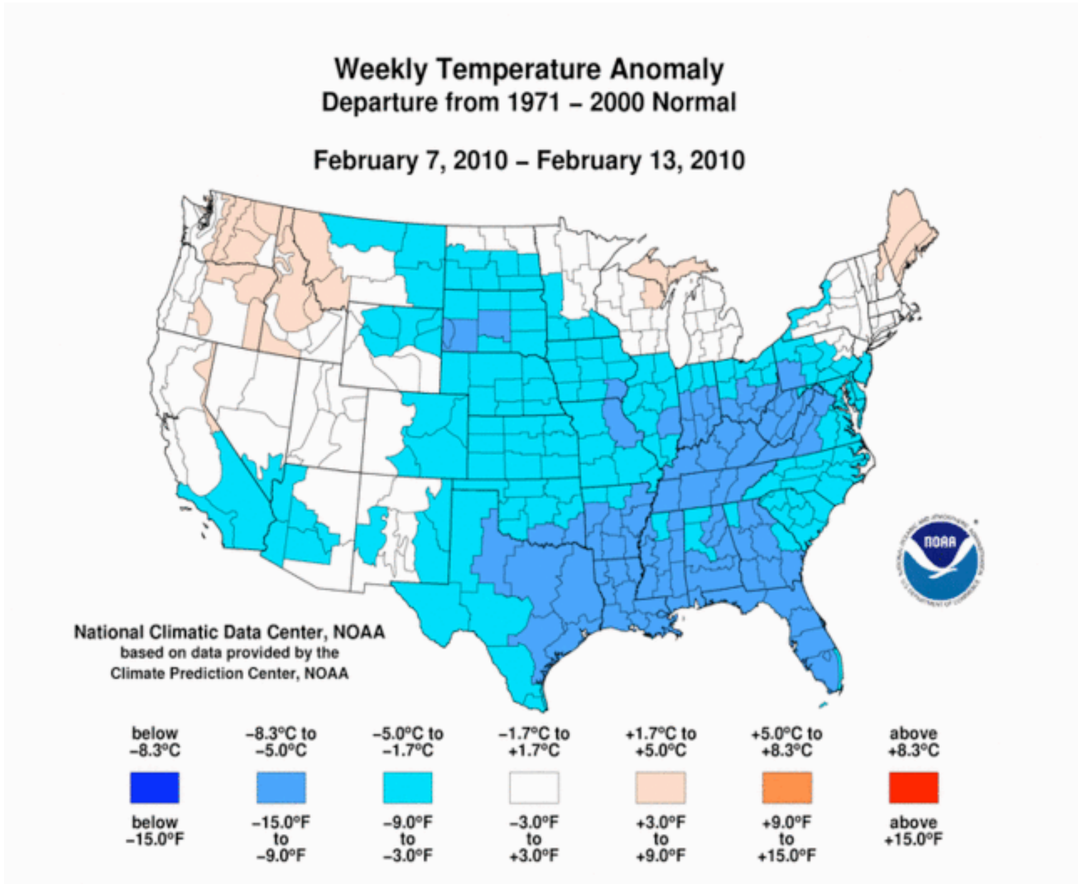
SNOW-ATMOSPHERE COUPLING STRENGTH



Snowmageddon 2010 Feb 6

How much temperature change is due to the snow boundary forcing?

Snow cover in the climate system

- Snow albedo effect (Direct impact)
  - Highest albedo (0.9-0.6)
  - High emissivity (0.98)
  - Low thermal conductivity (insulates and decouples A-L)
  - Latent heat sink $L_{subl}=2.8337 \times 10^6 J/kg$

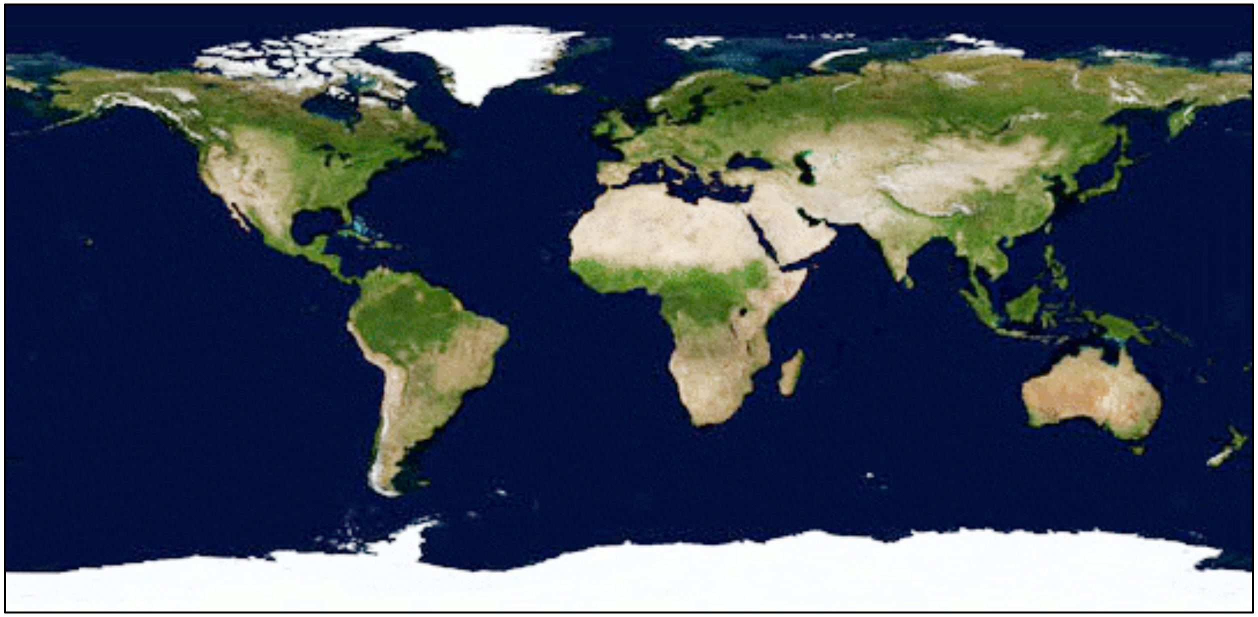
    $L_{melt}= 3.337 \times 10^5 J/kg$
- Snow hydrological effect

  (Indirect impact)
  - Snowmelt -> soil moisture anomalies

Snow anomalies may be as an important a predictability source as ENSO and soil moisture.

Global snow evolutions

From NASA MODIS

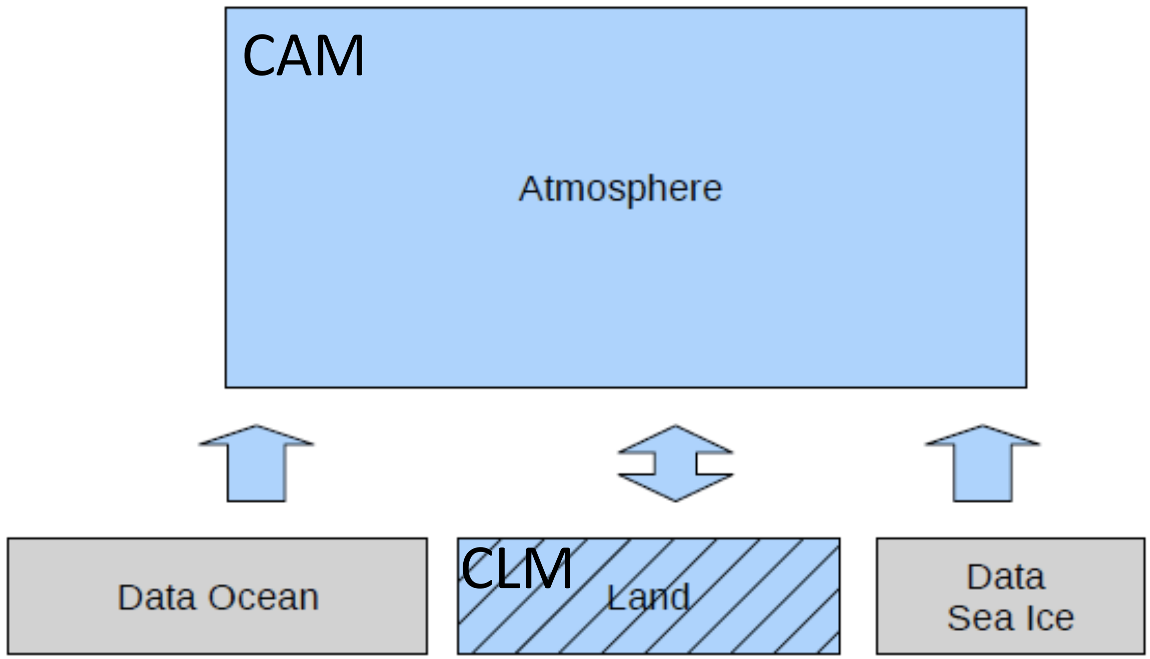


Large inter-annual variability in extent, duration and retreat

Key scientific questions:

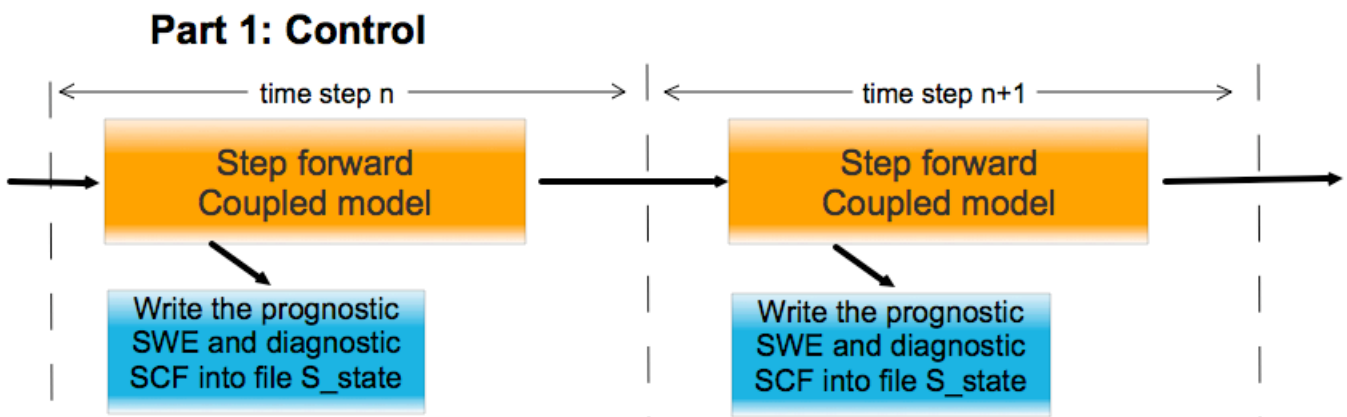
- How strong are snow-atmosphere coupled (the degree to which the snow affects atmosphere and subsequent interaction)?
- Where and when is the strongest coupling?
- By what mechanism? snow albedo and hydrological effects?
- How does snow contribute to climate predictability?

Model configuration



- Subset of NCAR CCSM model (CAM V 3.6.48 + CLM 3.5)
- Finite Volume dynamical core (mass conservation, sharp gradient etc.)
- 1.9°x2.5° resolution, 26 levels hybrid coordinate in the vertical

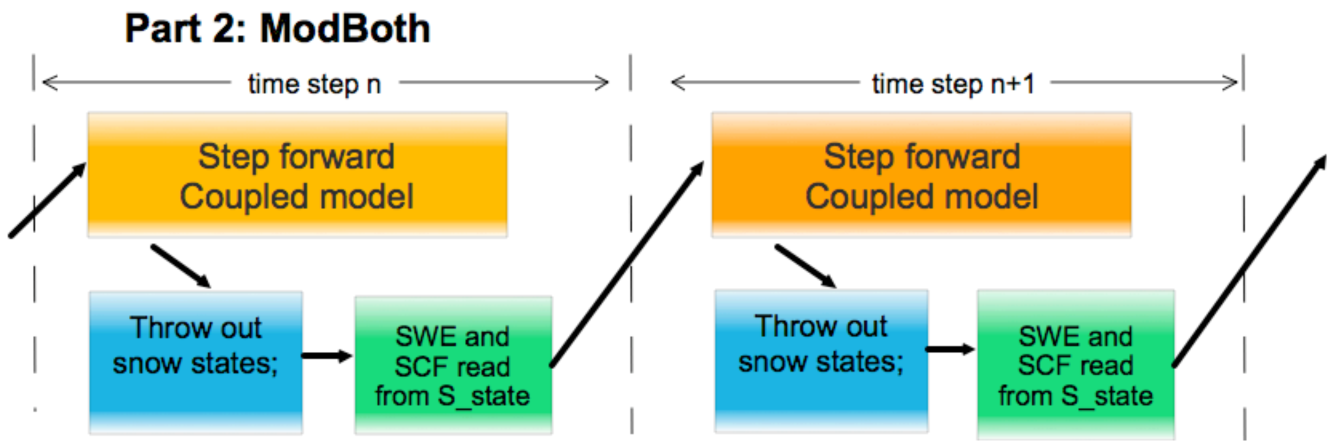
Snow-Atmosphere Coupling Experiment (SACE)



Detail:

1. 10 Ensemble member from March 1st to August 31th
2. Initialization: restart file March 1st 2000-2009 (AMIP runs)
3. Ocean: prescribed SST climatological annual cycle (removing ENSO impact)
4. Snow is fully coupled with atmosphere without any constraint
5. Reflects potential broad range of snow-atmosphere states
6. Recorded the SWE and SCF in each time step

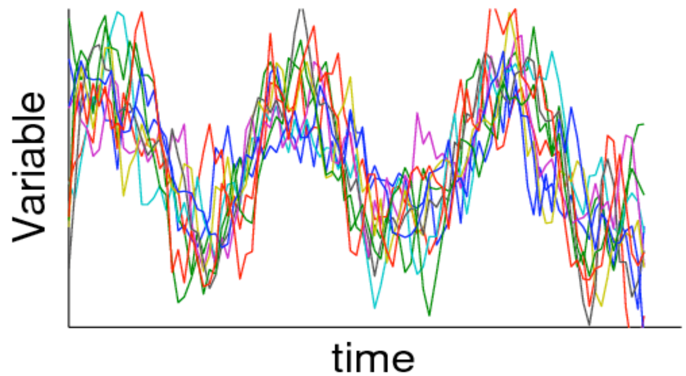
SACE: ideal model snow

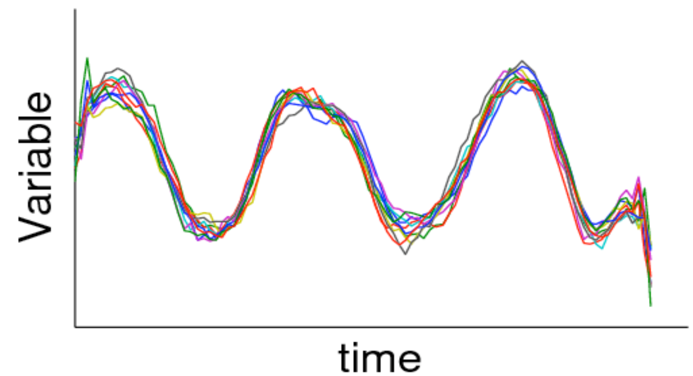


Detail:

1. Same as the **Control,** except soil moisture initialization (unified to same climatological value)
2. Prescribed to same SWE and SCF: one random selected from **Control S_state**
3. Eliminate snow-atmosphere interaction
4. Variability due to atmosphere internal chaos only

Key diagnostics & analysis





- **Ω** (similarity among m ensemble members, Koster et al. 2006 J. Hydromet.)

$$\Omega = \frac{m\sigma_b^2 - \sigma^2}{(m-1)\sigma^2}$$

$0 < \Omega < 1$

Ω behaves like correlation R^2 in linear processes

Simulations respond similarly to boundary forcing (high Ω) **-** Simulations have no coherent response (low Ω) **=** Approximate the fraction of variance explained by boundary forcing

Snow-atmosphere coupling strength : Ω(**ModBoth**)-Ω(**Control**)

RealSCF:

1. As in **ModBoth,** including same specified SWE from one random S_state
2. Except prescribed to 2000-2009 realistic SCF from MODIS
3. Eliminate the uncertainty associated with the SCF parameterization
4. Precisely represents snow albedo effect

Ω(**ModBoth**)-Ω(**RealSCF**): only due to albedo effect

RealSWE:

1. As in **ModBoth,** including the same specified SCF from S_state
2. Except prescribed to 2000-2009 realistic SWE from GLDAS
3. Eliminate any error with snow modeling of SWE
4. Precisely represent available snowmelt for hydrological effect

Ω(**ModBoth**)-Ω(**RealSWE**): only due to hydrological effect

RealBoth:

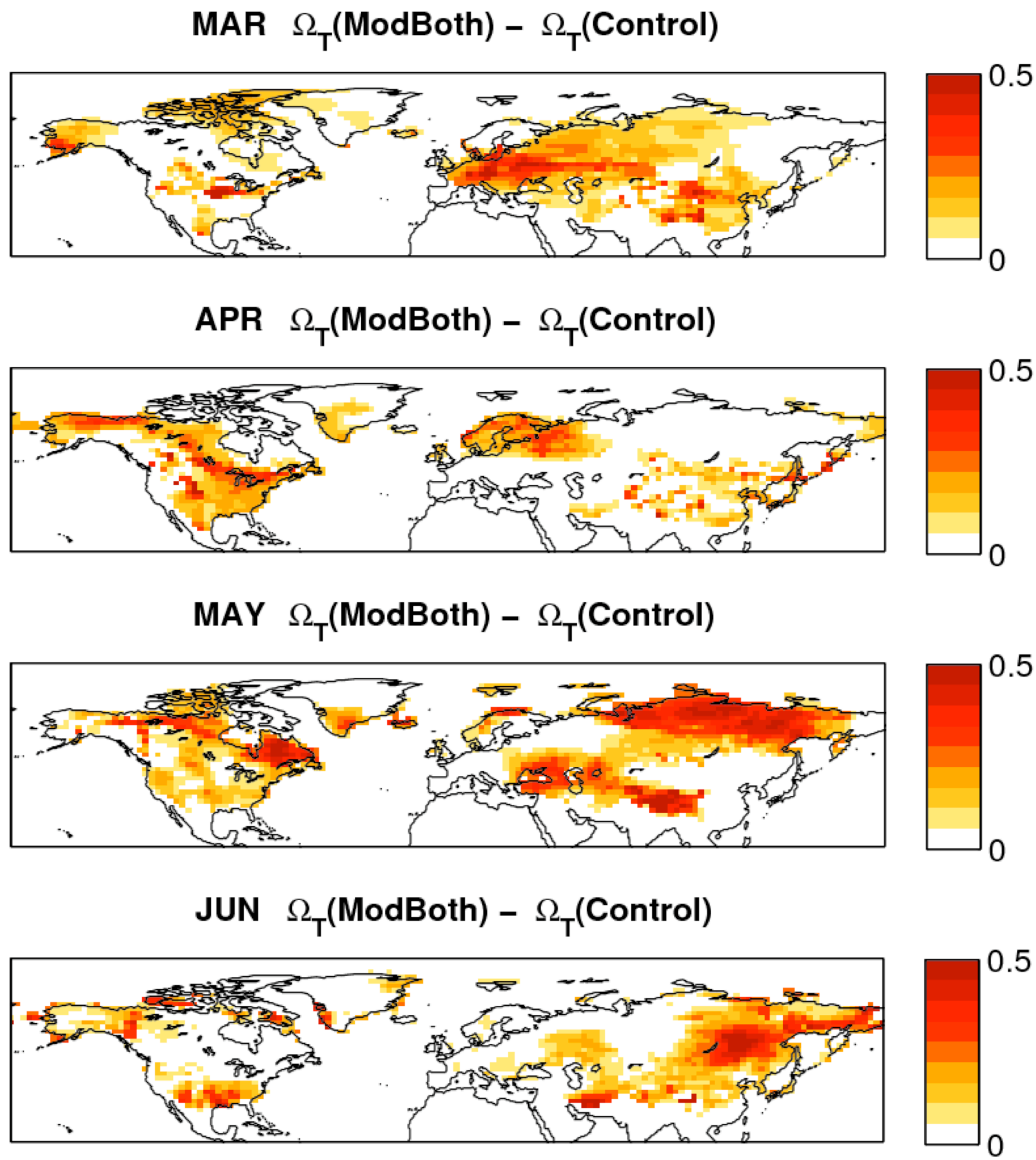
1. Prescribed both MODIS SCF and GLDAS SWE
2. Precisely represents both realistic snow forcings (albedo and hydrological effect)

Ω(**ModBoth**)-Ω(**RealBoth**): realistic snow forcings

Xu & Dirmeyer 2011 GRL; Xu & Dirmeyer 2011 J. hydromet. (submitted)

CCSM's inherent temperature coupling-strength (model simulated snow)

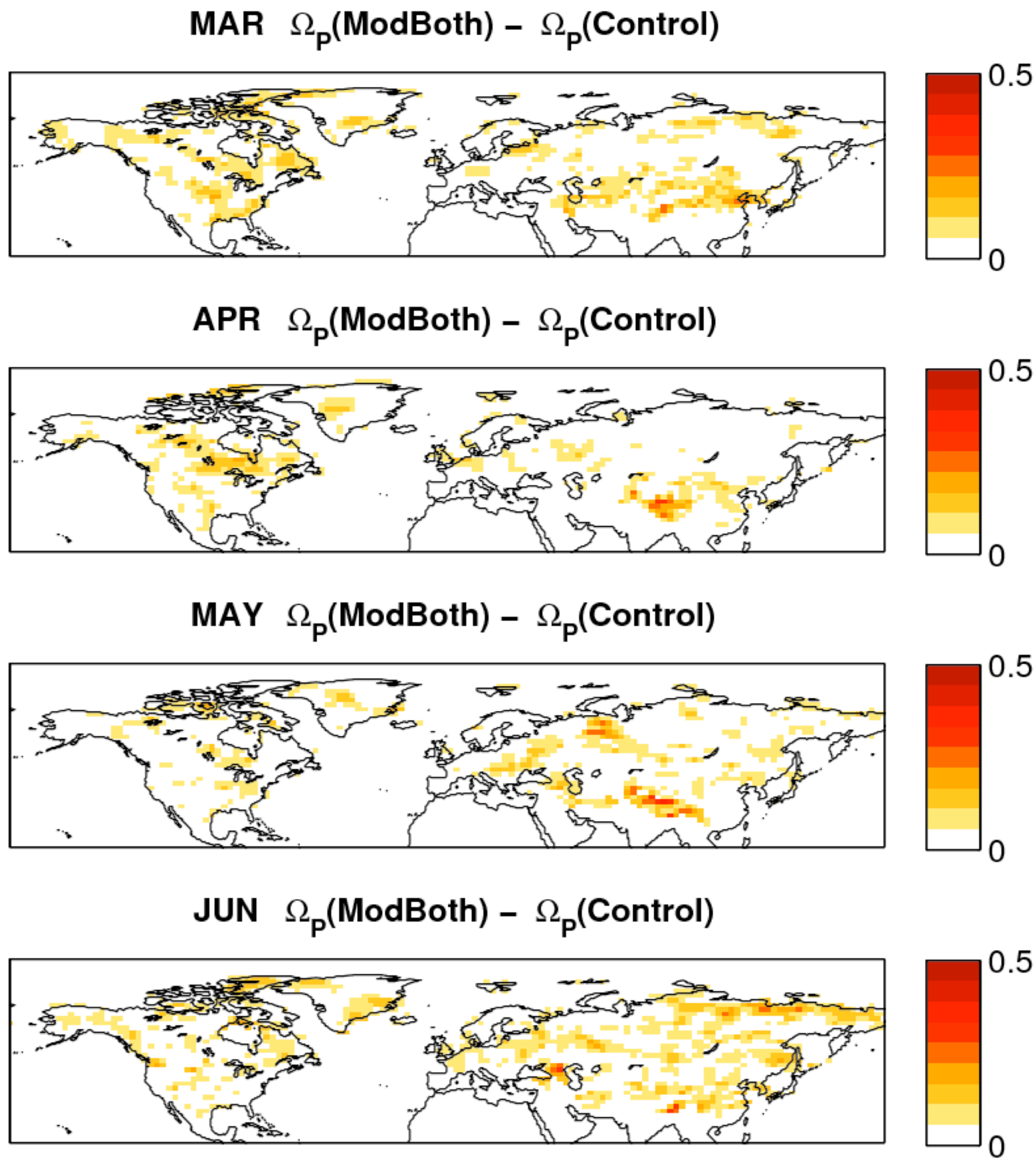
- Eastern Europe, Tibetan Plateau and mid-latitudes of North America
- Weakens in April
- Moves north toward Pole
- Delayed response after snowmelt
- Maximum 0.4, explains 40% synoptic scale temperature variability[1]



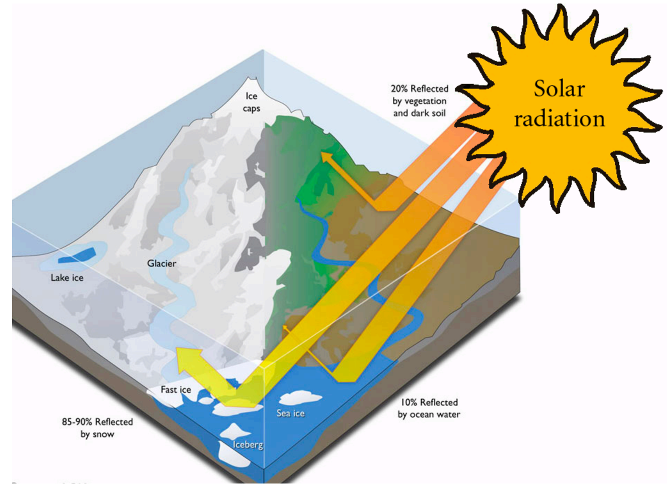
1. Koster et al. 2006 J. Hydromet

Precipitation coupling-strength (model simulated snow)

- Weaker than Temp
- More "Spotty"
- Increases after May



Snow Albedo Effect (SAE)



Ground albedo:

$$\alpha = (1 - f_s) * \alpha_{bg} + f_s \alpha_s$$

Assume: α_s/α_{bg} not change with latitude

$$\frac{d\alpha}{dy} = \frac{df_s}{dy}(\alpha_s - \alpha_{bg})$$

Net solar energy input:

$$E = (1 - \alpha) SW$$

$$\frac{dE}{dy} = -\frac{d\alpha}{dy} SW + (1 - \alpha)\frac{dSW}{dy}$$

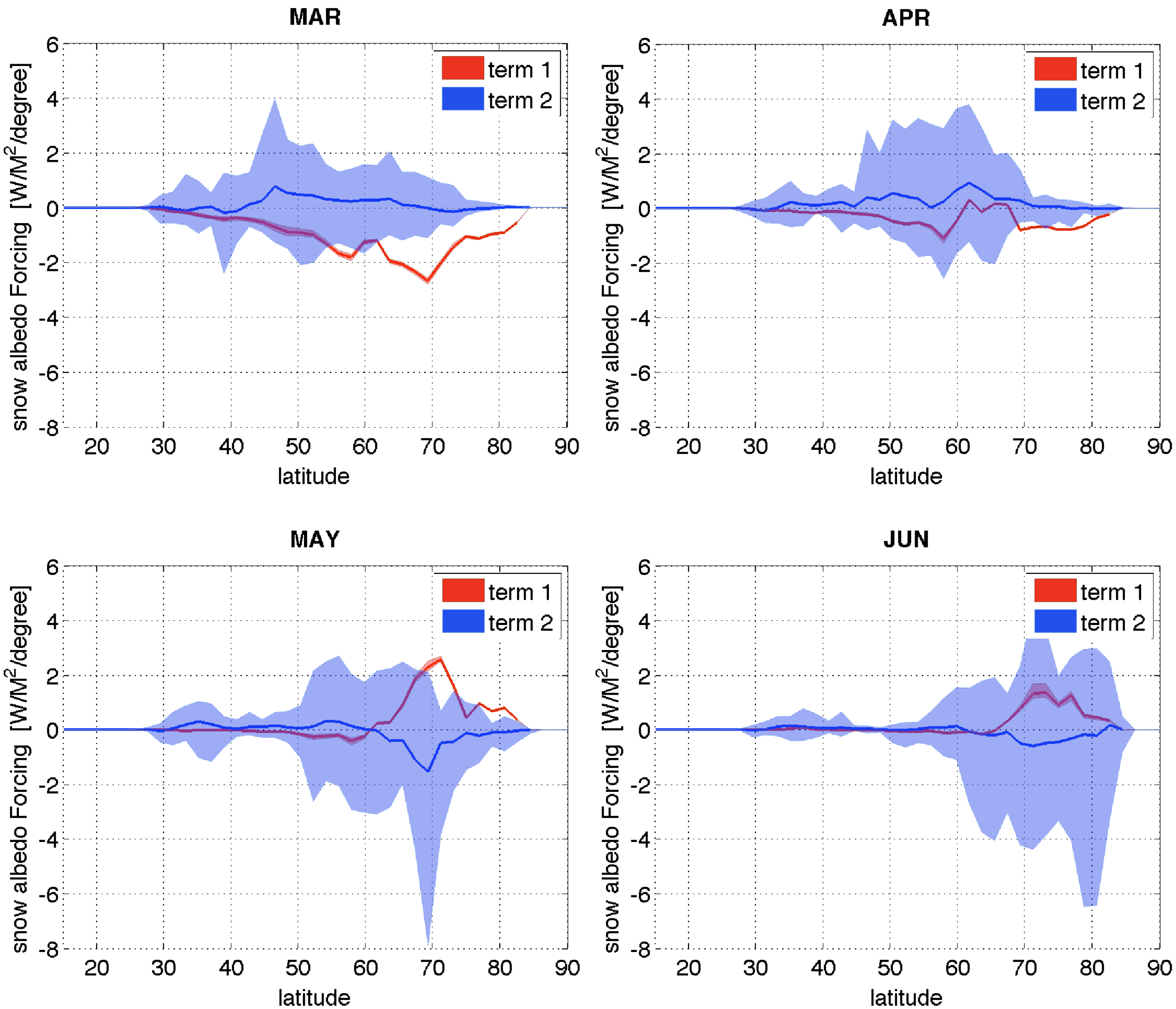
$$\frac{dE}{dy} = (1 - \alpha_{bg})\frac{dSW}{dy} - f_s(\alpha_s - \alpha_{bg})\frac{dSW}{dy} - \frac{df_s}{dy}(\alpha_s - \alpha_{bg}) SW$$

Without albedo effect

Term1: SCF

Term2: gradient of SCF

Zonal mean and inter-annual variability of SAE (SCF term and SCF gradient term)



Term1: SCF term **Term2: SCF gradient term**

Data:

- MODIS SCF
- Incident SW (model)

Unit: W/m^2/degree

Line: 10 yrs mean

Shaded: range (inter-annual variability)

SCF term: large in mean, small inter-annual variability

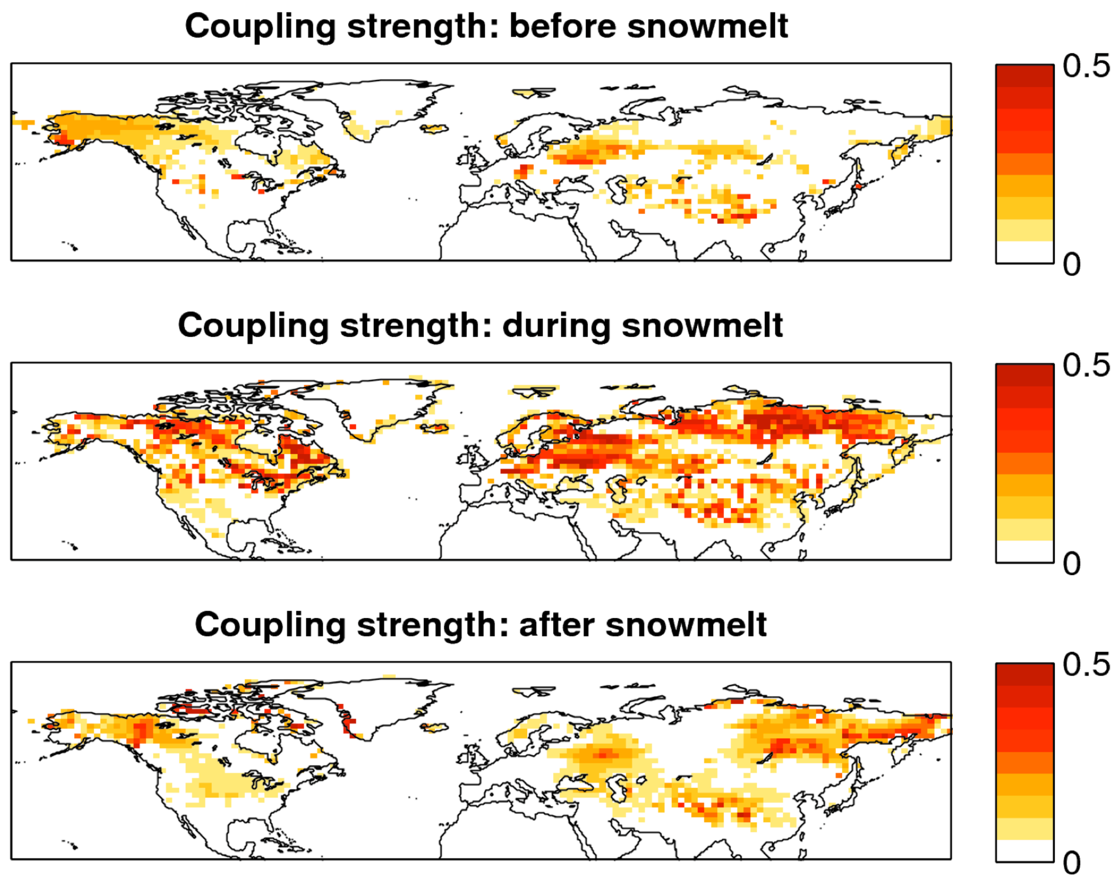
SCF gradient term: small in mean, huge inter-annual variability

SCF gradient term contributes the most of inter-annual variability of SAE (more important than SCF)

Albedo effect

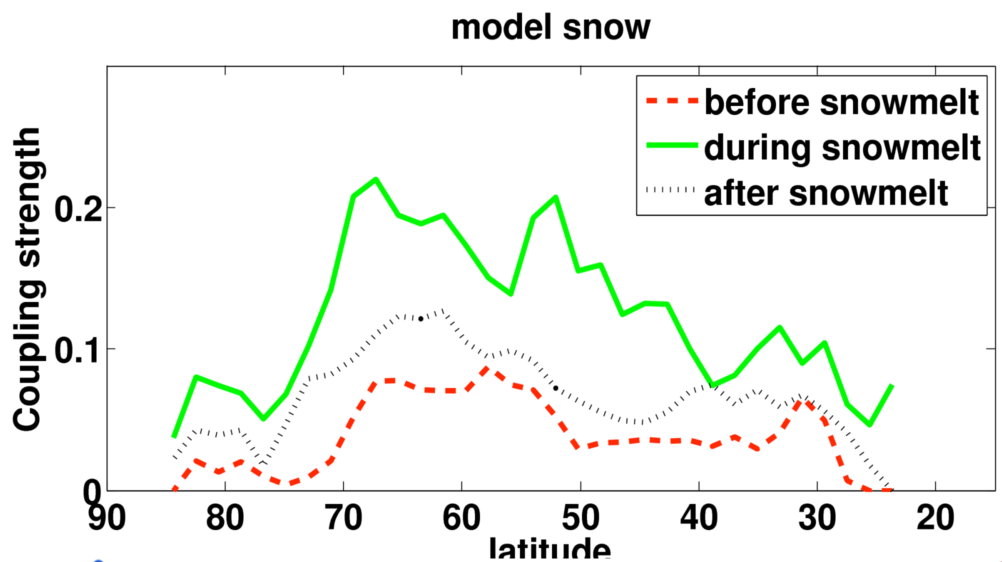
Mixed

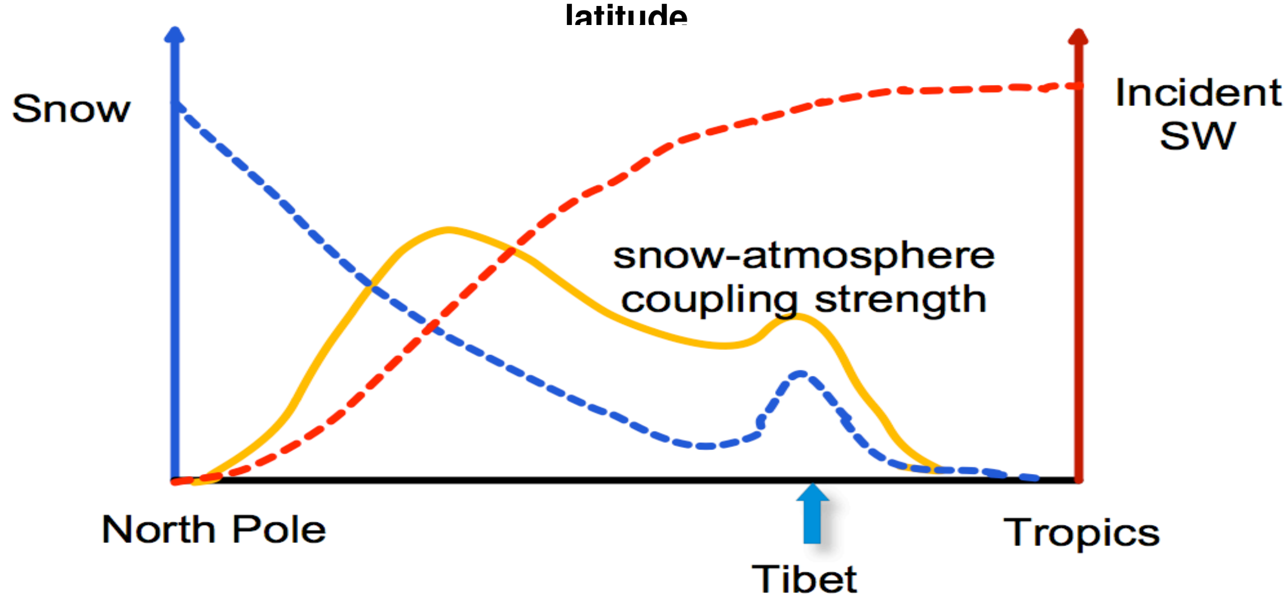
Hydrological effect



	Snow albedo effect	Snow hydrological effect
Impact	Direct	Indirect
Time scale	Instant	Delayed (week to months)
Mechanism	Reflect more SW radiation	Soil-moisture-evaporation-precipitation feedback
Consequence	Change net energy	Change partitioning of sensible heat and latent heat

Zonal mean snow-atmosphere coupling strength





conclusions

- How strong are snow-atmosphere coupled?
  Snow-atmosphere are coupled at varying degree at different regions. The maximum coupling strength could explain 40% temperature variability

- Where and when is the strongest coupling?
  Strongest coupling happened at middle-latitude (snow transient zone) during snowmelt stage

- Can we separate snow albedo and hydrological effects?
  Yes. Albedo effect mainly before snowmelt, and hydrological effect contribute after snowmelt. Hydrological effect exerts stronger impacts than albedo effect.

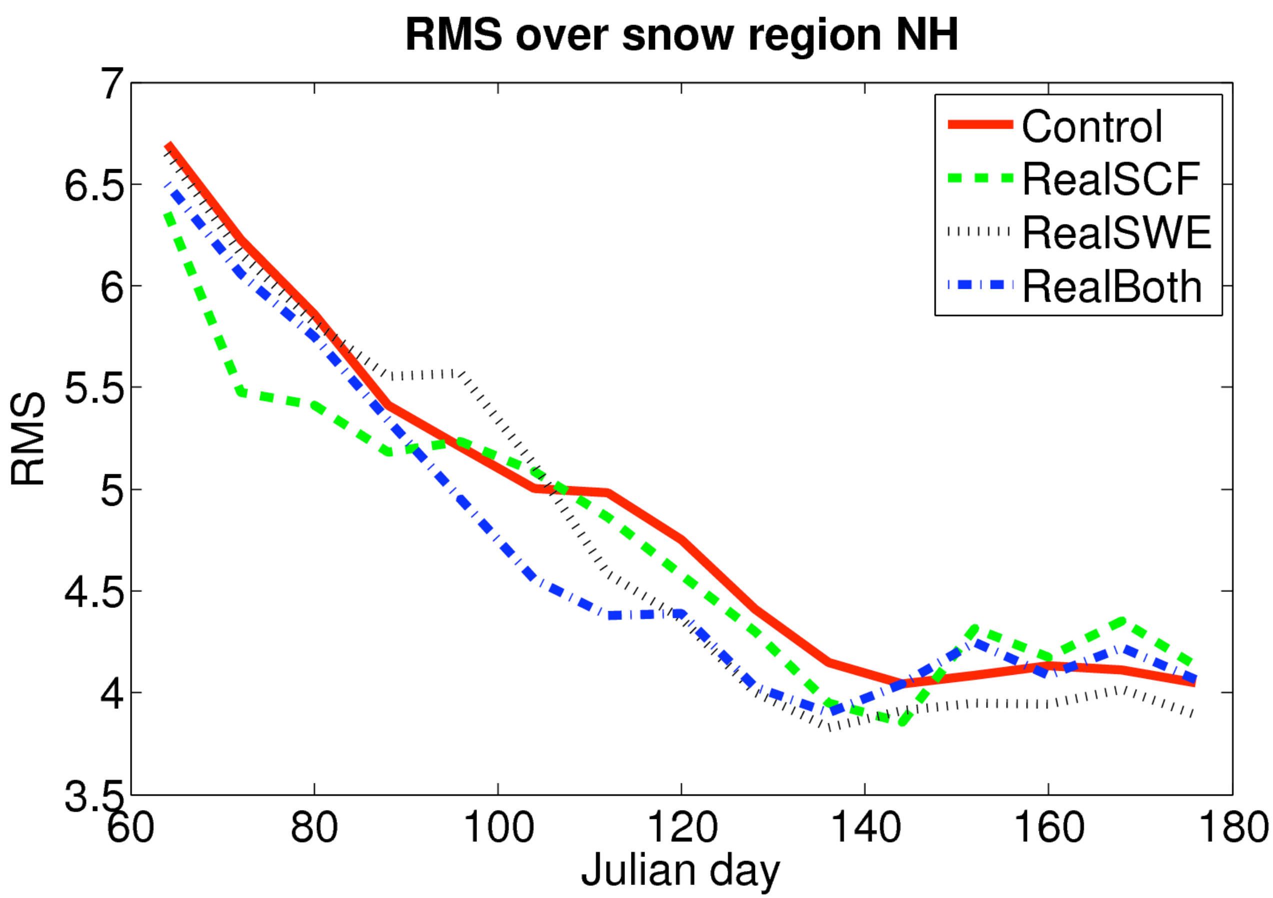
- How does snow contribute to climate predictability?
  Predictability enhancement in STR show identical pattern with coupling strength, implying the coupling contribute to potential predictability. SCF mainly improve simulation before snowmelt and SWE mainly improve afterward.

QUESTIONS?

Evaluation of temperature simulation with snow information

Spatial Root Mean Square Error
For T2m

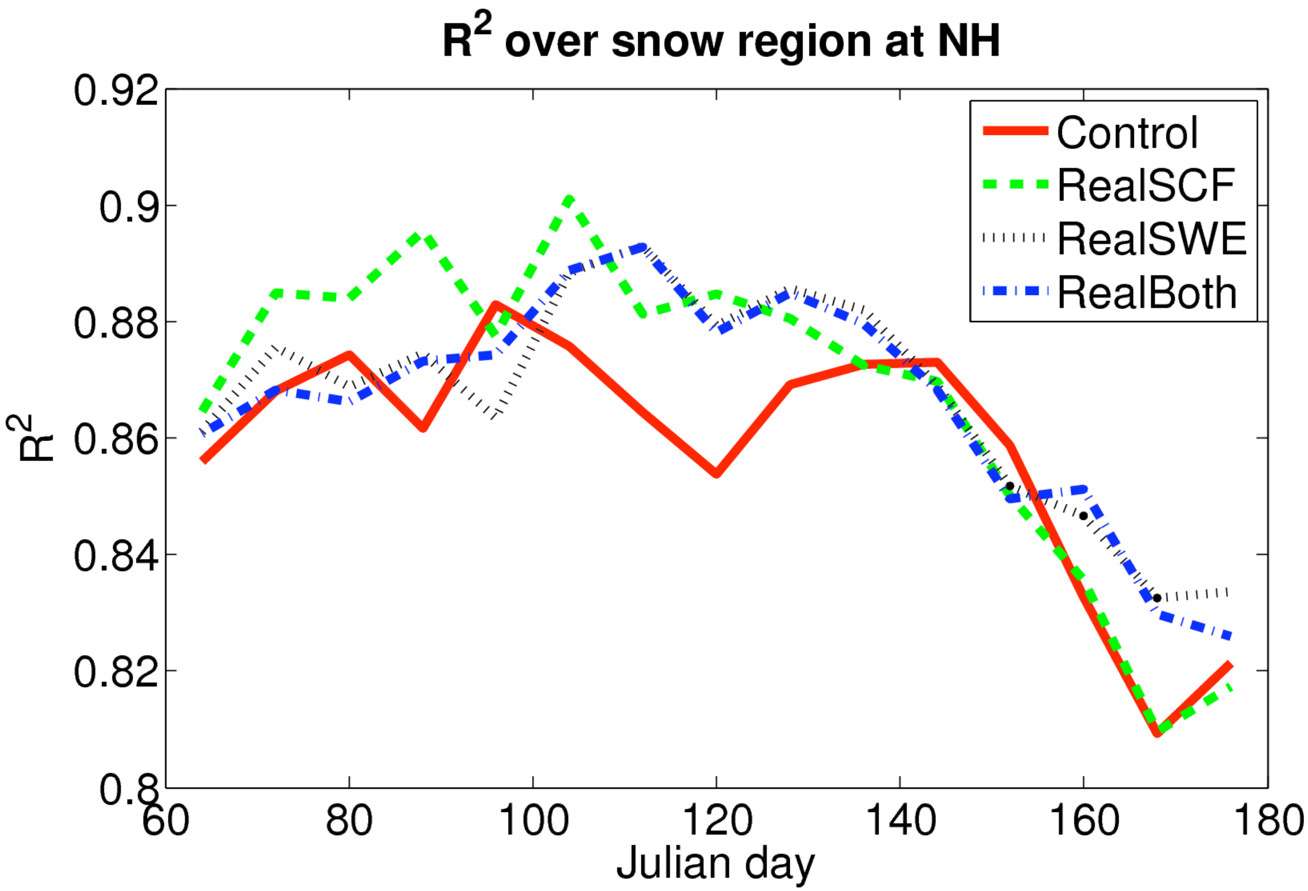
$$RMSE = \sqrt{\frac{\sum (O - P)^2}{n}}$$



Evaluation of the simulations with snow information

Spatial correlation for T2m

$$R^2 = \left[\frac{\sum (O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum (O_i - \overline{O})^2} \sqrt{\sum (P_i - \overline{P})^2}} \right]^2$$



Snow hydrological forcing with S-A coupling strength

$$SHSI = \sigma(W_{sno}) * R_{\inf}$$