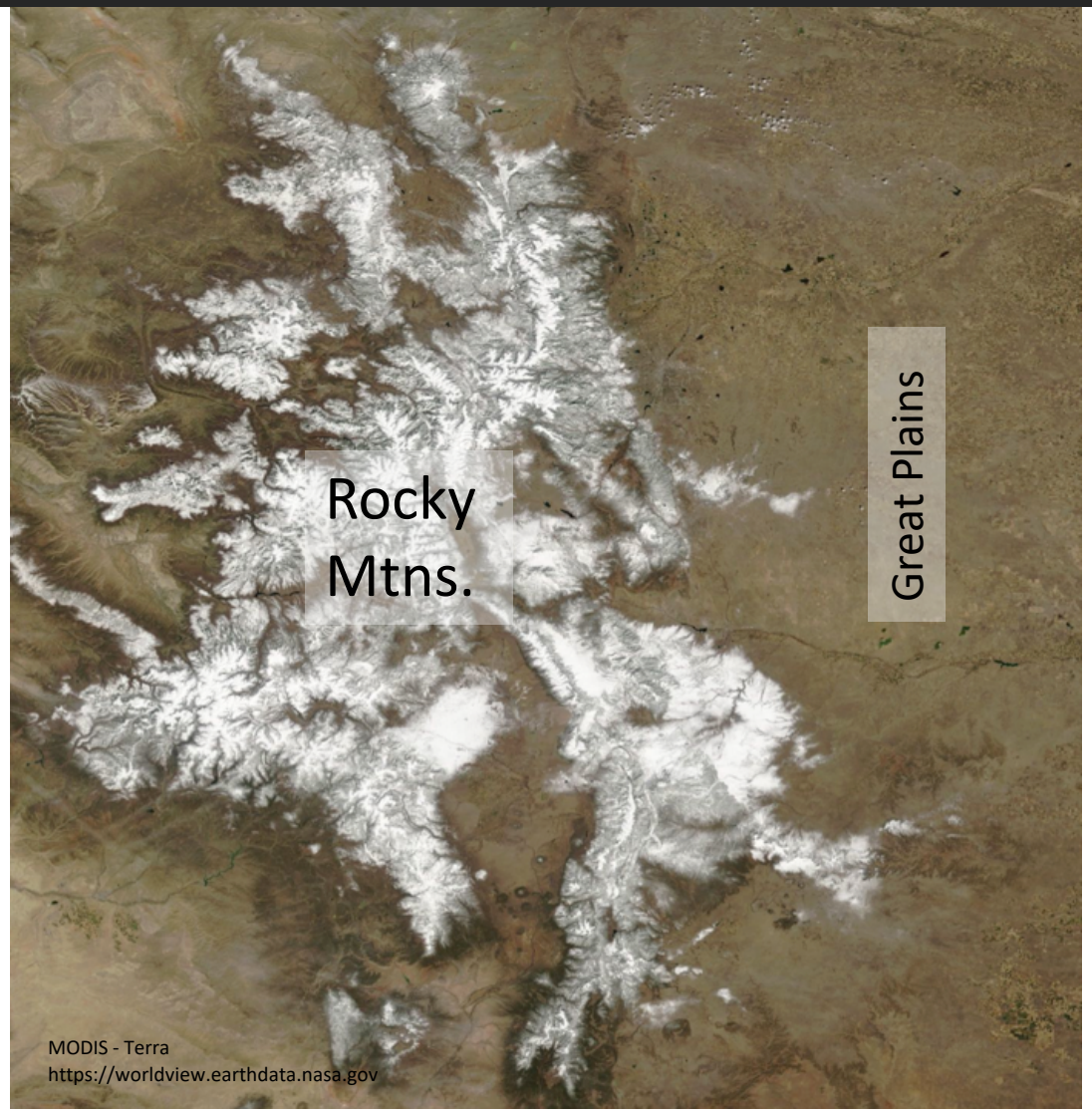
The importance of the snow albedo feedback for improved understanding and projection of climate warming over mountains



Justin R Minder

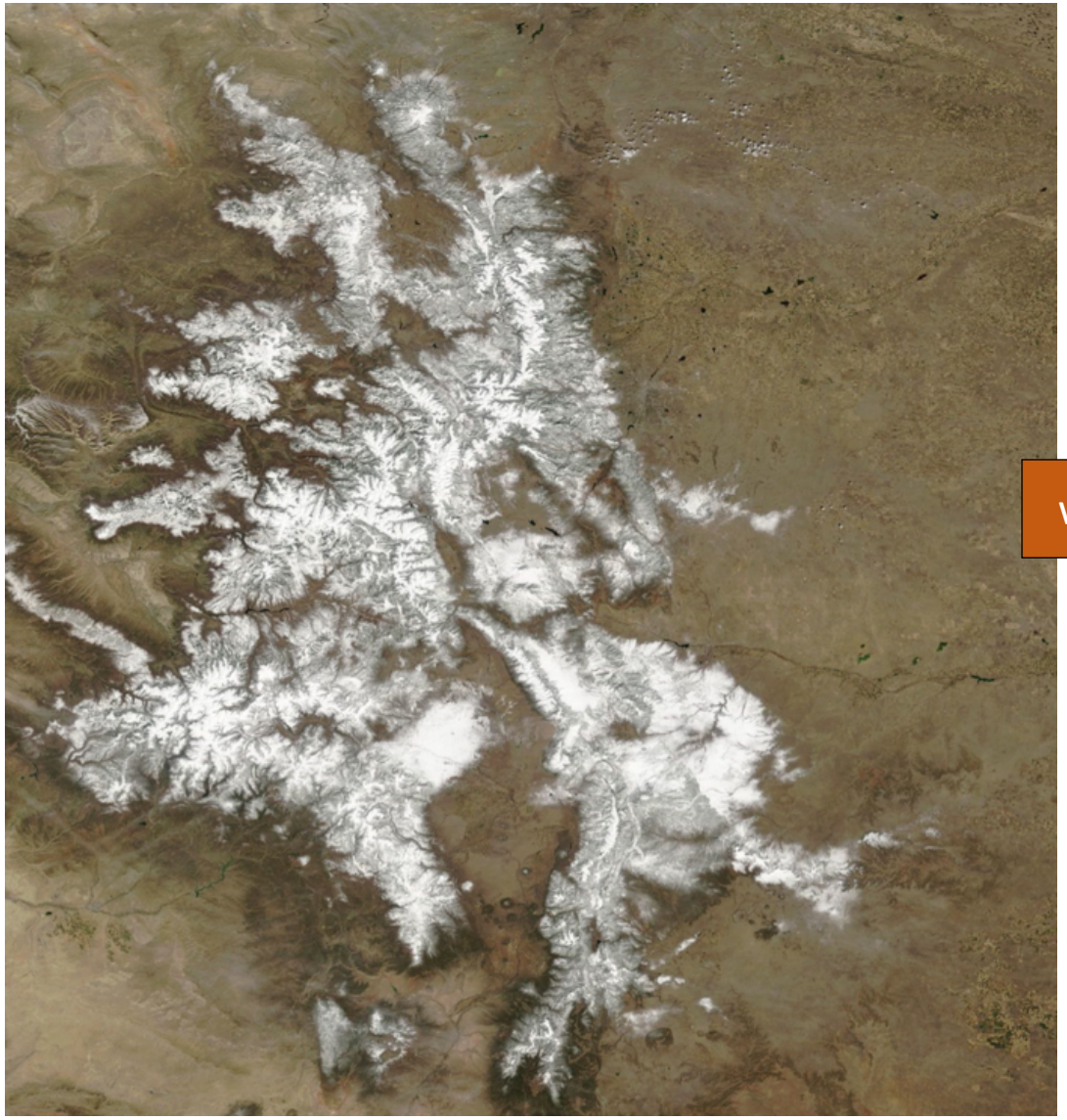
UNIVERSITY AT ALBANY
State University of New York

NSF

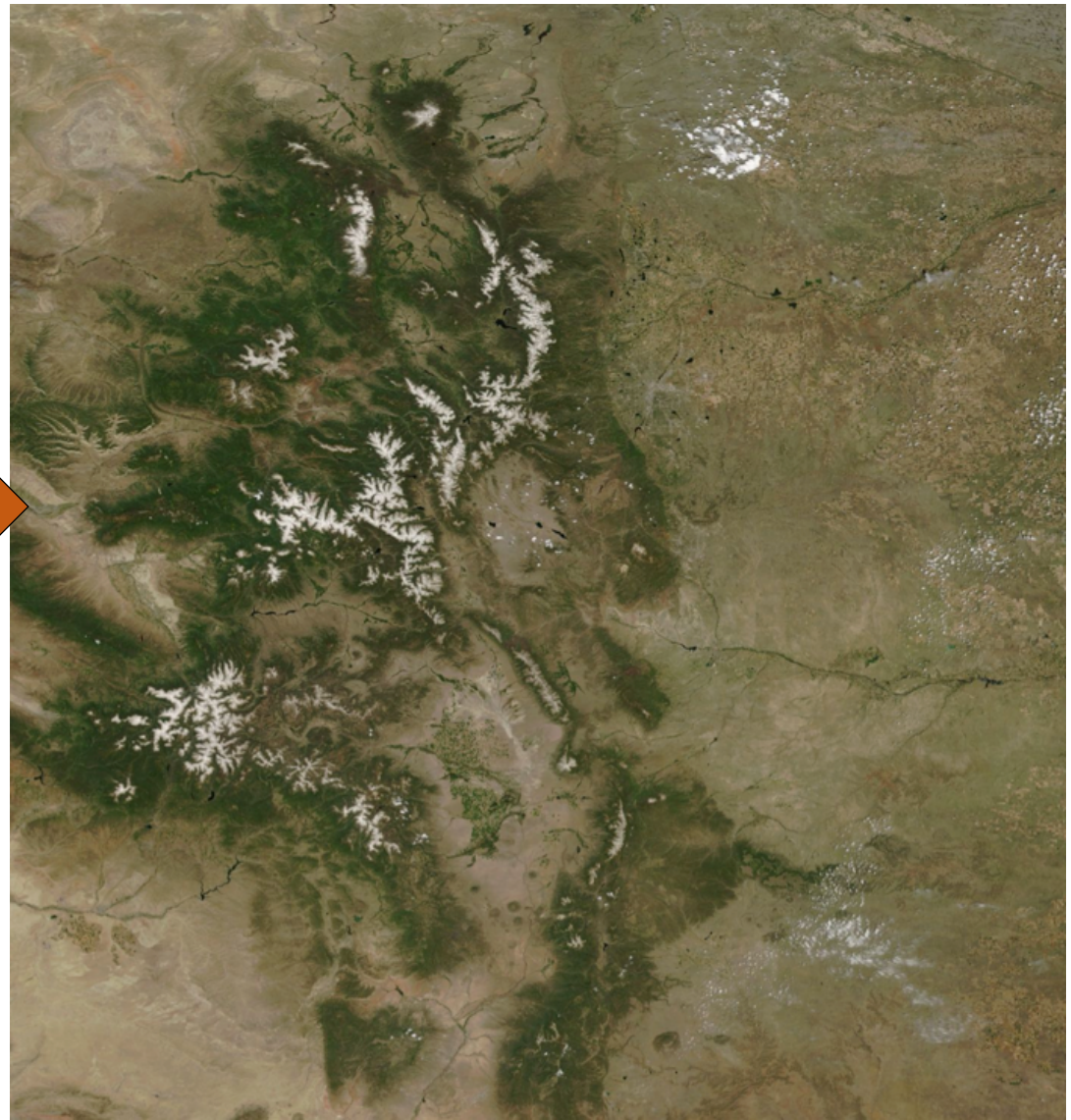
Supported by grant AGS-1349990

Thanks to:
Rachel McCrary (NCAR); Sebastien Biner (OURANOS)

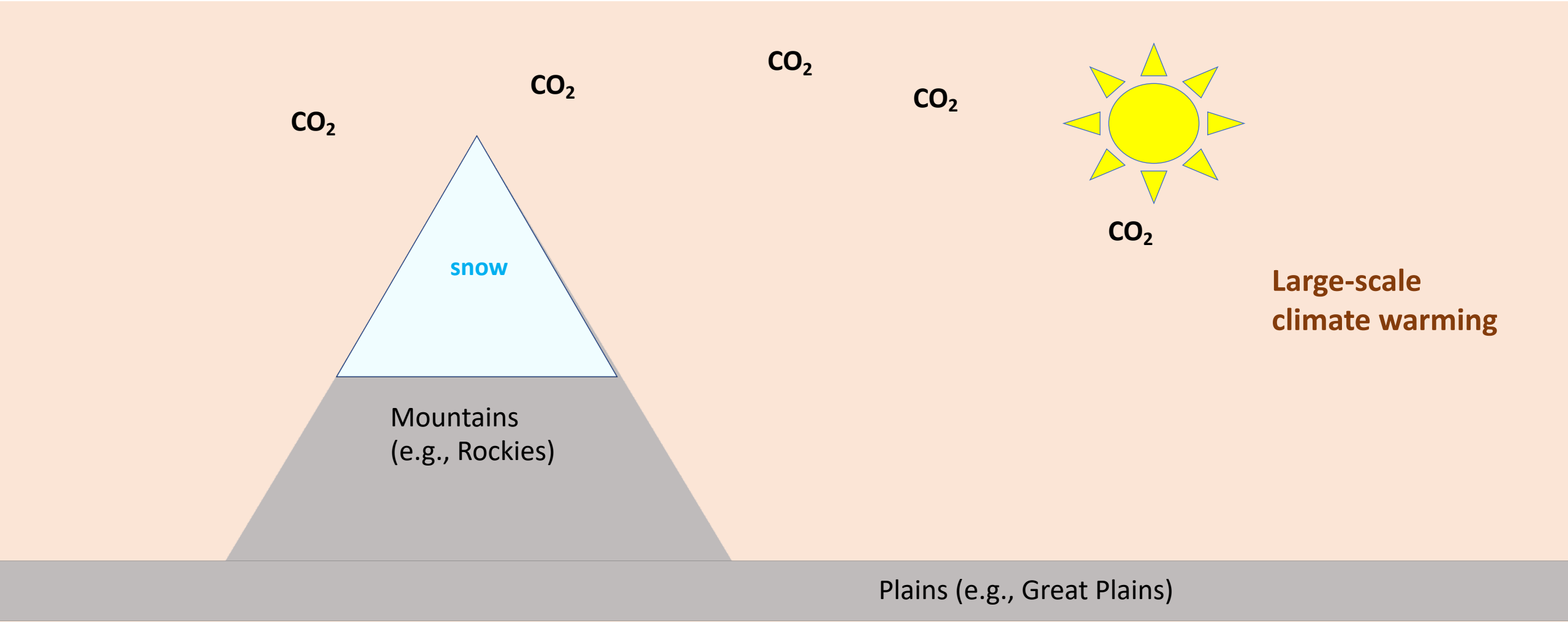
How will the snow albedo feedback (SAF) shape the pattern of future climate warming over mountains?



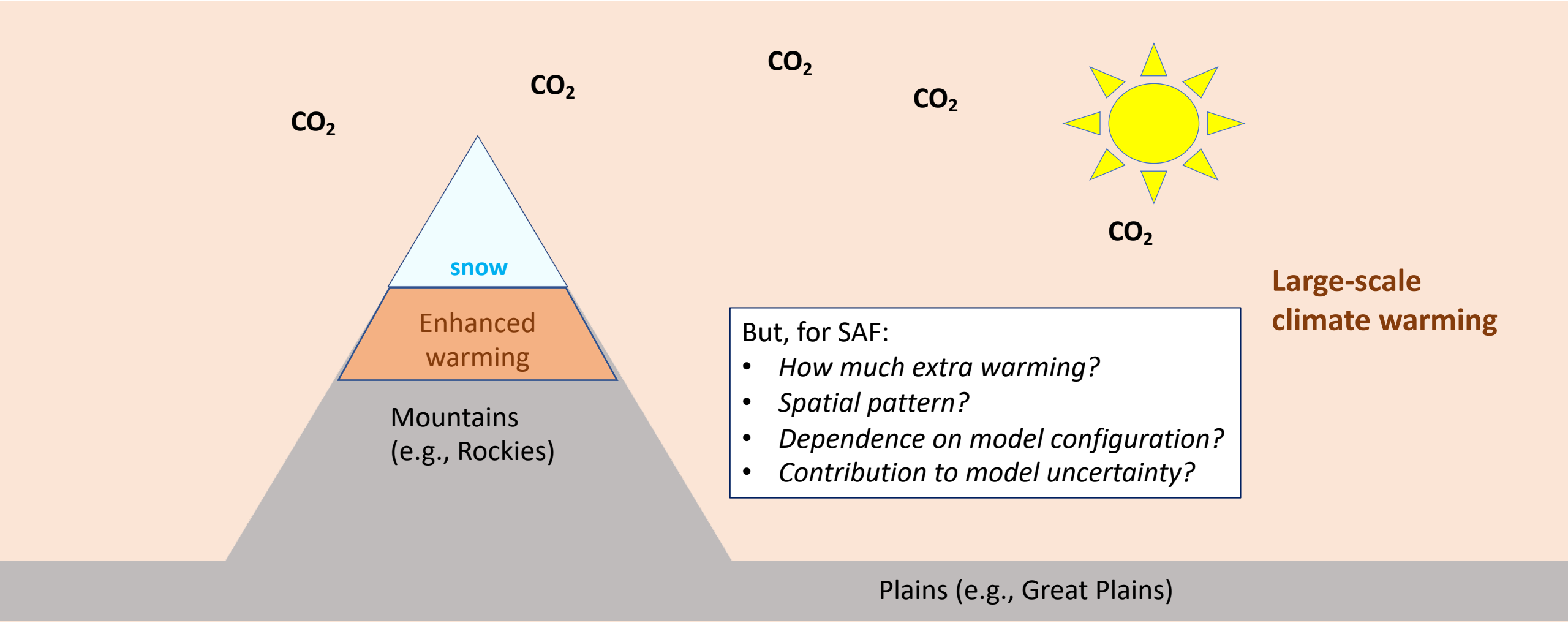
warming



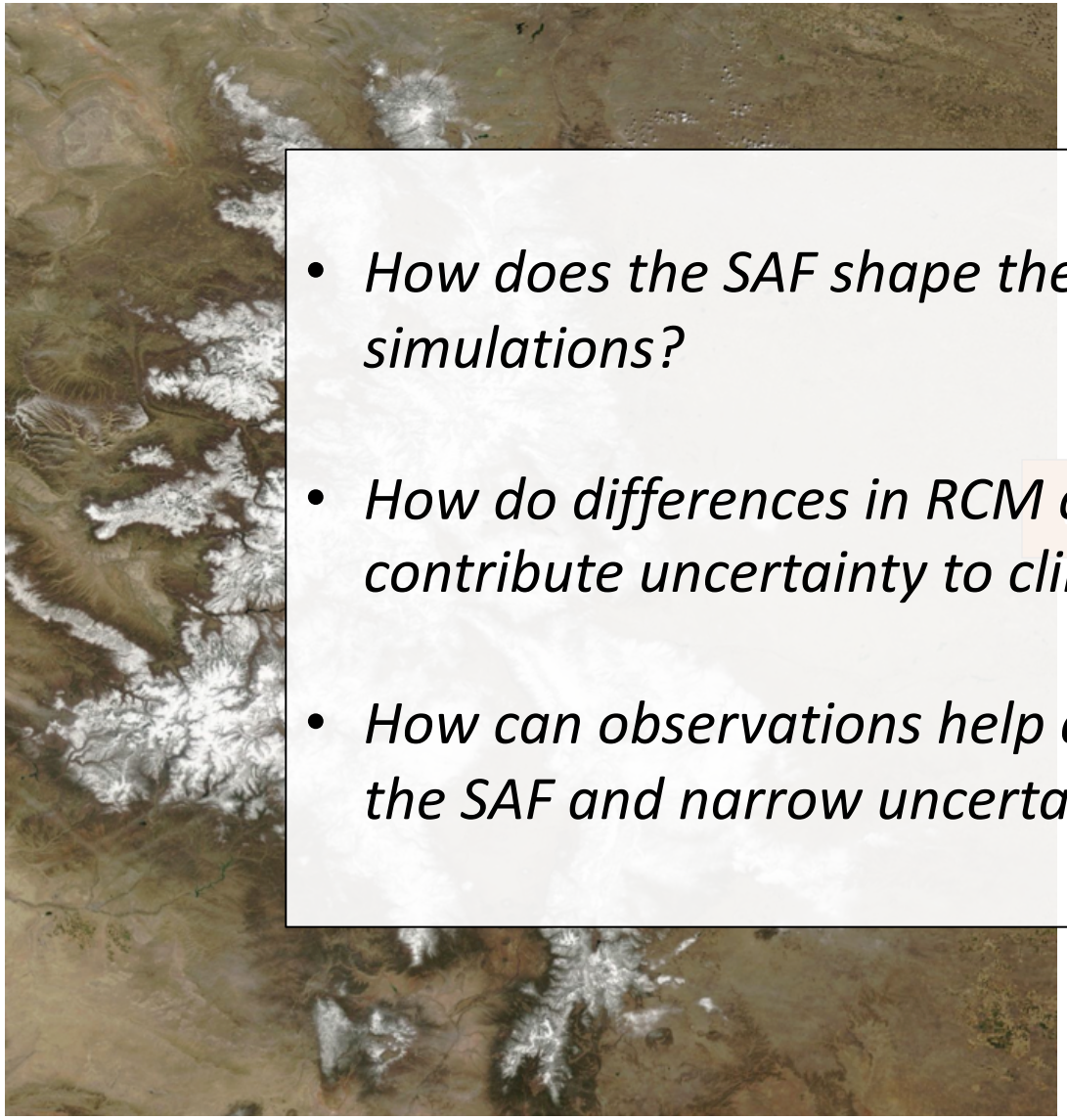
Regionally enhanced warming via the snow albedo feedback (SAF)

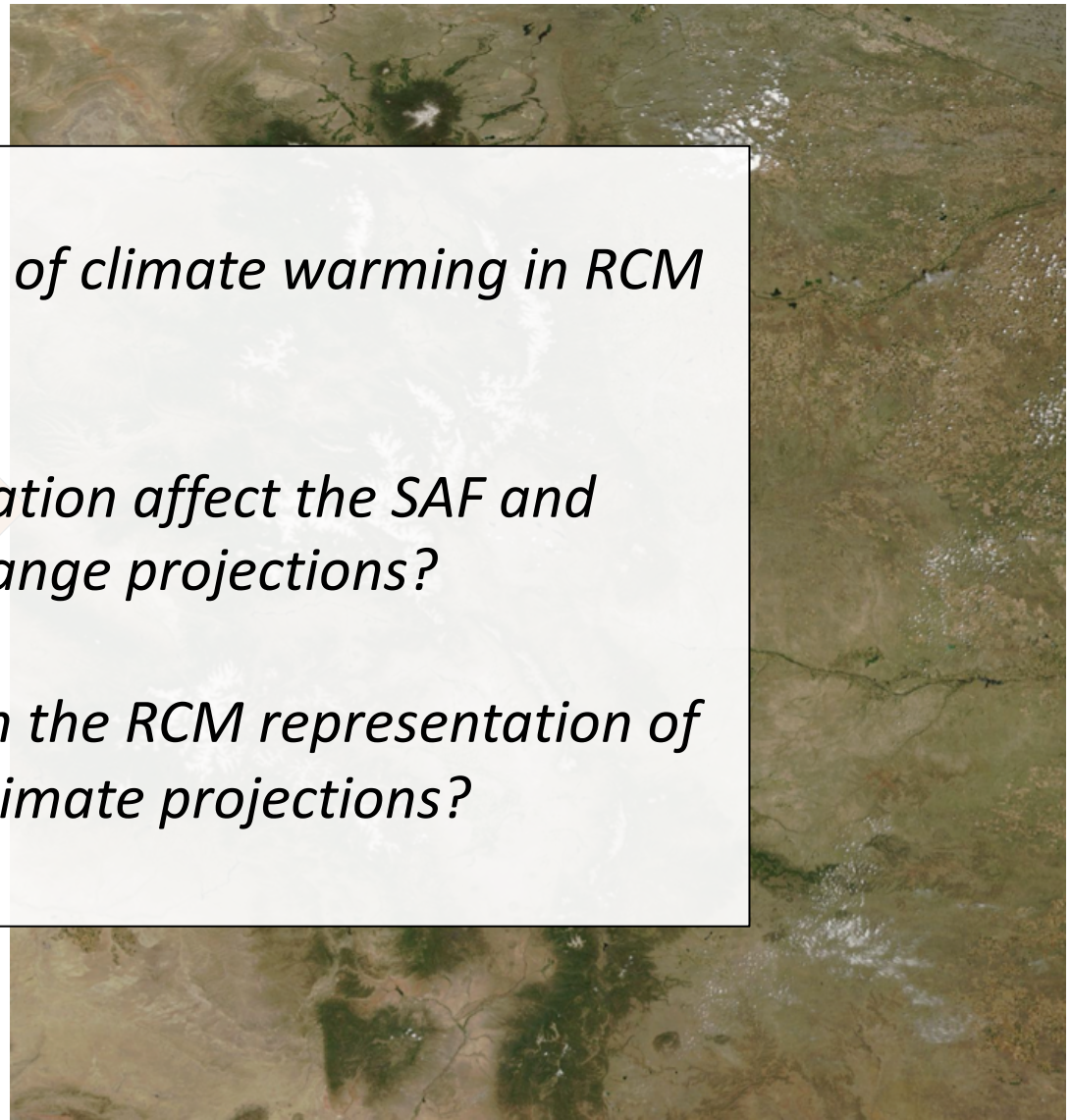


Regionally enhanced warming via the snow albedo feedback (SAF)



Using the snow albedo feedback (SAF) for improved understanding and projection of climate warming over mountains



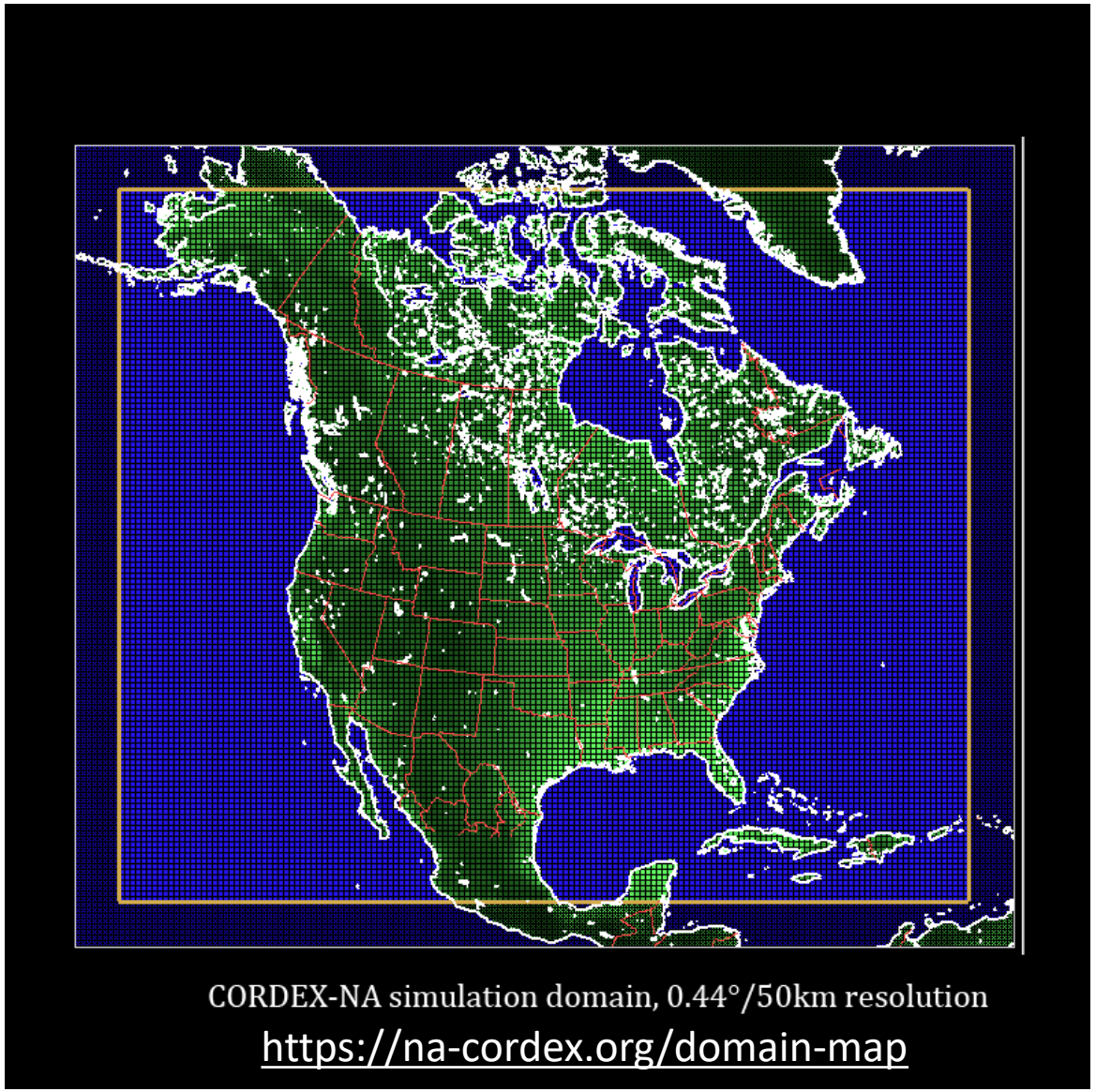


- *How does the SAF shape the pattern of climate warming in RCM simulations?*
- *How do differences in RCM configuration affect the SAF and contribute uncertainty to climate change projections?*
- *How can observations help constrain the RCM representation of the SAF and narrow uncertainty in climate projections?*

Data:

Ensemble regional climate model (RCM) projections of regional climate change

- North-American Coordinated Regional Downscaling Experiment (NA-CORDEX)
- Suites of regional climate model (RCM) experiments run with different…
  - *Emissions scenarios (RCP 4.5, 8.5)*
  - *Forcing GCMs (6)*
  - *RCMs (7)*
  - *Grid spacing ($\Delta x \approx 50, 25$ km)*
- 1950-2100



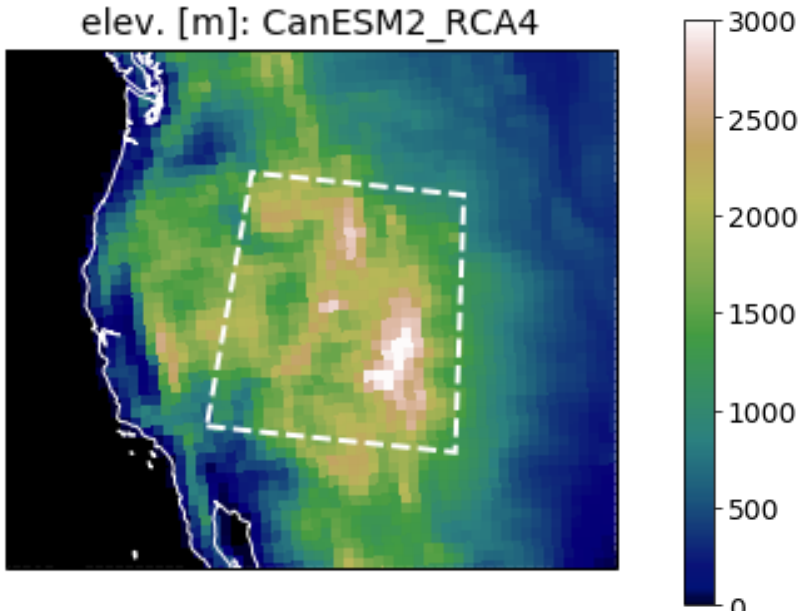
CORDEX-NA simulation domain, 0.44°/50km resolution

https://na-cordex.org/domain-map

Data /methods :

Ensemble RCM projections of regional climate change

- Analyzed all runs with available surface albedo
- Experiments
  - Historical *1960 – 1990*
  - RCP-8.5 *2070 – 2100*
- Average over Feb-May
- Average over “Rockies” domain



WCRP CORDEX NA-CORDEX

RCM

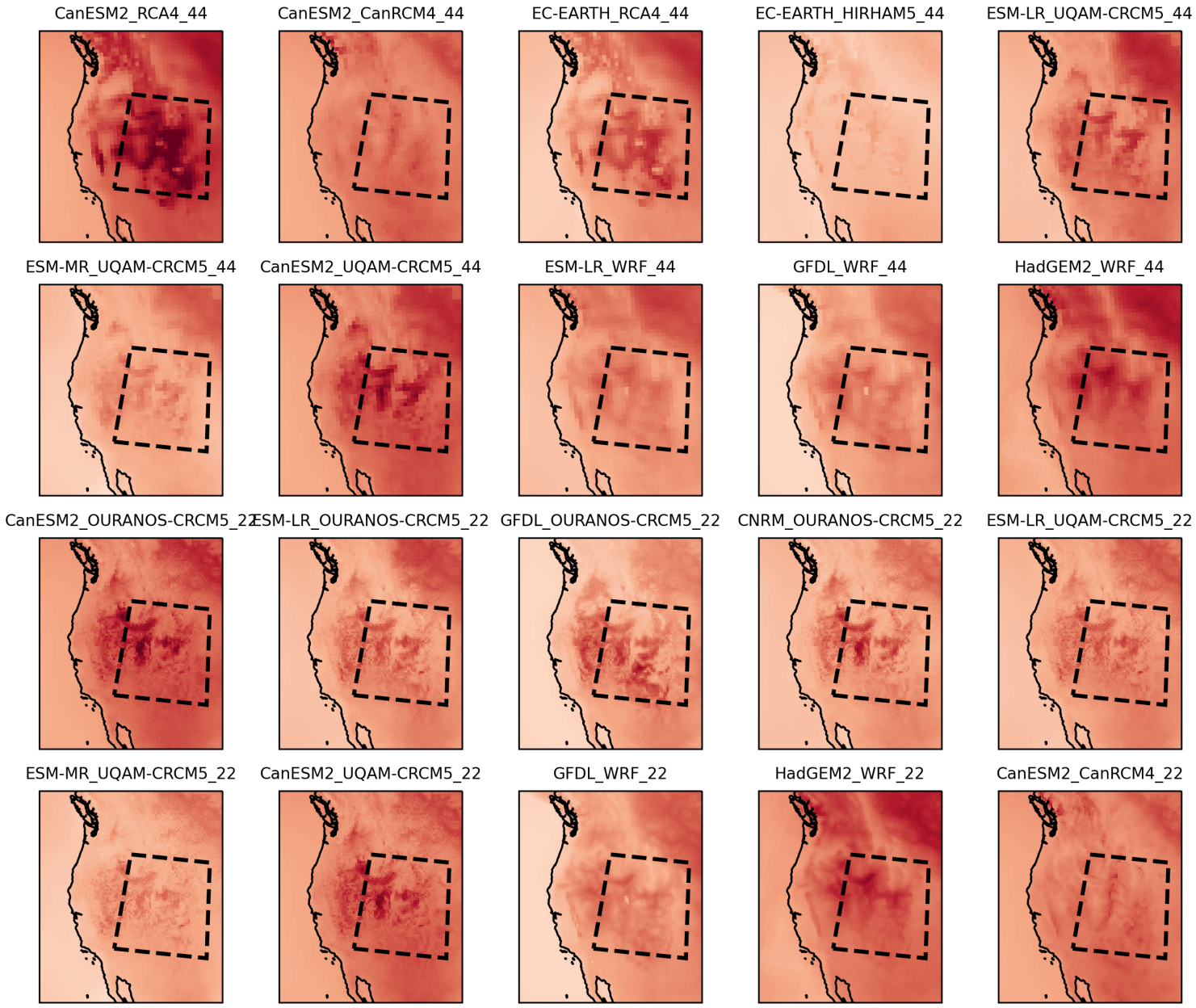
GCM

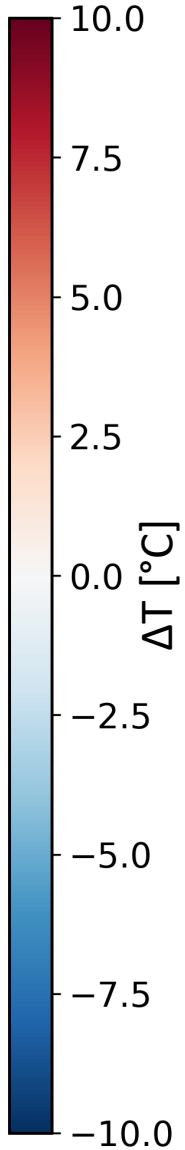
	CRCM5-UQAM	CRCM5-OURANOS	RCA4	WRF	CanRCM4	HIRHAM5
CanESM2	25km, 50km	25km	50km		50km	
EC-EARTH			50km			50km
GFDL-ESM2		25km		25km, 50km		
MPI-ESM-MR	25km, 50km					
MPI-ESM-LR	25km, 50km	25km		50km		
CNRM		25km				
HadGEM2				25km, 50km		

Mearns, L.O., et al., 2017: The NA-CORDEX dataset, version 1.0. NCAR Climate Data Gateway, Boulder CO, https://doi.org/10.5065/D6SJ1JCH

Warming (Feb.-May)

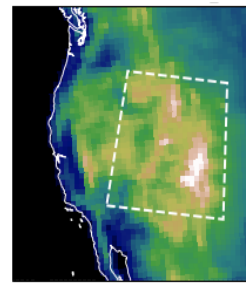
Δ: RCP8.5– Historical





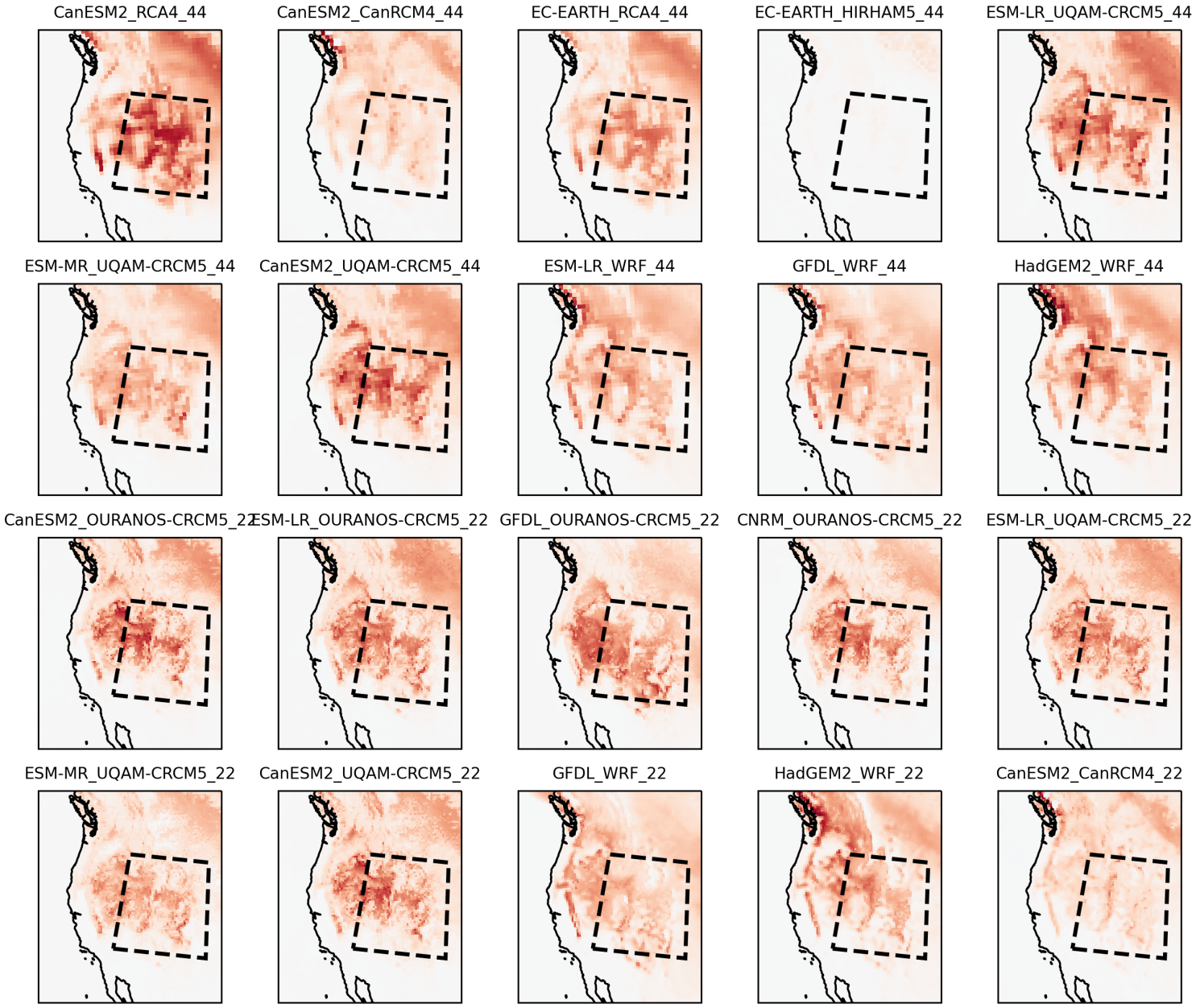
- Most show enhancement of warming over the Rockies
- … but large spread in magnitude of this enhancement

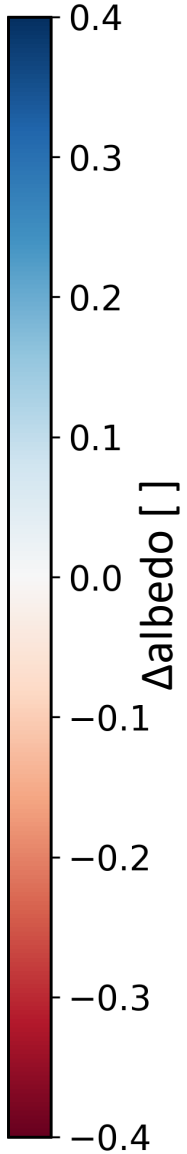
How much of variability between RCMs is attributable to differences in SAF?



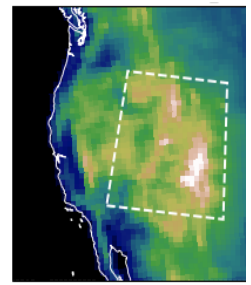
Albedo reduction (Feb.-May)

Δ: RCP8.5– Historical

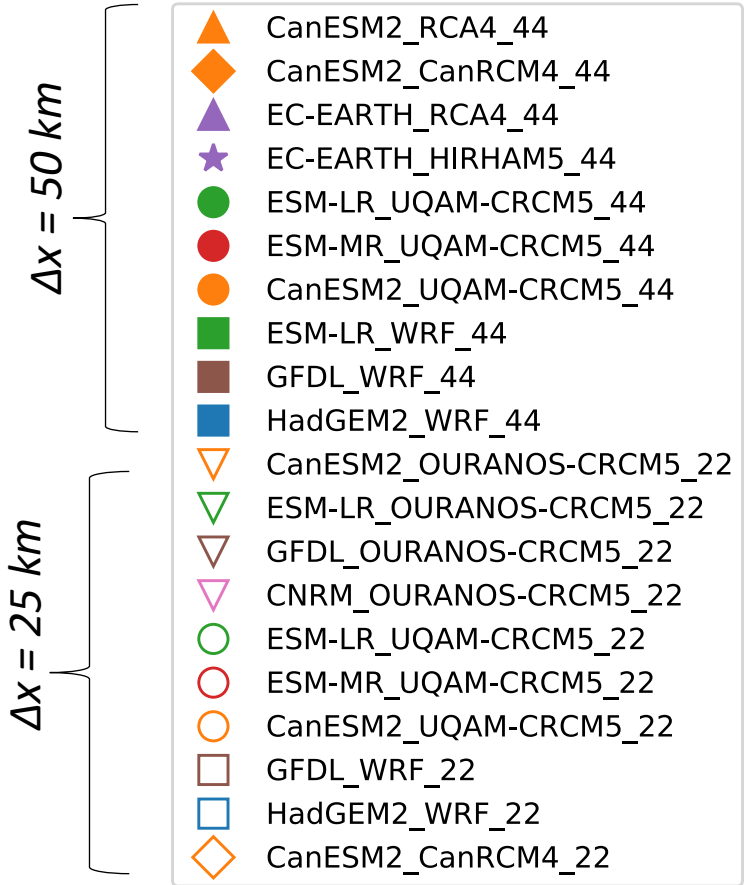




- Spatial pattern of albedo reduction tightly coupled to pattern of enhanced warming

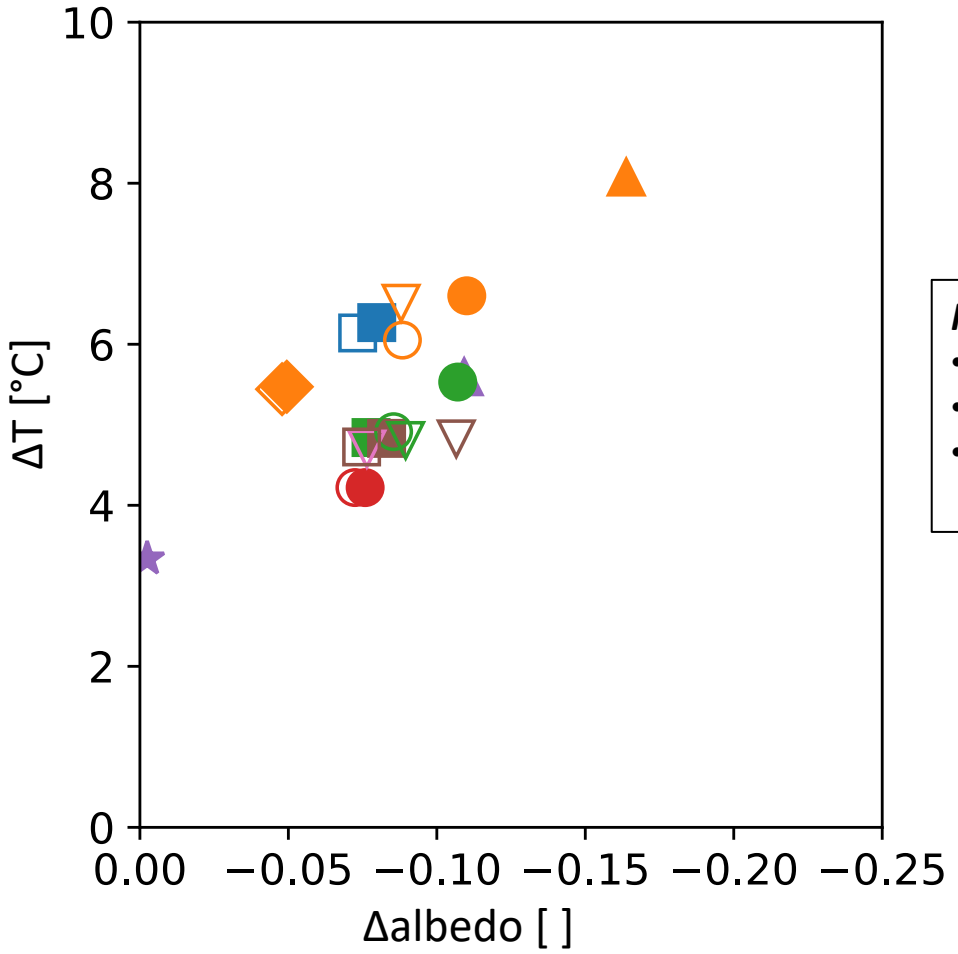


SAF-enhanced variability in RCM-projected warming
(Feb.-May; Rockies domain average)



Marker color : forcing GCM
Marker shape : RCM
Marker fill: grid spacing

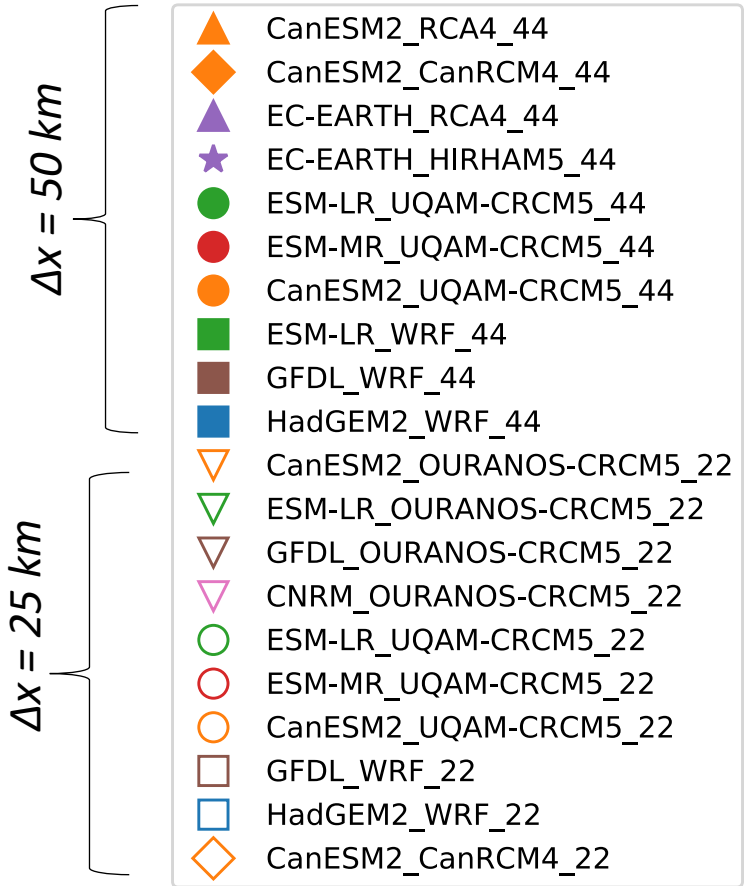
Δ: *RCP8.5– Historical*



***Notes*:**
- *Weak relationship*
- *Some clustering by GCM, RCM*
- *Only small dependence on RCM grid spacing*

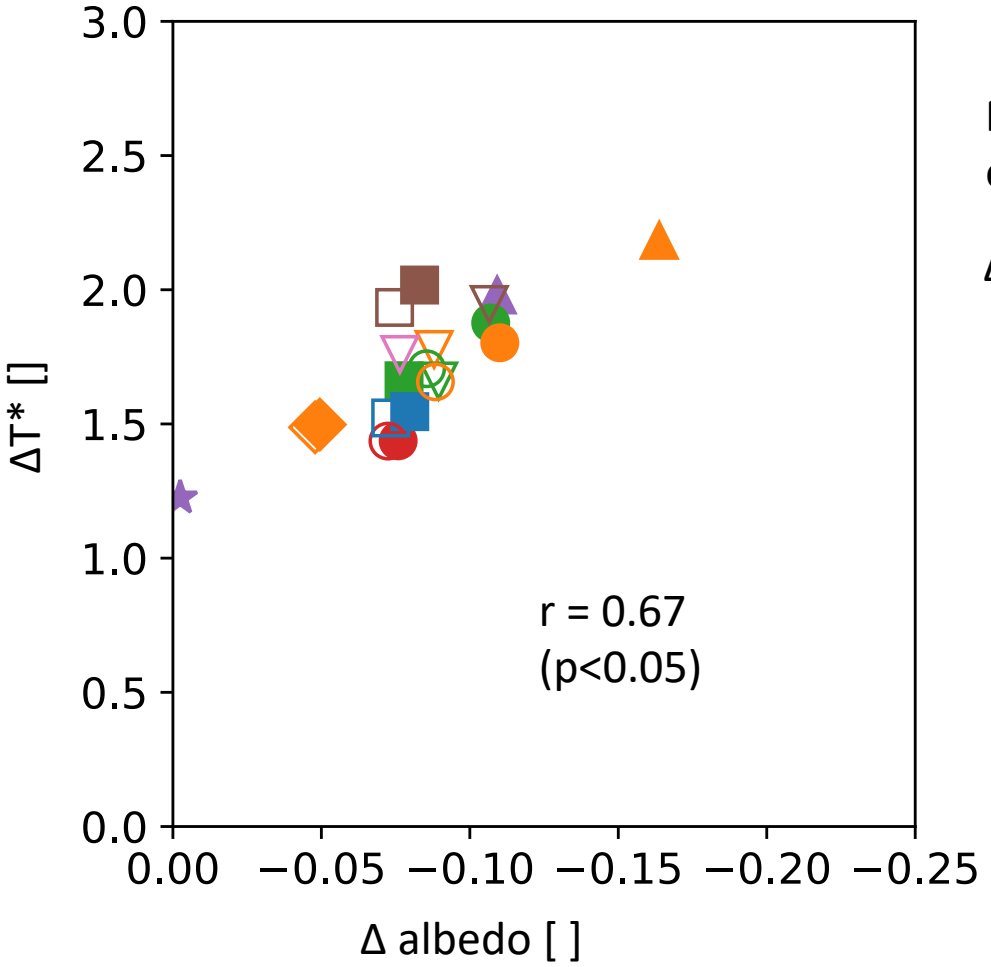
Limitations for quantifying SAF
- Some of the spread in warming is due to differences in forcing GCMs
- Albedo change is not the best quantification of SAF-strength

SAF-enhanced variability in RCM-projected warming
(Feb.-May; Rockies domain average)



Marker color : forcing GCM
Marker shape : RCM
Marker fill: grid spacing

Δ: *RCP8.5– Historical*



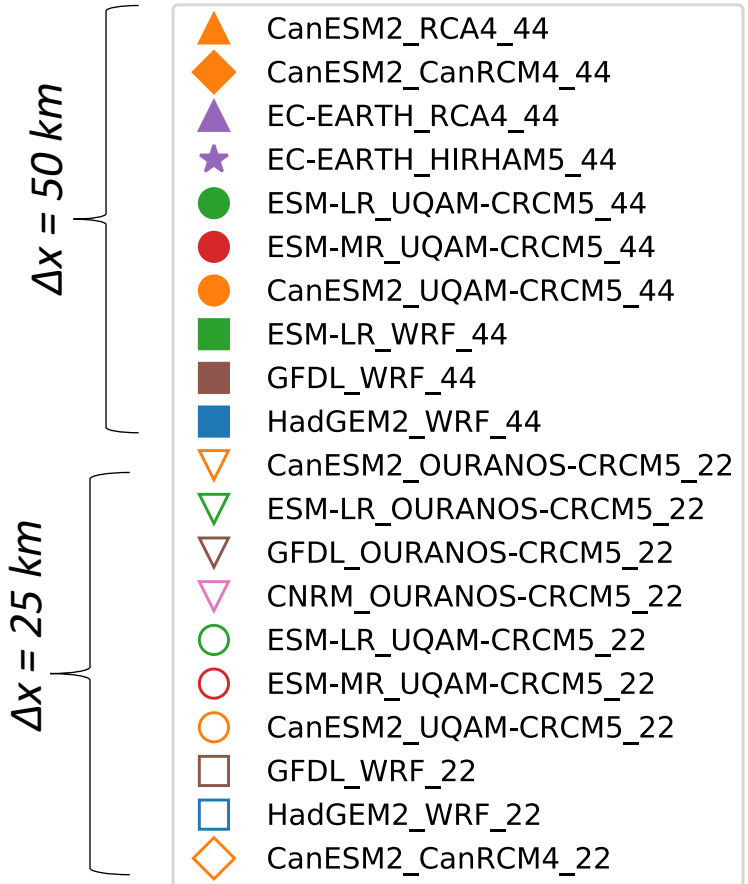
Normalize warming by upwind over-ocean warming:

$$\Delta T^* = \frac{\Delta T \text{ (Rockies)}}{\Delta T \text{ (Eastern Pacific)}}$$

Note:
- *Stronger relationship*
- *Different GCMs tend to collapse towards same line*
- *Some clustering by RCM remains*
- *Slightly weaker response in high-res. models*

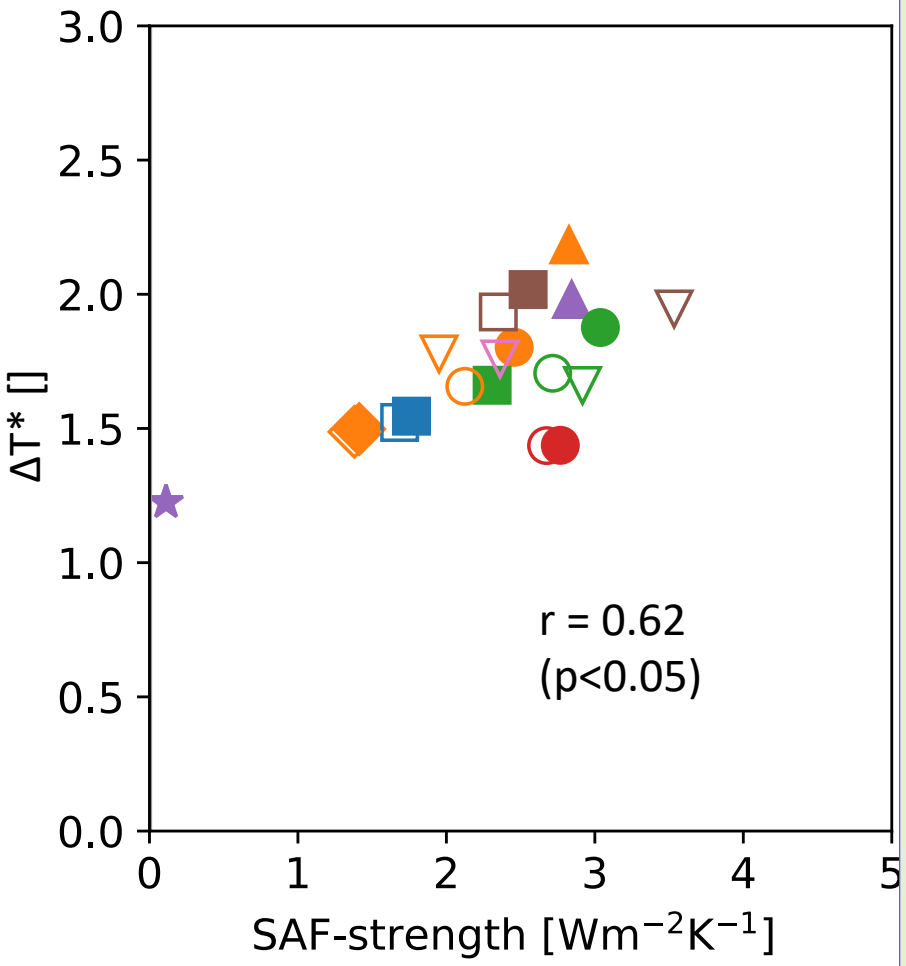
Limitations for quantifying SAF
- Some of the spread in warming is due to differences in forcing GCMs
- Albedo change is not the best quantification of SAF-strength

SAF-enhanced variability in RCM-projected warming
(Feb.-May; Rockies domain average)



Marker color : forcing GCM
Marker shape : RCM
Marker fill: grid spacing

Δ: *RCP8.5– Historical*



How to know which RCM has "right" SAF?

SAF-strength calculated following Qu and Hall (2004):

$$\left(\frac{\partial Q}{\partial T_s}\right)_{SAF} = -Q_0 \frac{\Delta\alpha_s}{\Delta T_s} \frac{\partial\alpha_p}{\partial\alpha_s}$$

TOA incoming Solar Insolation
Directly from RCM output

Relationship between surf. albedo (α_s) and Temperature (T_s)
Directly from RCM output (RCP8.5 – historical)

Dependence of planetary albedo on surface albedo
Assumed = 0.5

How to tell which RCM has the “right” SAF?

Estimating SAF from RCM seasonal cycle

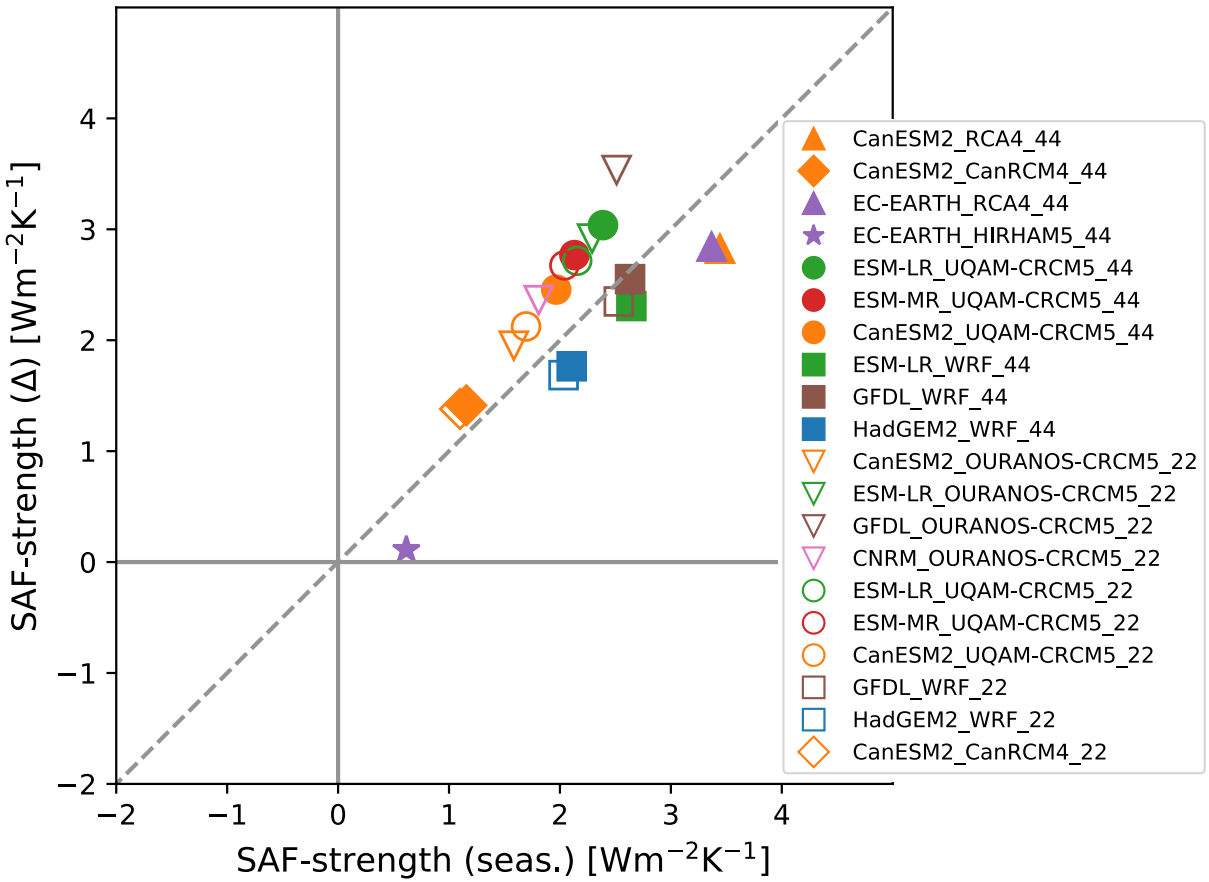
Desirable to estimate SAF from *Historical* runs alone, for comparison with observations

Calculate SAF-strength from seasonal cycle of *Historical* runs, using month-to-month differences

Following:

- *Hall & Qu (2006), Qu & Hall (2014), Letcher & Minder (2015)*

$$\left(\frac{\partial Q}{\partial T_s}\right)_{SAF} = -Q_0 \frac{\Delta \alpha_s}{\Delta T_s} \frac{\partial \alpha_p}{\partial \alpha_s}$$



SAF in seasonal cycle and climate change context are closely related

How to tell which RCM has the “right” SAF?

Comparing RCM seasonal-SAF with gridded observations

Estimate SAF-strength from gridded observations of seasonal cycle

- Following: *Hall & Qu (2006), Qu & Hall (2014)*
- 1998-2011

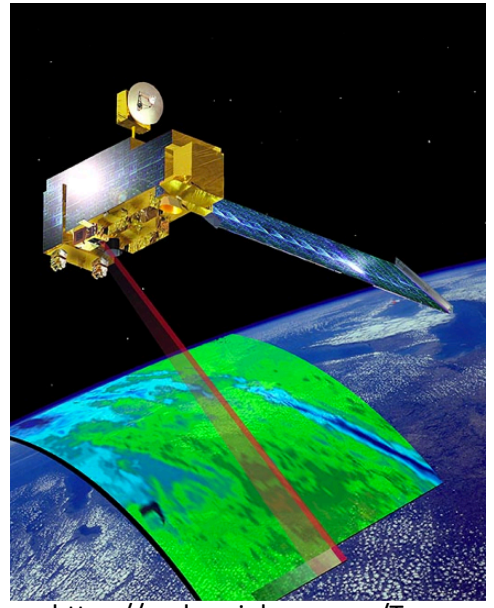
Δ Albedo (α_s)

- GlobAlbedo (http://www.globalbedo.org/)
- Merged from multiple satellites
- Δx = 0.05 deg.

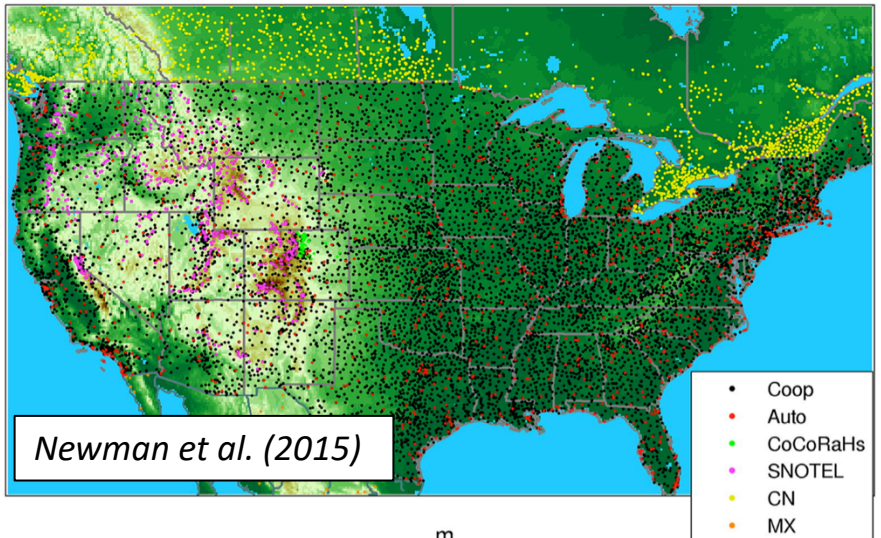
Δ T_s

- Gridded Meteorological Ensemble Tool (GMET)
- Newman et al. (2015)
- https://doi.org/10.5065/D6TH8JR2
- Gridded station observations
- Δx = 4 km

$$\left(\frac{\partial Q}{\partial T_s}\right)_{SAF} = -Q_0 \frac{\Delta \alpha_s}{\Delta T_s} \frac{\partial \alpha_p}{\partial \alpha_s}$$



https://podaac.jpl.nasa.gov/Terra



How to tell which RCM has the “right” SAF?

Comparing RCM seasonal-SAF with gridded observations

Estimate SAF-strength from gridded observations of seasonal cycle

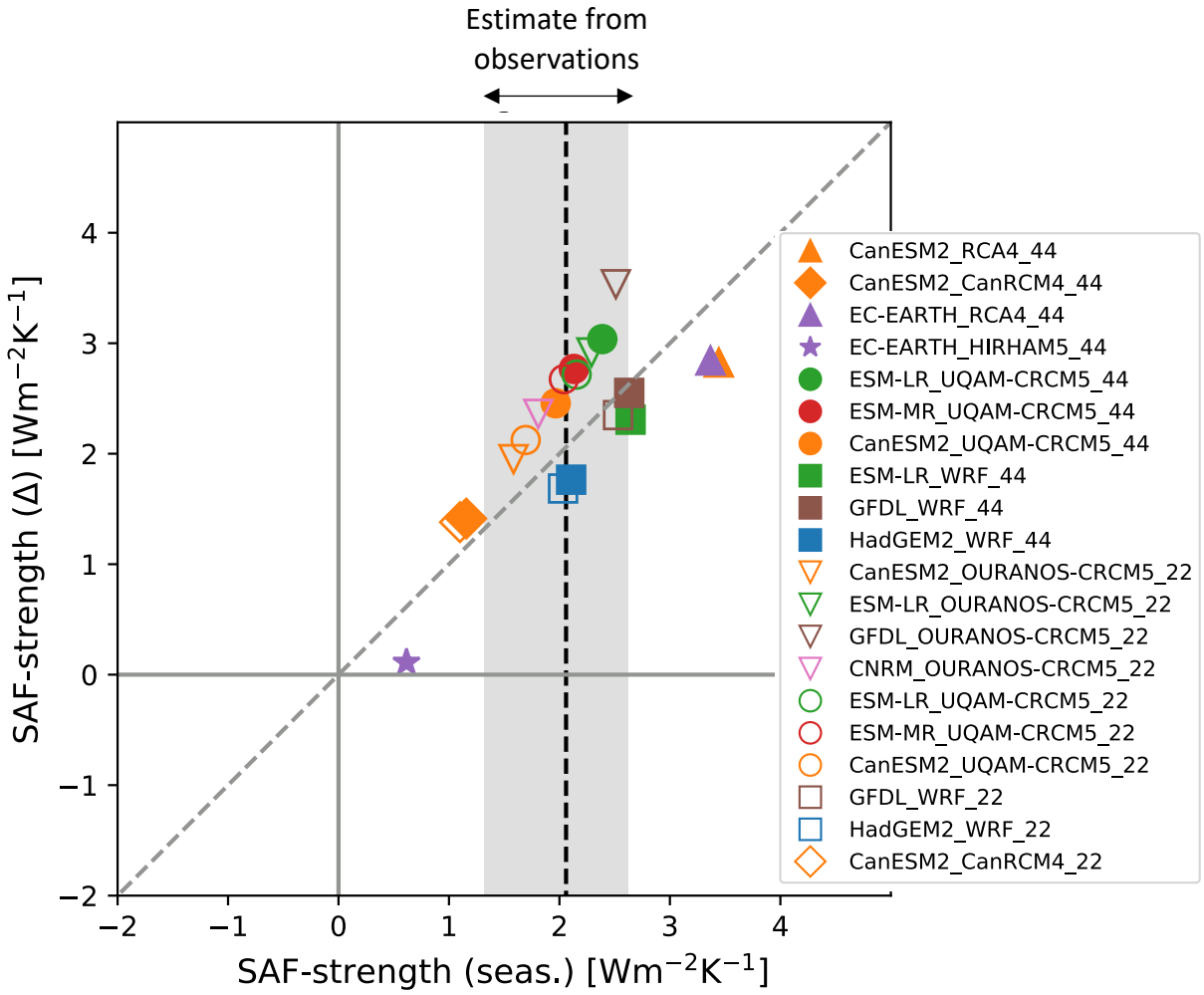
- Following: *Hall & Qu (2006), Qu & Hall (2014)*
- 1998-2011

Δ Albedo (α_s)

- GlobAlbedo (http://www.globalbedo.org/)
- Merged from multiple satellites
- Δx = 0.05 deg.

Δ T_s

- Gridded Meteorological Ensemble Tool (GMET)
- Newman et al. (2015)
- https://doi.org/10.5065/D6TH8JR2
- Gridded station observations
- Δx = 4 km

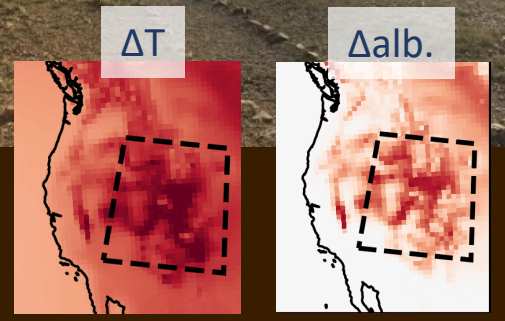


$$\left(\frac{\partial Q}{\partial T_s}\right)_{SAF} = -Q_0 \frac{\Delta\alpha_s}{\Delta T_s} \frac{\partial \alpha_p}{\partial \alpha_s}$$

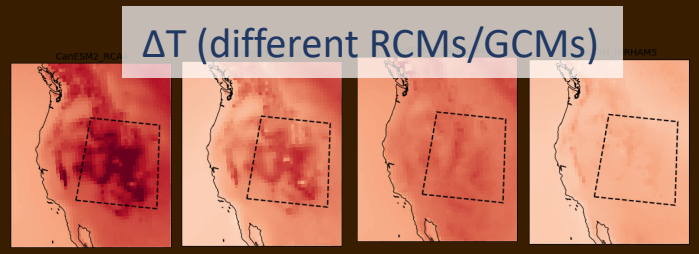
Observations may help constrain projected warming by identifying RCMs with unrealistic SAF

Conclusions

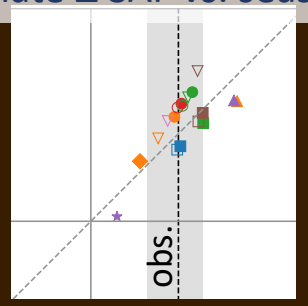
- SAF exerts strong control on simulated pattern and magnitude of climate warming over mountains



- Uncertainty in SAF helps explain spread in warming over mountains in NA-CORDEX



- Gridded observations show promise for constraining SAF in RCMs using the seasonal cycle



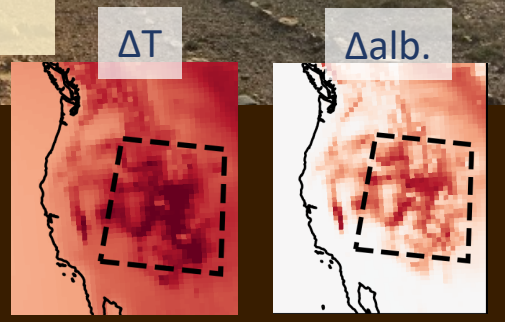
The importance of the snow albedo feedback for improved understanding and projection of climate warming over mountains

Justin R Minder

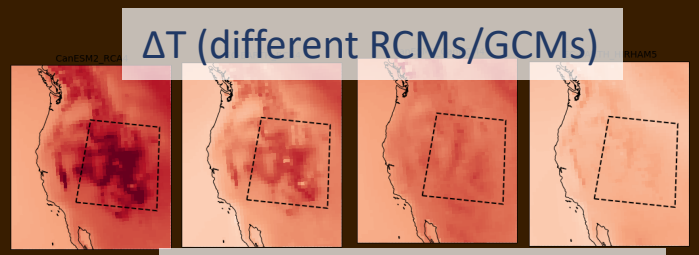
AGS-1349990

- Analyzed regional climate model (RCM) simulations from NA-CORDEX ensemble over the Rocky Mountains to quantify role of snow albedo feedback (SAF) in simulated warming.
- Compared simulated SAF to estimate from gridded observations in the context of seasonal cycle as an observational constraint.

- SAF exerts strong control on simulated pattern and magnitude of climate warming over mountains



- Uncertainty in SAF helps explain spread in warming over mountains in NA-CORDEX



- Gridded observations show promise for constraining SAF in RCMs using the seasonal cycle