Improving snow albedo modeling in Noah-MP v5 via coupling with a snow radiative transfer model

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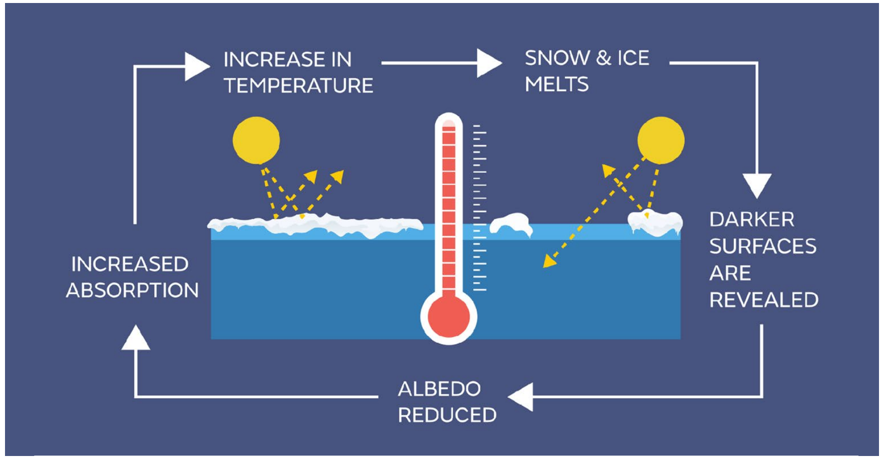
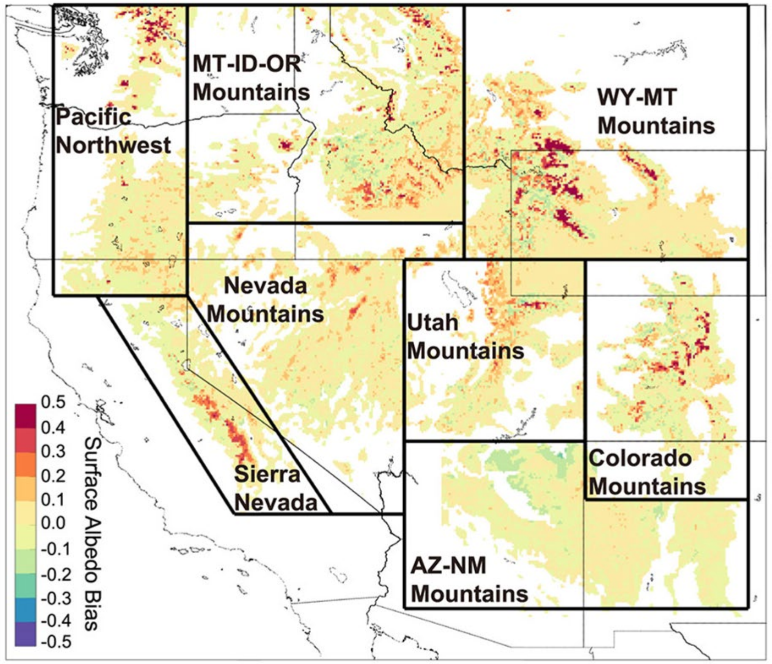
Snow albedo modeling and bias

- Snow albedo scheme in Noah-MP is semi-physical
  - The Biosphere-Atmosphere Transfer scheme, **BATS** (Dickinson et al., 1993; Yang et al., 1997)
    - Direct and diffuse radiation over visible and near-infrared wave bands
    - Fresh snow albedo, variations in snow age, solar zenith angle, grain size growth, and impurity (dirt or soot on snow)
  - A Canadian land surface scheme for GCMS, **CLASS** (Verseghy, 1991)
    - Overall snow surface albedo accounting for fresh snow albedo and snow age
- Snow albedo and temperature bias
  - E.g., overestimated snow albedo in the Western United States (He et al., 2019) and underestimated the variability of fresh snow albedo (Abolafia-Rosenzweig et al., 2022)

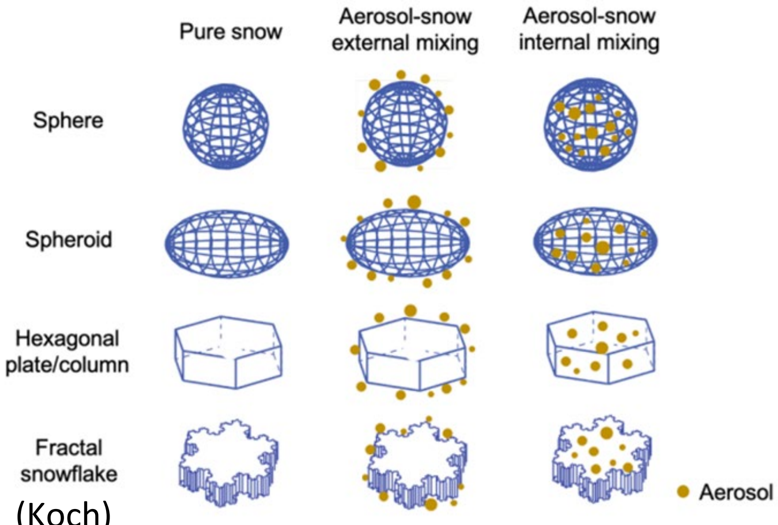




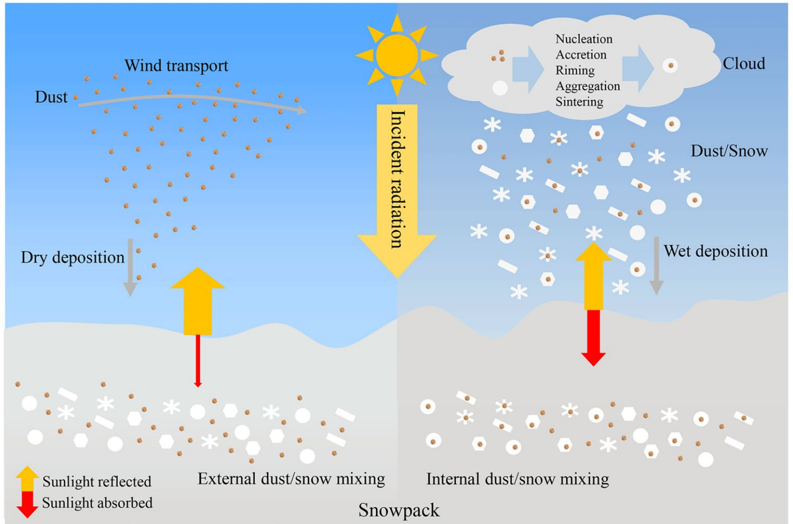
(He et al., 2019)

SNICAR model

- The latest version of Snow, Ice, and Aerosol Radiative (SNICAR) model (Flanner et al., 2021)
  - **Radiative transfer solver**
    - More accurate
  - **Different representations of ice optical properties**
    - More realistic
  - **Snow-radiation-aerosol interaction and feedback**
    - Light-absorbing particles: black carbon, organic carbon, dust, volcanic ash, and snow algae
    - Internal/External snow mixing
  - **Non-spherical snow grain** (Spheroids, hexagonal plates, and Koch snowflakes)
    - More realistic
  - **Hyperspectral calculations** (480-band, 10-nm spectral resolution)
    - More realistic
- **An old version of SNICAR transfer calculation has been coupled with an old version of Noah-MP LSM over Tibetan Plateau (Wang et al., 2020).**



(He et al., 2024)



(Shi et al., 2021)

Objectives and Methods

Coupling latest Noah-MP (v5.0) model with latest SNICAR version

↓ **Optimization**

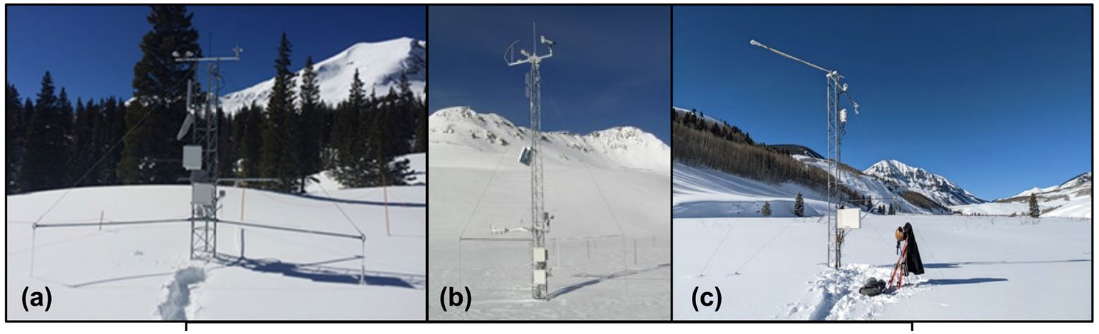
Constrain snow grain size from NoahMP-SNICAR with MODIS snow grain size data (MODSCAG)

↓ **Evaluation**

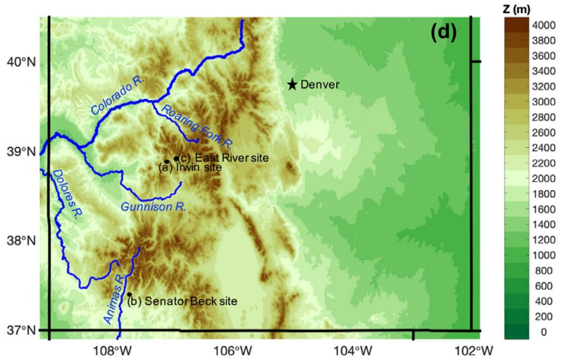
Evaluate NoahMP-SNICAR and default NoahMP-BATS against in-situ spectral albedo observations

↓ **Application**

Effects of snow grain size, shape, and light-absorbing particles on snow albedo and radiative forcing using NoahMP-SNICAR



(a) Irwin station, (b) Senator Beck station, and (c) East River station



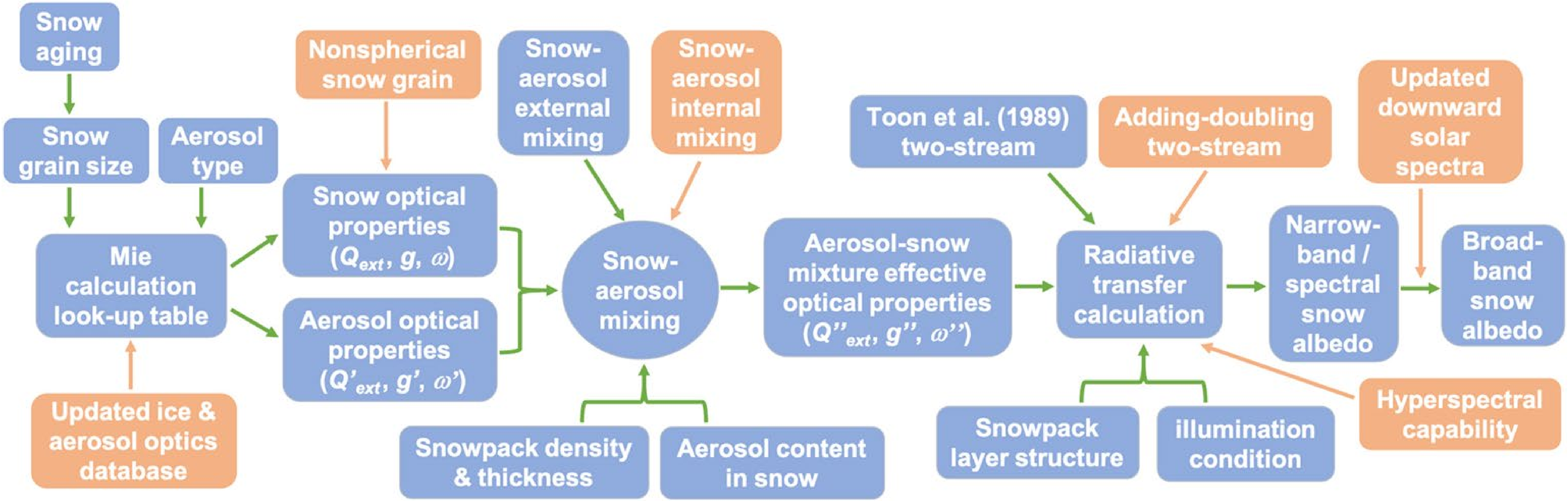
(Abolafia-Rosenzweig et al., 2022)

Experiments	Snow albedo scheme	Snow grain size	Snow shape	Snow impurities
Exp1 (baseline)	**SNICAR**	**Optimized**	**Hexagonal**	**LAPs**
Exp2	Same as Exp1	**Original**	Same as Exp1	Same as Exp1
Exp3	Same as Exp1	Same as Exp1	**Sphere**	Same as Exp1
Exp4	Same as Exp1	Same as Exp1	Same as Exp1	**no LAPs**
Exp5	**BATS**	-	-	-

- Climate: Hourly NOAA's Analysis of Record for Calibration data set merged with in-situ observation
- Vegetation type: Grass
- Aerosol deposition: MERRA-2
- Direct insertion of observed snow depth

Latest SNICAR model in CLM5

New Features and Enhancements in Community Land Model (CLM5) Snow Albedo Modeling: Description, Sensitivity, and Evaluation (He et al., 2024)



(He et al., 2024)

NoahMP-SNICAR model

New input variables

- Deposition flux (kg/m2/s)
  - hydrophilic black carbon
  - hydrophobic black carbon
  - hydrophilic organic carbon
  - hydrophobic organic carbon
  - mineral dust with five particle size bins (0.1-1.0, 1.0-2.5, 2.5-5.0, 5.0-10.0, and 10.0-100.0 µm in diameter)

New input optical properties (look-up table)

- snicar_optics_480bnd_c012422.nc
- snicar_optics_5bnd_c013122.nc

New input snow aging data (look-up table)

- snicar_drdt_bst_fit_60_c070416.nc

New processes

- SNICAR radiative transfer solver
- Snowpack heating on snow and soil temperature
- Snow-aerosol-radiation interactions
  - mass-conserving approach to account for the presence of light-absorbing particles within snowpack
- Snow grain growth and aging processes
  - wet and dry snow aging processes including liquid-water-induced metamorphism, dry snow metamorphism, refreezing of liquid water, and the addition of freshly fallen snow
  - vertical profiles of snow grain size

Multiple options in the namelist

SNOW_ALBEDO_OPTION = 1
! options for ground snow surface albedo [default = 1]
! **1 -> BATS
!   2 -> CLASS
!   **3 -> SNICAR**

SNICAR_BANDNUMBER_OPTION = 1
! number of wavelength bands used in SNICAR snow albedo calculation
! **1 -> 5
!   2 -> 480

SNICAR_SOLARSPEC_OPTION = 1
! type of downward solar radiation spectrum for SNICAR snow albedo calculation
! **1 -> mid-latitude winter
!   2 -> mid-latitude summer
!   3 -> sub-Arctic winter
!   4 -> sub-Arctic summer
!   5 -> Summit,Greenland,summer
!   6 -> High Mountain summer

SNICAR_SNOWOPTICS_OPTION = 3
! snow optics type using different refractive index databases in SNICAR
!   1 -> Warren (1984)
!   2 -> Warren and Brandt (2008)
! **3 -> Picard et al (2016)

SNICAR_DUSTOPTICS_OPTION = 1
! dust optics type for SNICAR snow albedo calculation
! **1 -> Saharan dust (Balkanski et al., 2007, central hematite)
!   2 -> San Juan Mountains dust, CO (Skiles et al, 2017)
!   3 -> Greenland dust (Polashenski et al., 2015, central absorptivity)

SNICAR_RTSOLVER_OPTION = 2
! option for two different SNICAR radiative transfer solver
!   1 -> Toon et a 1989 2-stream (Flanner et al. 2007)
! **2 -> Adding-doubling 2-stream (Dang et al.2019)

SNICAR_SNOWSHAPE_OPTION = 3
! option for snow grain shape in SNICAR (He et al. 2017 JC)
!   1 -> sphere
!   2 -> spheroid
! **3 -> hexagonal plate
!   4 -> Koch snowflake

SNICAR_USE_AEROSOL = .true.
! option to turn on/off aerosol deposition flux effect in snow in SNICAR
!   .false. -> without aerosol deposition flux effect
! **.true. -> with aerosol deposition flux effect

SNICAR_SNOWBC_INTMIX = .true.
! option to activate BC-snow internal mixing in SNICAR (He et al. 2017 JC)
!   .false. -> external mixing for all BC
! **.true. -> internal mixing for hydrophilic BC

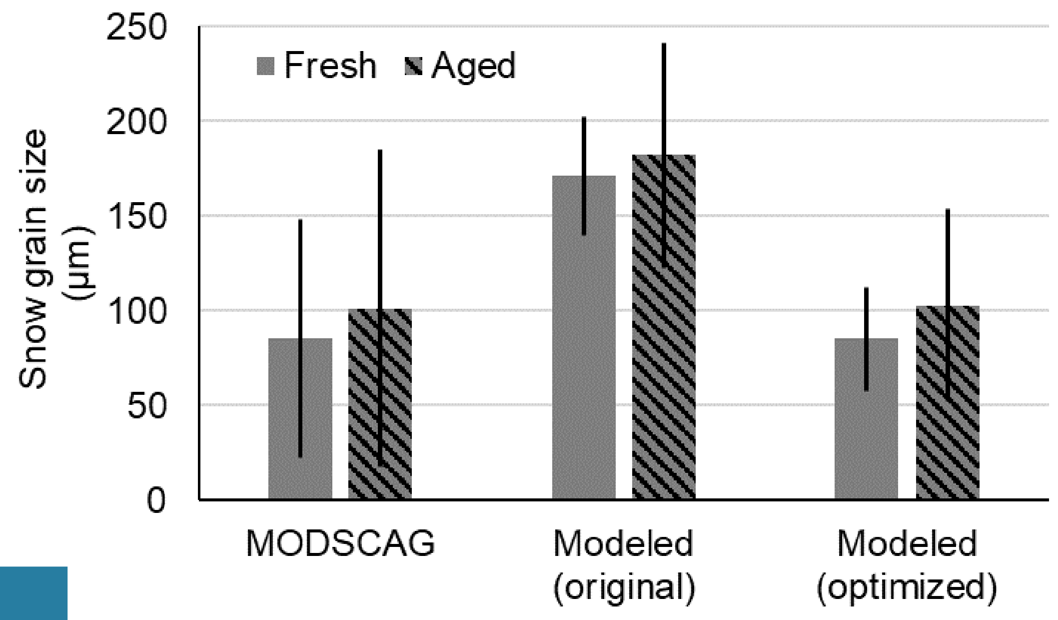
SNICAR_SNOWDUST_INTMIX = .true.
! option to activate dust-snow internal mixing in SNICAR (He et al. 2017 JC)
!   .false. -> external mixing for all dust
! **.true. -> internal mixing for all dust

SNICAR_USE_OC = .true.
! option to activate OC in snow in SNICAR
!   .false. -> without organic carbon in snow
! **.true. -> with organic carbon in snow

SNICAR_AEROSOL_READTABLE = .false.
! option to read aerosol deposition fluxes from table or not
! **.false. -> data read from NetCDF forcing file
!   .true. -> data read from table

Optimization of snow grain size

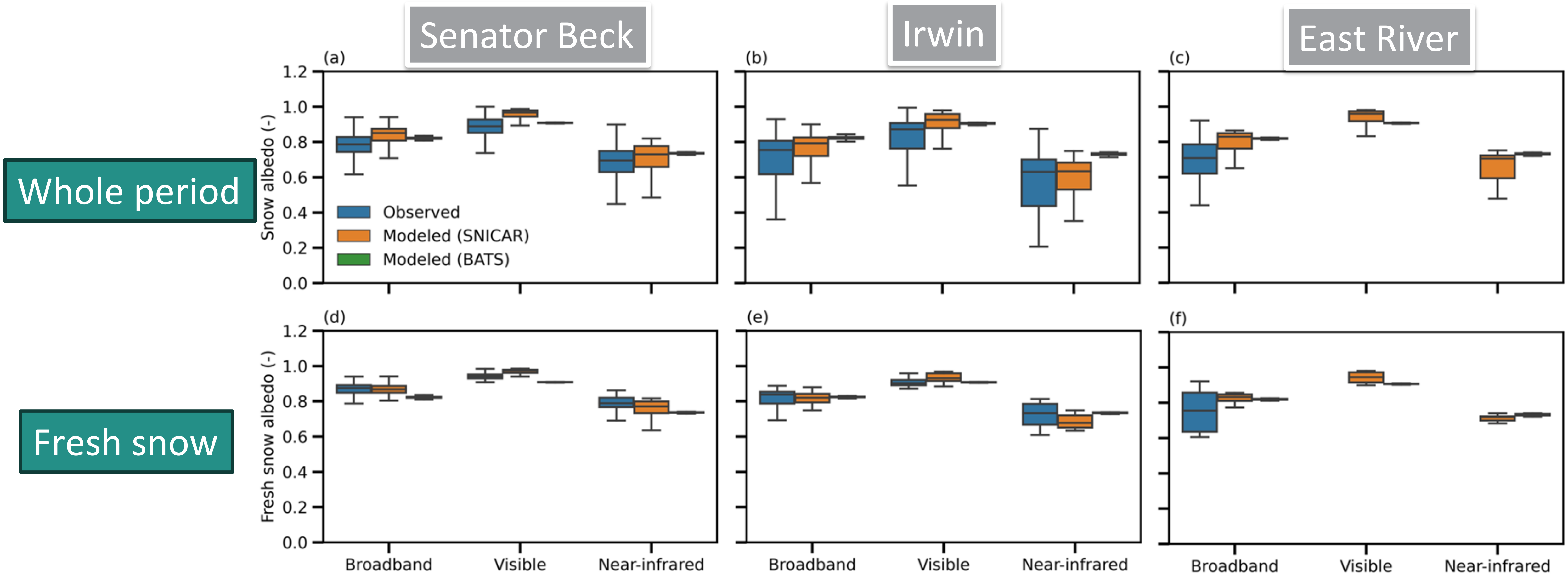
- MODIS snow covered area and grain size (MODSCAG; Painter et al, 2009; Rittger et al., 2020)
- Using daily 463-m MODSCAG data to evaluate and constrain snow grain size from NoahMP-SNICAR simulations



Parameters	Original	Optimized
Minimum values of freshly fallen snow grain size (μm)	54.526	33.0
Maximum values of freshly fallen snow grain size (μm)	204.526	91.0

- The **original** simulation of NoahMP-SNICAR grain size overestimates
- The **optimized** snow grain parameters matches well with the values obtained from MODSCAG

Evaluation of SNICAR and BATS against observations



- NoahMP-SNICAR slightly overestimated mean broadband albedo by about 0.072 mainly arise from the overestimated visible snow albedo by about 0.085 likely caused by the uncertainty in aerosol deposition flux and/or snow density

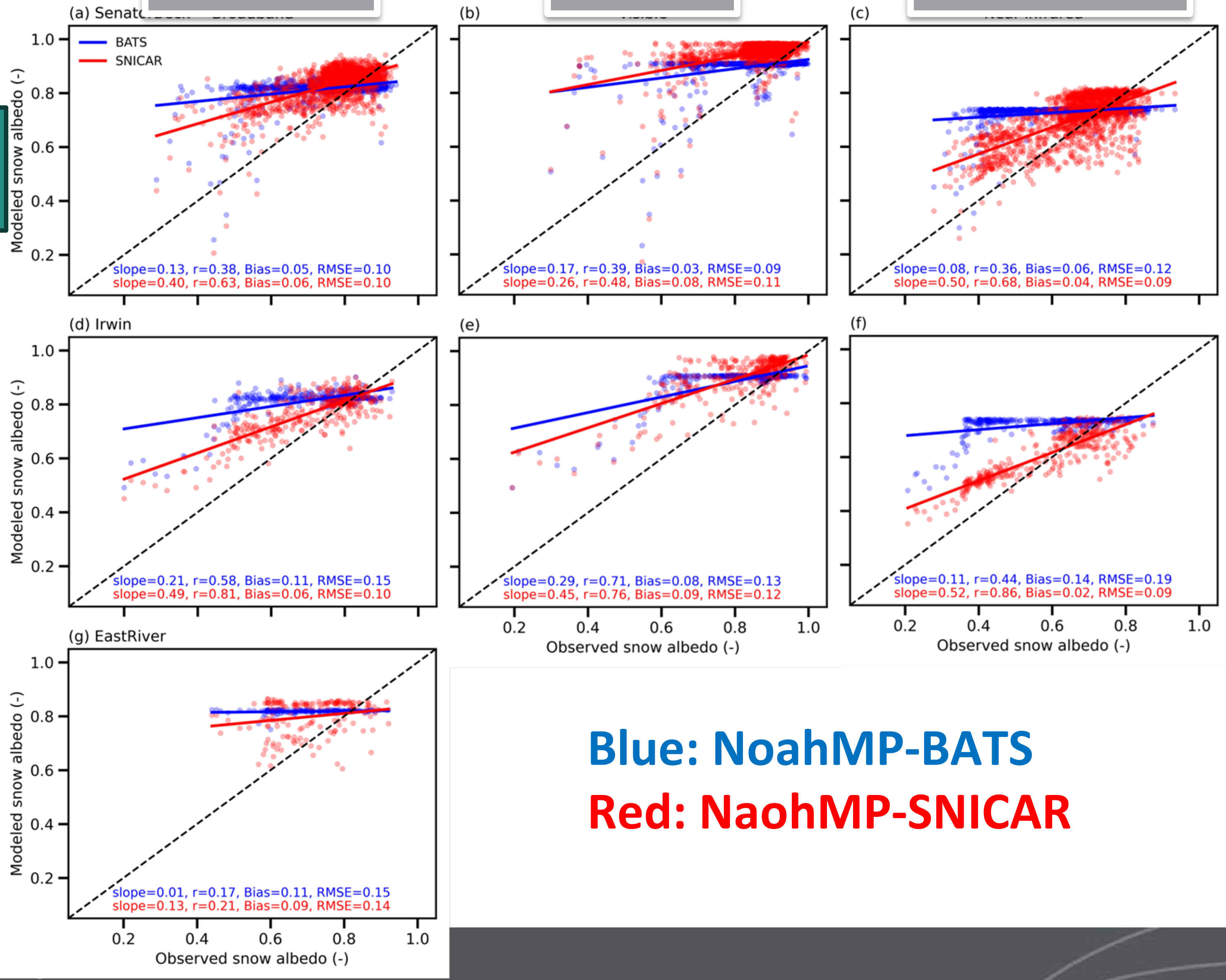
Evaluation of SNICAR and BATS against observations

Broadband | Visible | Near-infrared

Senator Beck

Irwin

East River



Blue: NoahMP-BATS

Red: NaohMP-SNICAR

- NoahMP-SNICAR improves the **temporal variability** of modeled snow albedo across different wavelength bands, with up to twofold higher correlation with observations than NoahMP-BATS

- **Fresh snow albedo**

  NoahMP-BATS: a constant parameter

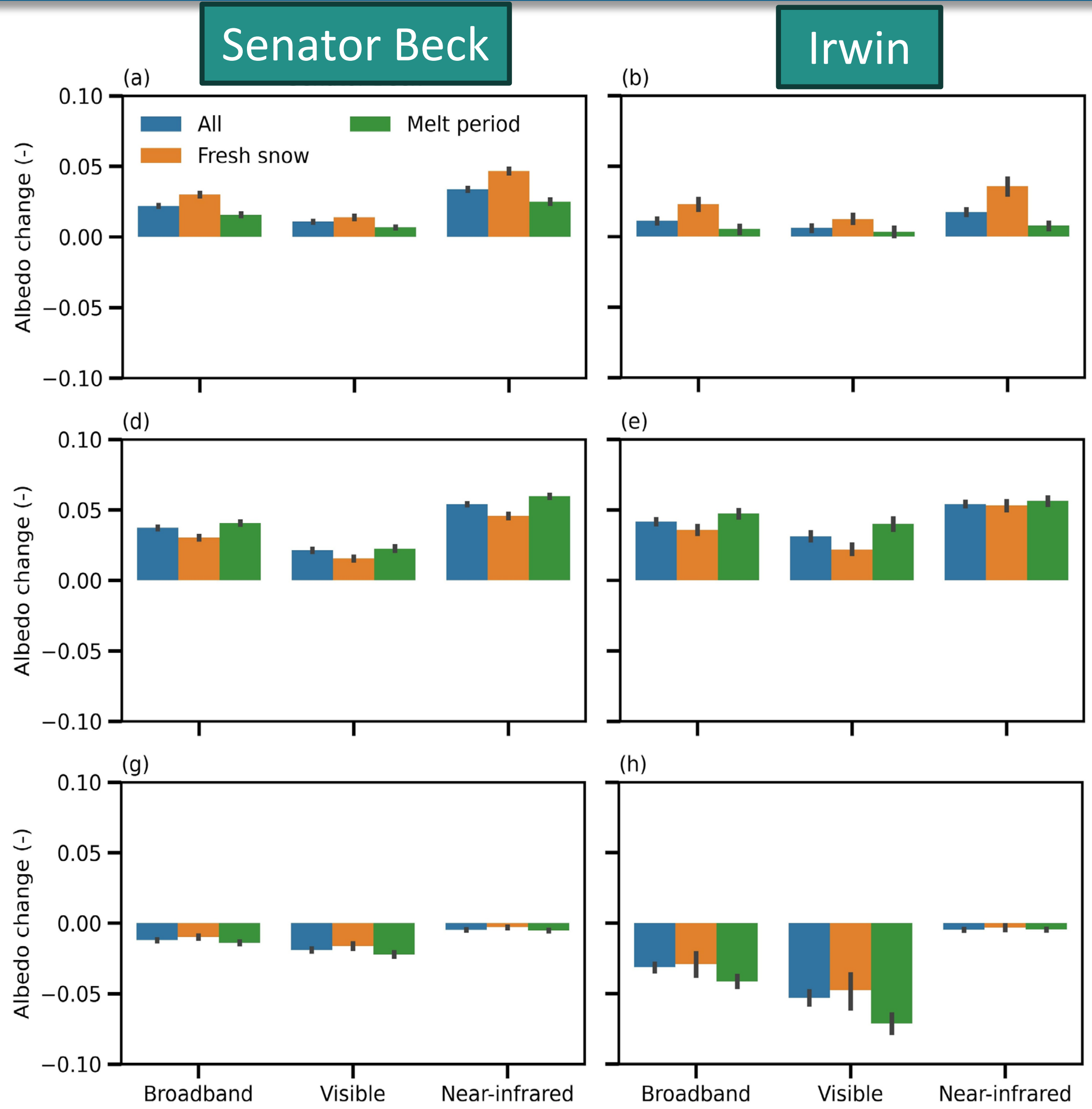
  NoahMP-SNICAR: dynamically dependent on environmental and snowpack conditions

Effects of snow grain size, snow grain shape, and LAPs on albedo

Smaller snow grain size

Non-spherical snow grain shape

With light-absorbing particles



- Smaller snow grain size increases snow albedo, more pronounced effect on the near-infrared than the visible band
- Non-spherical snow grains scatter less strongly in the forward direction and more to the sides, more pronounced in the near-infrared than the visible band
- Aerosol reduces albedo, more pronounced in the visible than the near-infrared band

Conclusions

- We enhance Noah-MP snow albedo processes by integrating physical snow radiative transfer and aging processes from the latest SNICAR model.
- Snow albedo evolution and variability exhibits superior performance in NoahMP-SNICAR version 5 compared to the default Noah-MP snow albedo scheme at three Rocky Mountain stations.
- Impacts of snow grain size, shape, and light-absorbing particles on snow albedo and radiative forcing are assessed in NoahMP-SNICAR version 5.

- **NoahMP-SNICAR model code** updates are publicly available: https://github.com/tslin2/hrldas_snicar.git
- **NoahMP-SNICAR preprint**: Tzu-Shun Lin, Cenlin He, Ronnie Abolafia-Rosenzweig, et al. Implementation and evaluation of SNICAR snow albedo scheme in Noah-MP (version 5.0) land surface model. ESS Open Archive . January 24, 2024. DOI: 10.22541/essoar.170612215.54848315/v1
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Thank you!