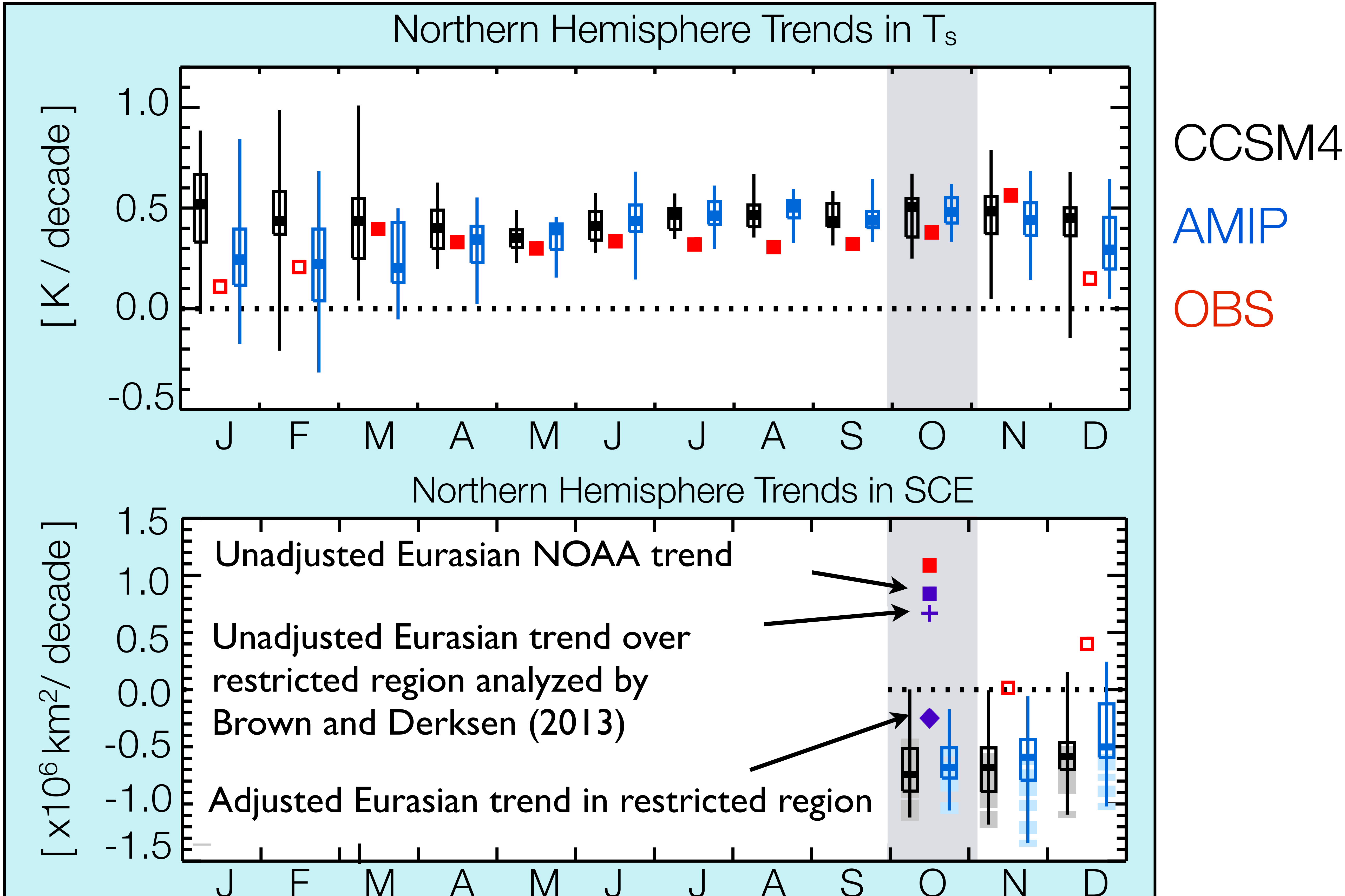
But this demonstrates coherence between SLP and snow signals.



Conclusions

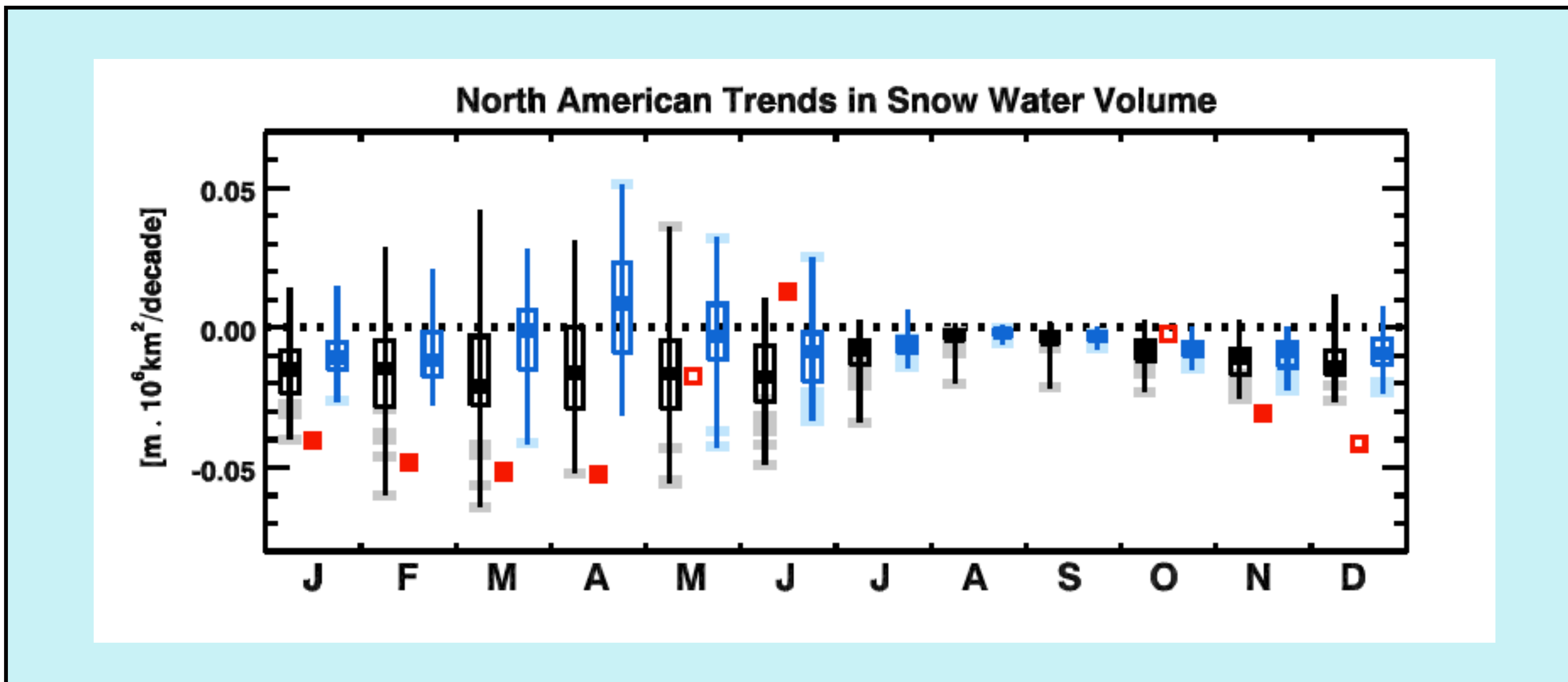
- CCSM4 2^0 large ensemble provides high quality snow simulation and range of plausible climate states to quantify range of trends and interpret obs.
- Trends falling outside range of natural variability:
  - Snow loss too strong in winter and too weak in spring.
  - Influence of tropical SST warming is reduced in AMIP ensemble.
- SST and SLP anomalies strongly influences North American trends.
- Inconsistency between model and obs in October could be related to observational uncertainty.
- Patterns of snow trends in North America show maritime influence:
  - Atmospheric circulation advecting SST anomalies.
  - The AMIP results suggest coherence between internally generated atmospheric circulation anomalies and snow trends.

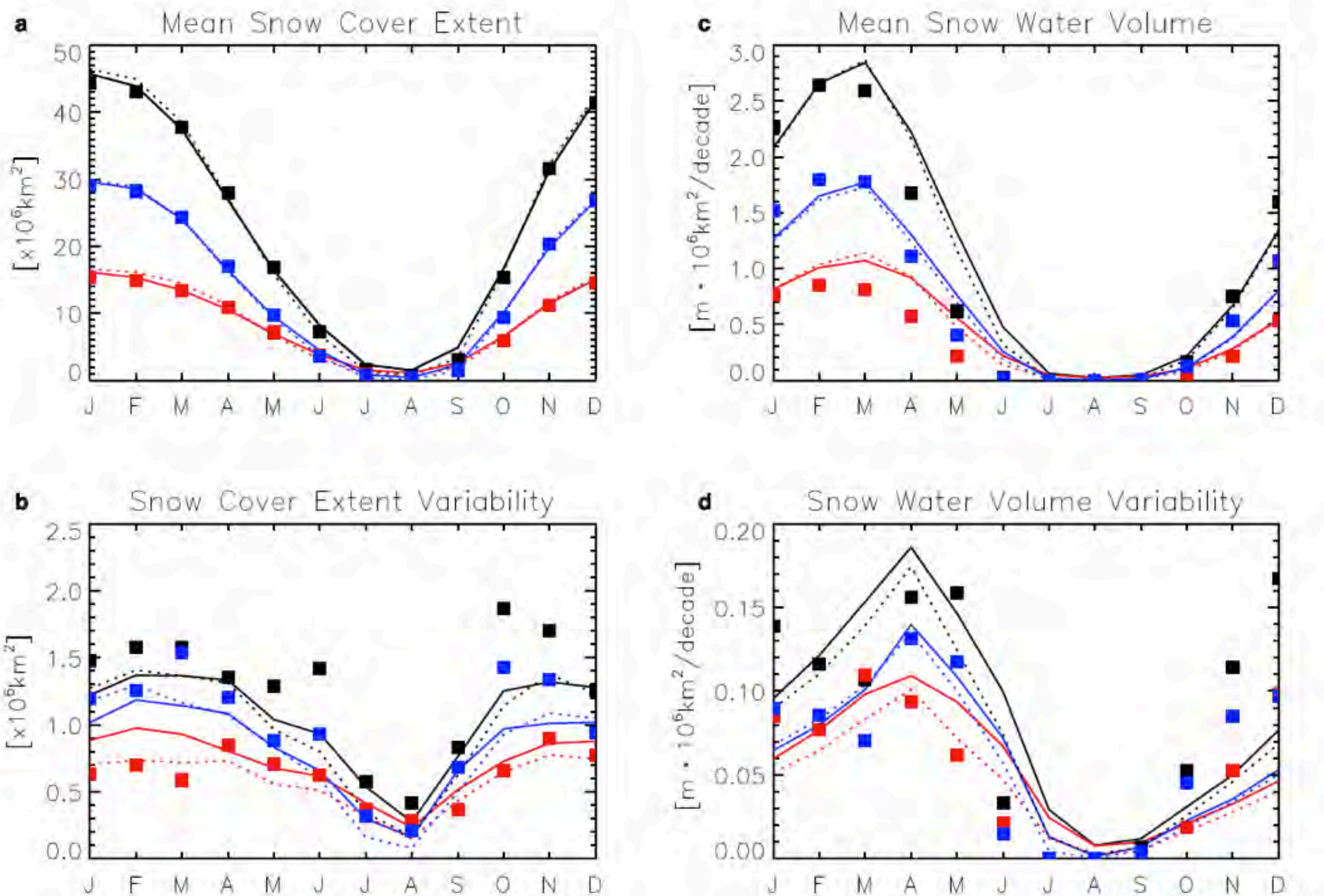
Northern Hemisphere SCE Trends



North American SWE

- GlobSnow JFMA SWV reductions are significant.
- These are found in a few of the CCSM4 realizations.
- But given excessive North American warming and SCE reduction, is CCSM4 doing this for the right reason?




a
Mean Snow Cover Extent
[x10^6km^2]
50
40
30
20
10
0
J F M A M J J A S O N D
c
Mean Snow Water Volume
[m · 10^6km^2/decade]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
J F M A M J J A S O N D
b
Snow Cover Extent Variability
[x10^6km^2]
2.5
2.0
1.5
1.0
0.5
0.0
J F M A M J J A S O N D
d
Snow Water Volume Variability
[m · 10^6km^2/decade]
0.20
0.15
0.10
0.05
0.00
J F M A M J J A S O N D

Conclusions

Model snow cover climatology and variability compare quite well with observations

Coupled model ensemble mean trends in snow cover fraction show weak seasonality and very strong, spatially coherent patterns.

AMIP experiment ensemble mean trends are more spatially varied during winter and spring seasons and seem to compare qualitatively better to observations

The trend magnitudes of individual realizations from either experiment compare better with observations

Models have overly strong winter time trends in snow cover extent but too weak spring time trends

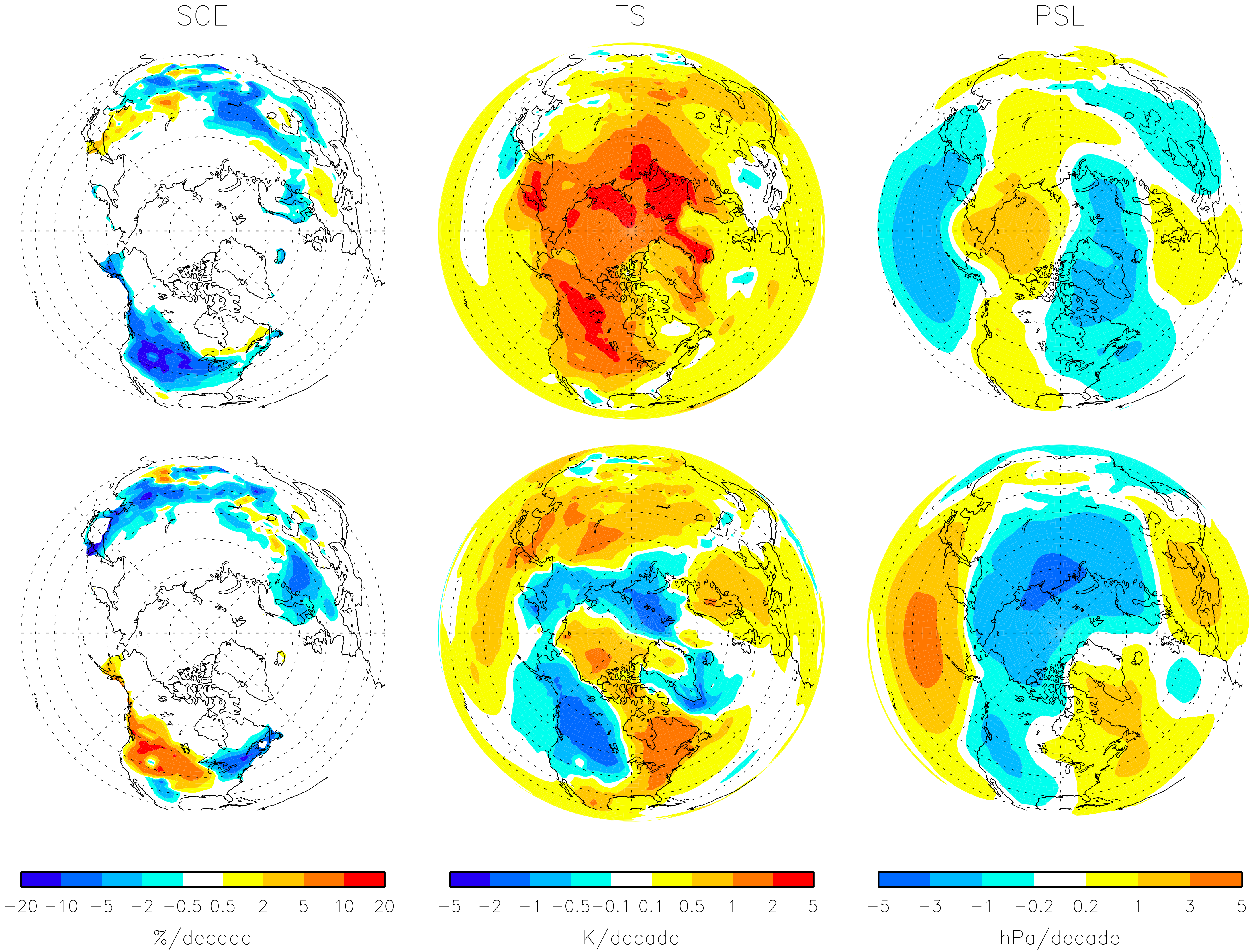
Conclusions

Differences between AMIP and coupled experiment snow cover trends stem from differences in wintertime land surface temperature trends

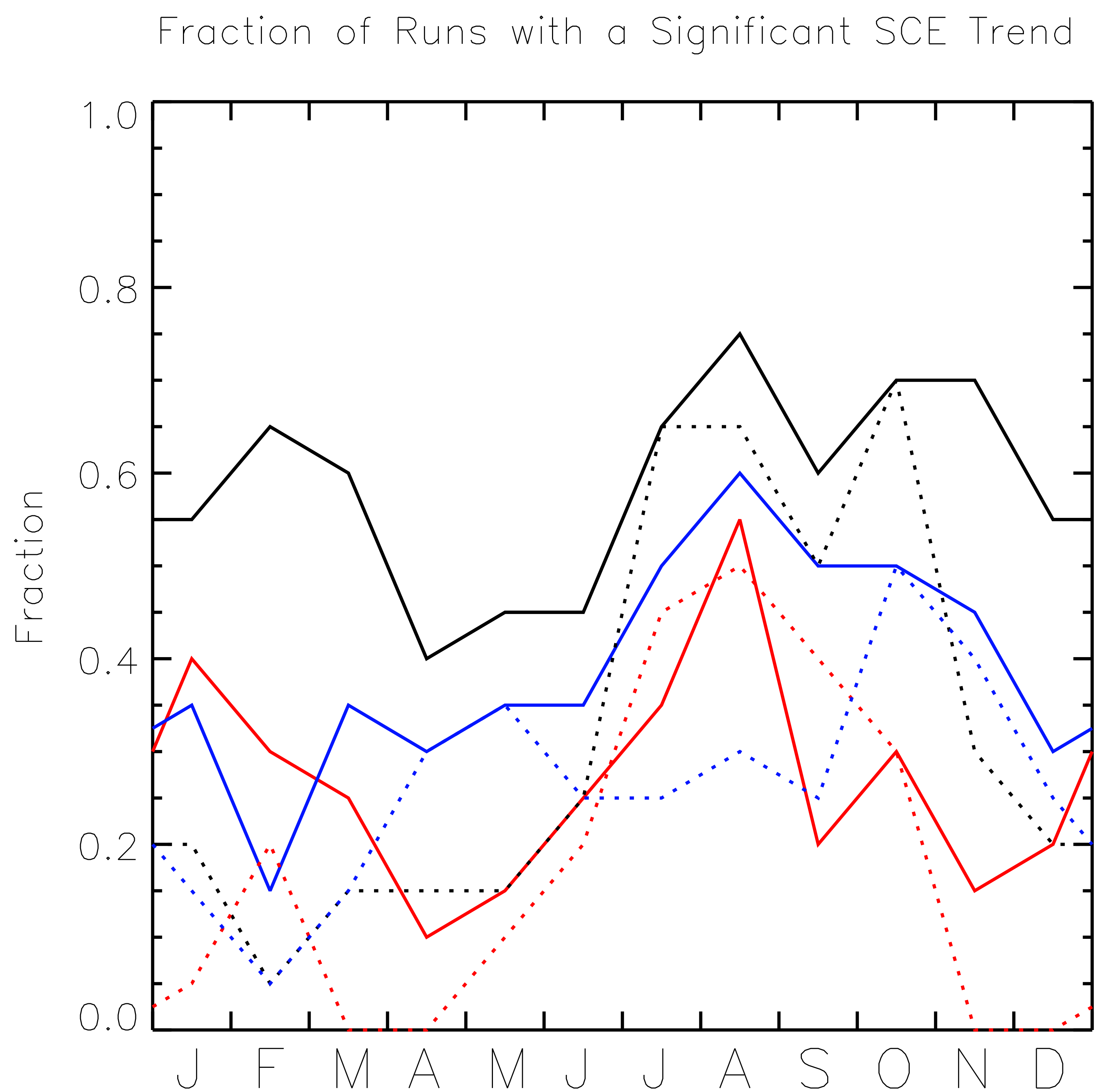
These land surface temperature trends are in turn related to the SST trends in the model

The coupled model shows too much tropical ocean warming in the ensemble mean

A subset of coupled model realizations runs show better correlation with historical SSTs. The snow cover fraction trends of these realizations show better agreement with the AMIP ensemble mean and the observations


SCE
TS
PSL
−20 −10 −5 −2 −0.5 0.5 2 5 10 20
%/decade
−5 −2 −1 −0.5 −0.1 0.1 0.5 1 2 5
K/decade
−5 −3 −1 −0.2 0.2 1 3 5
hPa/decade

Fraction of Significant Runs



Simulated Trends