Process-level enhancements of Noah-MP snowpack modeling

Ronnie Abolafia-Rosenzweig (NCAR/RAL)

with contributions from

Cenlin He, Fei Chen, Michael Barlage, David Gochis

Funding sources: USGS and NOAA

Noah-MP snowpack process enhancement lists

1. **Improve canopy turbulent scheme**: implementing roughness sublayer (RSL) with M-O theory [completed; need more comprehensive evaluations]: Abolafia-Rosenzweig et al. 2021

2. **Improve snow albedo scheme**:
   optimizing existing parameters [completed]: Abolafia-Rosenzweig et al. 2022
   coupling with SNICAR [on-going; Tzu-Shun Lin]

3. **Improve snow compaction/densification** [completed]: Abolafia-Rosenzweig et al. in prep

4. **Improve snow cover**: optimizing snow depletion curve [just started]

5. **Improve canopy snow interception** [future work]

Existing publications

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JGR Atmospheres

RESEARCH ARTICLE
10.1029/2021JD035284

Key Points:

- WRF 4-km early-spring SWE underestimates are due to strong melting caused by enhanced sensible heat to snow and solar radiation absorption
- The enhanced surface heat exchange coefficient and thus sensible heat

What Causes the Unobserved Early-Spring Snowpack Ablation in Convection-Permitting WRF Modeling Over Utah Mountains?

Cenlin He[1], Fei Chen[1], Ronnie Abolafia-Rosenzweig[1], Kyoko Ikeda[1], Changhai Liu[1], and Roy Rasmussen[1]

[1]Research Applications Laboratory, National Center for Atmospheric Research, Boulder, CO, USA

He et al. (2021, JGR): process-level snowpack analyses of WRF reveal possible deficiencies in Noah-MP: canopy processes, snow cover fraction and snow albedo

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JAMES | Journal of Advances in Modeling Earth Systems®

RESEARCH ARTICLE
10.1029/2021MS002665

Key Points:

- This study presents a new physics option for Noah-MP that accounts for canopy-induced turbulence in the roughness sublayer
- Simulated SWE over shrublands using the new turbulence scheme agree more with observations than

Implementation and Evaluation of a Unified Turbulence Parameterization Throughout the Canopy and Roughness Sublayer in Noah-MP Snow Simulations

Ronnie Abolafia-Rosenzweig[1], Cenlin He[1], Sean P. Burns[1,2], and Fei Chen[1]

[1]National Center for Atmospheric Research, Boulder, CO, USA, [2]Department of Geography, University of Colorado, Boulder, CO, USA

Abolafia-Rosenzweig et al. (2021, JAMES): accounting for canopy-induced turbulence in the RSL tends to improve accuracy of Noah-MP snow simulations at densely vegetated sites

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RESEARCH ARTICLE
10.1029/2022MS003141

Key Points:

- The Biosphere-Atmosphere Transfer Scheme (BATS) snow albedo formulation is highly sensitive to fresh-snow albedo and snow age input parameters
- Parameter optimization substantially improves accuracy for BATS simulated ground snow albedo,

Evaluation and Optimization of Snow Albedo Scheme in Noah-MP Land Surface Model Using In Situ Spectral Observations in the Colorado Rockies

Ronnie Abolafia-Rosenzweig[1], Cenlin He[1], S. McKenzie Skiles[2], Fei Chen[1], and David Gochis[1]

[1]National Center for Atmospheric Research, Boulder, CO, USA, [2]Department of Geography, University of Utah, Salt Lake City, UT, USA

Abolafia-Rosenzweig et al. (2022, JAMES): Optimizing BATS snow albedo parameters improves simulated snow albedo accuracy, particularly during ablation periods

Noah-MP snow compaction formulation

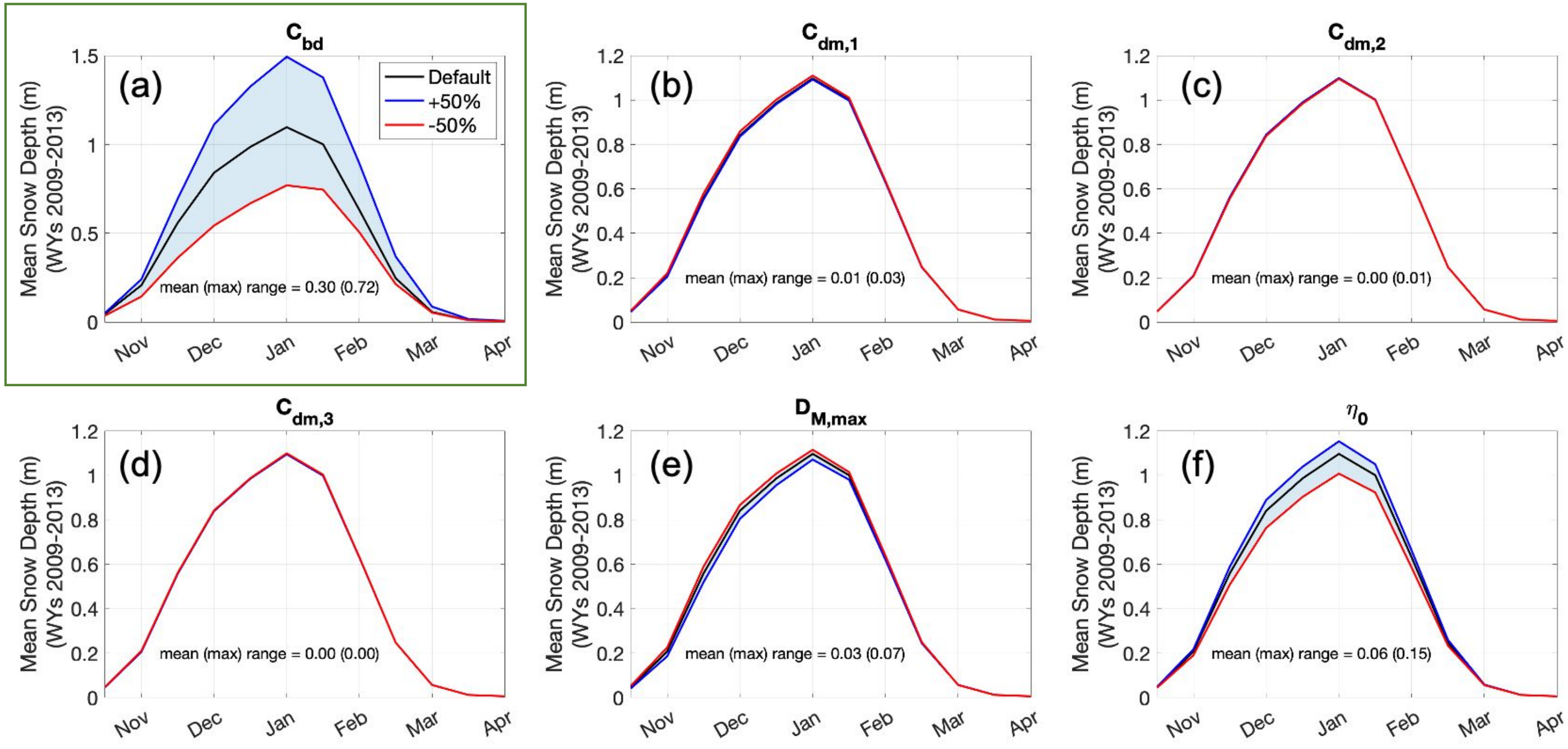
<u>compaction from overburden and metamorphic changes</u>

$$\Delta F_{DZ,sno-i} = max(-0.5\,, D_{DZ,dm-i} + \boxed{D_{DZ,bd-i}} + D_{DZ,melt-i}) \times \Delta t$$

$\Delta F_{DZ,sno-i}$ = time rate of fractional snow depth change
$D_{DZ,dm}$ = compaction from destructive metamorphism
$D_{DZ,bd}$ = compaction from overburden
$D_{DZ,metl}$ = melt metamorphism

He et al. (2023) for detailed description

Parameter sensitivity



Snow depth from three simulations for each compaction parameter with +/-50% perturbations to each parameter

$$D_{DZ,bd} = \frac{-(W_{abv} + 0.5\times W_{sno-i})\times e^{\left(-0.08\times(T_{frz} - TSNO_i) - C_{bd}\times\frac{W_{ice,sno-i}}{Dzsno-i}\right)}}{\eta_0}$$

(Compaction from overburden)

The Noah-MP snow densification scheme still uses parameters derived over 50-years ago

Densification of Seasonal Snow Cover*

Kenji KOJIMA
小 島 賢 治
The Institute of Low Temperature Science
Hokkaido University, Sapporo, Japan

Abstract

The theory of densification of snow, which is based on an empirical relation between the compactive viscosity factor and the density, has been applied to the numerical computations of depth-density profiles of snow cover under various conditions of mass accumulation of snow. This paper is concerned with the theoretical computations of time variation of density profiles of snow and the depth of seasonal snow cover under varying accumulation rates, where Sorge's law does not hold. The computed results are found to be in good agreement with the data observed in Sapporo and Moshiri, Hokkaido.

Densification of slightly wet snow is found to occur at nearly the same rate as that for dry

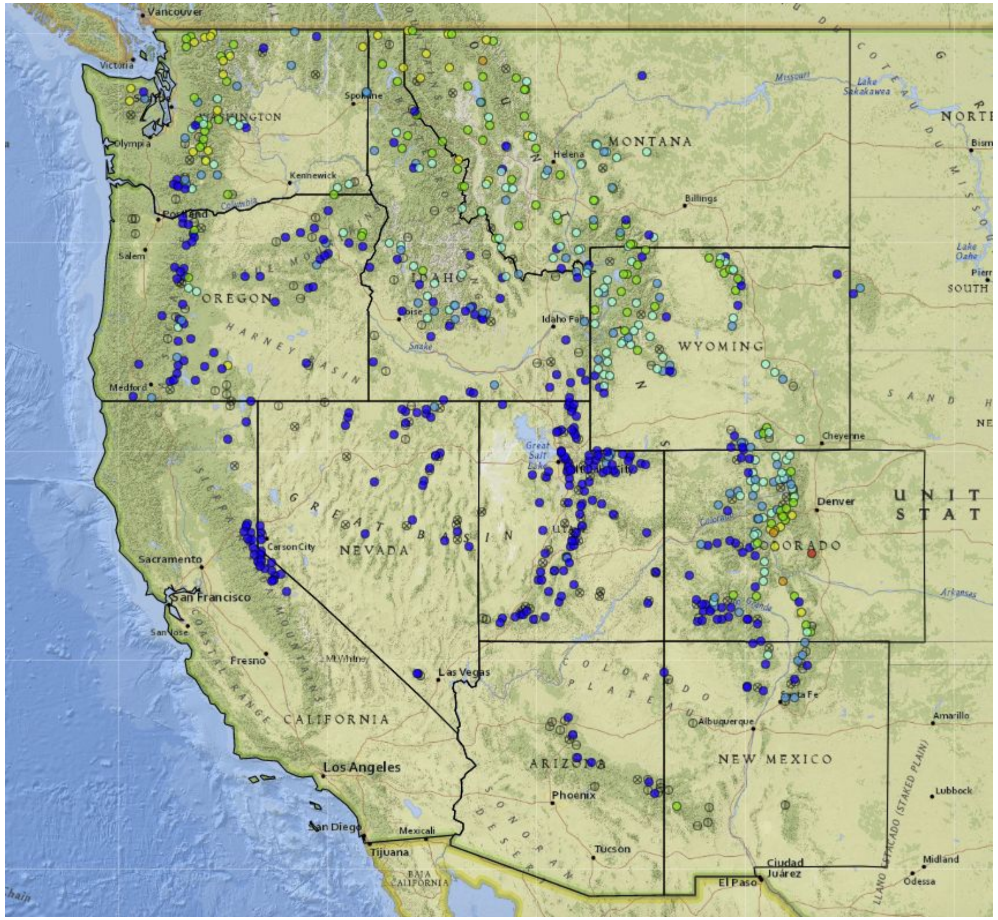
$$\eta_C(\rho) = Ce^{k\rho}, \qquad (2\text{ a})$$

where C is the value of η_{C1} when ρ_1 is reduced to zero. It was also found that k had the value 21 $g^{-1} \cdot cm^3$ for most dry compact snow layers and C was dependent not only

2 locations in Hokkaido with <5-year record

Kojima (1967)

Today we have dense networks of snow observations!



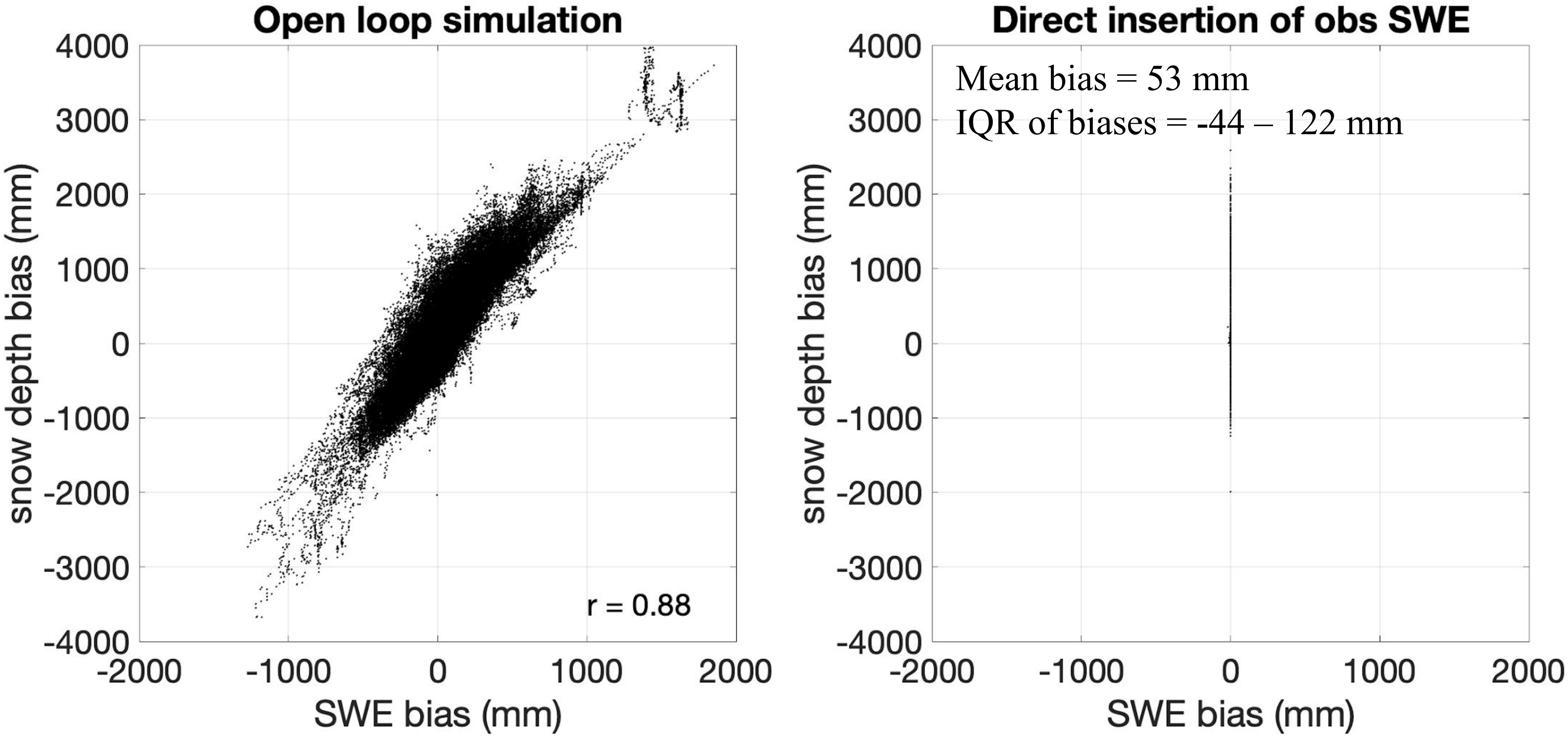
SNOTEL

- >800 stations
- decades of data
- >2,000,000M observations

https://www.nrcs.usda.gov/

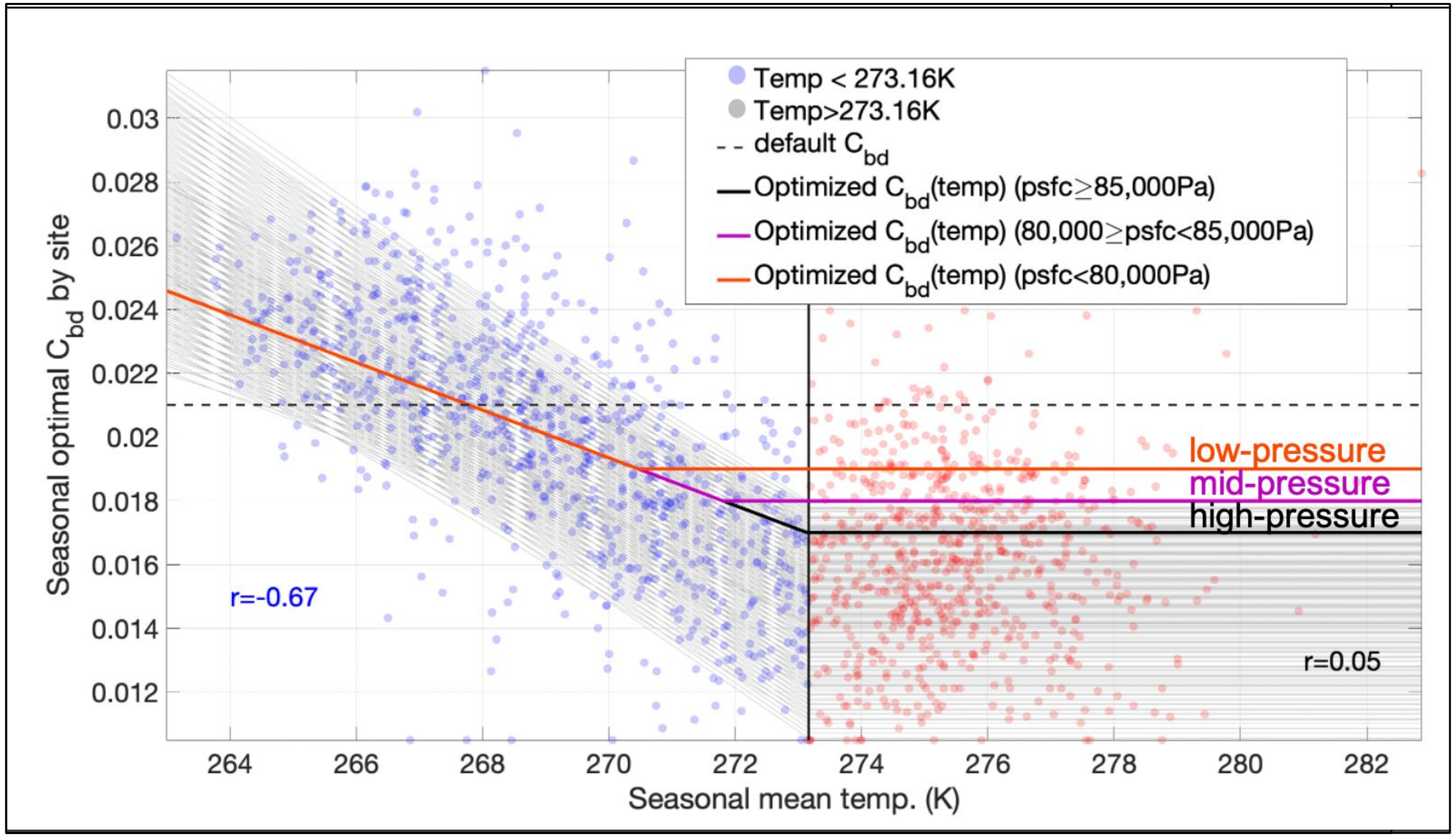
There are biases in this snow compaction formulation used by Noah-MP

Even when simulated SWE is constrained by observations



Optimizing C_{bd} based on temperature

- Ran 40 sims with varied C_{bd}: [0.0105 – 0.0315] (+/-50% of default value: 0.0210)
- For each of the 804 WUS SNOTEL sites we select optimal C_{bd} for accumulation seasons (Nov. – Mar.) and ablation seasons (post April 1)



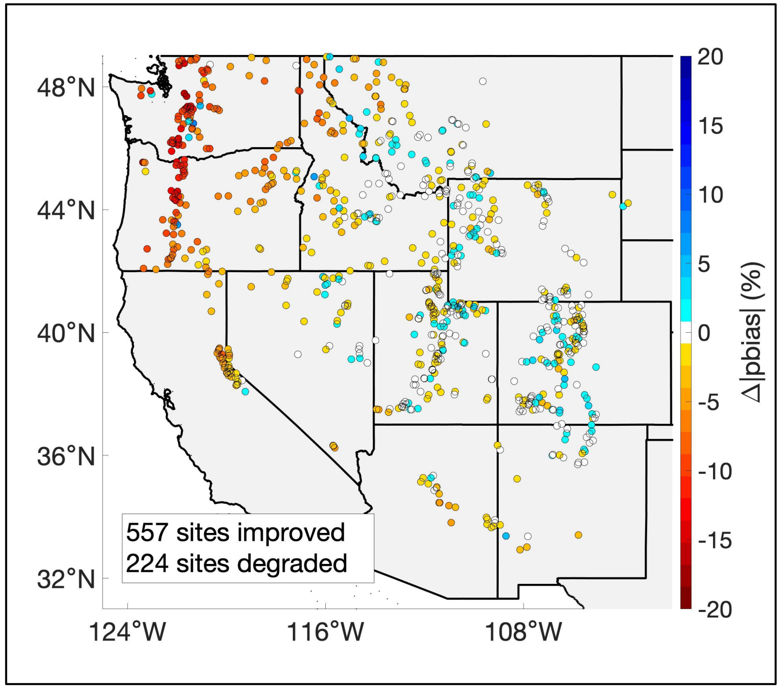
Given that there is a relationship between optimal C_{bd} w/ temp can we formulate C_{bd} as a function of temp using a linear (ie C_{bd} = m*temp +b) equation?

 Test 160 unique linear equations based on perturbations of this seasonal relationship between C_{bd} & temp

 Choose the “optimal” equation that results in the closest agreement with observed snow depth (small bias & RMSE)

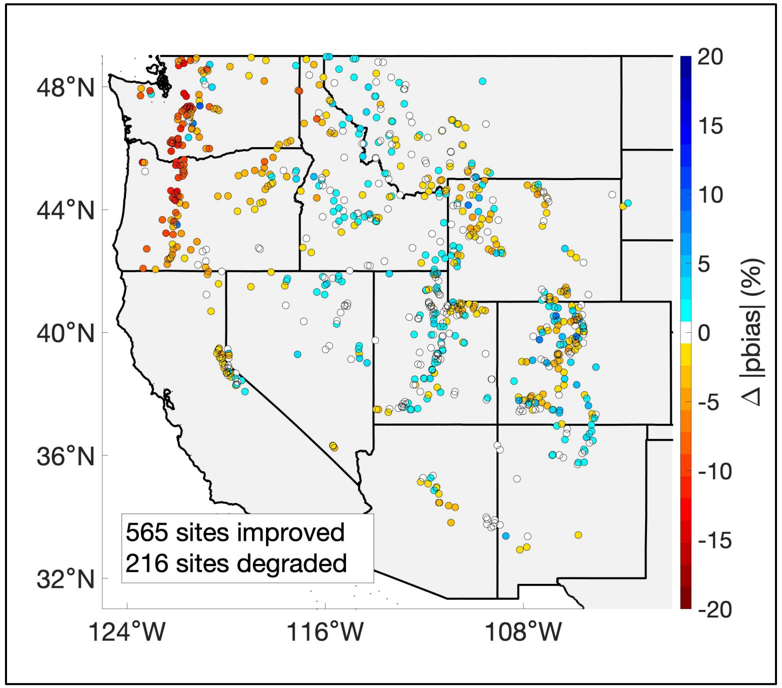
Change in bias for western US SNOTEL sites (enhanced – default simulation)

Total period (WYs 2009-2018)



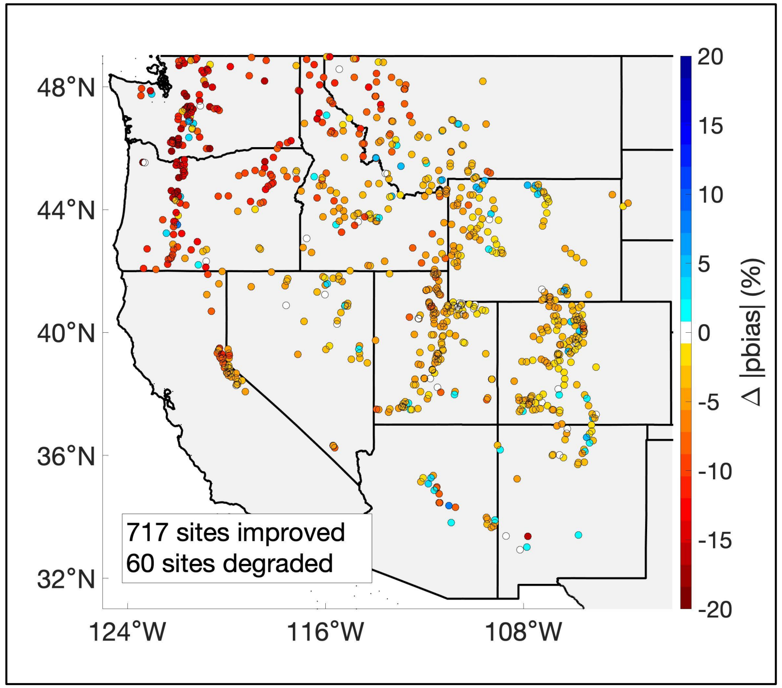
71% of sites with reduced bias

Accumulation periods



72% of sites with reduced bias

Ablation periods

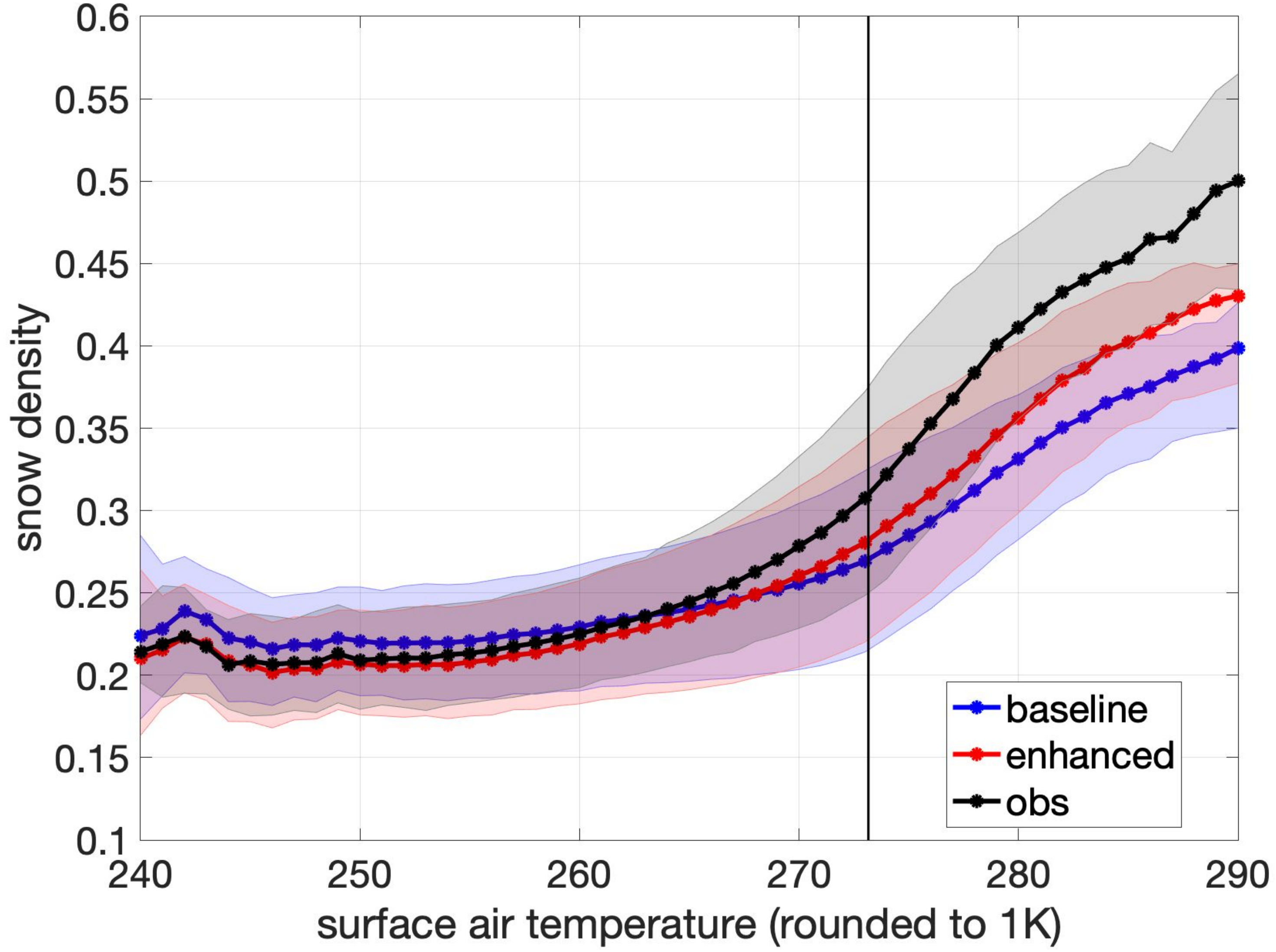


92% of sites with reduced bias

Larger improvements in western sites where temperatures are warmer, where default parameter is too high

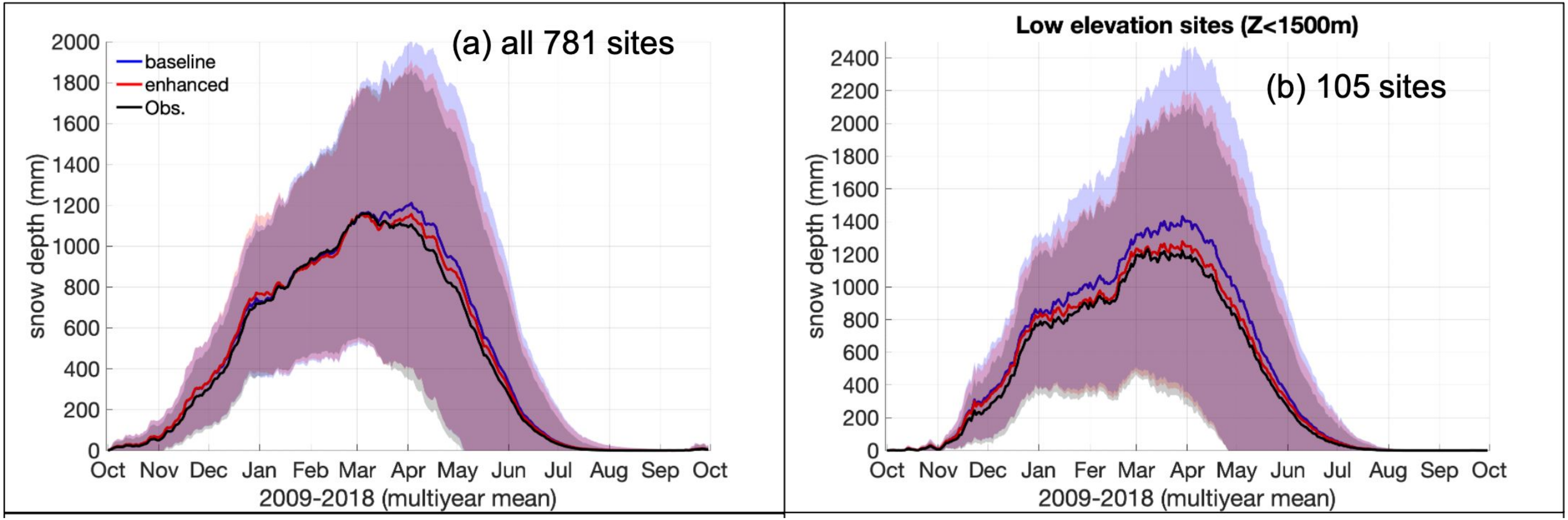
Snow density = SWE/snow depth

Snow density evaluation

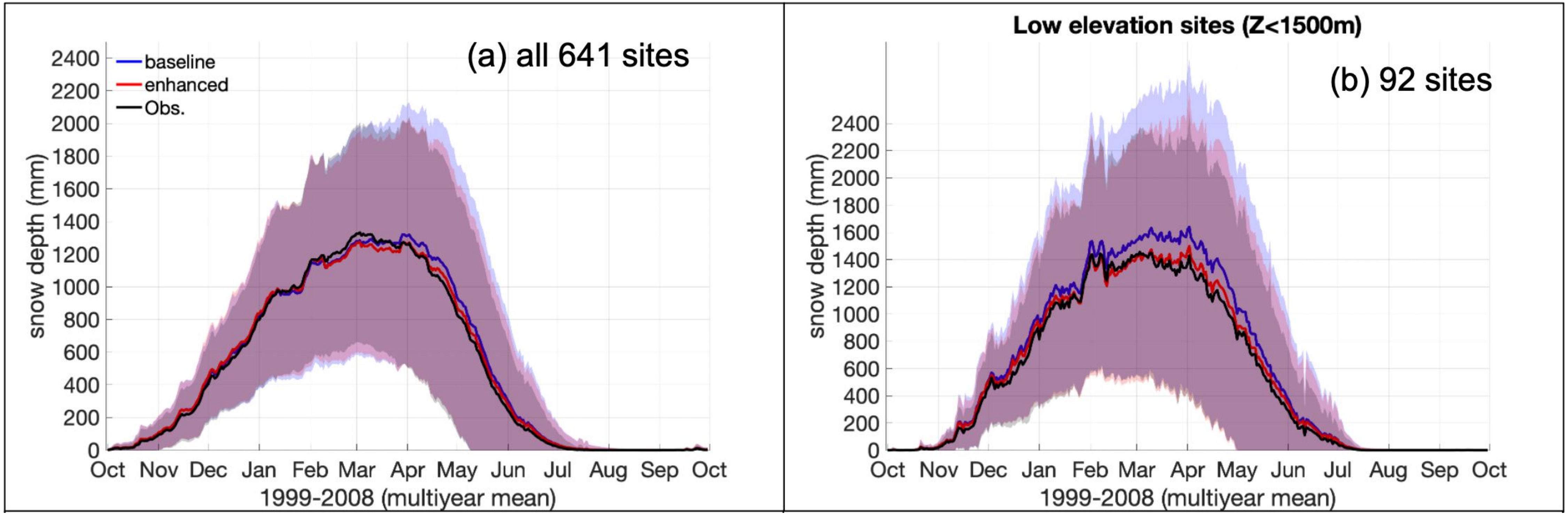


Significantly improved snow density in ablation period (reduced biases)

Improvements most substantial for low elevation sites

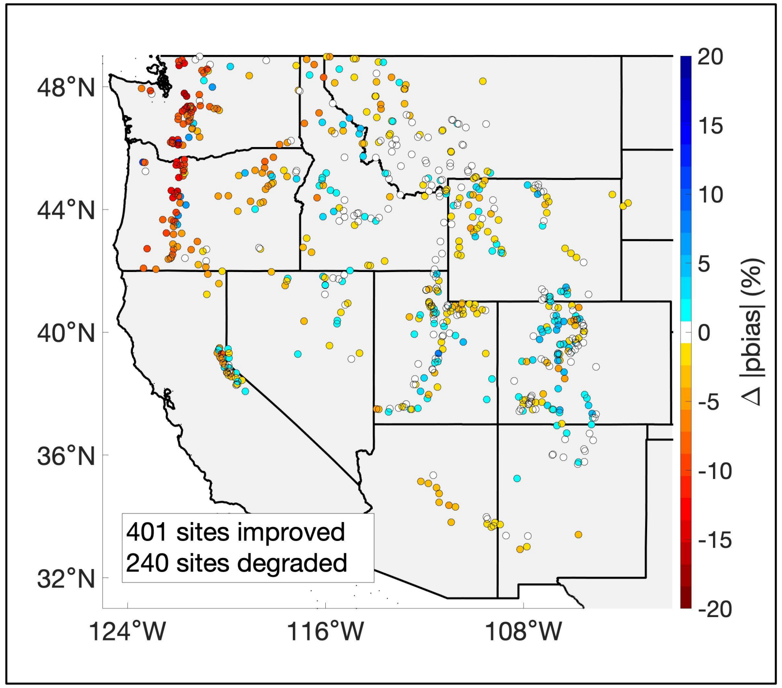


Compaction enhancements are temporally transferable: evaluation WYs 1999-2008



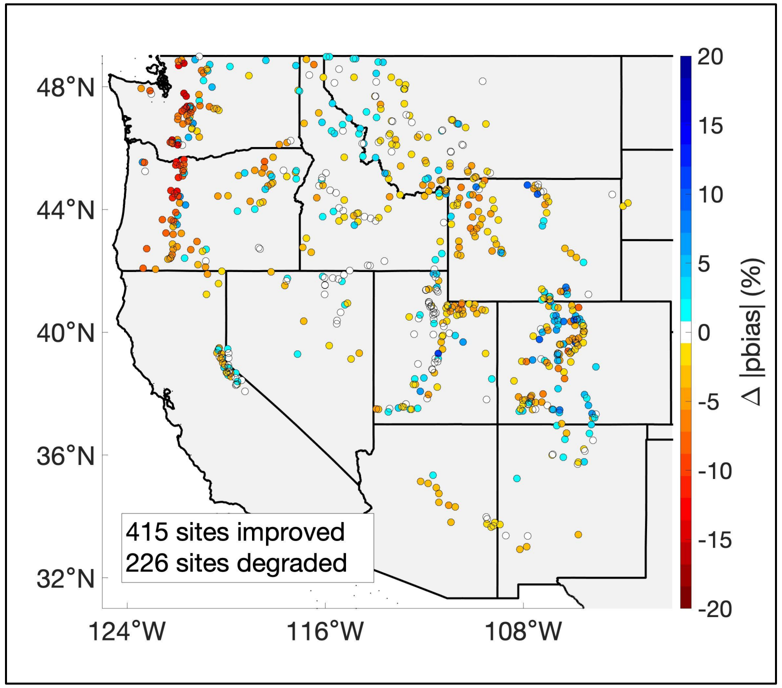
Site-by-site temporal transferability

Total period (WYs 1999-2008)



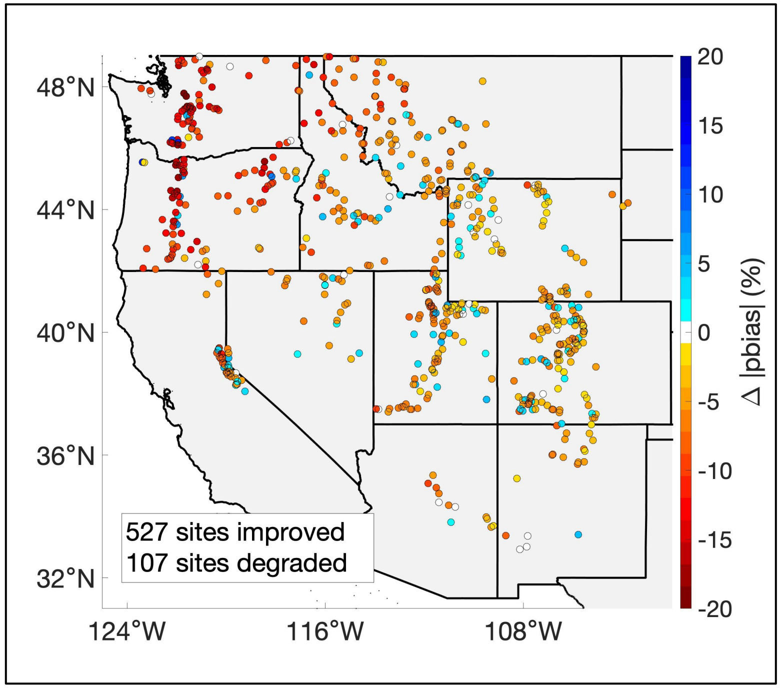
63% of sites with reduced bias

Accumulation periods



65% of sites with reduced bias

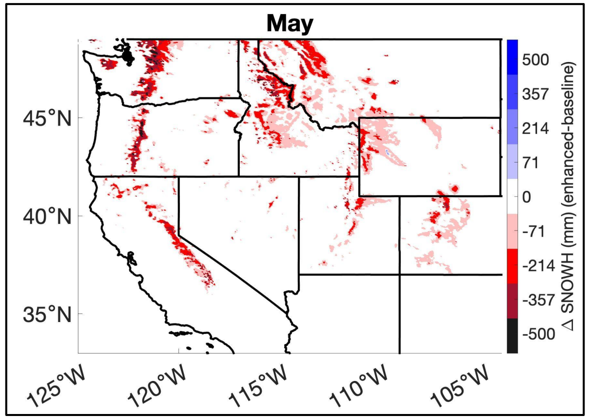
Ablation periods



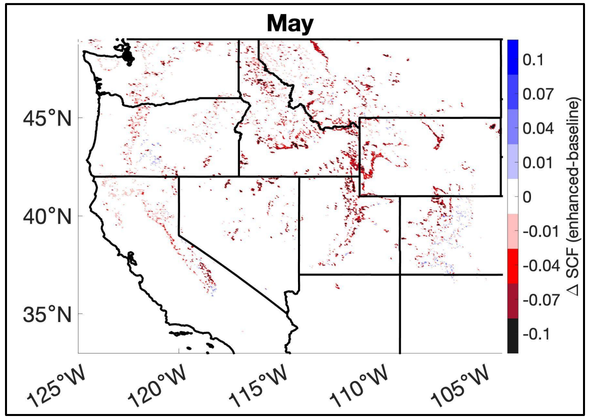
82% of sites with reduced bias

Open loop enhanced – baseline snow states from 4-km gridded W. US simulation

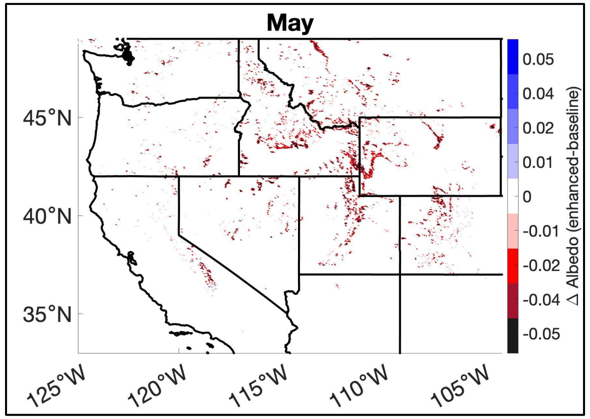
Snow depth



Snow fraction



Albedo



May 2011

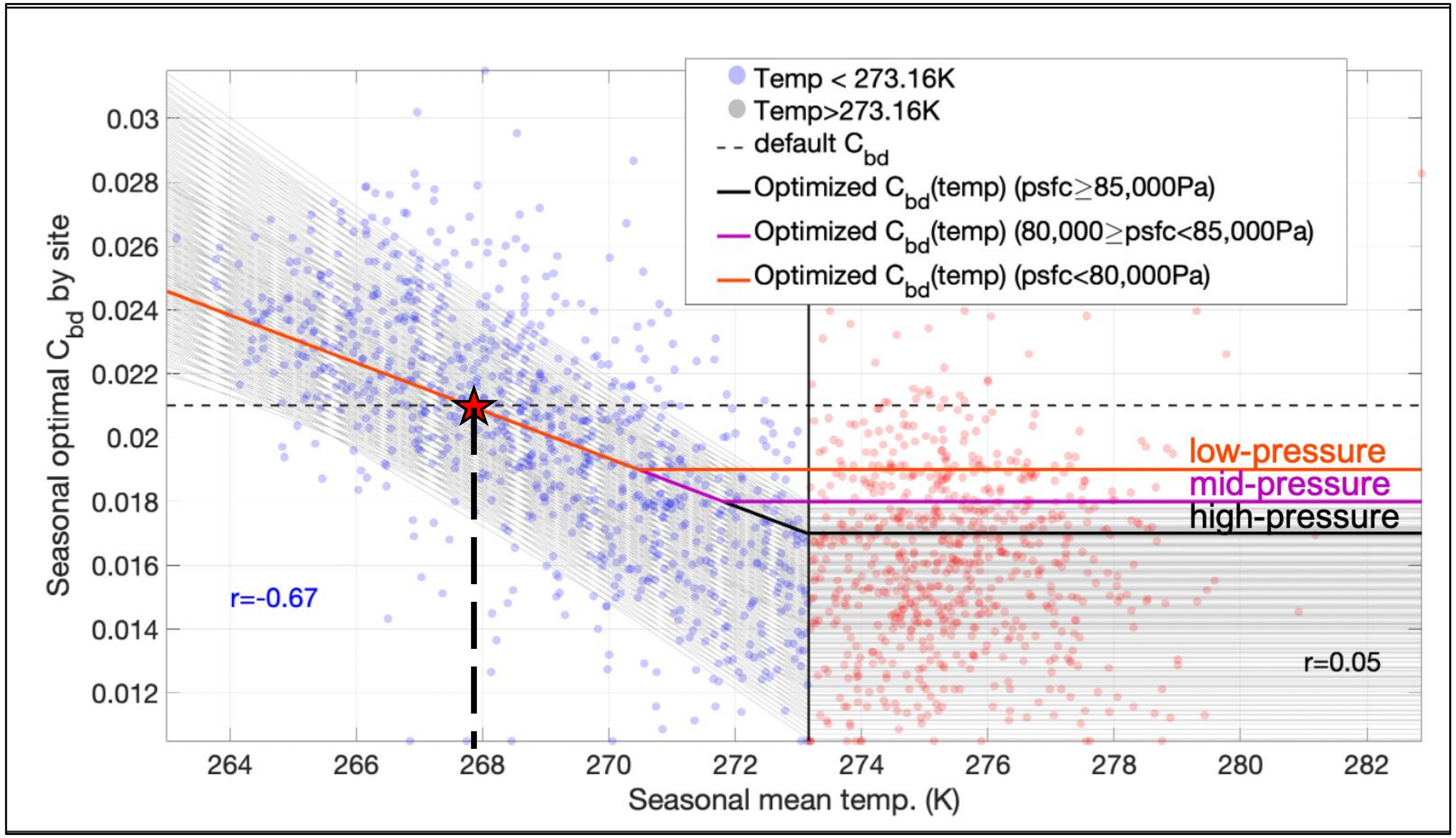
Conclusions

- Process level enhancements for Noah-MP are being performed to improve snowpack modeling
- Existing enhancements include:
  - Accounting for canopy-induced turbulence in the RSL
  - BATS snow albedo parameter optimization
  - Snow compaction enhancement
- Future work will focus on enhancing
  - Snow cover fraction
  - Canopy snow interception


Thank you!
abolafia@ucar.edu

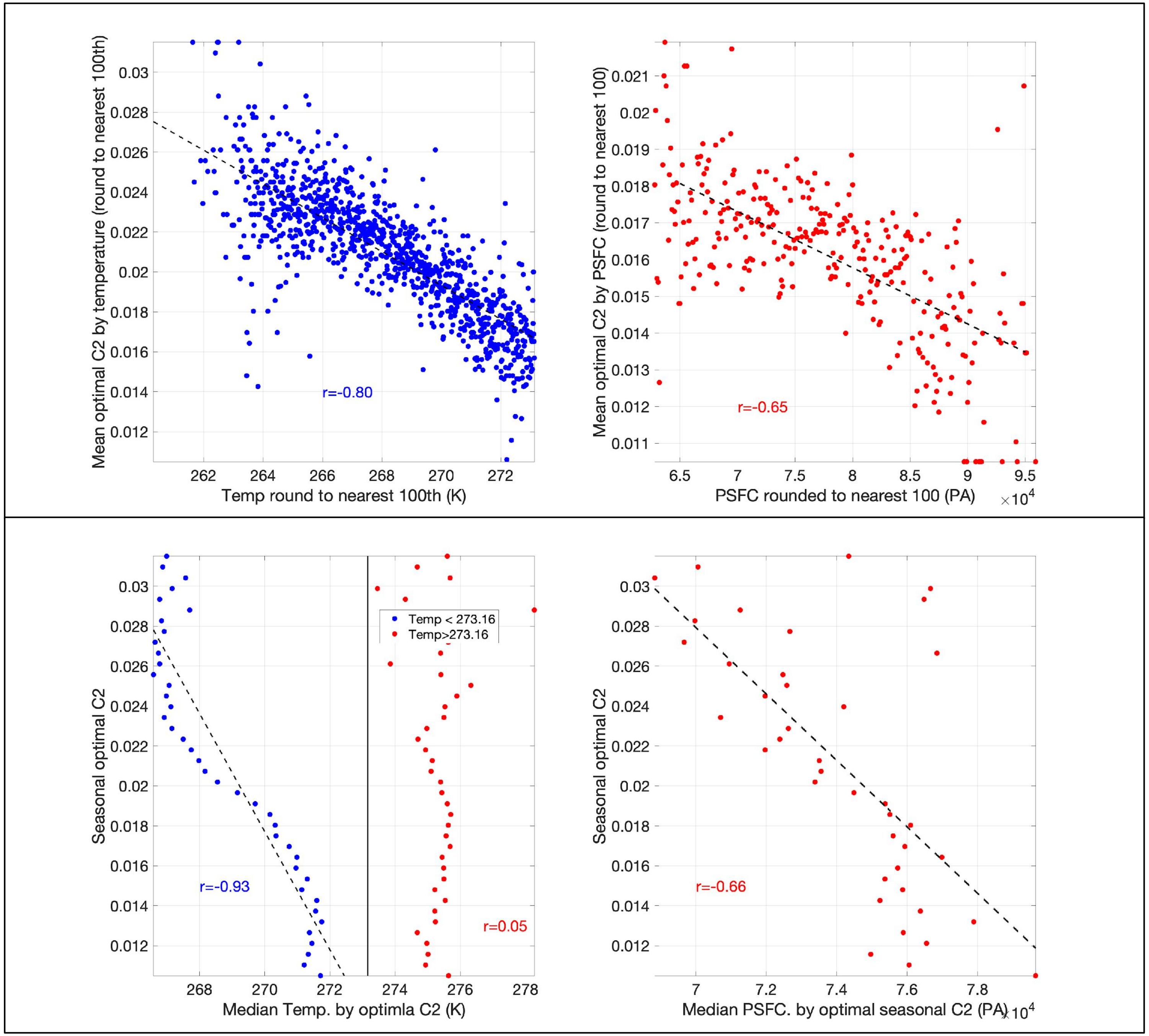
SI

Why does the enhancement have greatest improvements for warm conditions?

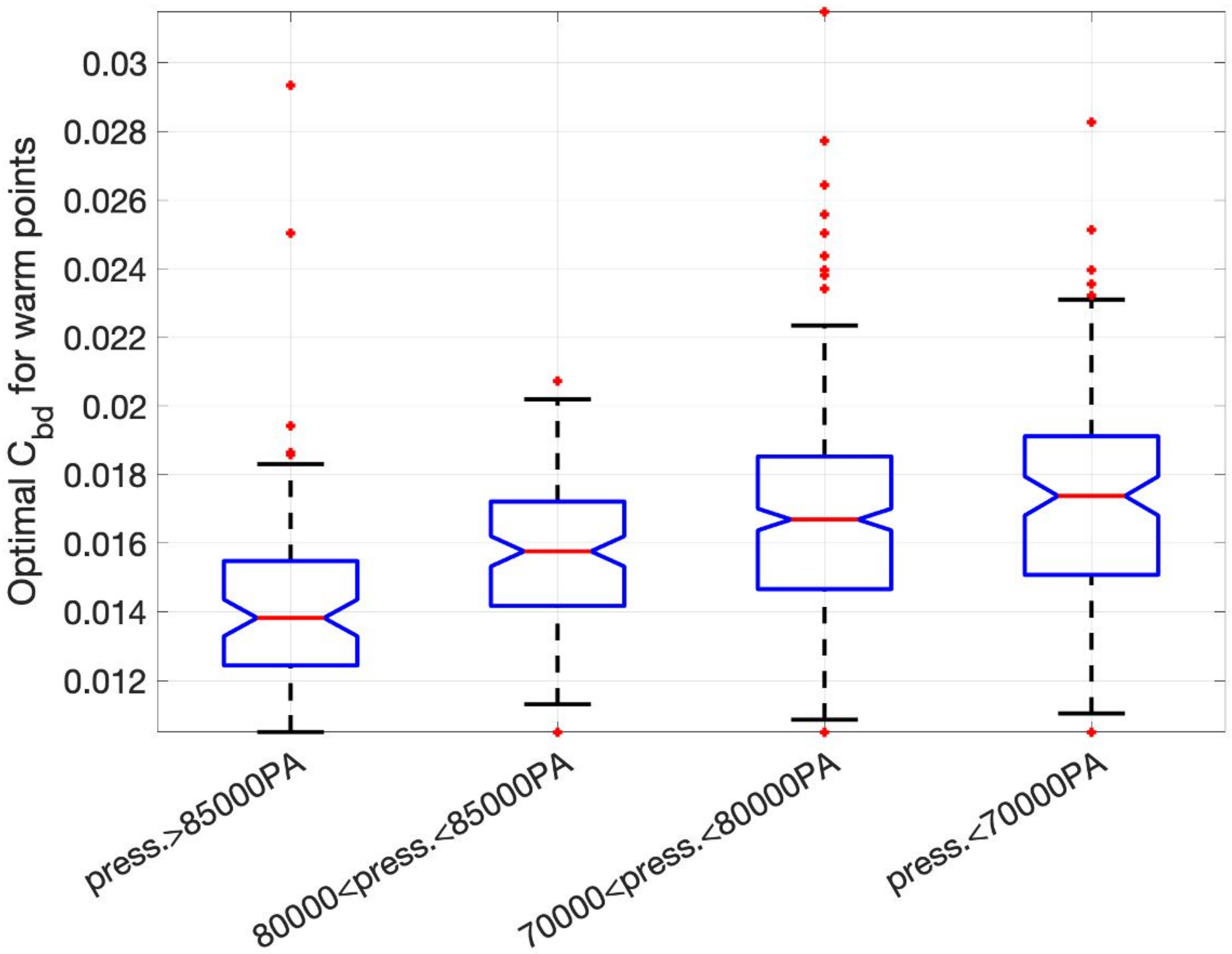


Default parameter value is suitable for cold temperatures (~ -5°C)…

but too high for warm temperatures

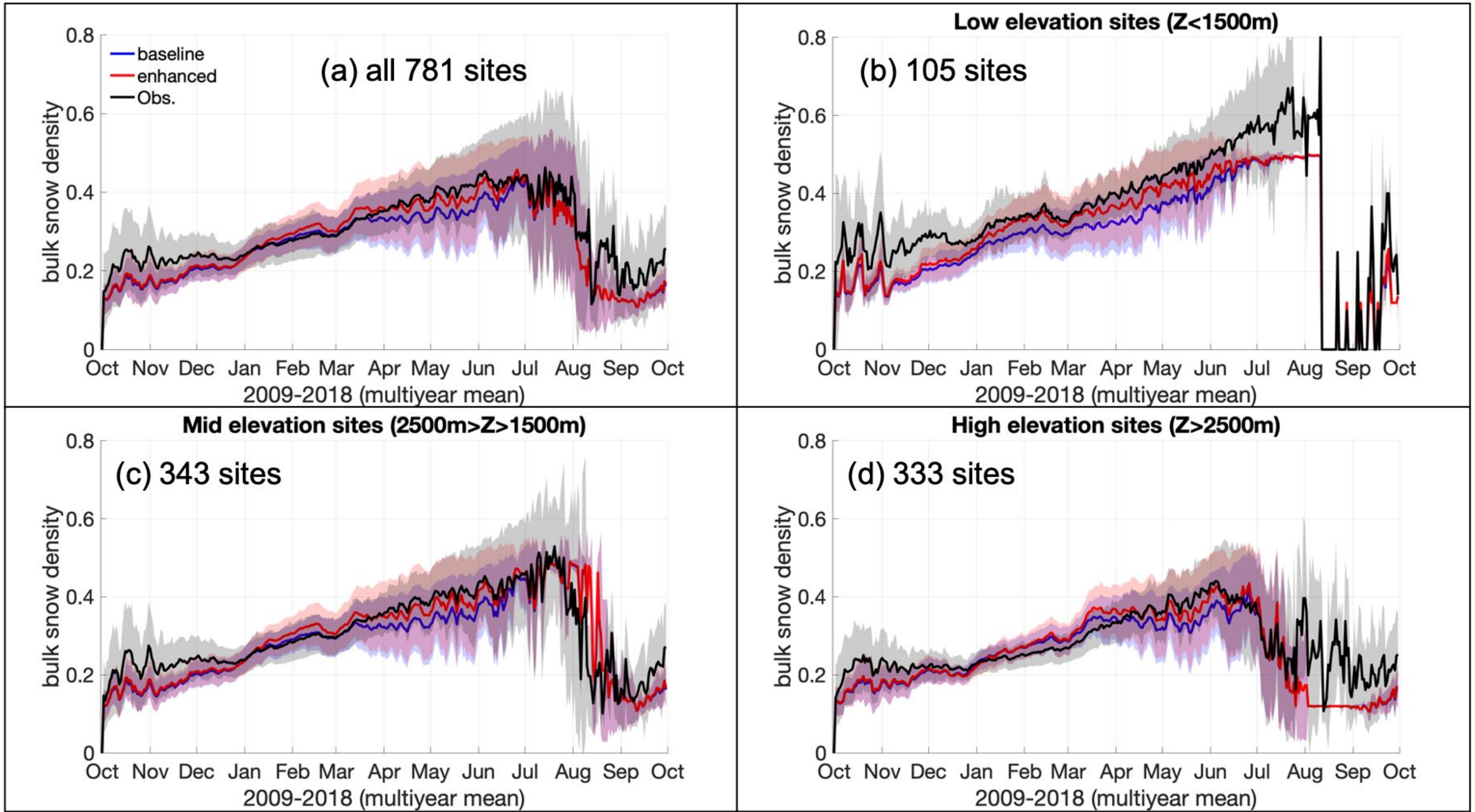


Mean optimal C2 by temperature (round to nearest 100th)
Temp round to nearest 100th (K)
r=-0.80
Mean optimal C2 by PSFC (round to nearest 100)
PSFC rounded to nearest 100 (PA)
$\times 10^4$
r=-0.65
Seasonal optimal C2
Median Temp. by optimla C2 (K)
Temp < 273.16
Temp>273.16
r=-0.93
r=0.05
Seasonal optimal C2
Median PSFC. by optimal seasonal C2 (PA)
$\times 10^4$
r=-0.66

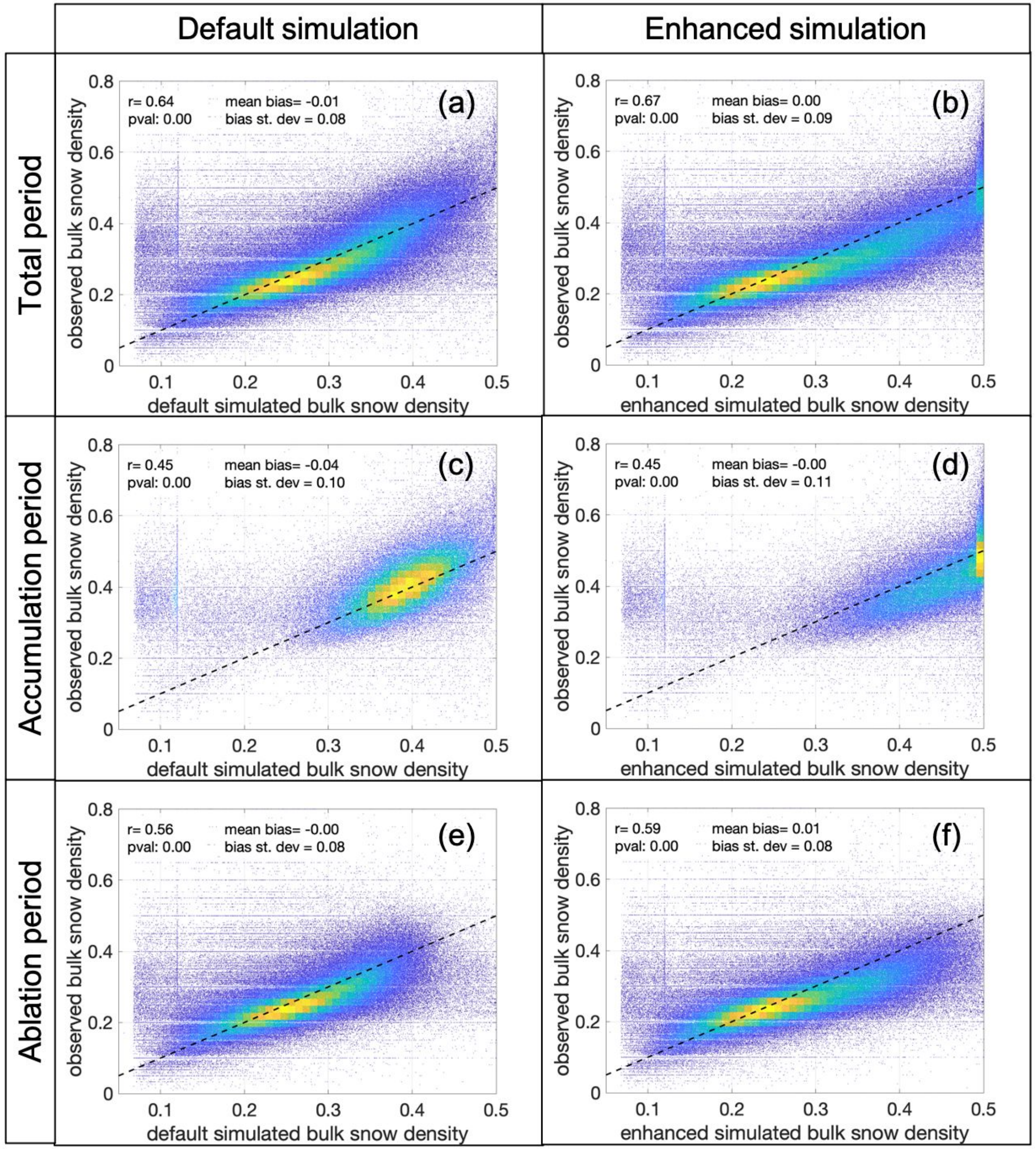


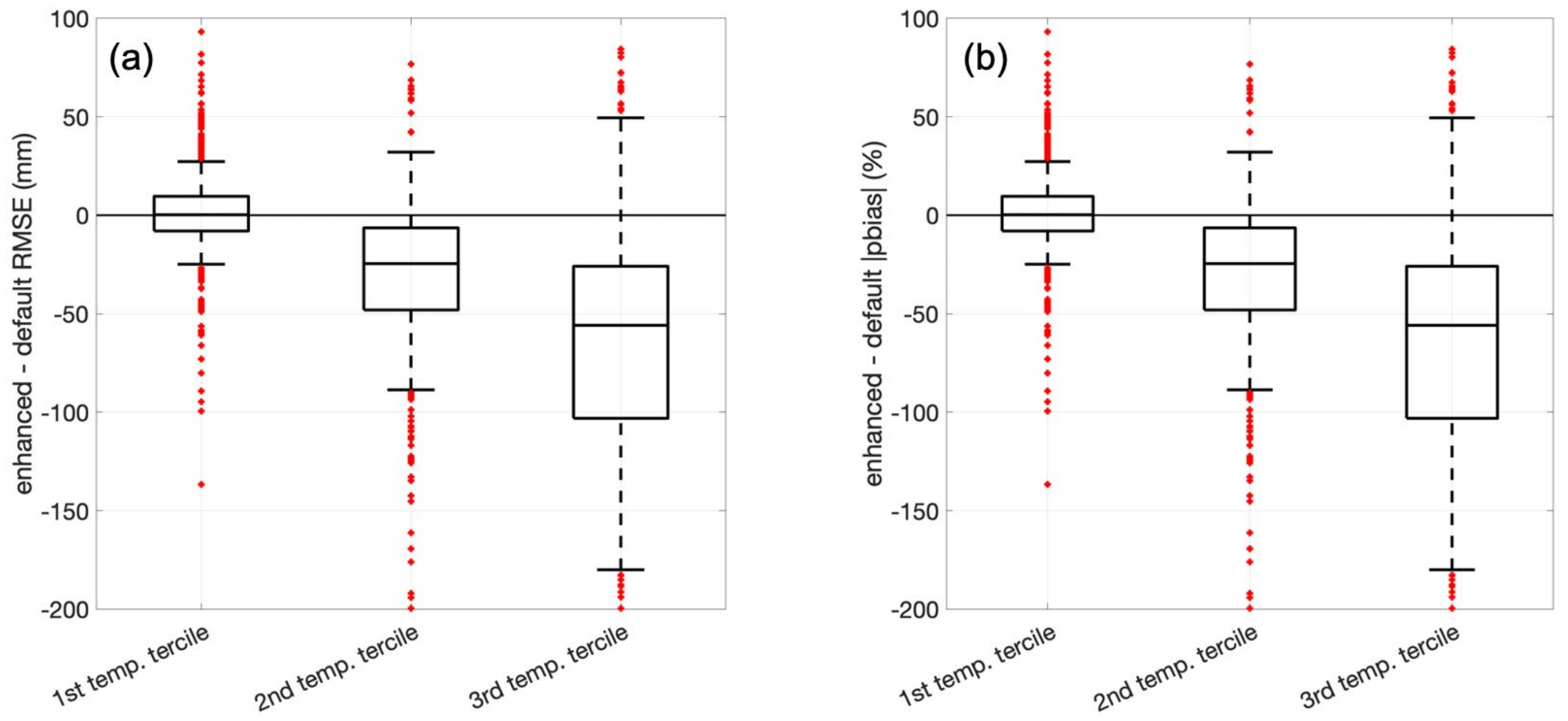
Optimal C_{bd} for warm points
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
press.>85000PA
80000<press.<85000PA
70000<press.<80000PA
press.<70000PA

Biases in snow density in OL sims are smaller with the enhanced simulation

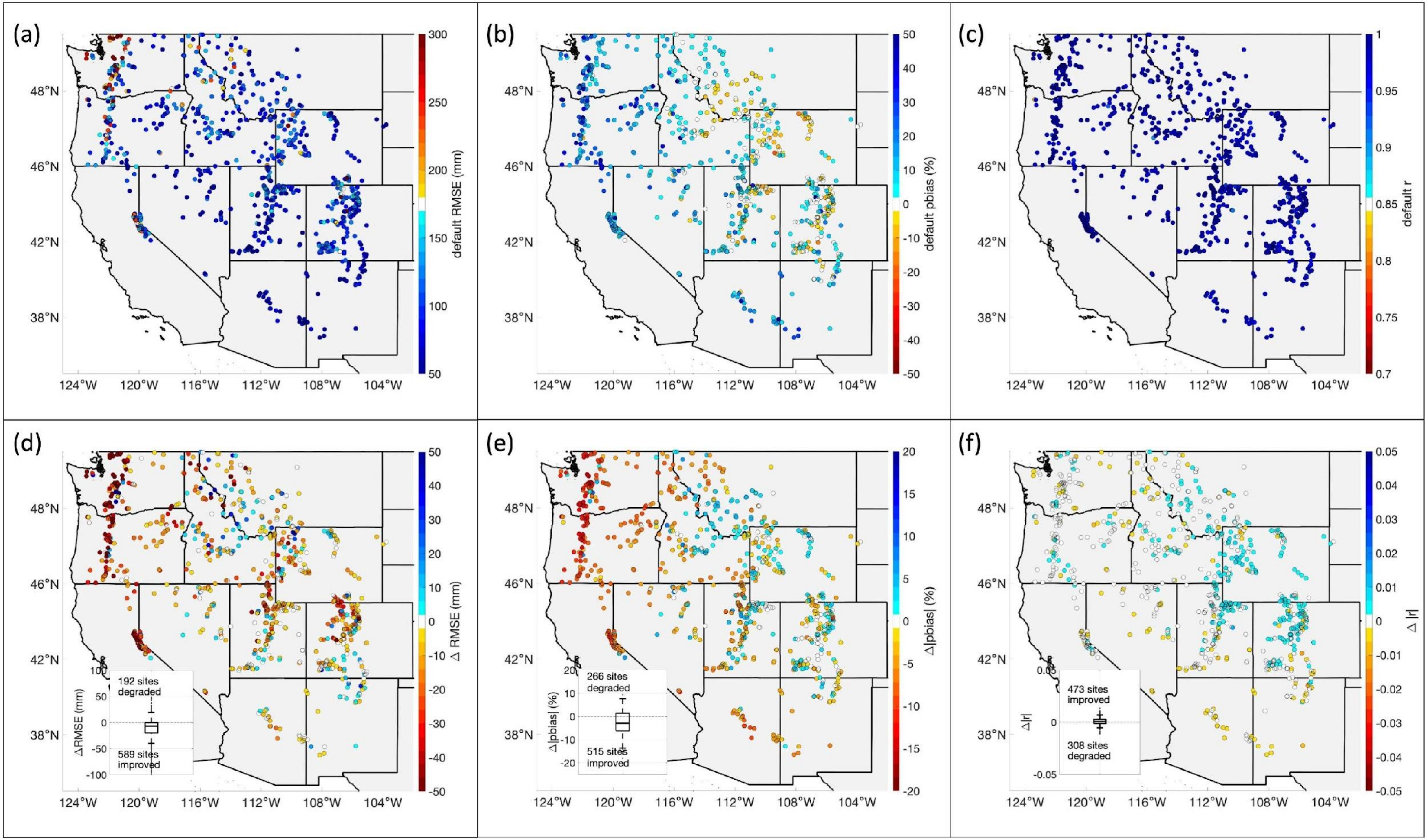


OL snow density comparison

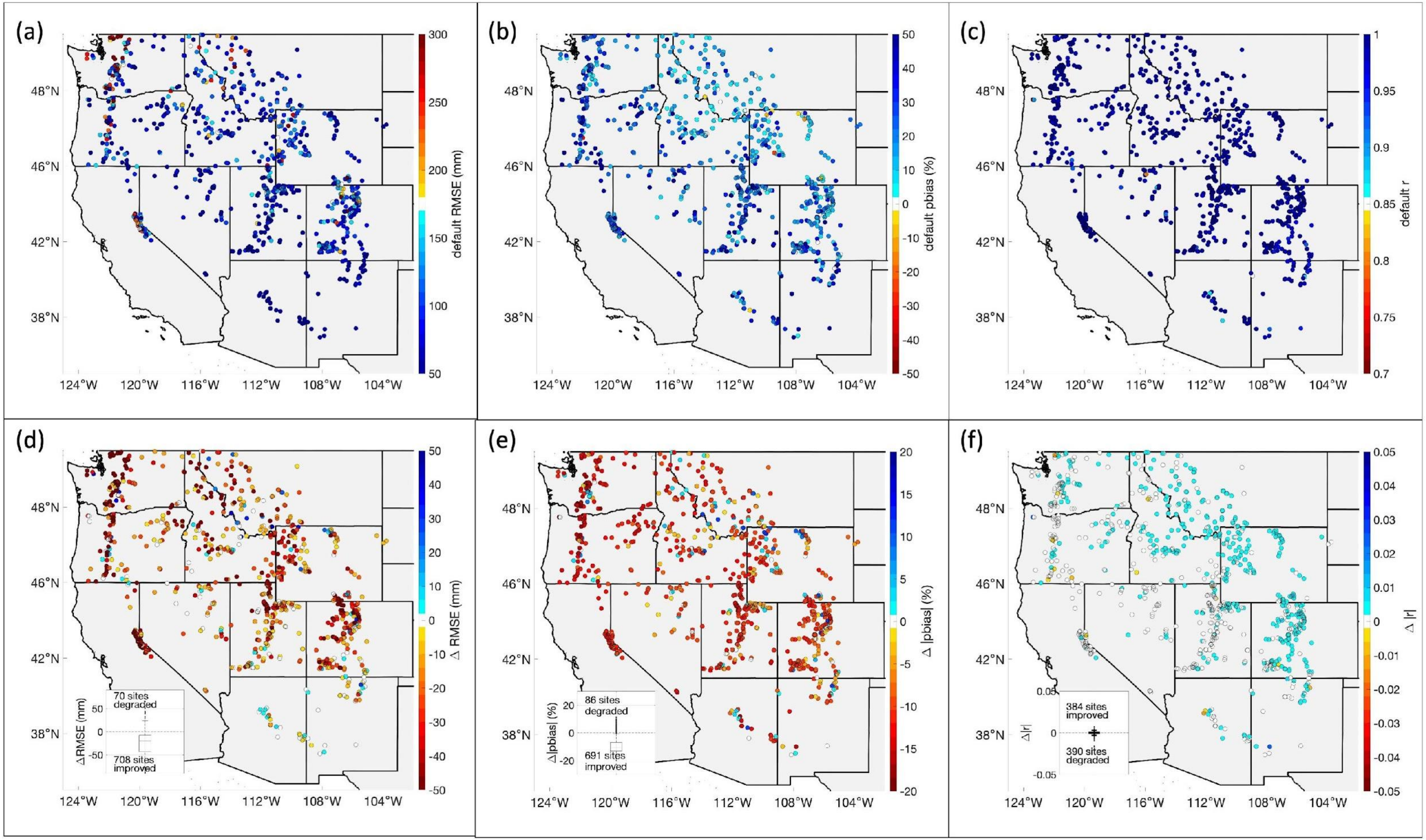




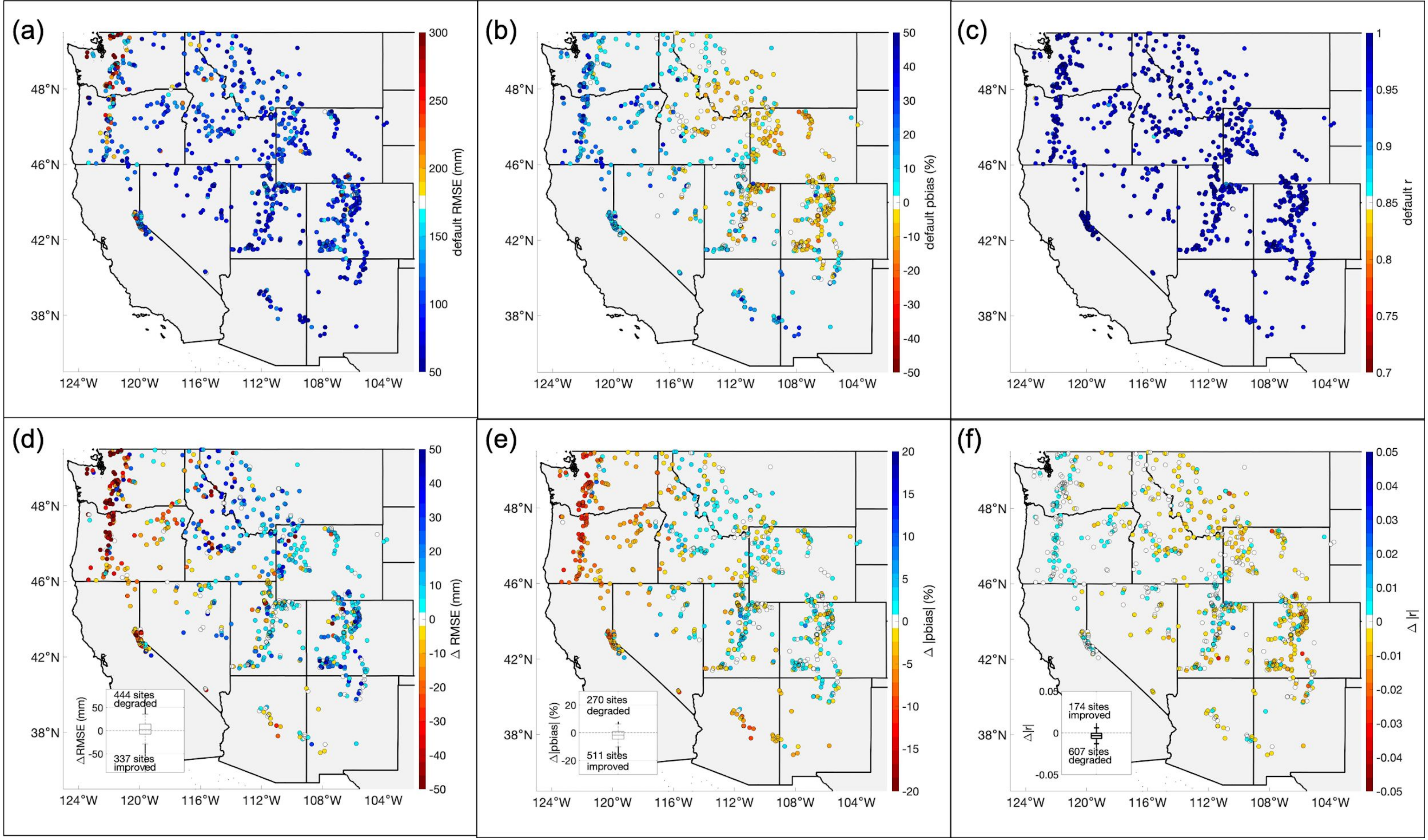
(a)
(b)
enhanced - default RMSE (mm)
enhanced - default |pbias| (%)
100
50
0
-50
-100
-150
-200
1st temp. tercile
2nd temp. tercile
3rd temp. tercile



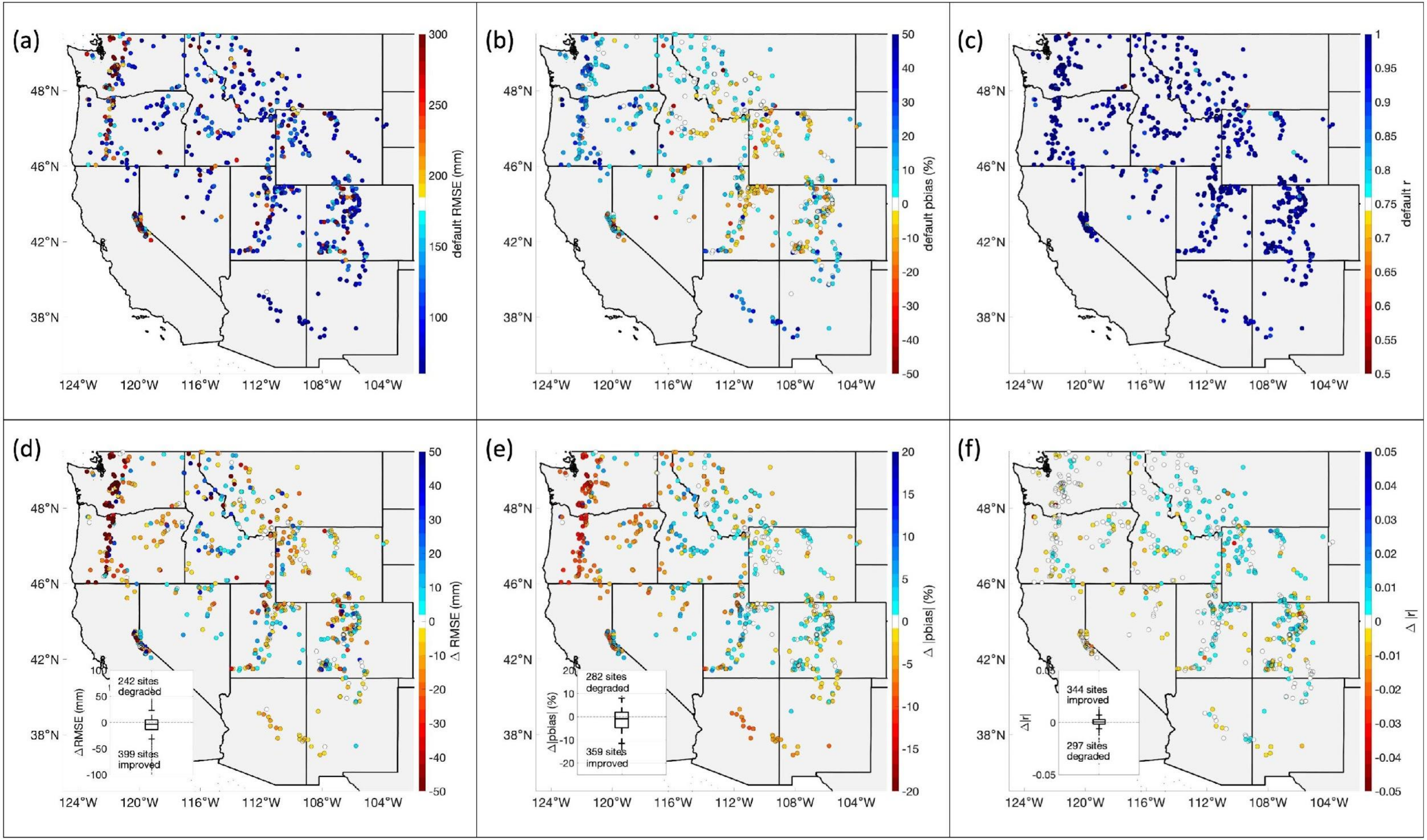
(a)
default RMSE (mm)
(b)
default pbias (%)
(c)
default r
(d)
Δ RMSE (mm)
192 sites degraded
589 sites improved
ΔRMSE (mm)
(e)
Δ|pbias| (%)
266 sites degraded
515 sites improved
(f)
Δ |r|
473 sites improved
308 sites degraded
48°N
46°N
42°N
38°N
124°W
120°W
116°W
112°W
108°W
104°W



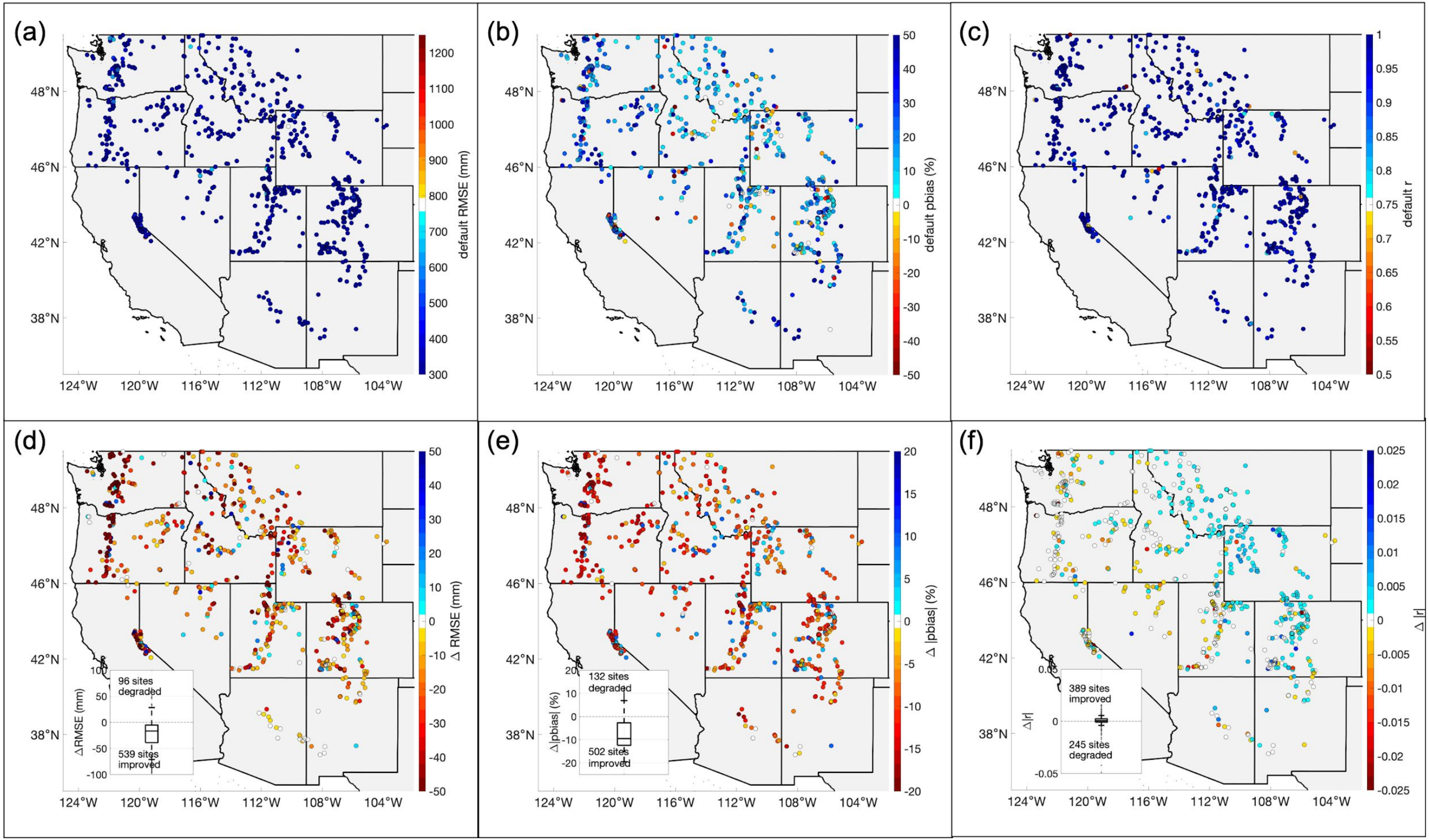
(a)
default RMSE (mm)
(b)
default pbias (%)
(c)
default r
(d)
Δ RMSE (mm)
70 sites degraded
708 sites improved
ΔRMSE (mm)
(e)
Δ |pbias| (%)
86 sites degraded
691 sites improved
Δ|pbias| (%)
(f)
Δ |r|
384 sites improved
390 sites degraded
Δ|r|
124°W
120°W
116°W
112°W
108°W
104°W
48°N
46°N
42°N
38°N

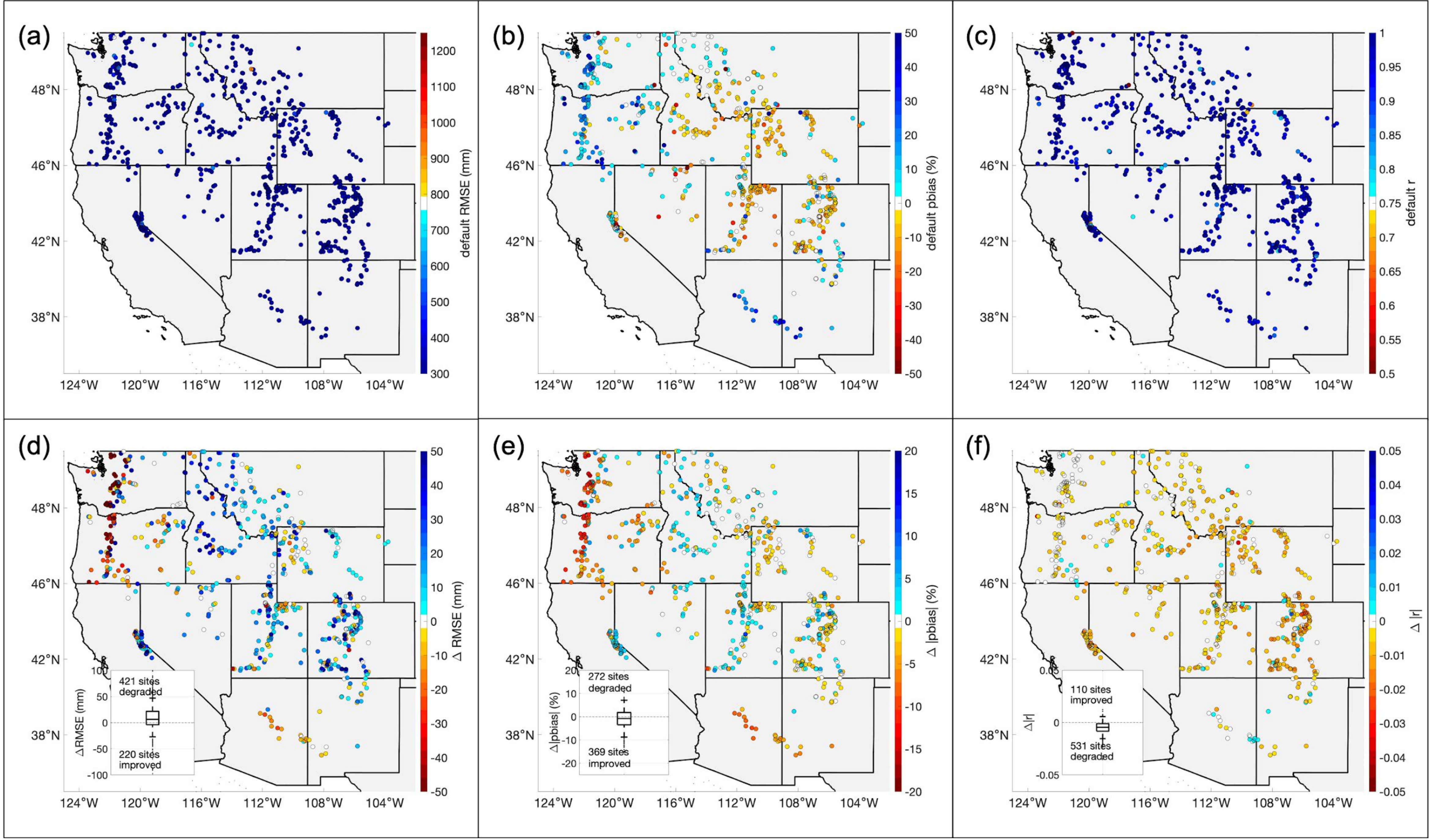


(a)
(b)
(c)
(d)
(e)
(f)
default RMSE (mm)
default pbias (%)
default r
Δ RMSE (mm)
Δ |pbias| (%)
Δ |r|
48°N
46°N
42°N
38°N
124°W
120°W
116°W
112°W
108°W
104°W
444 sites degraded
337 sites improved
ΔRMSE (mm)
270 sites degraded
511 sites improved
Δ|pbias| (%)
174 sites improved
607 sites degraded
Δ|r|



(a)
default RMSE (mm)
(b)
default pbias (%)
(c)
default r
(d)
Δ RMSE (mm)
242 sites degraded
399 sites improved
ΔRMSE (mm)
(e)
Δ |pbias| (%)
282 sites degraded
359 sites improved
Δ|pbias| (%)
(f)
Δ |r|
344 sites improved
297 sites degraded
Δ|r|
48°N
46°N
42°N
38°N
124°W
120°W
116°W
112°W
108°W
104°W


(a)
default RMSE (mm)
(b)
default pbias (%)
(c)
default r
(d)
Δ RMSE (mm)
96 sites degraded
539 sites improved
ΔRMSE (mm)
(e)
Δ |pbias| (%)
132 sites degraded
502 sites improved
Δ|pbias| (%)
(f)
Δ |r|
389 sites improved
245 sites degraded
Δ|r|
48°N
46°N
42°N
38°N
124°W
120°W
116°W
112°W
108°W
104°W


(a)
(b)
(c)
(d)
(e)
(f)
48°N
46°N
42°N
38°N
124°W
120°W
116°W
112°W
108°W
104°W
default RMSE (mm)
1200
1100
1000
900
800
700
600
500
400
300
default pbias (%)
50
40
30
20
10
0
-10
-20
-30
-40
-50
default r
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
Δ RMSE (mm)
ΔRMSE (mm)
421 sites degraded
220 sites improved
100
50
0
-50
-100
Δ |pbias| (%)
Δ|pbias| (%)
272 sites degraded
369 sites improved
20
15
10
5
0
-5
-10
-15
-20
Δ |r|
Δ|r|
110 sites improved
531 sites degraded
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05