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An evaluation of regional climate model simulated fractional snow cover using high-resolution satellite data (with implications for the simulated snow-albedo feedback)

jminder@albany.edu

Justin R Minder & *Theodore Letcher*

University at Albany, Albany, New York, USA

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Snow cover is an important aspect of regional climate over mountains, but regional climate model (RCM) simulations of it are poorly constrained

Mountain snow cover helps to control the extent of mountain ecosystems and affects regional climate by altering the surface albedo and surface energy budget. **Changes in mountain snow cover may substantially amplify regional climate change via the snow-albedo feedback**. However, detailed observations of mountain snow cover are difficult due to remote rugged terrain and high spatial and temporal variability. High-resolution regional climate models (RCMs) are now being run at spatial scales (1's-10's of km grid spacing) where the effects of complex terrain on snow cover can begin to be resolved. Skillful simulation requires realistic meteorology and an adequate treatment of snowpack processes. However **detailed evaluation of RCM performance in simulating mountain snow cover is very limited.**

Our questions:

- How skillful are high-resolution RCMs at simulating mountain snow cover and its effect on surface albedo?
- How does RCM skill depend on model configuration (e.g., choice of land surface model)?
- How do differences in RCM-modeled snow cover translate to differences in snow-albedo feedback and climate change response?

Comparing RCM-simulated and satellite-estimated snow cover over the Rocky Mountains

WRF regional climate simulations

High-resolution simulations of the current climate are analyzed:

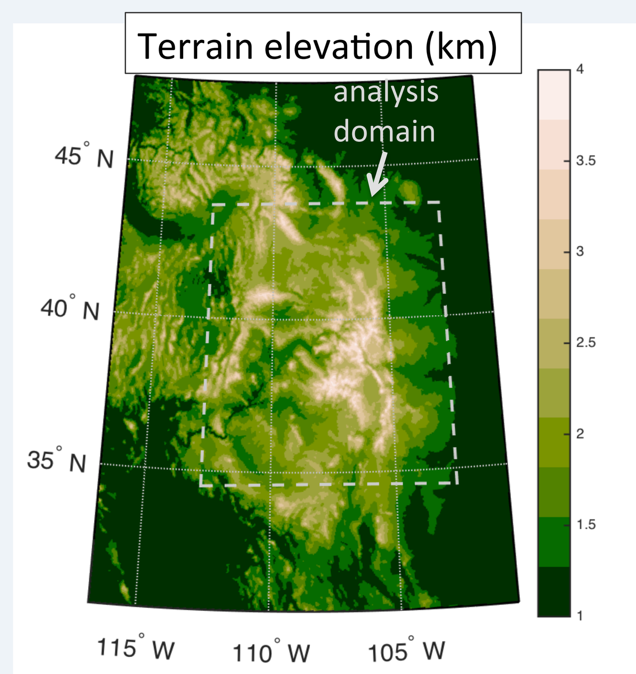
- Weather Research and forecasting (WRF) model
- Δx = 4 km
- Forced by NARR reanalysis boundary conditions
- 2000 – 2008 (discard first year for spin-up)
- Snowpack & surface albedo predicted by a coupled land surface model (LSM)
- More details: *Rasmussen et al. (2014)*

Two different sets of simulations are analyzed…

1. Colorado Headwaters domain, Noah LSM **(HW-N)**
   - **Domain encompasses "headwaters" region of US Rocky Mountains**
   - Simple **Noah LSM** simulates snowpack. No explicit treatment of canopy effects.
2. Continental US domain, Noah-MP LSM **(CONUS-NMP)**
   - **Domain encompasses entire continental US (CONUS)**
   - More-sophisticated **Noah-MP LSM** simulates snowpack. Explicit treatment of canopy effects.

Strategy: Over central Rocky Mountains of the USA, compare RCM-simulated and satellite-estimated:

- *Fractional snow covered area (FSCA)*
- *Surface albedo*



MODIS satellite observations

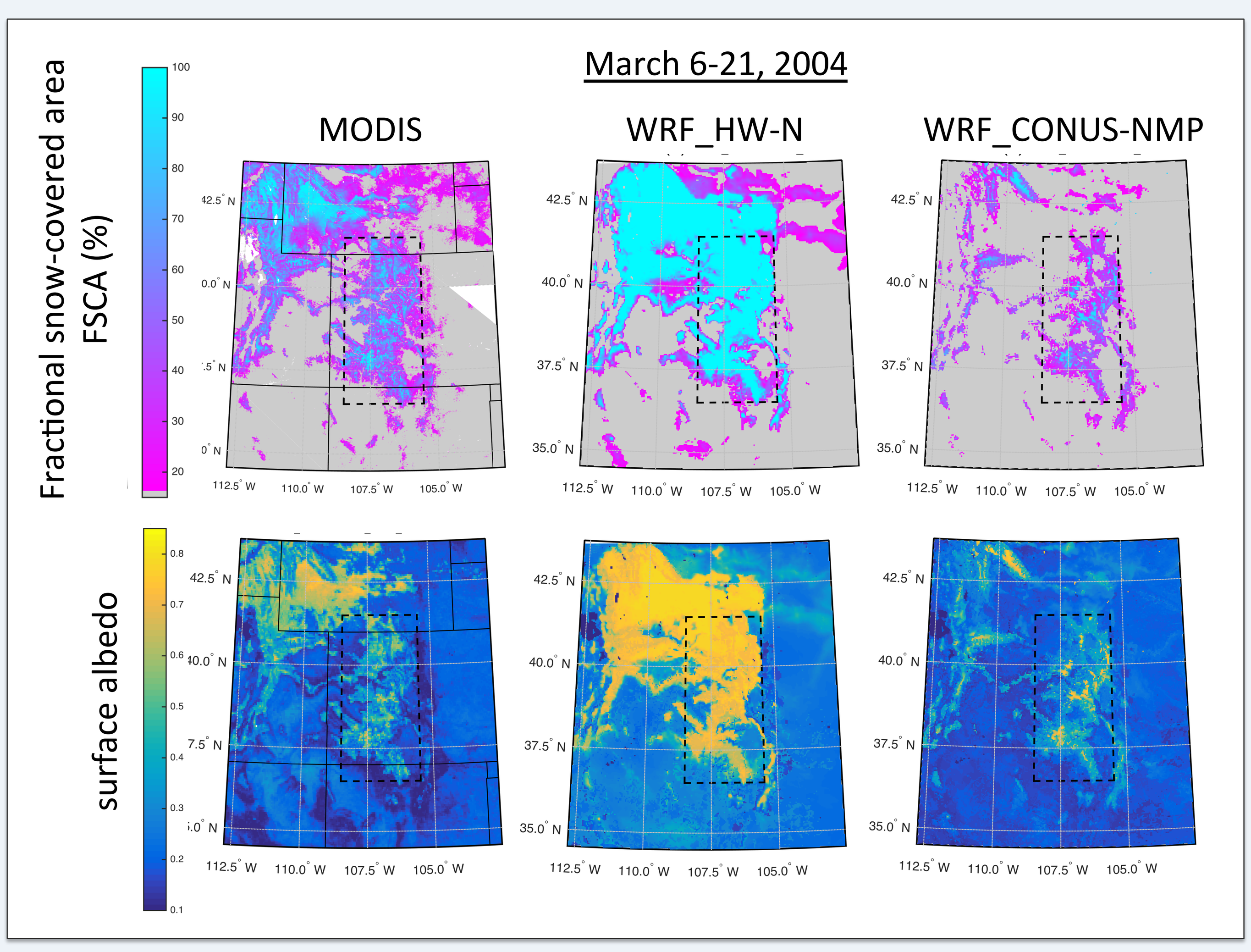
Satellite observations are used to evaluate RCM simulations because they provide detailed snow cover and surface albedo data with a spatial resolution comparable to RCM and good data availability.

We use two products from NASA's Moderate Resolution Imaging spectroradiometer (MODIS) sensor aboard the Terra satellite:

1. **Fractional snow covered area (FSCA)**
   - MODSCAG gridded product, derived using spectral mixing (Painter et al. 2009)
   - ~500 m pixel size, provides sub-pixel fractional snow cover
   - Daily
   - 15% snow cover detection threshold
2. **Surface albedo**
   - MCD43C3 gridded product (Schaff et al., 2002)
   - 5 km pixel size
   - 16-day averages
   - White-sky albedo used (similar results for black-sky)

Example maps of snow cover & albedo

All data are averaged using a 16-day sliding window. Missing MODIS data (e.g., cloudy pixels) are neglected in averaging. Maps are compared to reveal spatial structure of differences. Below is a representative example for a single 16-day period.



- Complex fine-scale structures associated with terrain features in both model and observations
- In snowy regions, WRF_HW-N simulations have excessive sub-grid FSCA, leading to excessive albedo (compared to observations). WRF_HW-NMP seems to do better.
- Spatial extent of simulated snow cover is greater in WRF_HW-N relative to WRF_CONUS-NMP.

Multi-year domain-averaged statistics

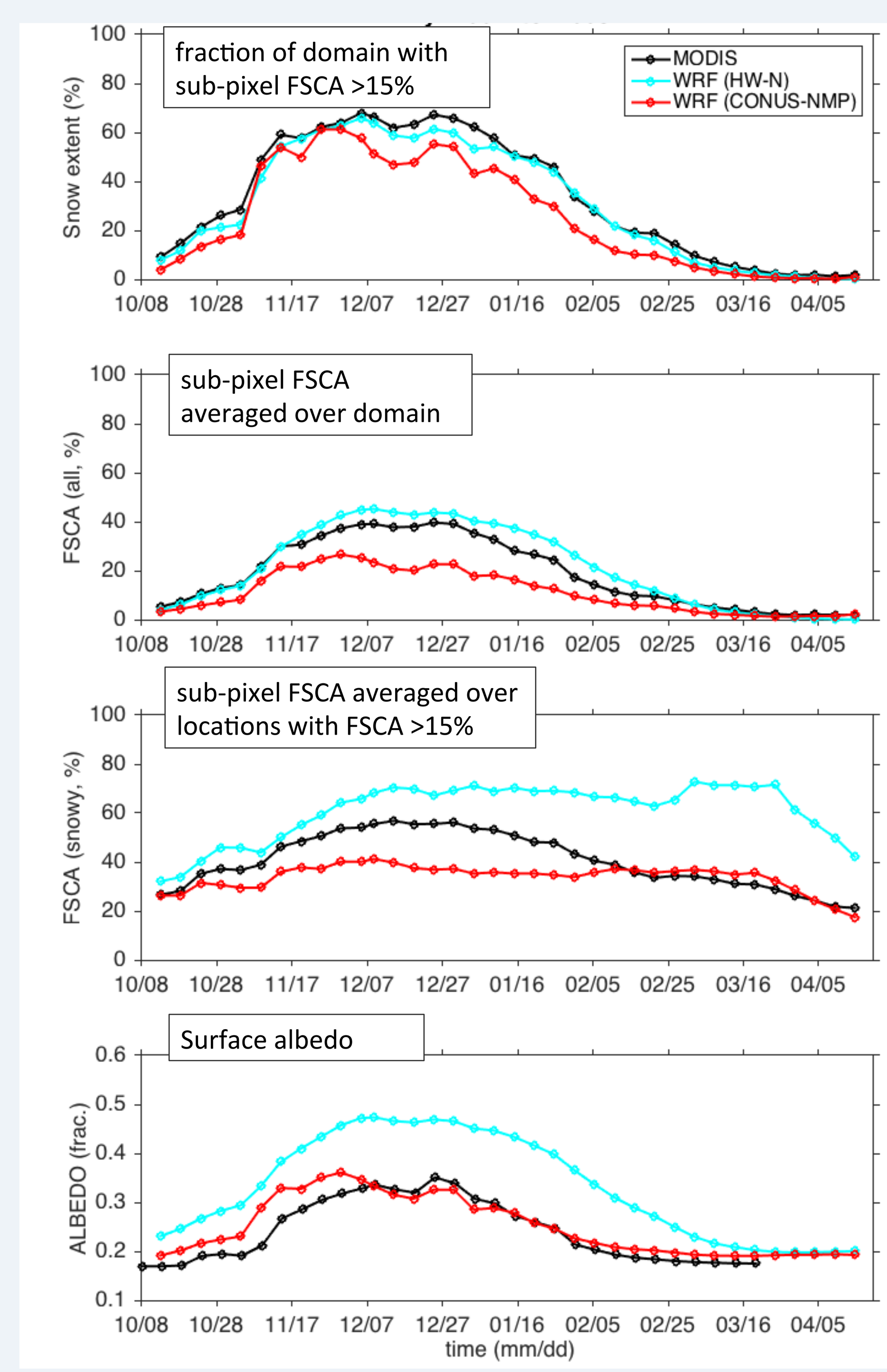
Bulk statistics are calculated by **averaging over analysis domain** (shown above) **and over 7-years** (water years 2002-2008).

WRF_HW-N

- Snow extent simulated well
- Sub-pixel fractional snow cover of snowy pixels is consistently too high in HW-N runs. Likely due to neglect of masking by canopy.
- Positive bias in FSCA of snowy pixels biases domain-averaged FSCA high.
- Surface albedo is far too high, in part due to biases in FSCA of snowy pixels (also positive. bias of snow albedo?)

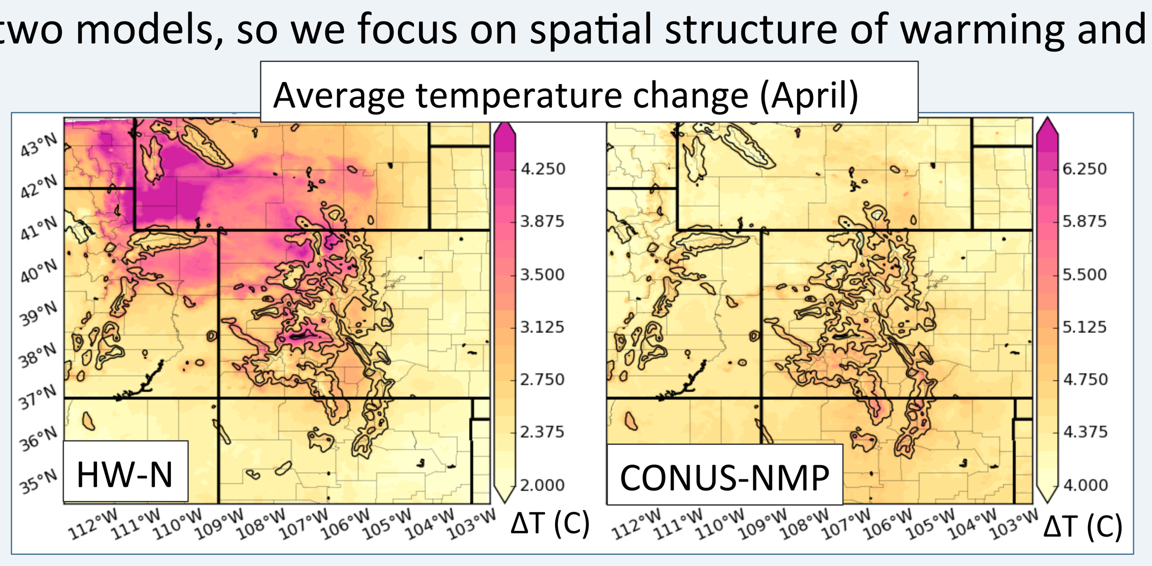
WRF_CONUS-NMP

- Snow extent is poorer. Biased low. (perhaps due to weaker BC constraints of larger domain)
- FSCA of snowy pixels is too low in mid-winter, reasonable in spring.
- Domain-averaged FSCA is consistently too low.
- Surface albedo is surprisingly good. (compensating bias in snow-albedo?)



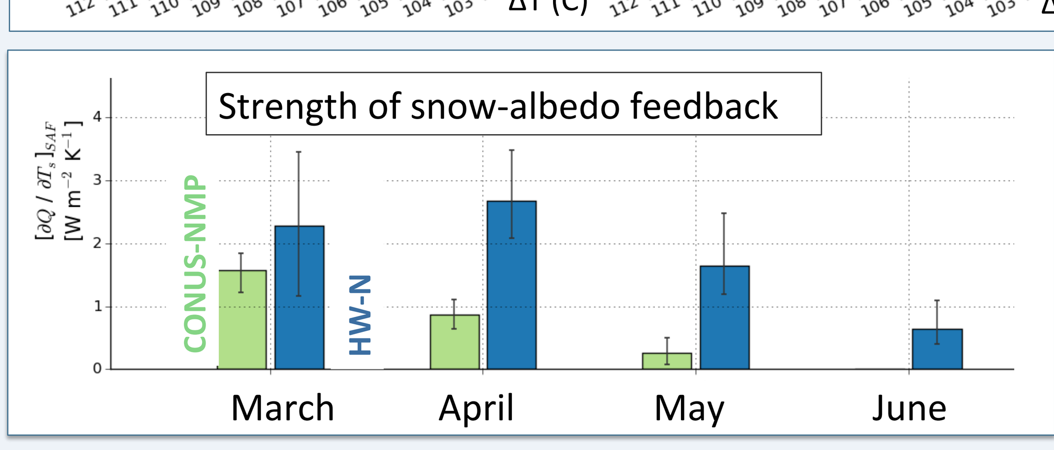
Differences in RCM simulated snow cover lead to differences in snow-albedo feedback and warming under climate change

We contrast the response of our two RCMs to forced climate change by considering **additional 7-year simulations of a warmed climate where model boundary conditions are perturbed under a pseudo-global warming framework** (Schar et al. 1996; Rasmussen et al. 2015). Different forcing scenarios are used for the two models, so we focus on spatial structure of warming and feedback strength.



Spatial pattern of warming

- HW-N run show stronger enhancement of warming in marginal snow zone.
- Due to larger snow extent and higher FSCA of snowy pixels.
- Enhanced warming in HW-N run is likely excessive based on FSCA and albedo biases.



Strength of snow-albedo feedback

- Quantify feedback strength using linear feedback analysis (Letcher & Minder, 2015).
- Snow-albedo feedback is stronger in HW-N runs due to more extensive snow cover and larger albedo contrast between bare and snowy pixels.

Conclusions

- High-resolution RCMs begin to capture effects of complex terrain on snow cover and surface albedo
- MODIS satellite products are valuable for evaluating RCM simulations of snow cover over complex terrain.
- RCM performance varies widely depending on boundary forcing (regional vs. continental) and land surface model (simple vs. complex).
- Differing treatment of fractional snow cover (and canopy effects) has large impacts on local and regional surface albedo.
- Biases in modeled snow cover translate into marked differences in the character of regional climate warming due to the snow-albedo feedback.

References

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