Evaluating Snow-Albedo Feedback in Climate Models

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Outline

- Introduction
  Snow albedo feedback (SAF) and knock-on effects in CMIP3 simulations.

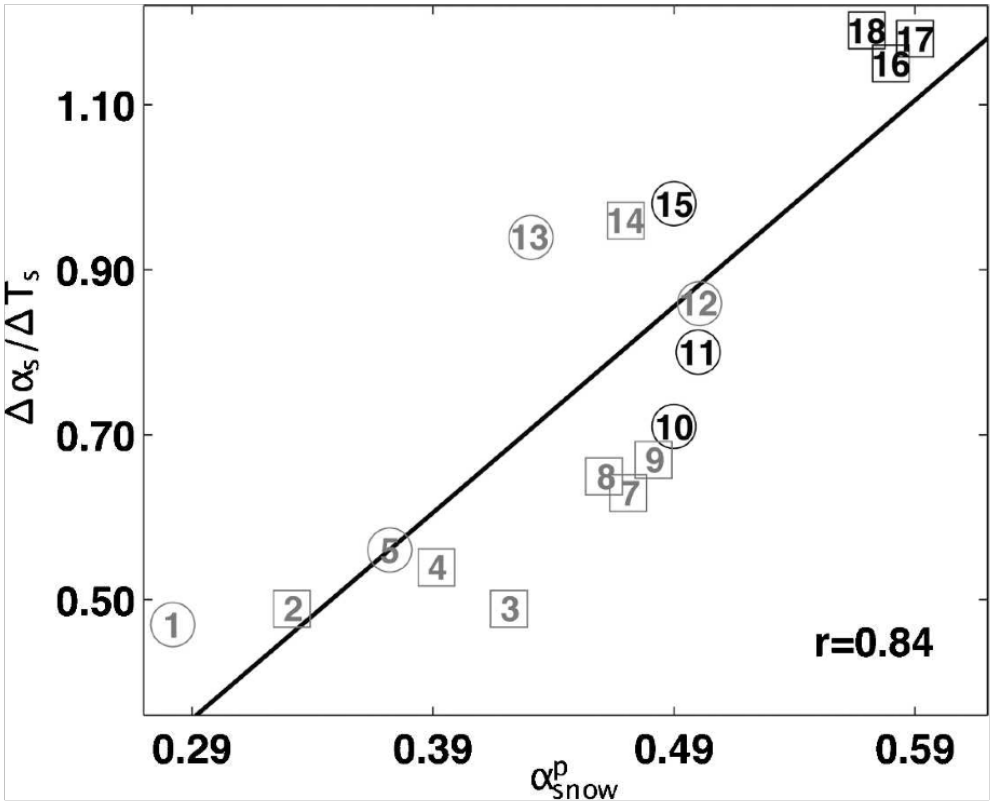
- Comparison with observations
  Method, Results, Focus on CCSM3

- Conclusion

Introduction

- Qu and Hall: CMIP3 models show large spread in snow-albedo feedback (SAF) in climate change.
- SAF in climate change is well correlated with SAF in seasonal cycle.
- SAF is well correlated with the effective snow albedo.

SAF vs. Snow Albedo for CMIP3 Models

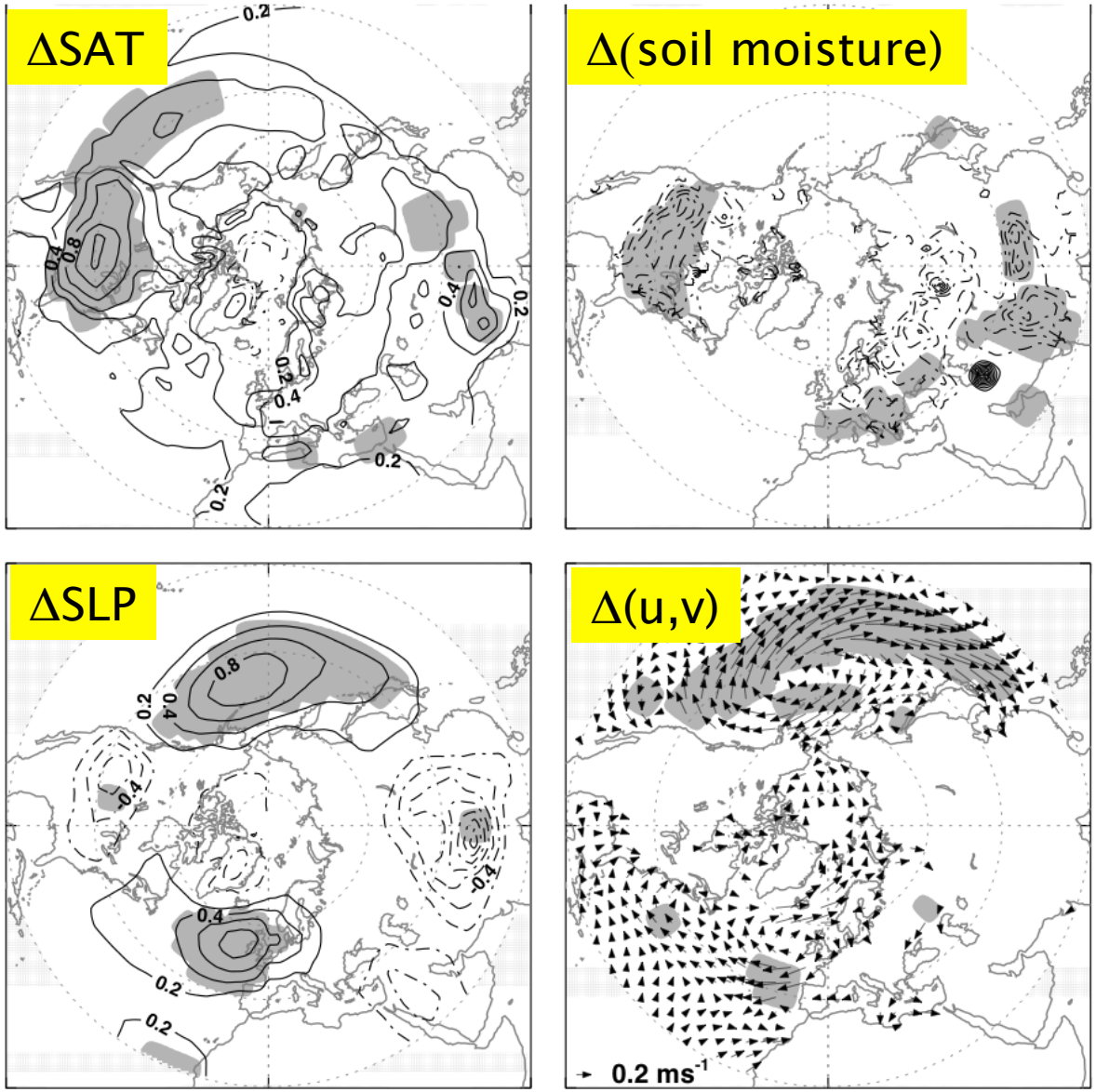


Qu and Hall 2007

Knock-on Effects of Snow Albedo Feedback (SAF)

Spread in SAF partially explains spread in model responses in climate change.

Models with larger SAF show:
- Greater summertime surface warming and drying (Qu, Hall, Neelin).
- Remote changes in summertime circulation (Fletcher et al. 2009).



Fletcher et al. [2009]

Aims of This Work

- SAF processes have important local and hemispheric consequences for climate.
- NRCan/CCSRS (Zhao and Fernandes 2009, Fernandes et al. 2009) have recently produced improved observational estimates of SAF related processes.
- Fletcher et al. (Toronto and NRCan) have been working on comparing these new estimates with CMIP3 models.
- We would like to better understand how SAF processes work in CCSM.

Contributors to SAF

- Suppose surface albedo α depends on snow cover S and temperature T, and snowcover depends on temperature:

$$\alpha = \alpha(S, T), \quad S = S(T)$$

- A change in temperature will change surface albedo:

$$T \rightarrow T + \delta T$$

$$\delta\alpha = \left.\frac{\partial\alpha}{\partial S}\right|_T \delta S + \left.\frac{\partial\alpha}{\partial T}\right|_S \delta T$$

$$\delta\alpha = \left(\left.\frac{\partial\alpha}{\partial S}\right|_T \frac{dS}{dT} + \left.\frac{\partial\alpha}{\partial T}\right|_S \right) \delta T$$

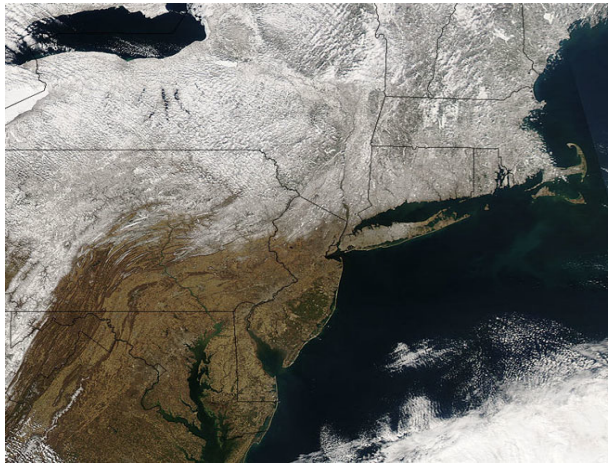
$$\frac{d\alpha}{dT} = \left.\frac{\partial\alpha}{\partial S}\right|_T \cdot \frac{dS}{dT} + \left.\frac{\partial\alpha}{\partial T}\right|_S$$

$$\frac{d\alpha}{dT} = \left.\frac{\partial \alpha}{\partial S}\right|_T \cdot \frac{dS}{dT} + \left.\frac{\partial \alpha}{\partial T}\right|_S$$

NET SNOWCOVER METAMORPHOSIS

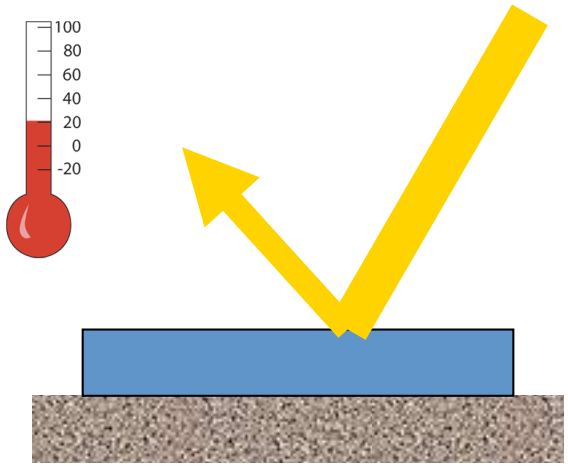
Snow Cover Changes

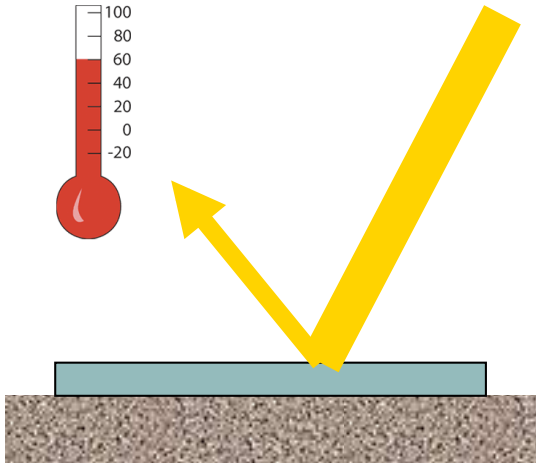
MODIS: Feb 6, 2005



MODIS: Mar 14, 2005

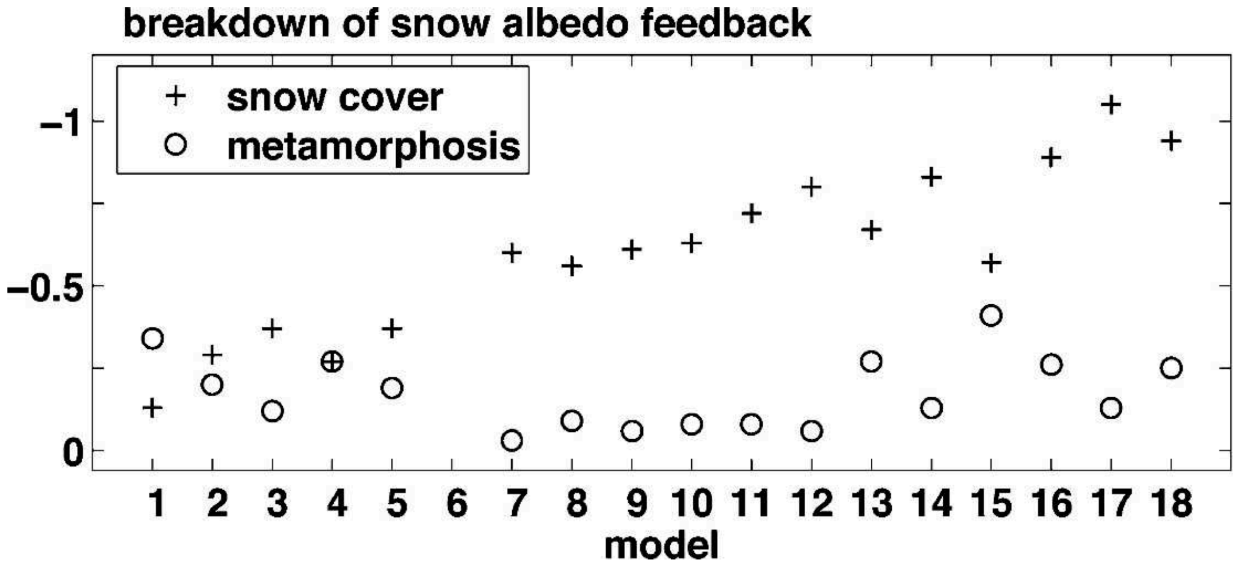
Metamorphosis





$$\frac{d\alpha}{dT} = \left.\frac{\partial\alpha}{\partial S}\right|_T \cdot \frac{dS}{dT} + \left.\frac{\partial\alpha}{\partial T}\right|_S$$

NET SNOWCOVER METAMORPHOSIS



Qu and Hall 2007

Qu and Hall calculate SNOWCOVER and METAMORPHOSIS in CMIP3 simulations' climate change.

They find SNOWCOVER explains most of the spread.

How can we compare to obs?

Method: Obs-Model Comparison

- Observational daily data:
  - T from ERA40
  - α from AVHRR (Wang and Key 2005)
  - S from NRCan/CCRS analysis (Zhao and Fernandes 2009)
- Simulation: CMIP3 20c3m runs

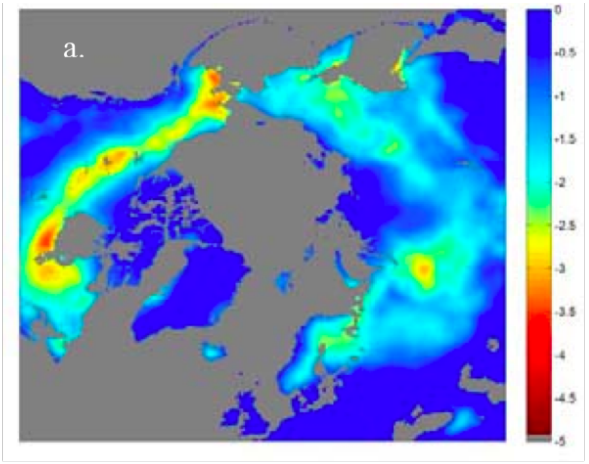
$$\frac{d\alpha}{dT} = \left.\frac{\partial\alpha}{\partial S}\right|_T \cdot \frac{dS}{dT} + \left.\frac{\partial\alpha}{\partial T}\right|_S$$

NET SNOWCOVER METAMORPHOSIS

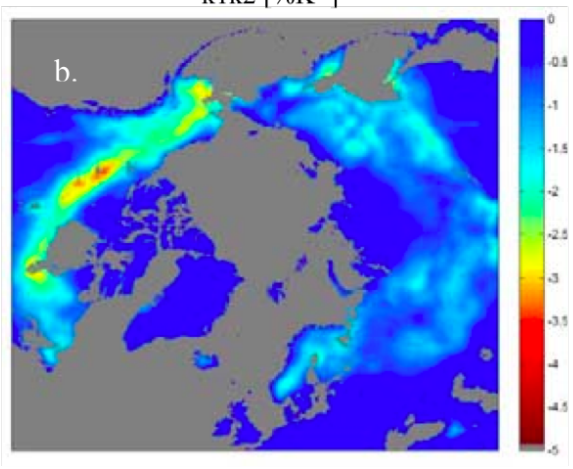
- NET and SNOWCOVER calculated from seasonal cycle.
- METAMORPHOSIS hard to infer from obs so use

METAMORPHOSIS = NET – SNOWCOVER

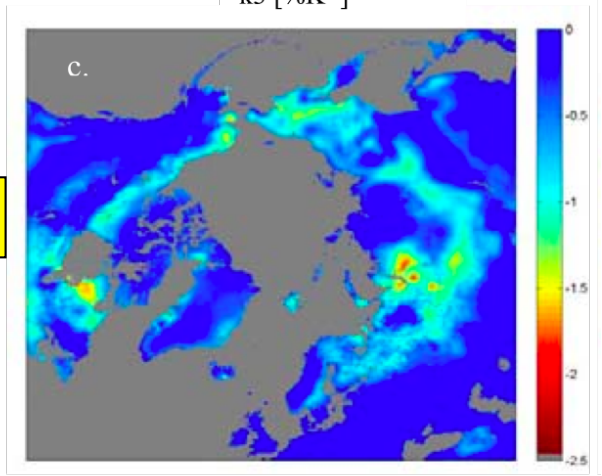
NET



SNOWCOVER

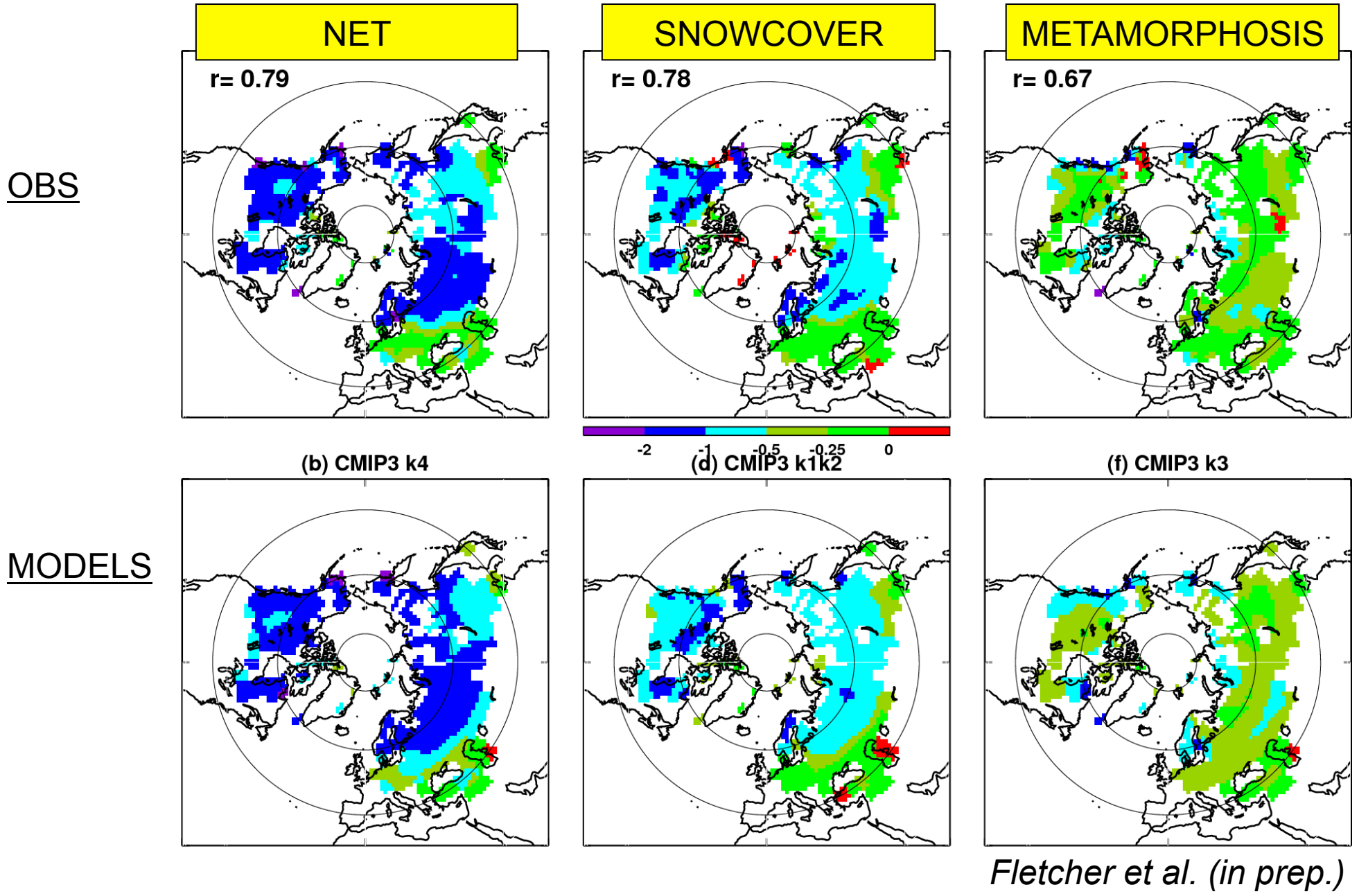


METAMORPHOSIS



Fernandes et al. 2009

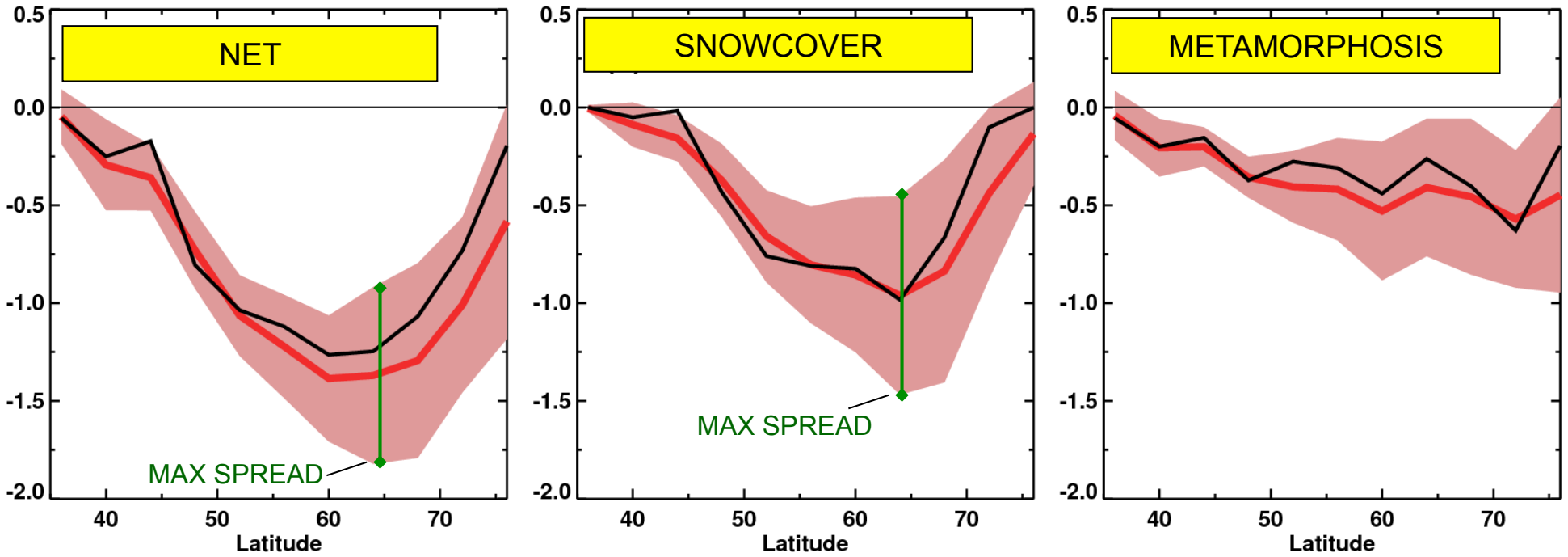
- Left: Observational estimate from 1982-1999 satellite record (Fernandes et al. 2009).
- Fletcher et al. use a different approach in model-obs comparison.



Fletcher et al. (in prep.)

On *average*, the models do well, even at a regional scale.

Zonal Mean SAF Parameters



Fletcher et al. (in prep.)

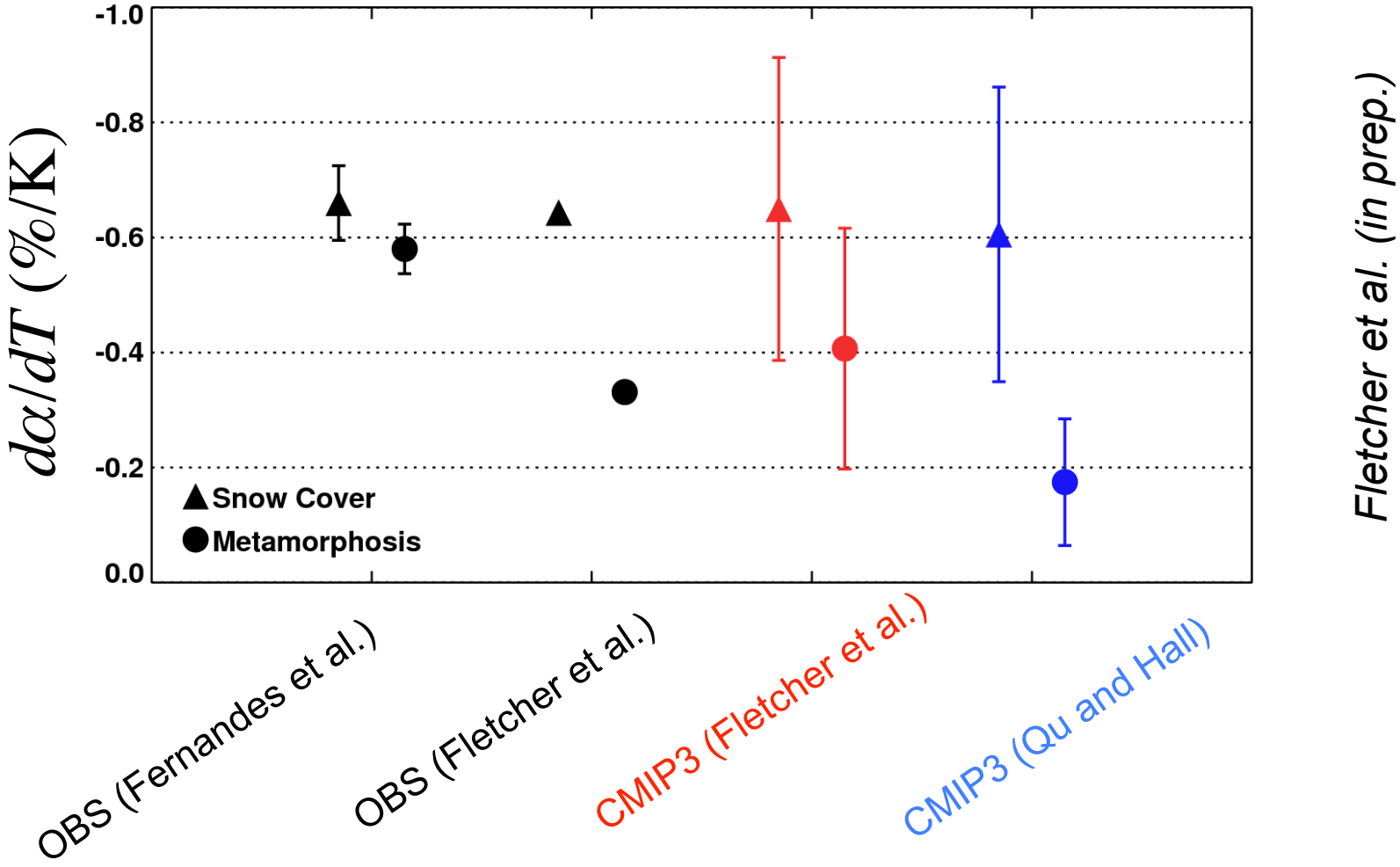
OBS

17-model mean

Model std dev

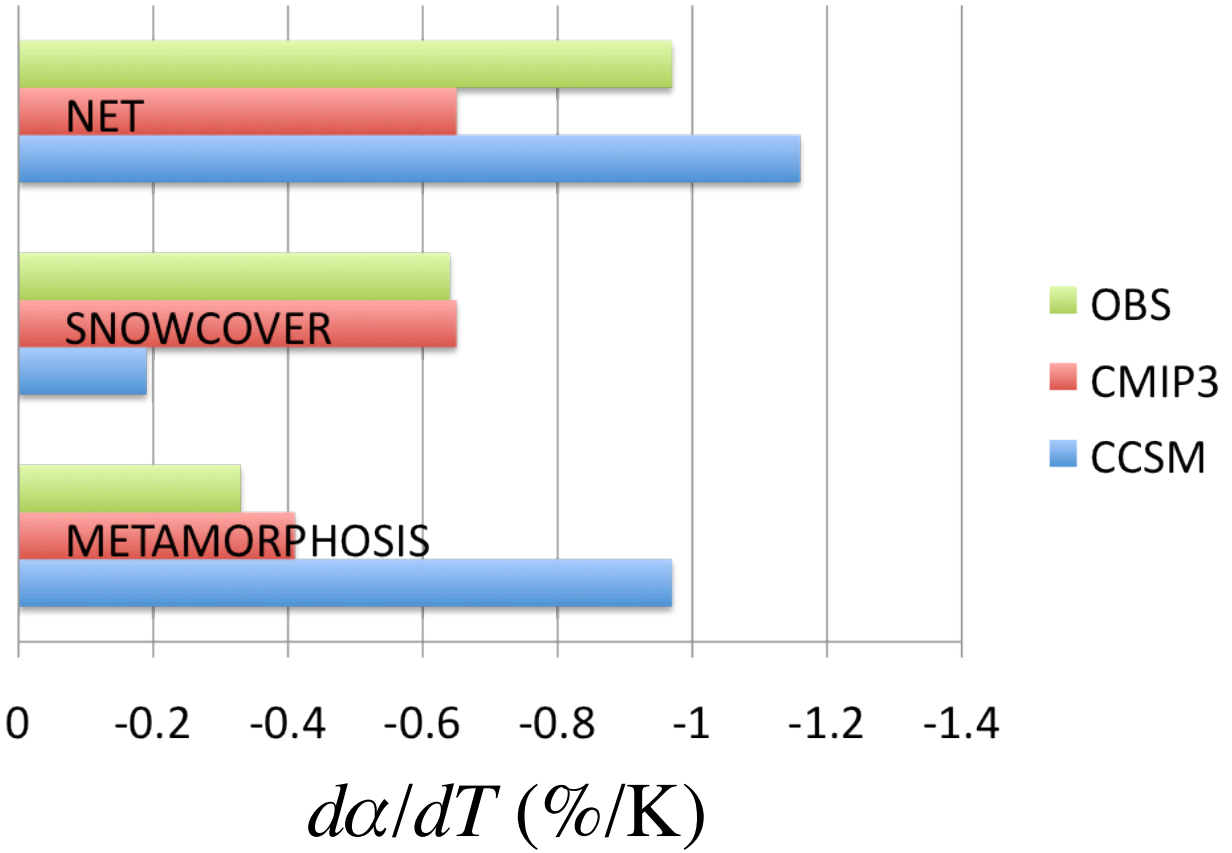
While the mean bias in the models is about 20%, the spread is about twice this.
These figures do not include insolation weighting, which would reduce bias and spread.

Insolation Weighted NH SAF Parameters



- METAMORPHOSIS effect is method dependent.
- METAMORPHOSIS effect is more important in Fletcher et al. than in Qu and Hall, for both mean and spread.

Focus on CCSM3



- For Fletcher et al. method, CCSM3 has the smallest SNOWCOVER effect of the CMIP3 models (seasonal retreat of snow is small).
- But CCSM3 has an above average NET effect.
- Therefore CCSM3's diagnosed METAMORPHOSIS effect is the largest.
- For Qu and Hall method, CCSM3 is not such an outlier.

Conclusion

- SAF has important local and remote effects in climate change.
- Constraining model representations of SAF could help reduce the uncertainty in simulated climate responses.
- New observations make this possible, and we are now trying to determine an optimal observational-model comparison, and hopefully have this feedback into model development.
- For some reason, CCSM3 seems to have a large snow METAMORPHOSIS effect and a small SNOWCOVER effect. Why?
- *Note added this morning*: CLM4 albedo seasonal cycle greatly amplified, so this might change a lot in CCSM4.