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Introduction

Snow cover fraction (SCF) accuracy in land surface models (LSMs) impacts the accuracy of surface albedo and land-atmosphere interactions. However, SCF can be one of the largest snow modeling uncertainty sources. We implement and evaluate enhancements in the Noah-MP land surface model to: (i) enhance the Noah-MP snow compaction process, and (ii) create a new enhanced scale-aware ground SCF parameterization. Model evaluations for the enhanced scheme are conducted using western U.S. SNOTEL sites, MODSCAG SCF retrievals, and MODIS albedo retrievals.

Science questions

Snow compaction

1. How accurate is the baseline Noah-MP snow compaction scheme?
2. Can Noah-MP snow compaction be enhanced to improve agreement with observed snow depth and snow density?

Ground snow cover fraction

1. Is the scale dependent nature of snow depletion curves observable?
2. Can a scale-aware ground SCF parameterization be derived using reference snow data?
3. Can the scale-aware parameterization be transferred to model simulations to more accurately simulate ground SCF and surface albedo relative to baseline simulations?

Methods & Data

Snow compaction

Study domain: western U.S. SNOTEL sites

Meteorological forcing: Downscaled NLDAS-2; precipitation and temperature from BCQC ground-observations at SNOTEL sites

Snow compaction formula (Anderson, 1976):

$$\Delta F_{DZ,sno,i} = \max(-0.5, D_{DZ,dm,i} + D_{DZ,bd-i} + D_{DZ,melt,i}) \times \Delta t \quad \text{Eq. 1}$$

destructive metamorphism overburden melt metamorphism

Optimization simulations use direct insertion to remove SWE errors:

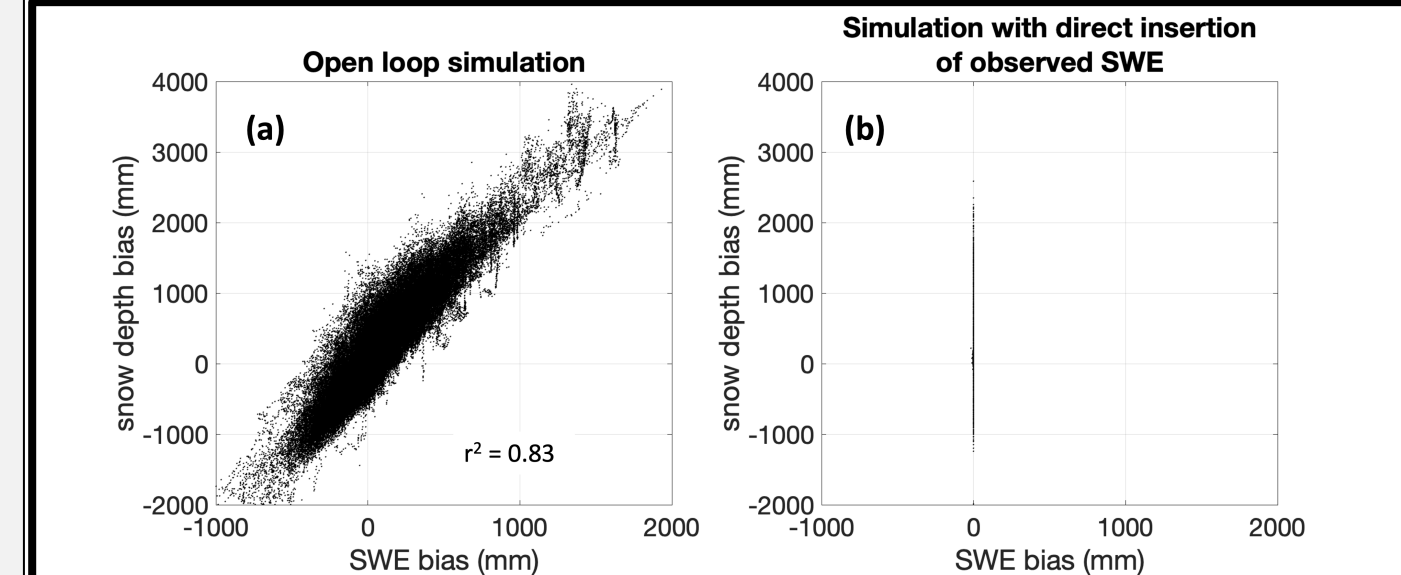


Figure 1. Simulated biases in SWE compared with snow depth biases from (a) the baseline open loop simulation and (b) the baseline direct insertion simulation relative to SNOTEL observations.

Ground snow cover fraction

Study domain: western U.S. at 1-36km spatial resolutions

Meteorological forcing: 1-km AORC; precipitation and temperature from PRISM

SCF formula (Niu and Yang, 2007):

$$SCF = \tanh\left(\frac{h_{sno}}{F_{sno} \times f_{melt}}\right) \quad \text{Eq. 2} \quad f_{melt} = \left(\frac{\rho_{snow}}{\rho_{new}}\right)^m \quad \text{Eq. 3}$$

Reference snow data: MODSCAG SCF, SNODAS snow depth and SWE

Motivation: snow model uncertainty feedbacks

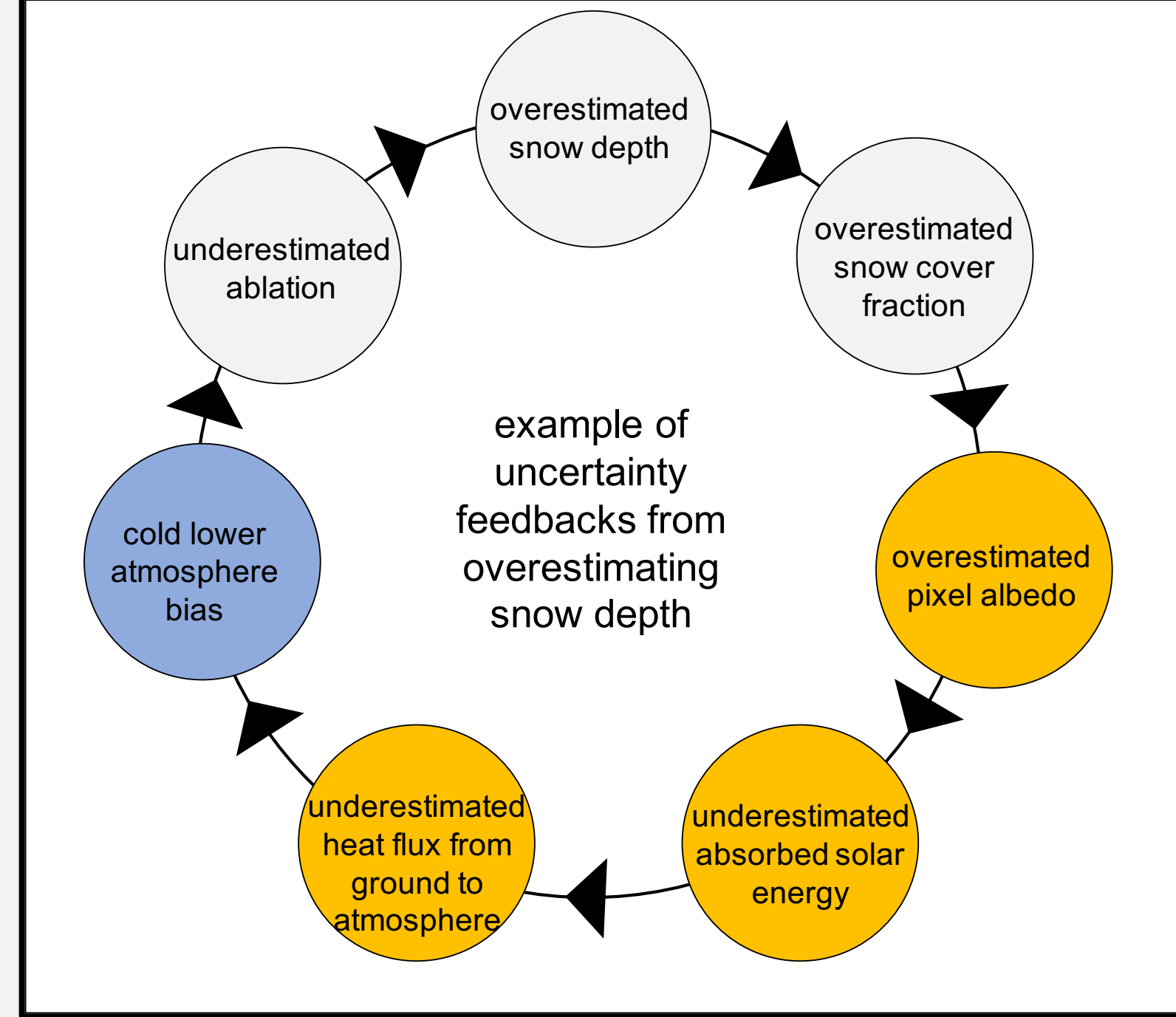


Figure 2. Example for Noah-MP land surface model (Niu et al., 2011; He et al., 2023) uncertainty feedback loop under overestimated snow depth conditions (i.e., underestimated snow density).

Enhanced snow compaction parameterization

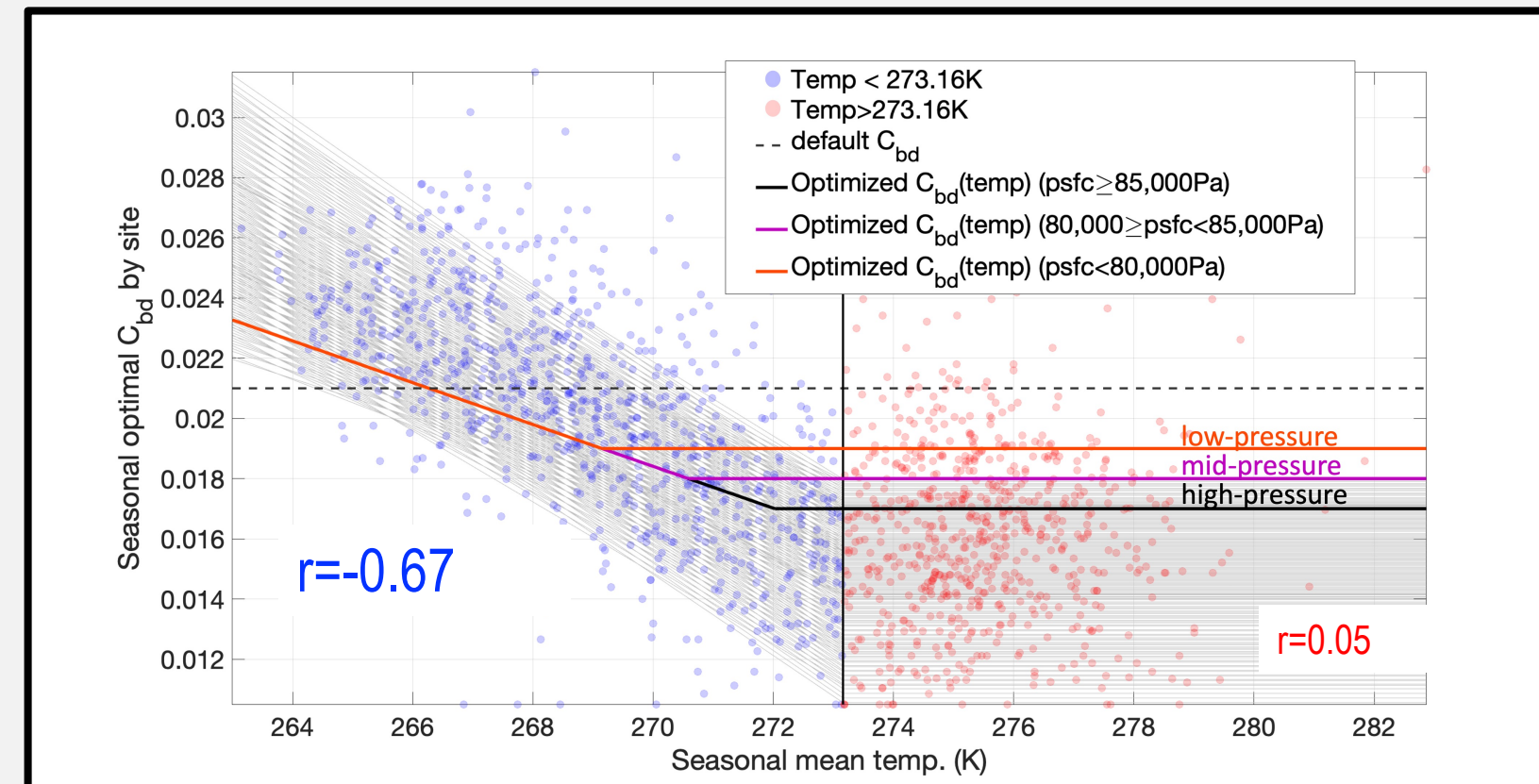


Figure 3. Scatter plot comparing the multiyear (2009-2018 water years) seasonally averaged surface air temperature with optimized C_{bd} parameters from Noah-MP simulations. Two dots for each station correspond to accumulation and ablation periods. 160 grey lines represent perturbations of the best-fit linear equation for the blue data points with lower constraints for above freezing instances. Bold orange, purple and black lines represent the optimized equations for C_{bd} across surface pressure bins.

$$D_{DZ,bd} = \frac{-(W_{abv} + 0.5 \times W_{sno,i}) \times e^{-0.08 \times \max(0, T_{frz} - T_{sno,i}) - C_{bd} \times \frac{W_{ice,sno,i}}{D_{Zsno,i}}}}{\eta_0} \quad \text{Eq. 4}$$

$$C_{bd} = -0.00074789 \times T_{air} + 0.22127489 \quad \text{Eq. 5}$$

$$C_{bd} = \begin{cases} \min(C_{bd}, 0.019), & psfc < 80,000 \text{ Pa} \\ \min(C_{bd}, 0.018), & 80,000 \leq psfc < 85,000 \text{ Pa} \\ \min(C_{bd}, 0.017), & psfc \geq 85,000 \text{ Pa} \end{cases} \quad \text{Eq. 6}$$

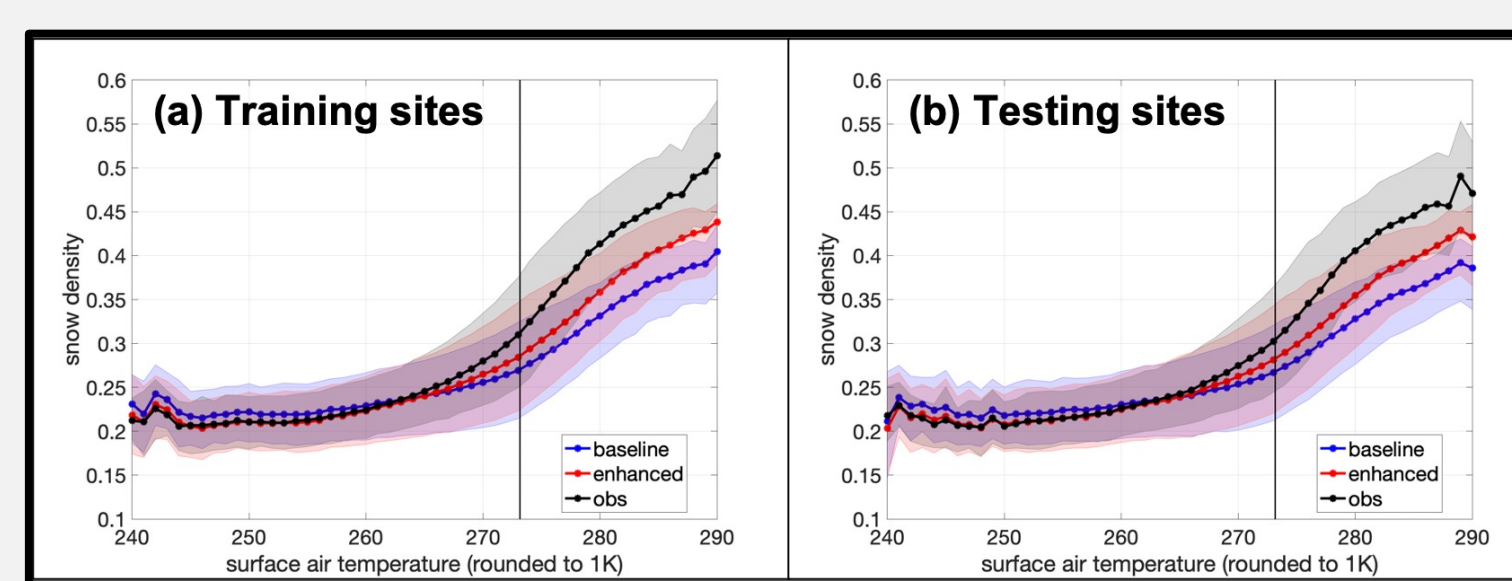
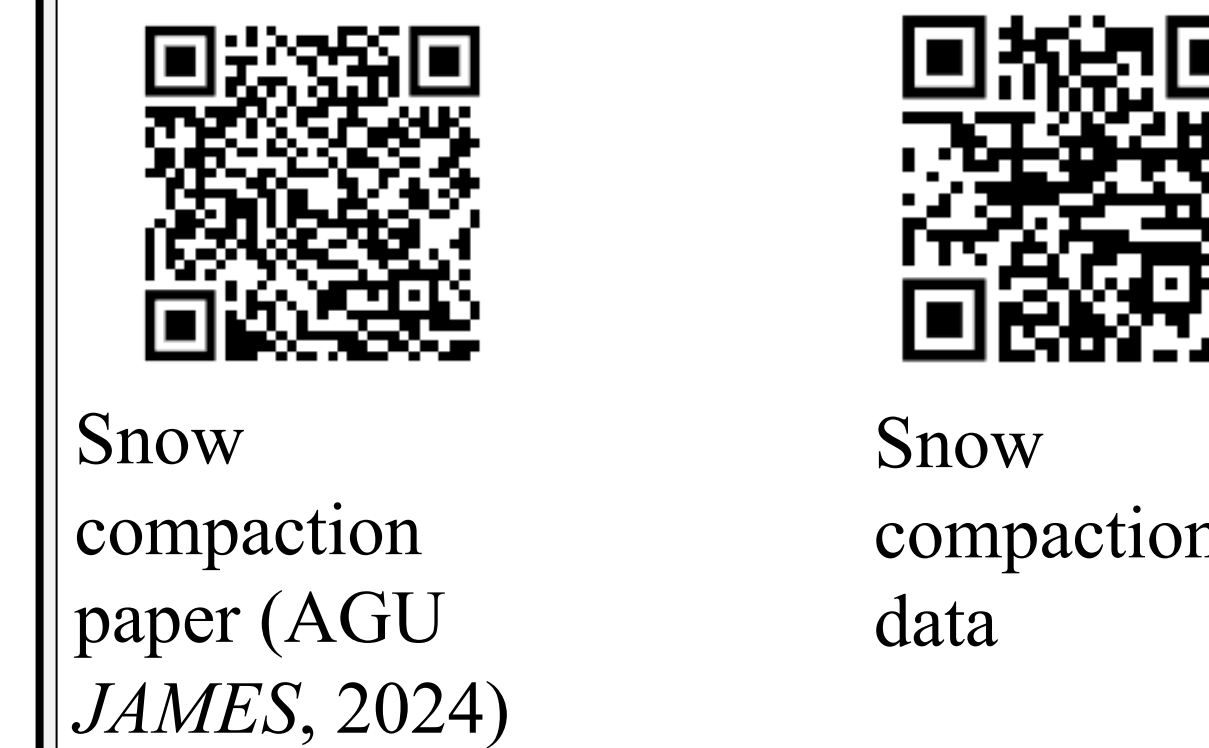


Figure 4. Mean snow density from observations (black), enhanced (red) and baseline (blue) simulations averaged by 1K temperature bins. Shading represents respective IQR.

References:

Anderson, E.A., 1976. A point energy and mass balance model of a snow cover, NOAA Tech. Rep.
Niu et al., 2011. The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements. J. Geophys. Res.
He et al., 2023. The Community Noah-MP Land Surface Modeling System Technical Description Version 5.0 (No. NCAR/TN-575+STR);
Niu and Yang 2007. An observation-based formulation of snow cover fraction and its evaluation over large North American river basins. J. Geophys. Res.



Snow compaction paper (AGU JAMES, 2024)

Snow compaction data

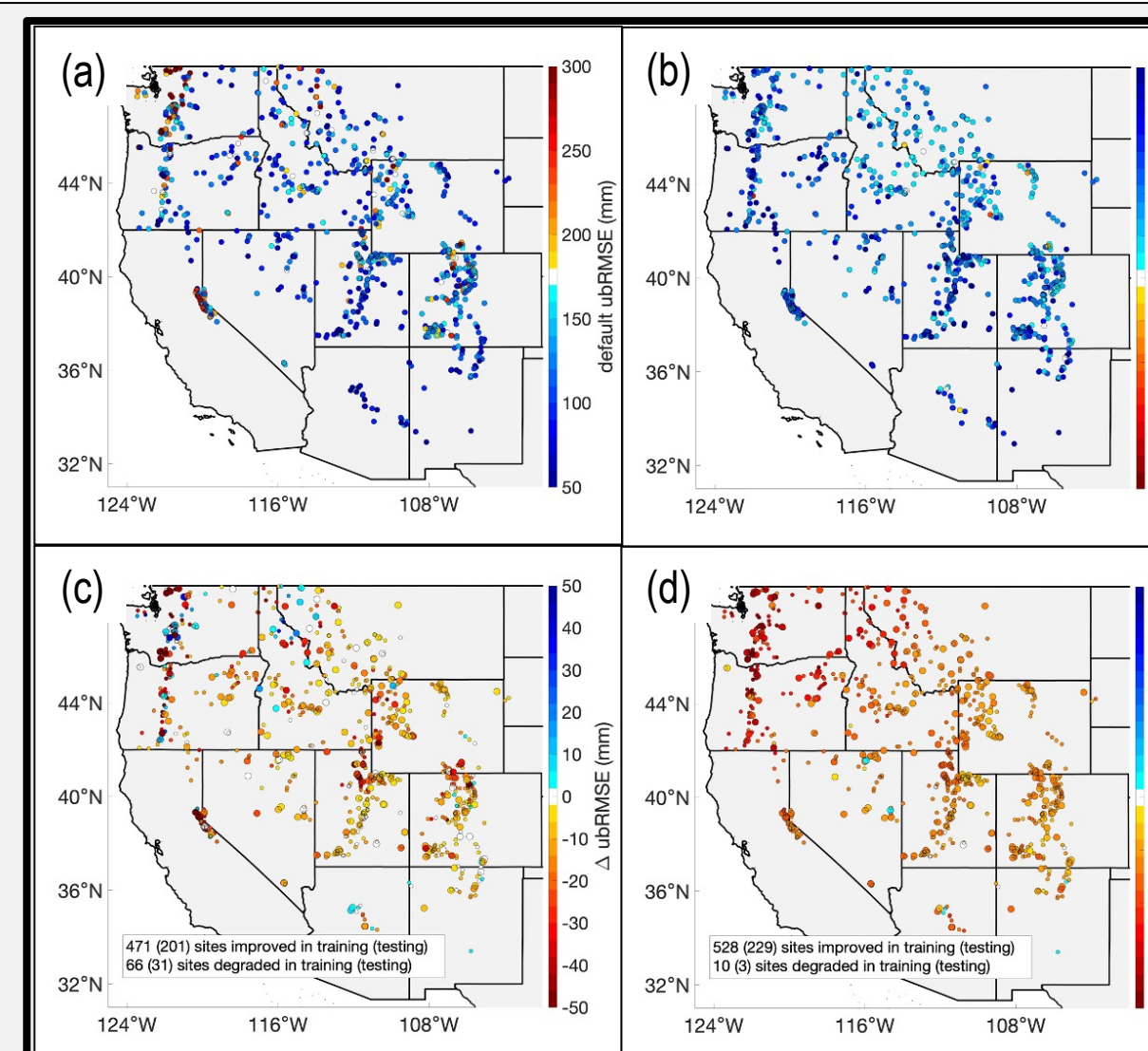


Figure 5. Ablation period skill scores (a) ubRMSE, and (b) pbias from the baseline simulation at SNOTEL sites and (c,d) changes in skill scores (enhanced-baseline). Small (large) dots correspond with training (testing) sites.

Enhanced ground SCF parameterization

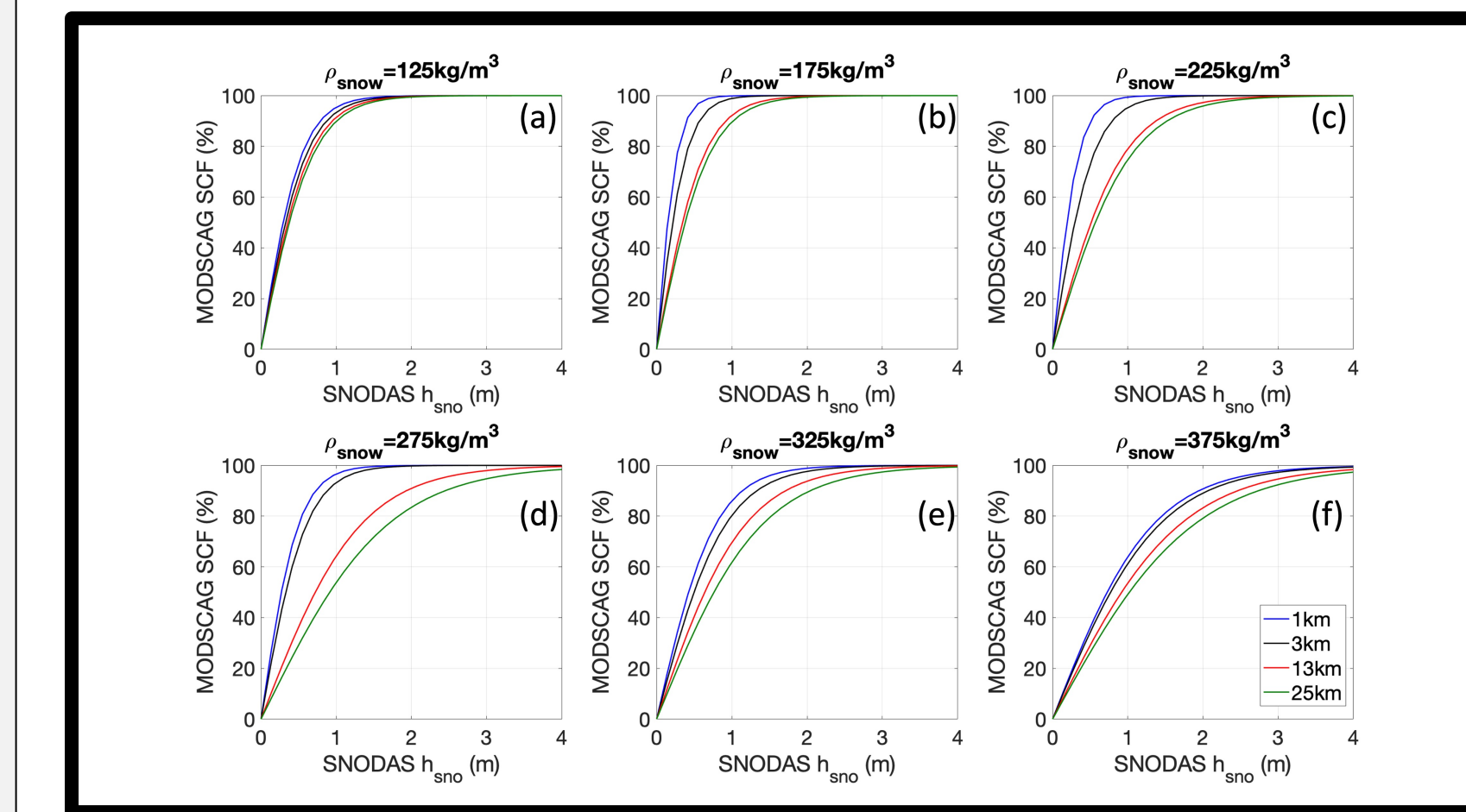


Figure 6. Snow depletion curves from the NY07 ground SCF scheme when semi-empirical parameters are fit to reference snow data from MODSCAG and SNODAS using the least-squares method.

$$F_{sno} = \beta_{1,fno} \times \sinh(\beta_{2,fno} \times DX) + \beta_{2,fno} \quad \text{Eq. 7}$$

$$m = \beta_{1,m} + \tanh(\beta_{2,m} \times DX) \quad \text{Eq. 8}$$

Enhanced SCF Box Model Evaluation

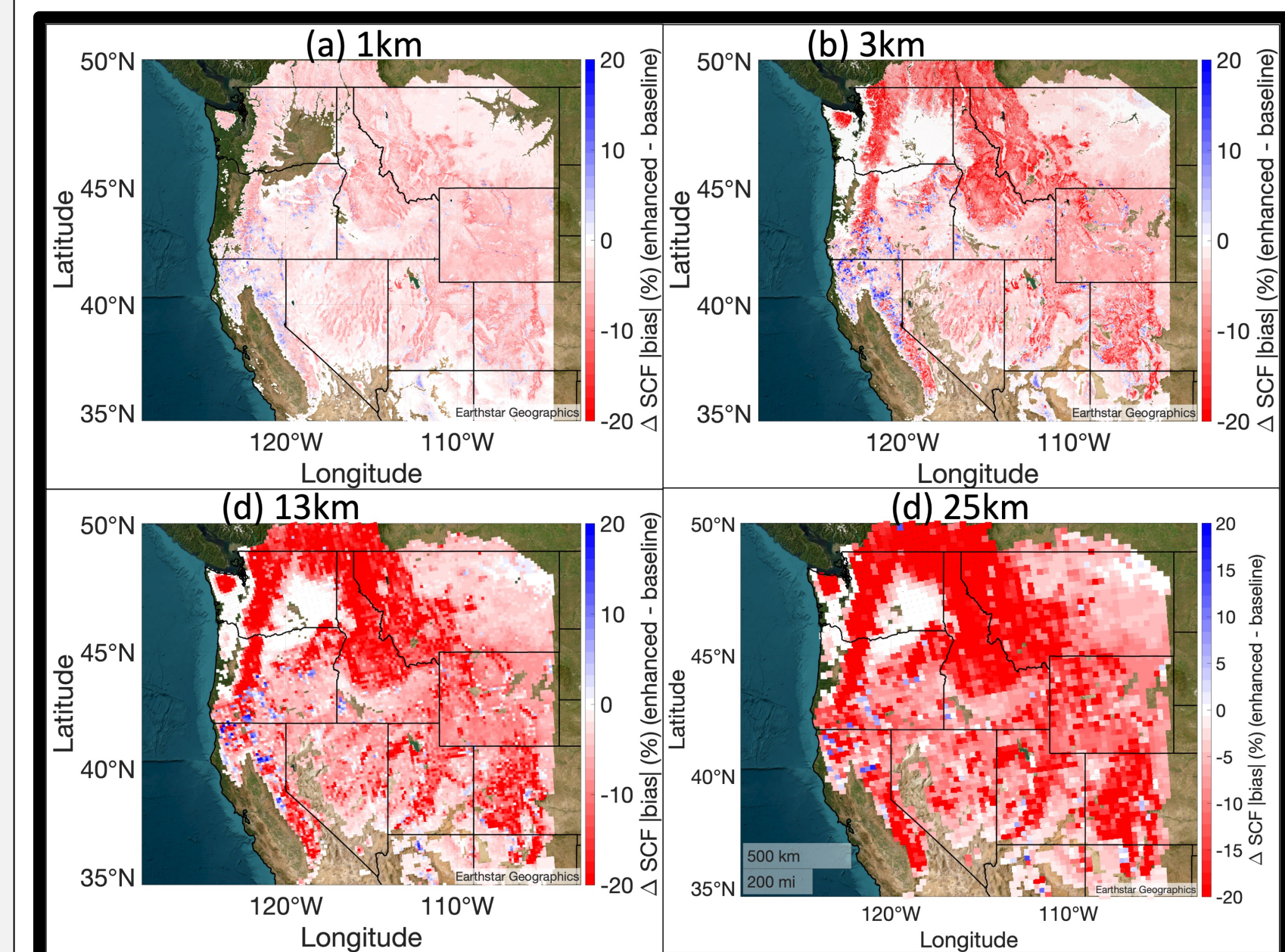


Figure 7. Difference between the snow cover fraction (SCF) |bias| from the box model using the scale-aware parameterization relative to that using the default formulation across the western U.S. at (a) 1-km, (b) 3-km, (c) 13-km, and (d) 25-km spatial resolutions from the 2014-2018 water years.

Enhanced SCF Noah-MP Evaluation

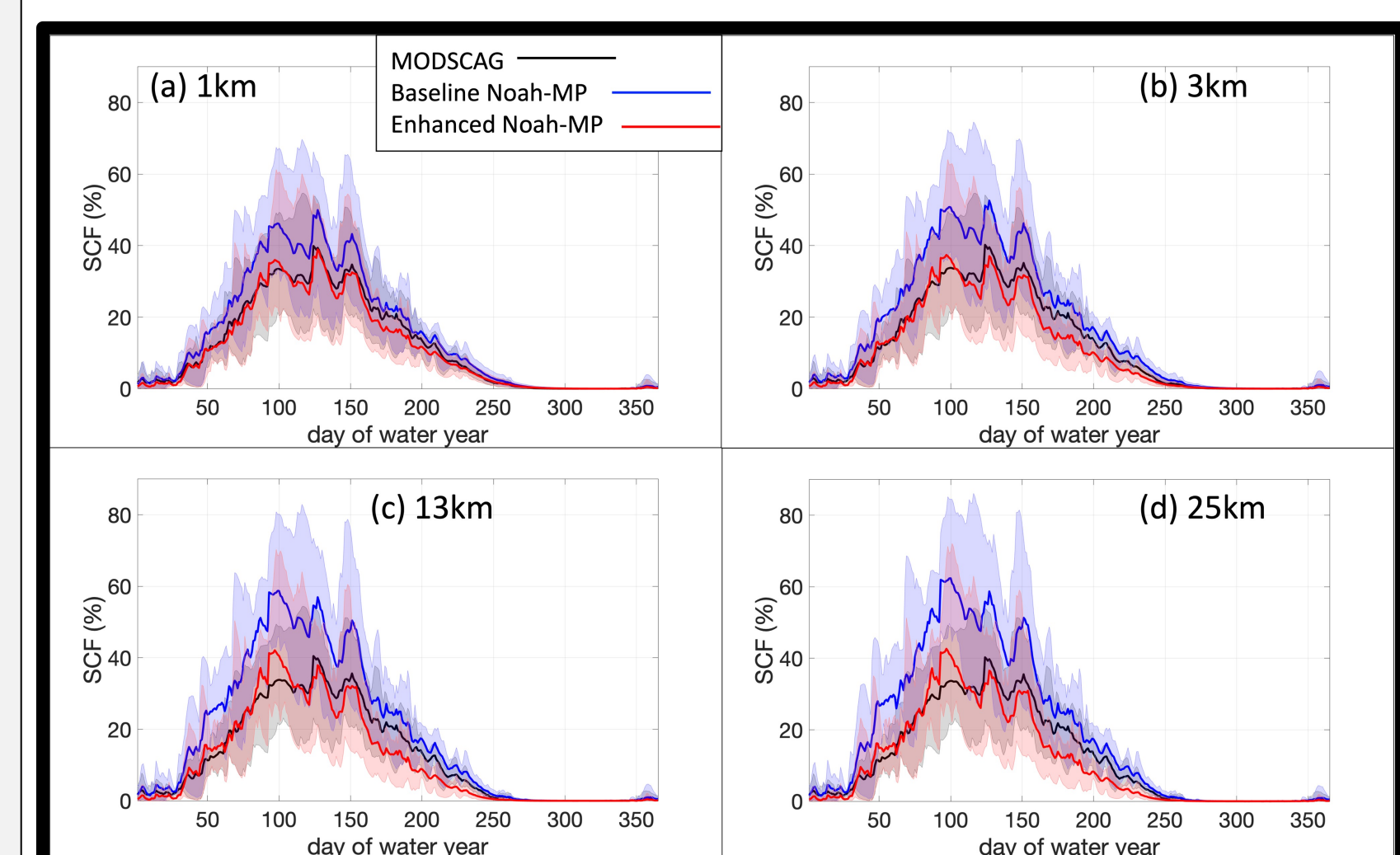


Figure 8. Multiyear mean daily comparisons (2014-2018) between MODSCAG observed and Noah-MP simulated ground snow cover fraction (SCF) using the baseline (blue) and enhanced (red) SCF parameterizations averaged across the western U.S. at (a) 1-km, (b) 3-km, (c) 13-km, and (d) 25-km resolutions.

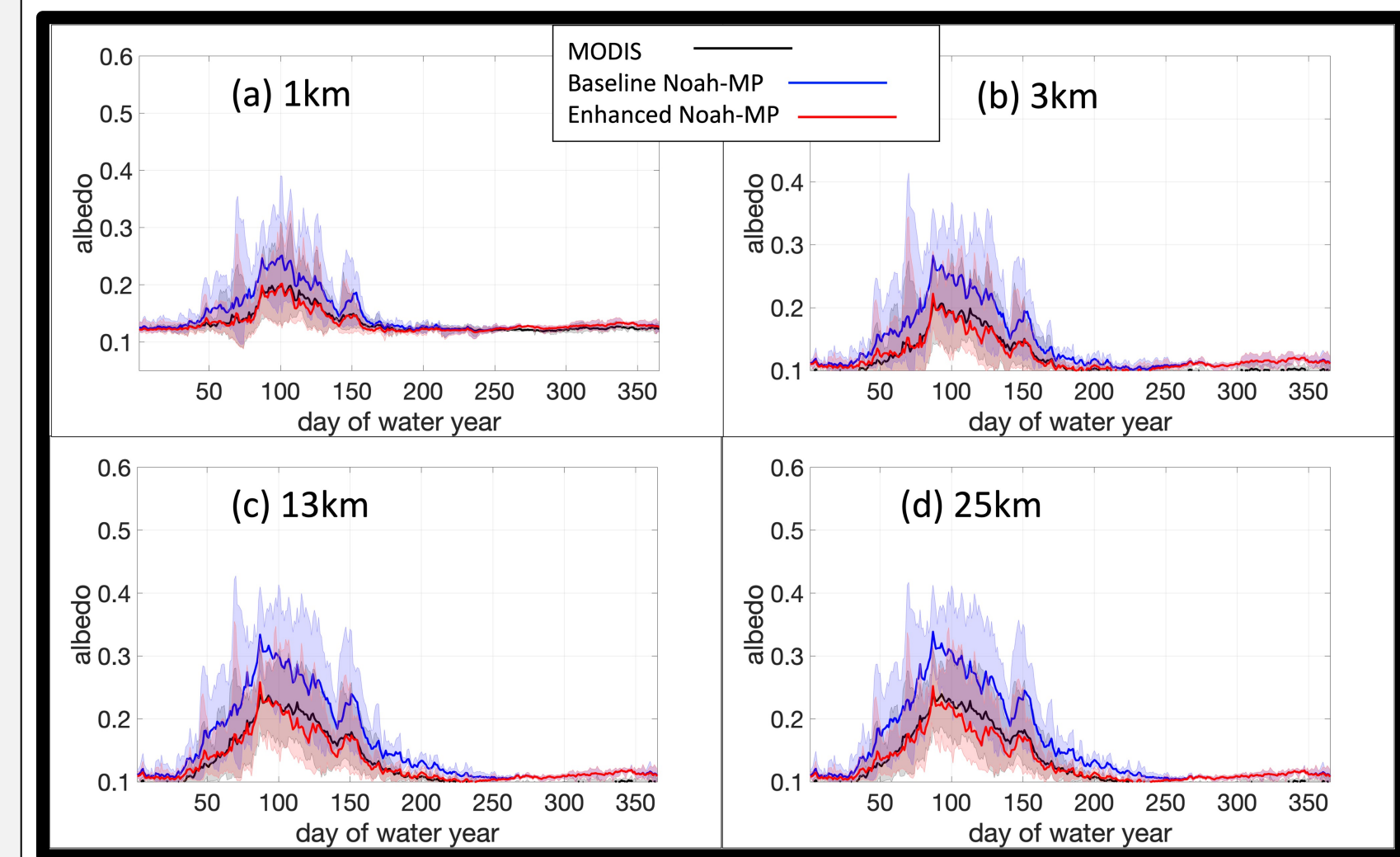


Figure 9. Multiyear mean daily comparisons (2014-2018) between MODIS observed albedo using the baseline (blue) and enhanced (red) SCF parameterizations across the western U.S. at (a) 1-km, (b) 3-km, (c) 13-km, and (d) 25-km resolutions.