

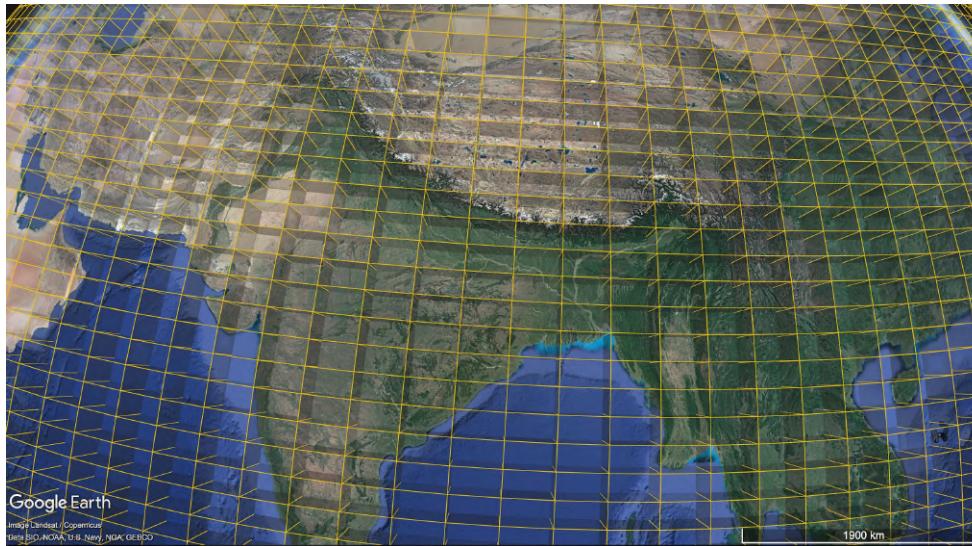
Adaptation of a snow cover scheme for complex topography areas: regional calibration over High Mountain Asia and application in global models



OSUG



Observatoire des
Sciences de l'Univers
de Grenoble



LABORATOIRE DES SCIENCES DU CLIMAT
& DE L'ENVIRONNEMENT

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¹ Univ. Grenoble Alpes, CNRS, IRD, G-INP, IGE, 38000 Grenoble, France

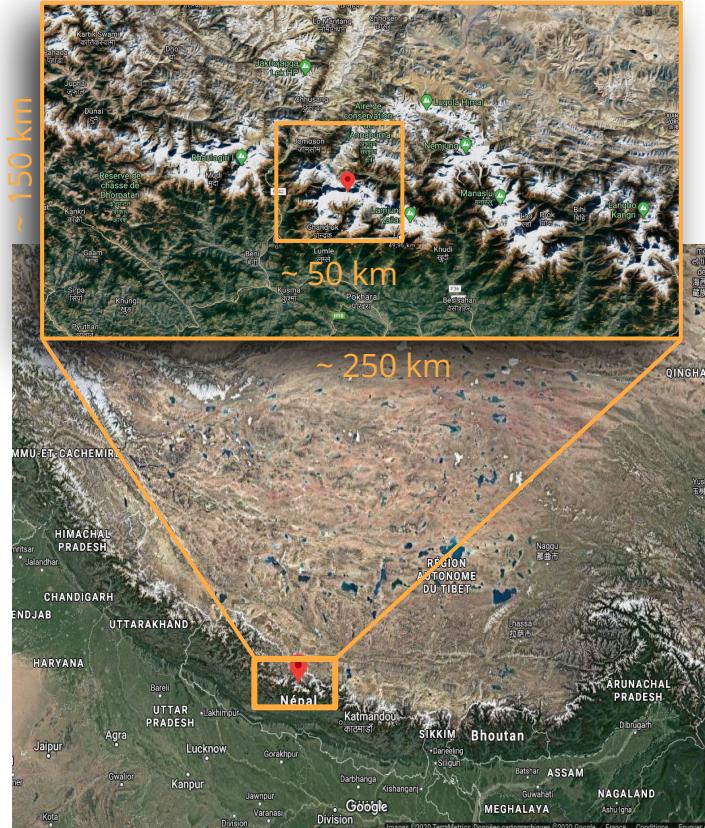
² LSCE-IPSL (CNRS-CEA-UVSQ), Université Paris-Saclay, Gif-sur-Yvette, France







Snow cover over mountainous areas in global climate models

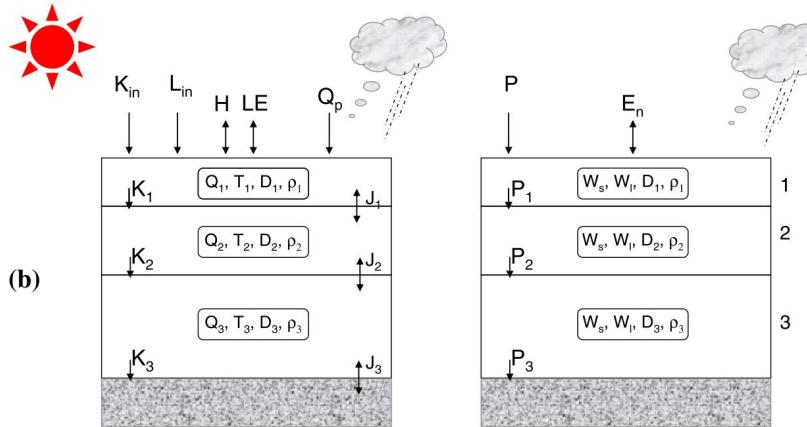


IPSL-CM6A

HOW DO WE COMPUTE THE
SNOW COVER FRACTION (SCF)
IN GLOBAL CLIMATE MODELS?

&
HOW DOES THE SCF EVOLVES
OVER MOUNTAINOUS AREAS?

Snow scheme



K_{in} (short wave radiation), L_{in} (longwave radiation), H (sensible heat flux), LE (latent heat flux), J (conduction heat flux), Q (snow layer heat content), Q_p (advection heat from rain and snow), W (snow layer SWE), W_l (snow layer liquid water content), D (snow layer depth), ρ (snow layer density), P (precipitation), E_n (evaporation)

snow scheme in the ORCHIDEE land surface model

(Wang et al., 2013)

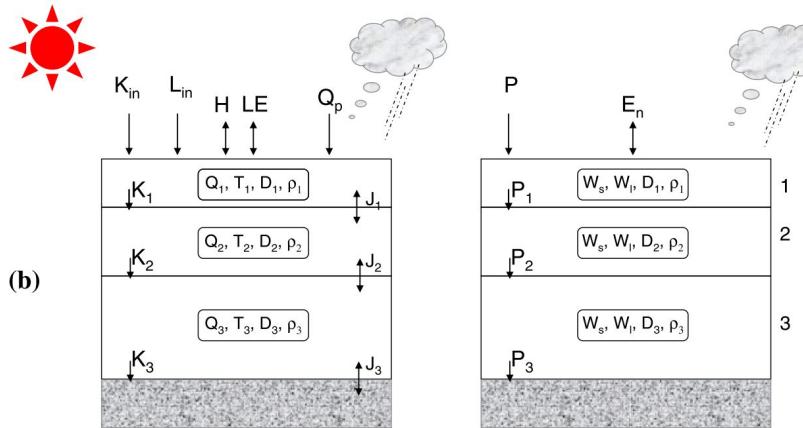


SNOW DEPTH

SNOW WATER EQUIVALENT

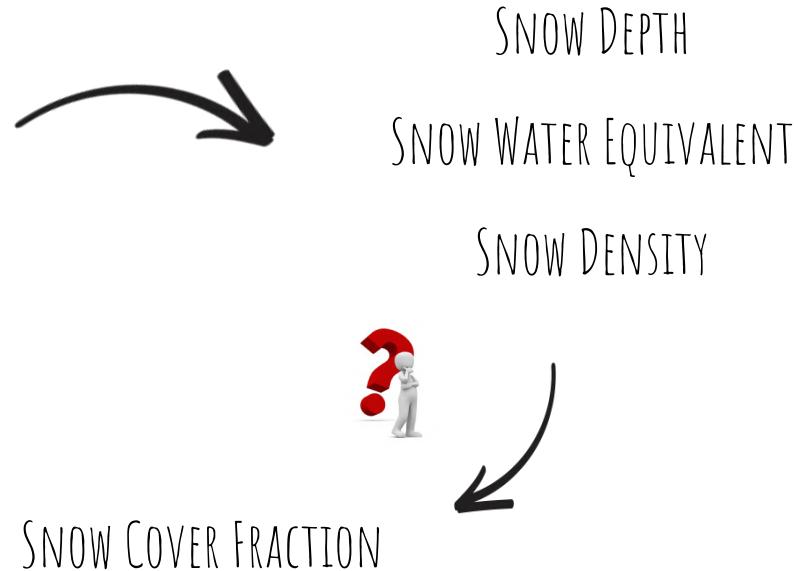
SNOW DENSITY

Snow scheme



K_{in} (short wave radiation), L_{in} (longwave radiation), H (sensible heat flux), LE (latent heat flux), J (conduction heat flux), Q (snow layer heat content), Q_p (advection heat from rain and snow), W (snow layer SWE), W_l (snow layer liquid water content), D (snow layer depth), ρ (snow layer density), P (precipitation), E_n (evaporation)

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Snow cover parameterizations

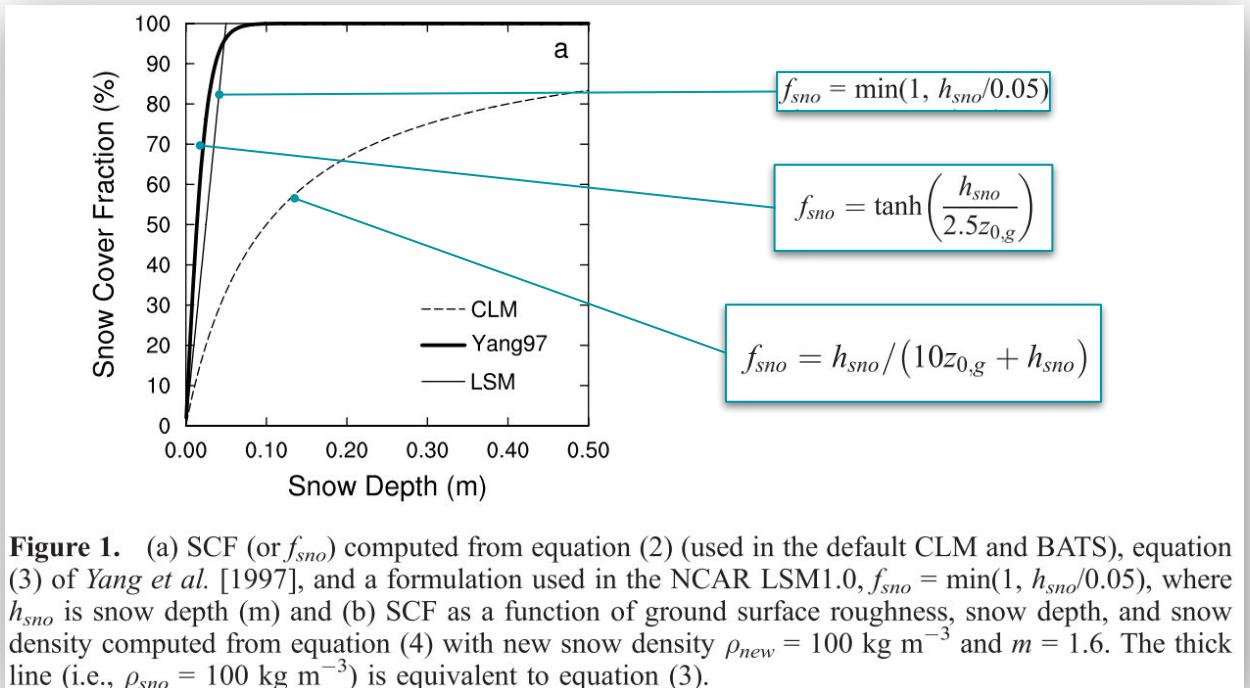


Figure 1. (a) SCF (or f_{sno}) computed from equation (2) (used in the default CLM and BATS), equation (3) of Yang *et al.* [1997], and a formulation used in the NCAR LSM1.0, $f_{sno} = \min(1, h_{sno}/0.05)$, where h_{sno} is snow depth (m) and (b) SCF as a function of ground surface roughness, snow depth, and snow density computed from equation (4) with new snow density $\rho_{new} = 100 \text{ kg m}^{-3}$ and $m = 1.6$. The thick line (i.e., $\rho_{sno} = 100 \text{ kg m}^{-3}$) is equivalent to equation (3).

Niu and Yang ([2007](#))

Snow Cover parameterization: Niu and Yang (2007) - NY07

$$f_{sno} = \tanh\left(\frac{h_{sno}}{2.5z_0g(\rho_{sno}/\rho_{new})^m}\right)$$



Snow Density

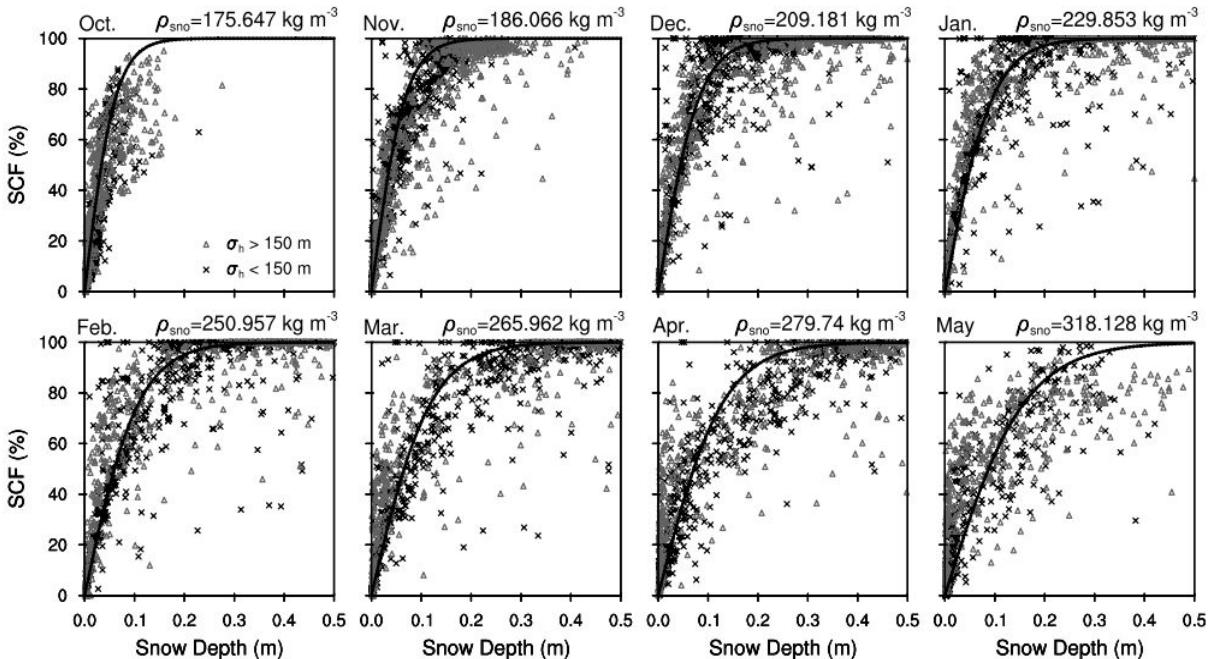


Figure 2. Relationship between AVHRR SCF (%) and CMC snow depth (m) in $1^\circ \times 1^\circ$ grid cells of major NA river basins including the Mackenzie, Yukon, Churchill, Fraser, St. Lawrence, Columbia, Colorado, and Mississippi from October to May. The darker crosses stand for $1^\circ \times 1^\circ$ grid cells where the standard deviation of topography $\sigma_h < 150$ m, and the lighter triangles stand for $1^\circ \times 1^\circ$ grid cells where $\sigma_h > 150$ m. The fitted lines are computed from equation (4) ($m = 1.6$) with the mean snow densities shown above each frame.

Snow Cover parameterization: Niu and Yang (2007) - NY07

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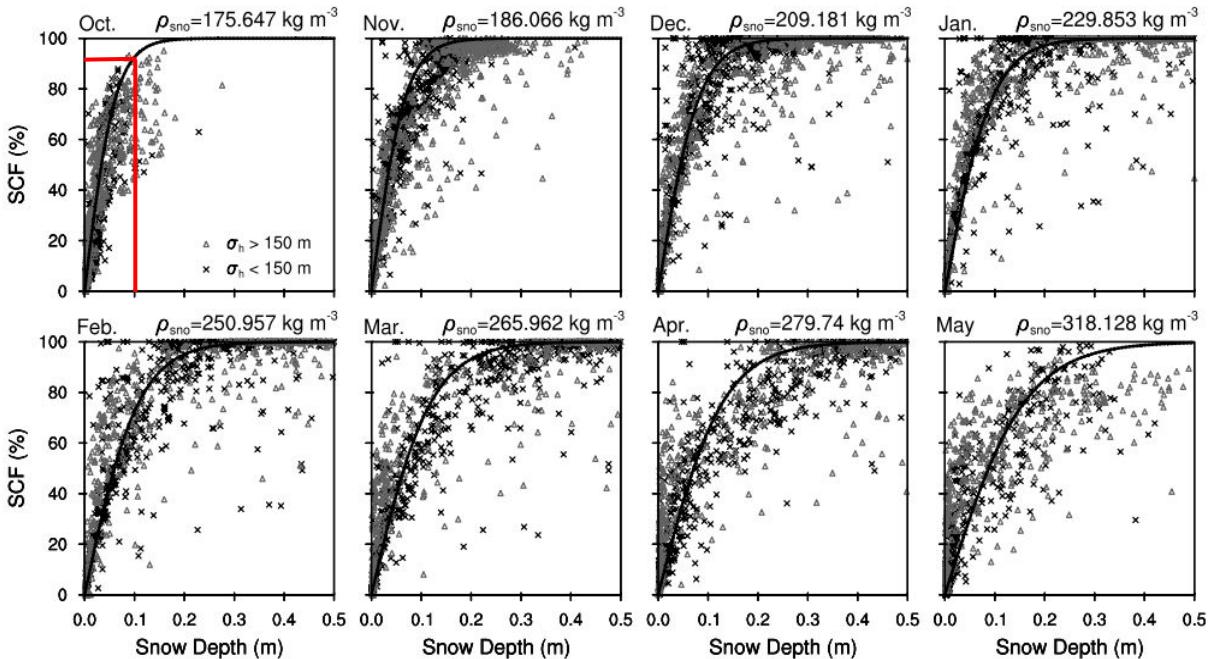


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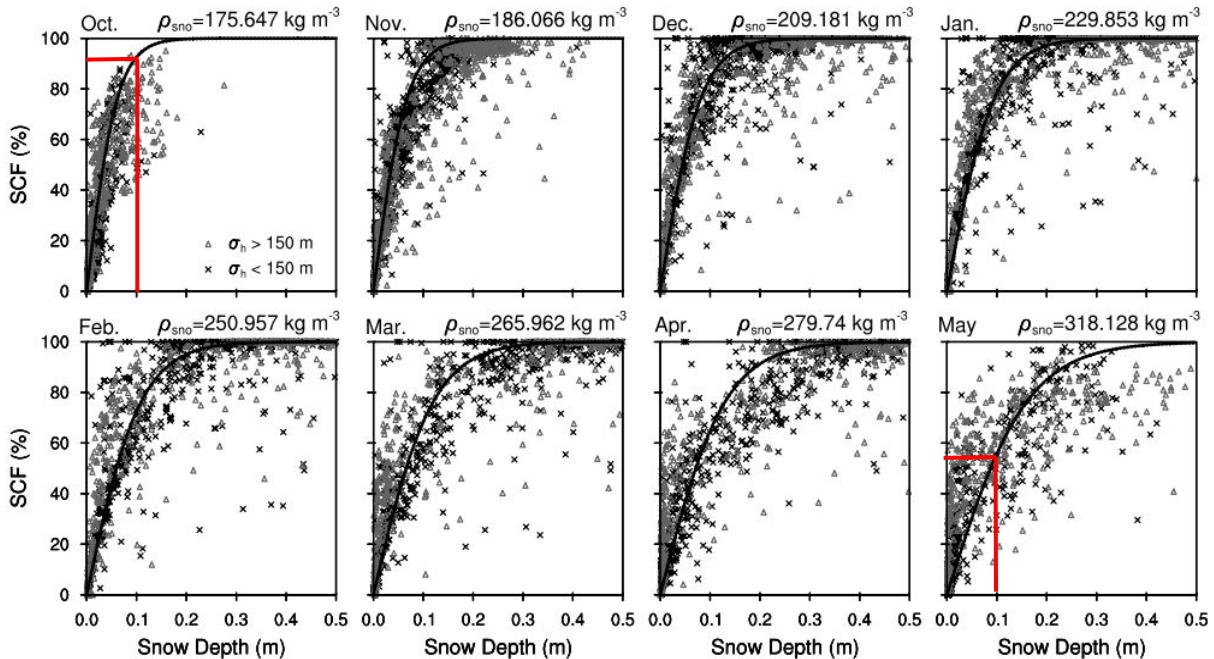
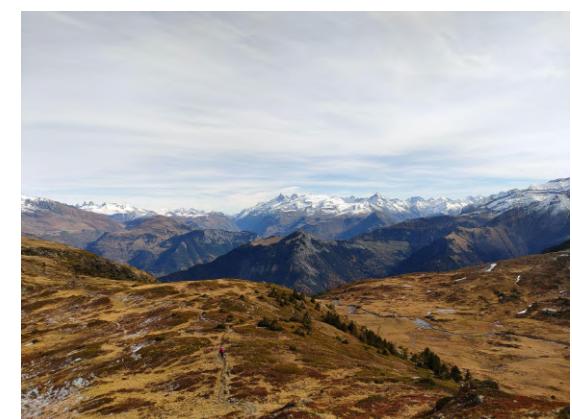
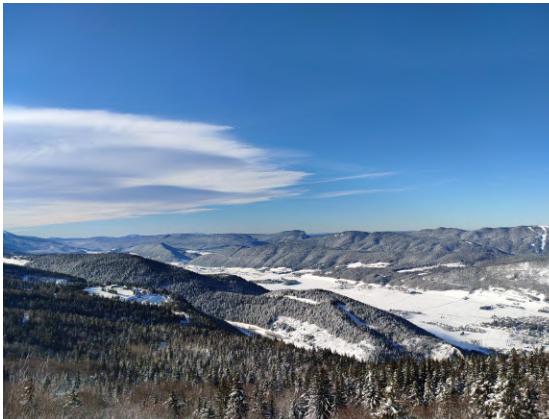


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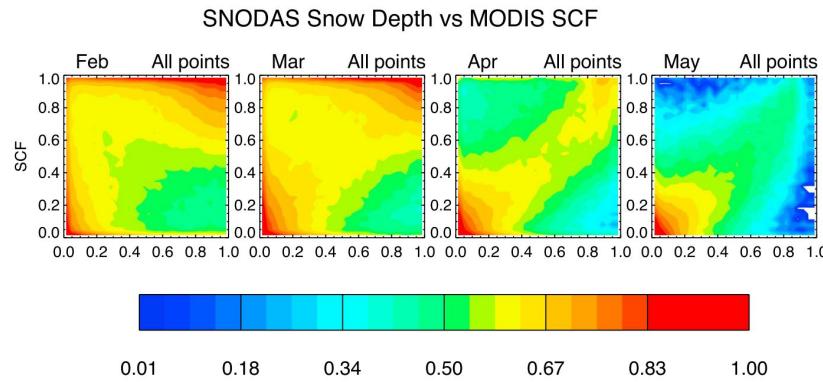
Snow cover micro to macro



Snow cover micro to macro

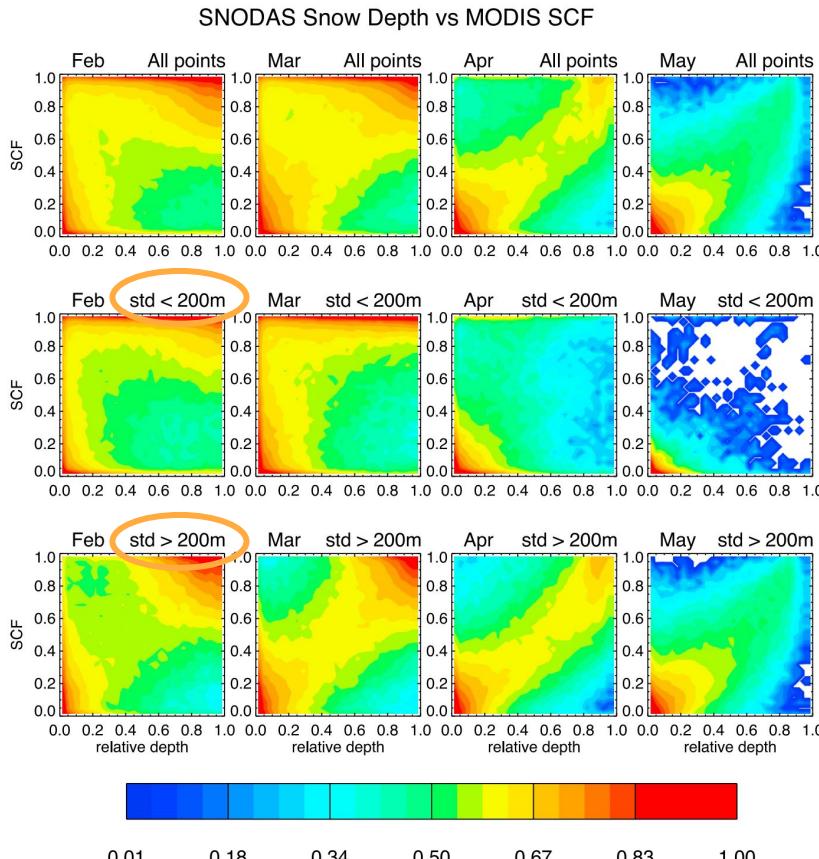


Snow cover in mountainous area: Swenson & Lawrence ([2012](#)) - SL12



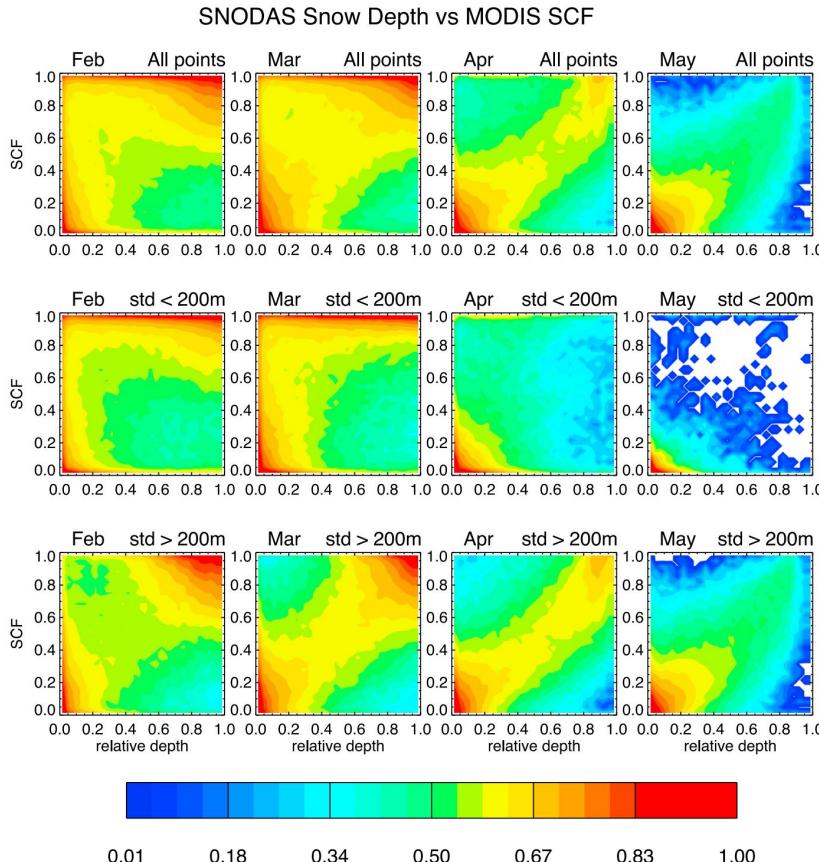
Swenson & Lawrence ([2012](#))

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Swenson & Lawrence ([2012](#))

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Swenson & Lawrence (2012)

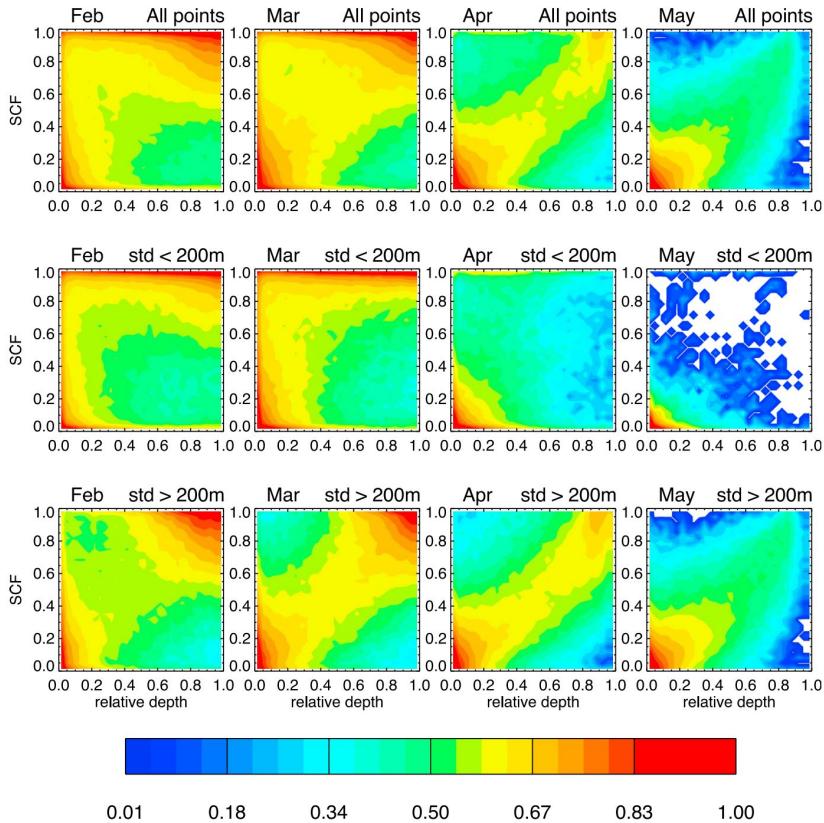
Standard deviation of topography
(σ_{topo}) in SCF parameterization first
introduced by Douville et al. (1995),
then Roesch et al. (2001), etc.

$$\text{SCF} = 1 - \left[\frac{1}{\pi} \arccos \left(2 \frac{\text{SWE}}{\text{SWE}_{\max}} - 1 \right) \right]^{N_{\text{melt}}}$$

$$N_{\text{melt}} = \frac{200}{\max(30, \sigma_{\text{topo}})}$$

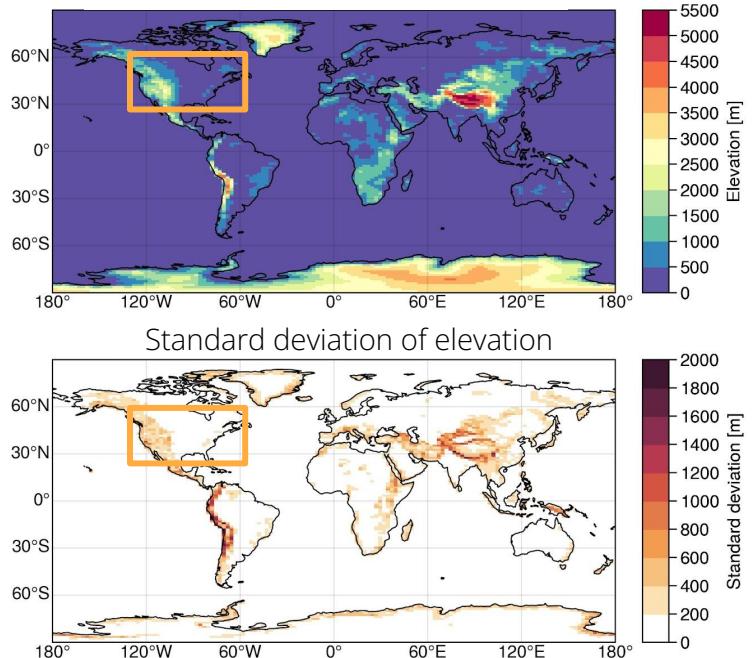
Snow cover in mountainous area: Swenson & Lawrence (2012) - SL12

SNODAS Snow Depth vs MODIS SCF

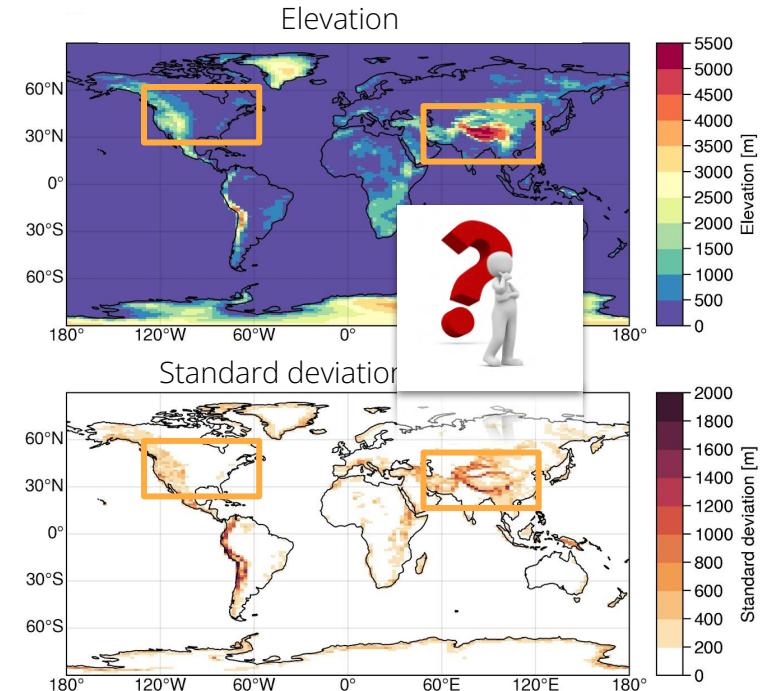
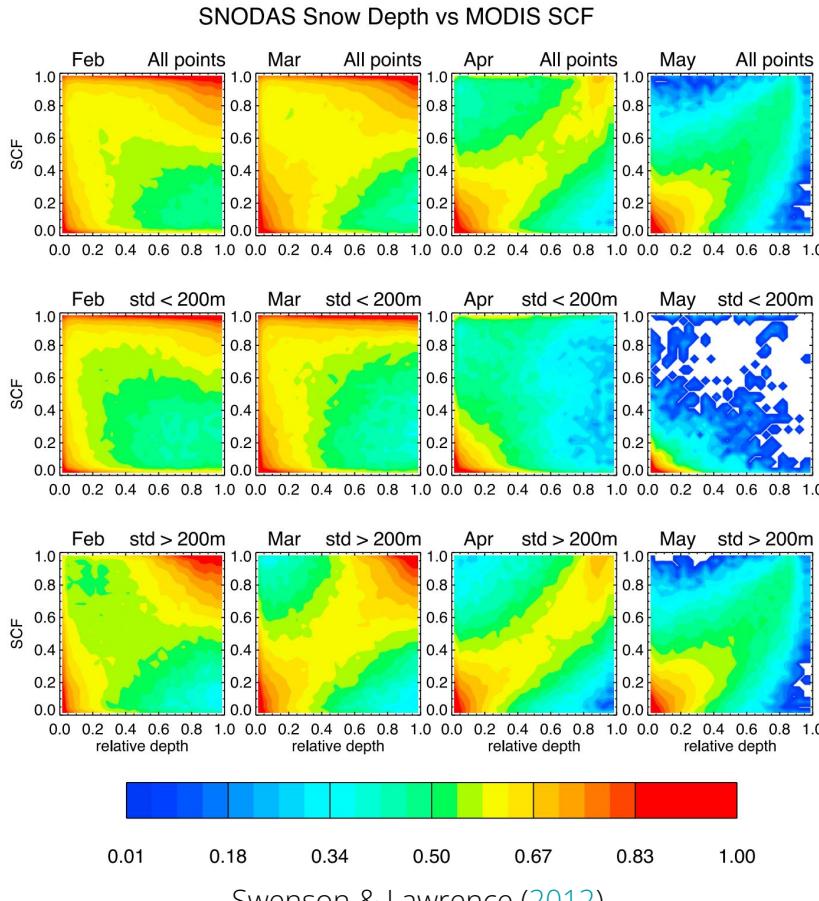


Swenson & Lawrence (2012)

Elevation



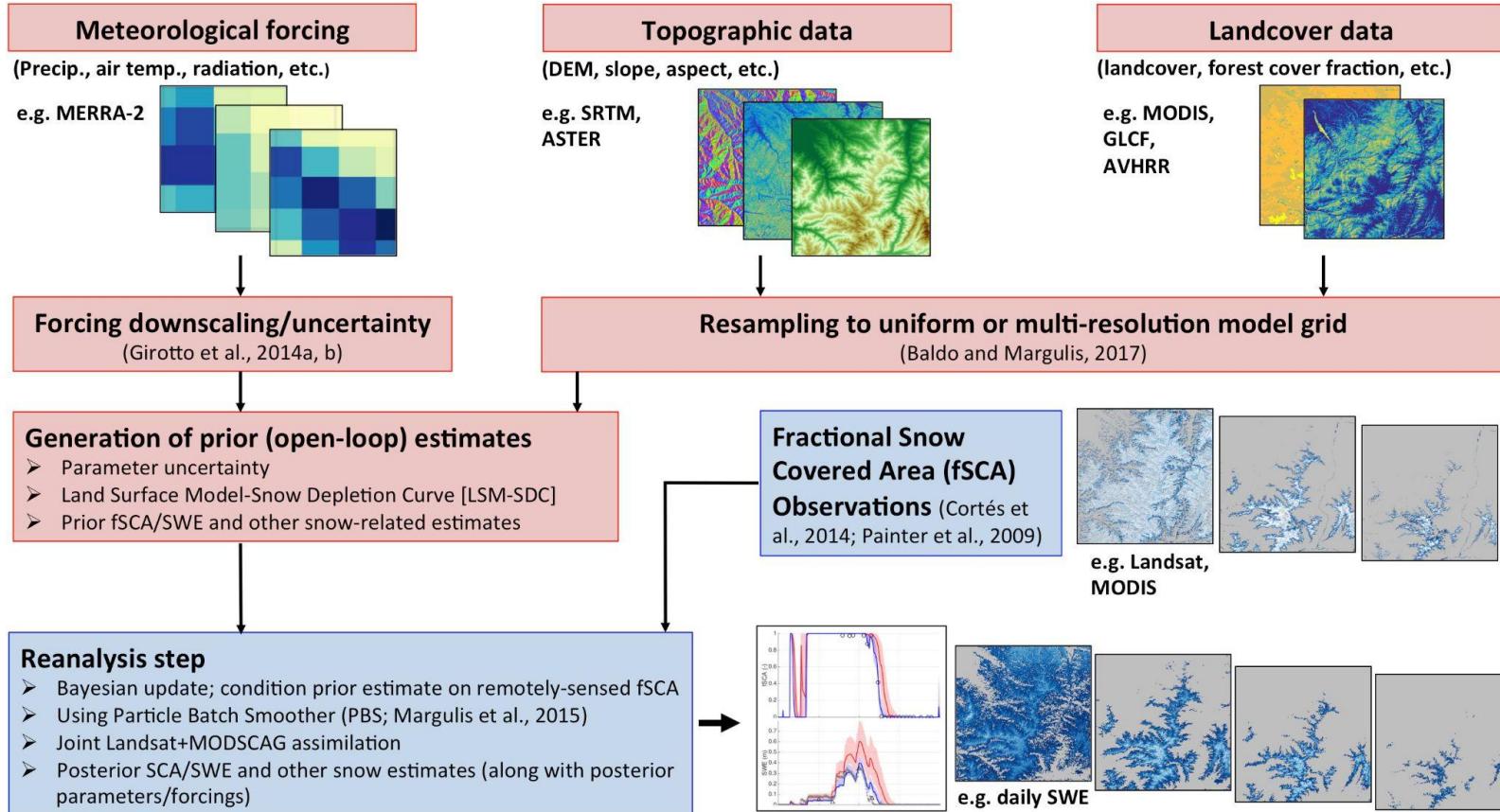
Snow cover in mountainous area: Swenson & Lawrence (2012)



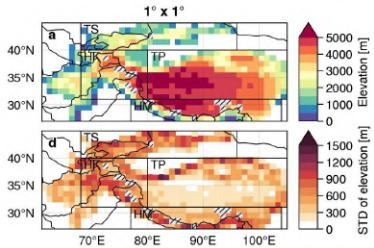
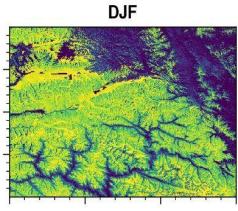
*"Estimating the spatial distribution of snow water equivalent (SWE)
in mountainous terrain is currently
the most important unsolved problem in snow hydrology."*

Dozier et al. (2016)

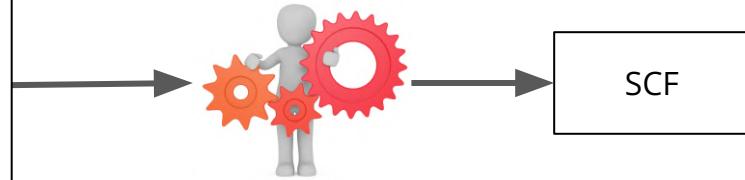
High Mountain Asia UCLA Daily Snow Reanalysis ([HMASR](#))



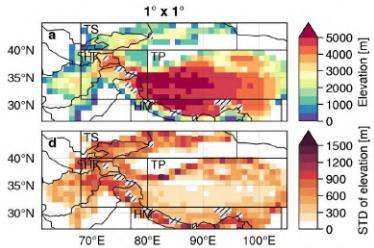
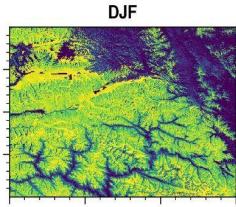
HMASR -> snow cover parameterizations



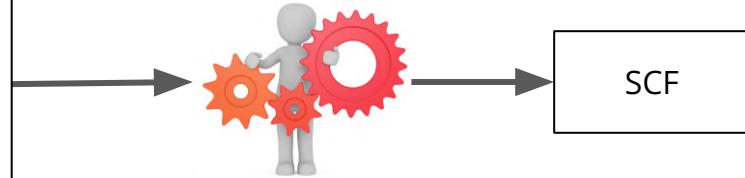
HMASR
SD / SWE / density
+ STD topo
at 1°x1°



HMASR -> snow cover parameterizations



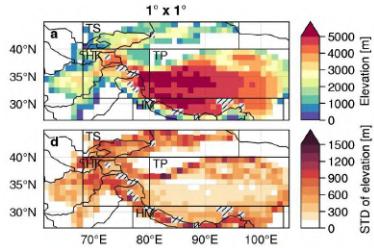
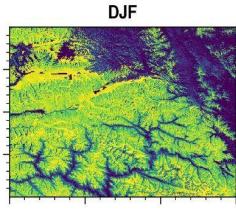
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SD / SWE / density
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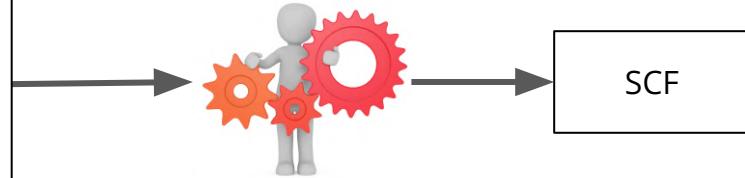
R01 ([Roesch et al., 2001](#))

$$SCF = 0.95 \cdot \tanh(100 \cdot SWE) \sqrt{\frac{1000 \cdot SWE}{1000 \cdot SWE + \varepsilon + 0.15 \cdot \sigma_z}}$$

HMASR -> snow cover parameterizations



HMASR
SD / SWE / density
+ STD topo
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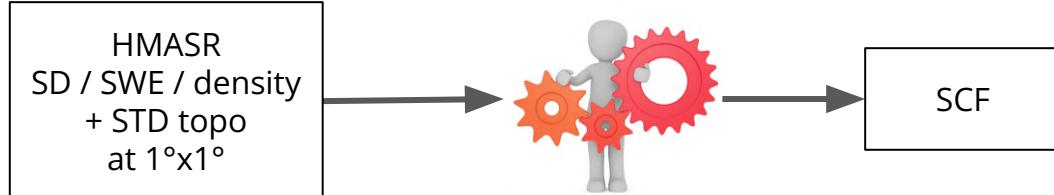
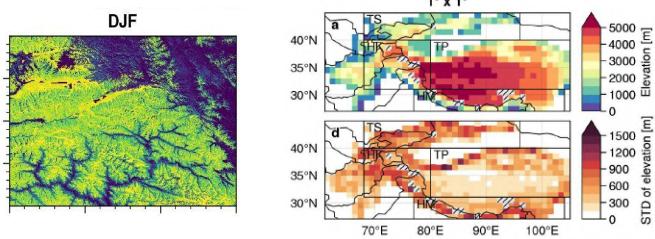
SL12 ([Swenson and Lawrence, 2012](#))

$$SCF = 1 - \left[\frac{1}{\pi} \arccos \left(2 \frac{SWE}{SWE_{max}} - 1 \right) \right]^{N_{melt}}$$

$$N_{melt} = \frac{200}{\max(30, \sigma_{topo})}$$

$$SWE_{max} = \frac{2 \cdot SWE}{\cos[\pi(1 - SCF)^{1/N_{melt}}] + 1}$$

HMASR -> snow cover parameterizations



R01 ([Roesch et al., 2001](#))

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NY07 ([Niu and Yang, 2007](#))

$$\text{SCF} = \tanh\left(\frac{\text{SD}}{2.5 \cdot z_{0g} (\rho_{\text{snow}} / \rho_{\text{new}})^m}\right)$$

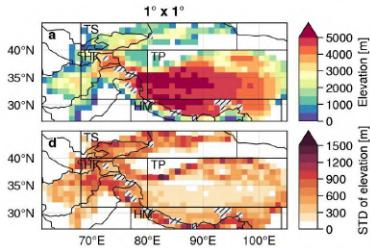
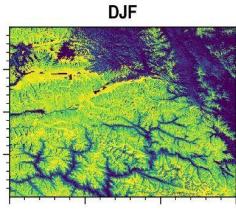
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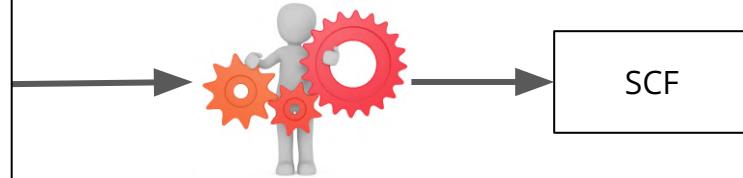
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HMASR -> snow cover parameterizations



HMASR
SD / SWE / density
+ STD topo
at $1^\circ \times 1^\circ$



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+ σ_{topo} (LA22)

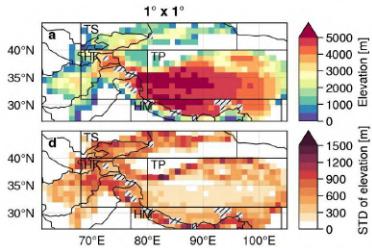
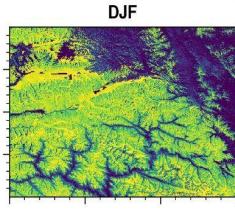
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HMASR -> snow cover parameterizations



HMASR
SD / SWE / density
+ STD topo
at $1^\circ \times 1^\circ$



R01 ([Roesch et al., 2001](#))

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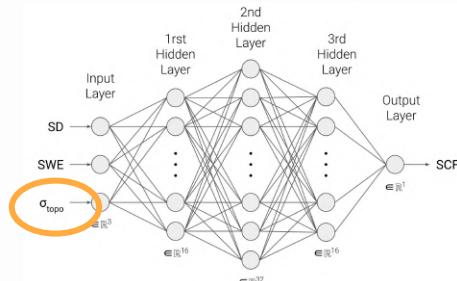
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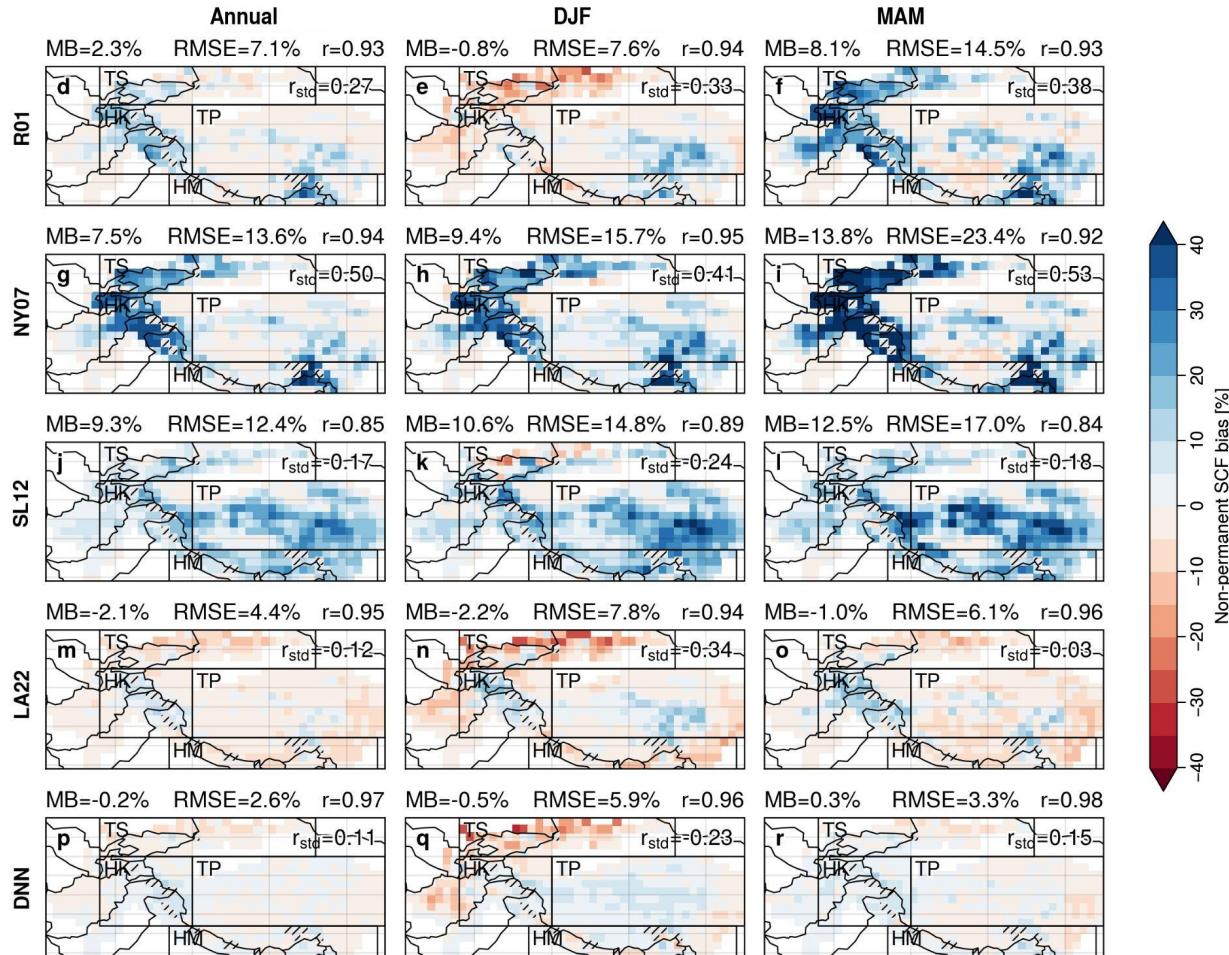
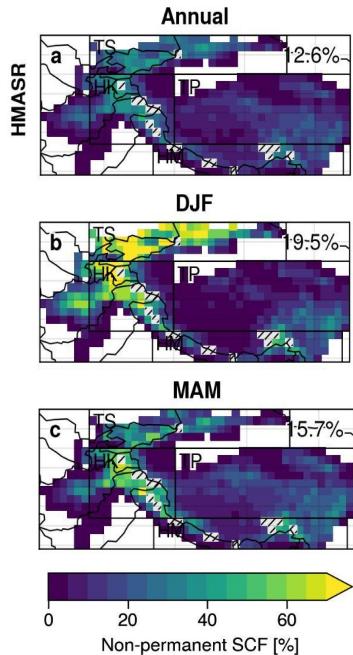
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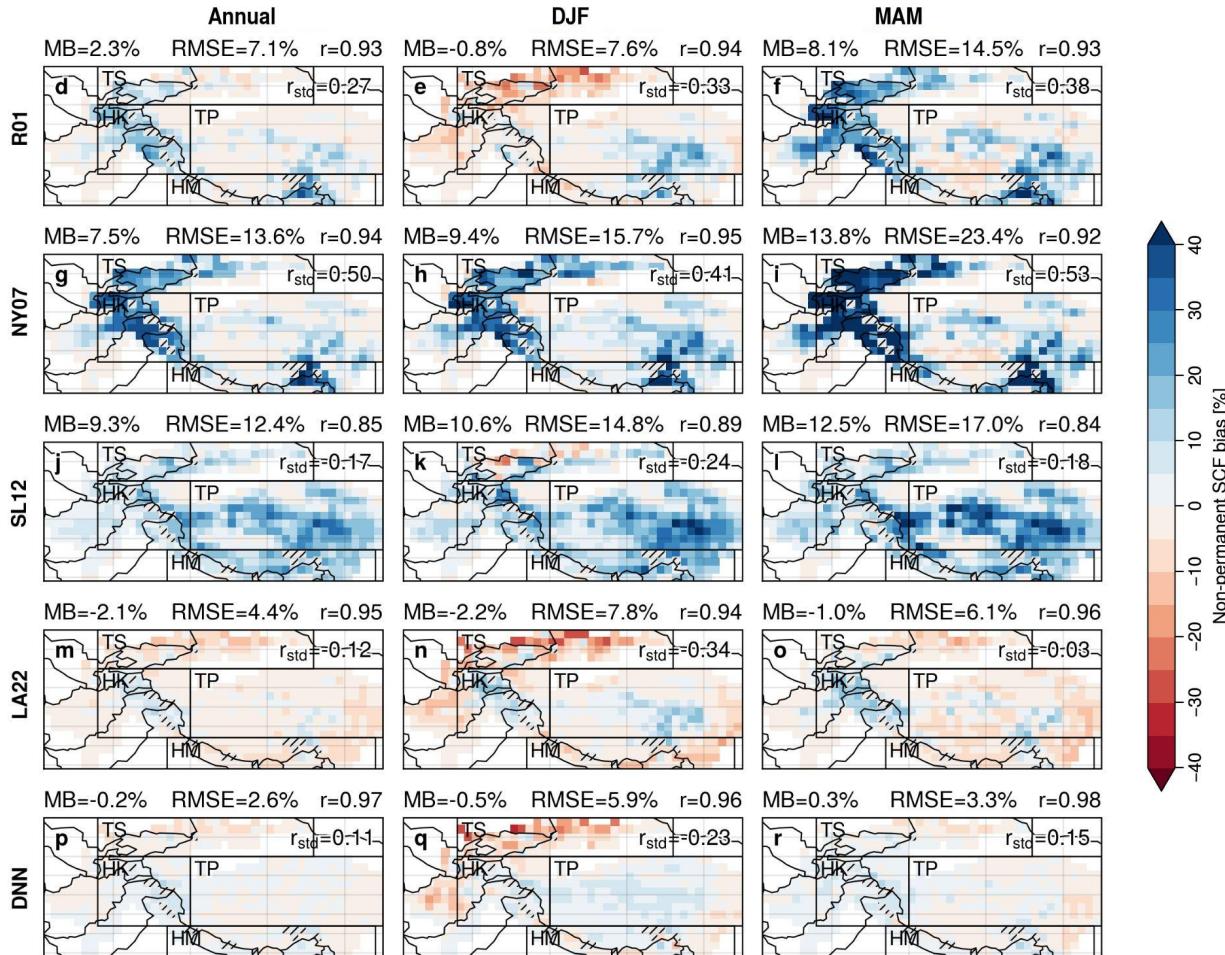
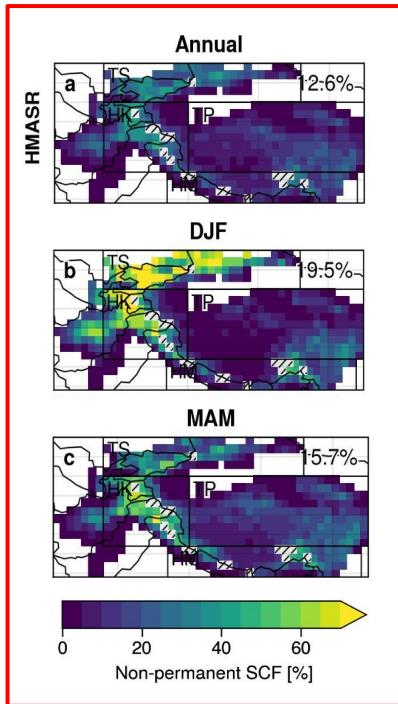
DNN (deep neural network)



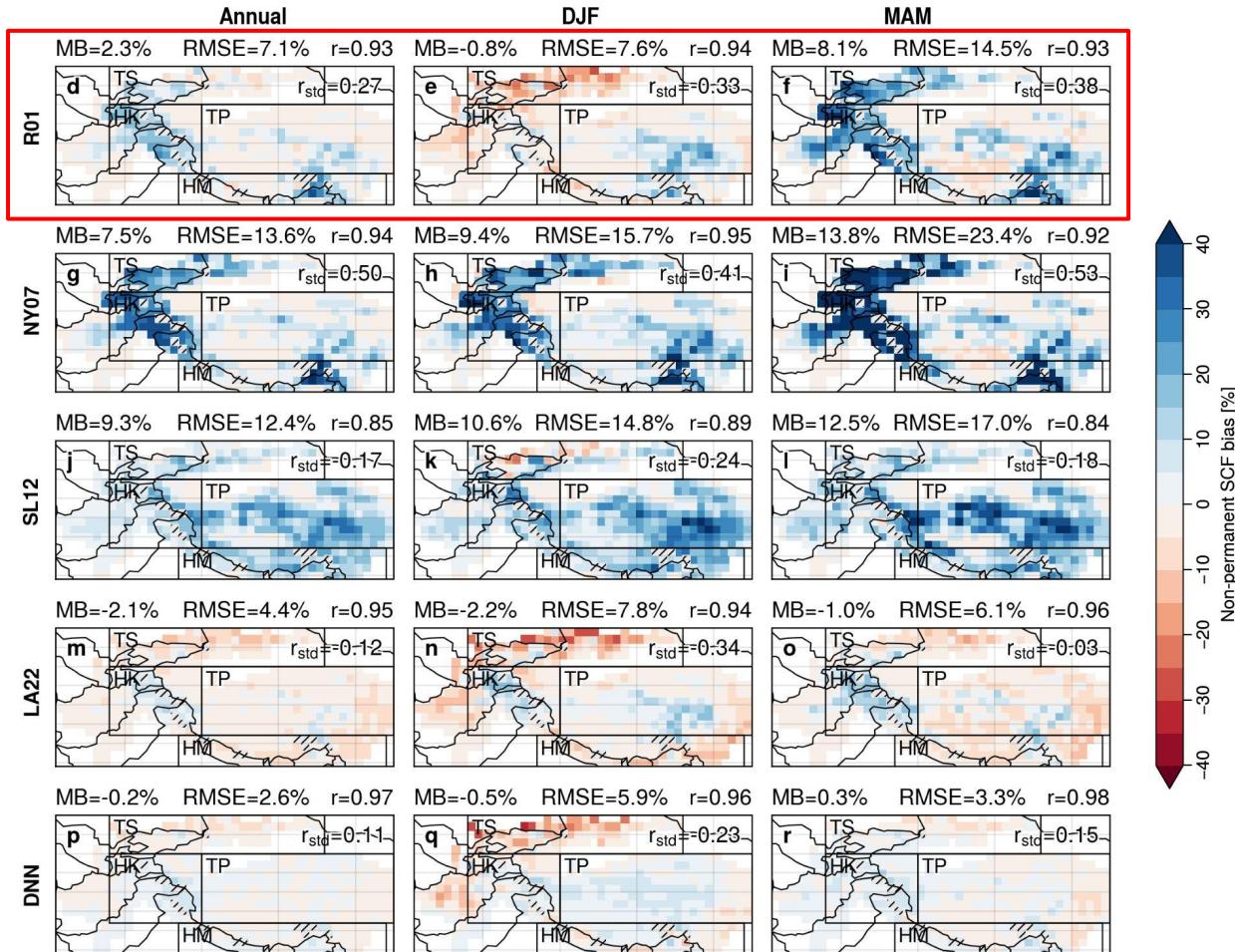
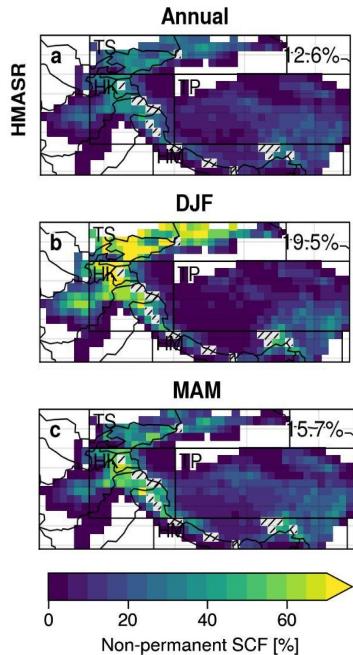
HMASR -> snow cover parameterizations



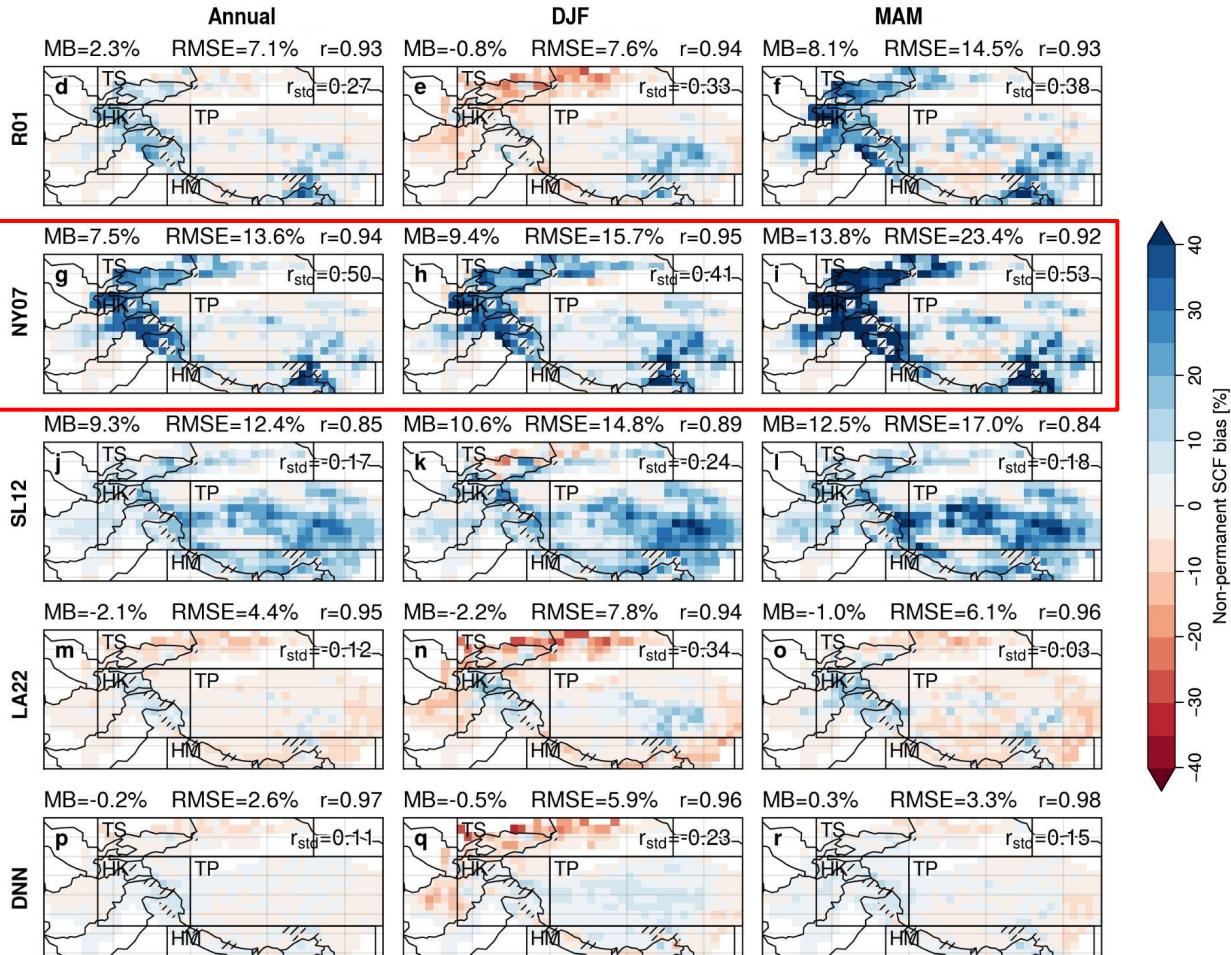
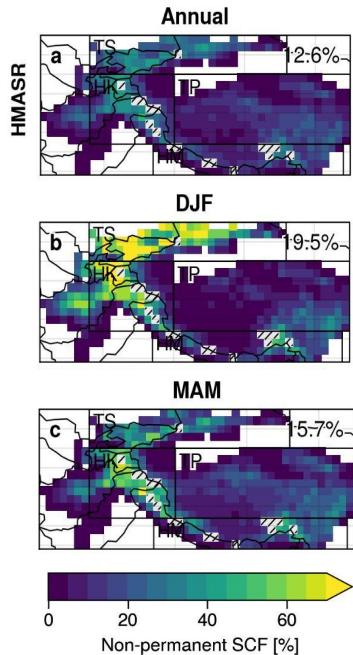
HMASR -> snow cover parameterizations



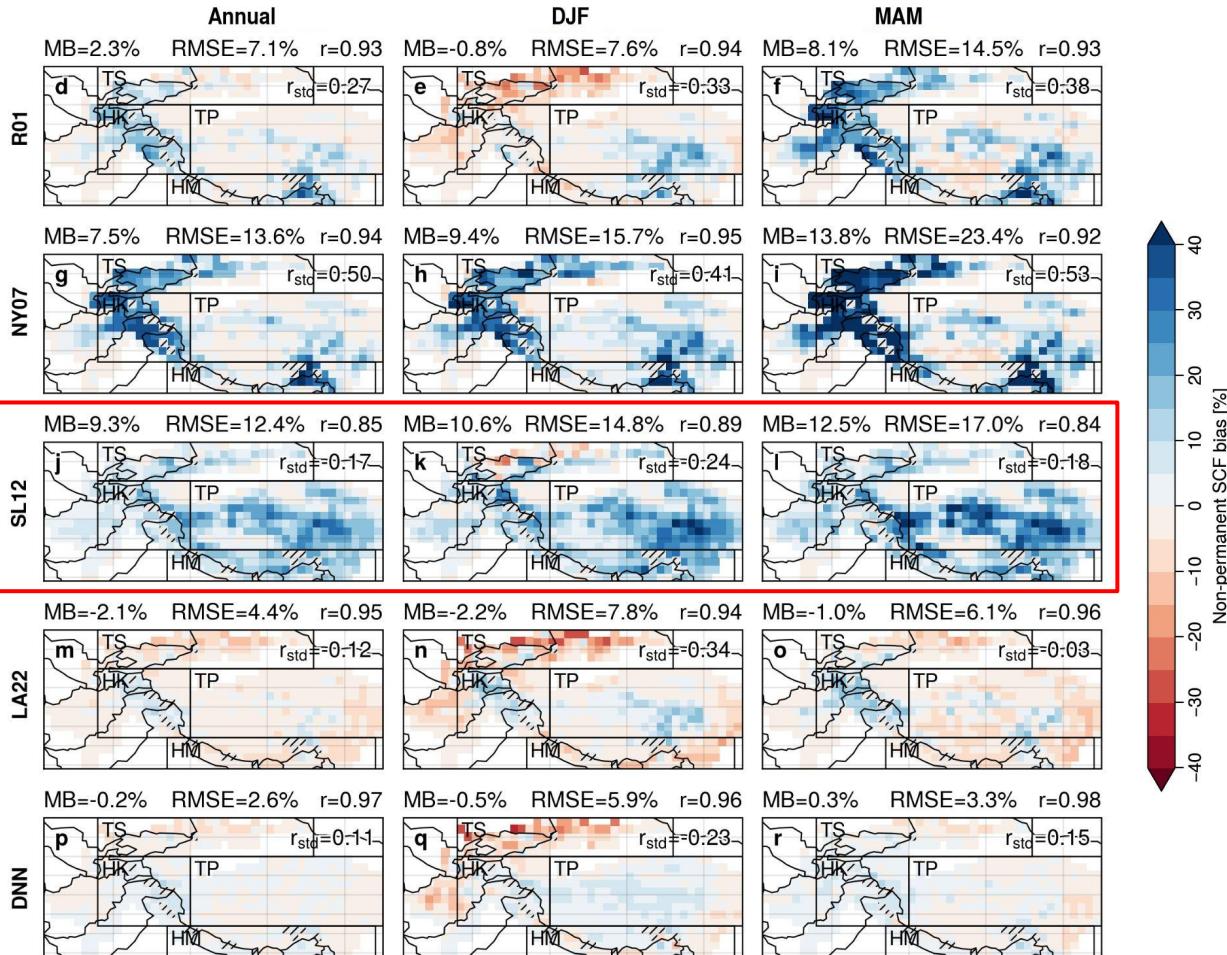
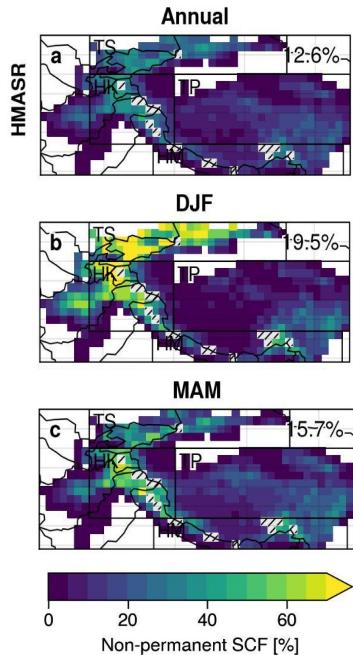
HMASR -> snow cover parameterizations



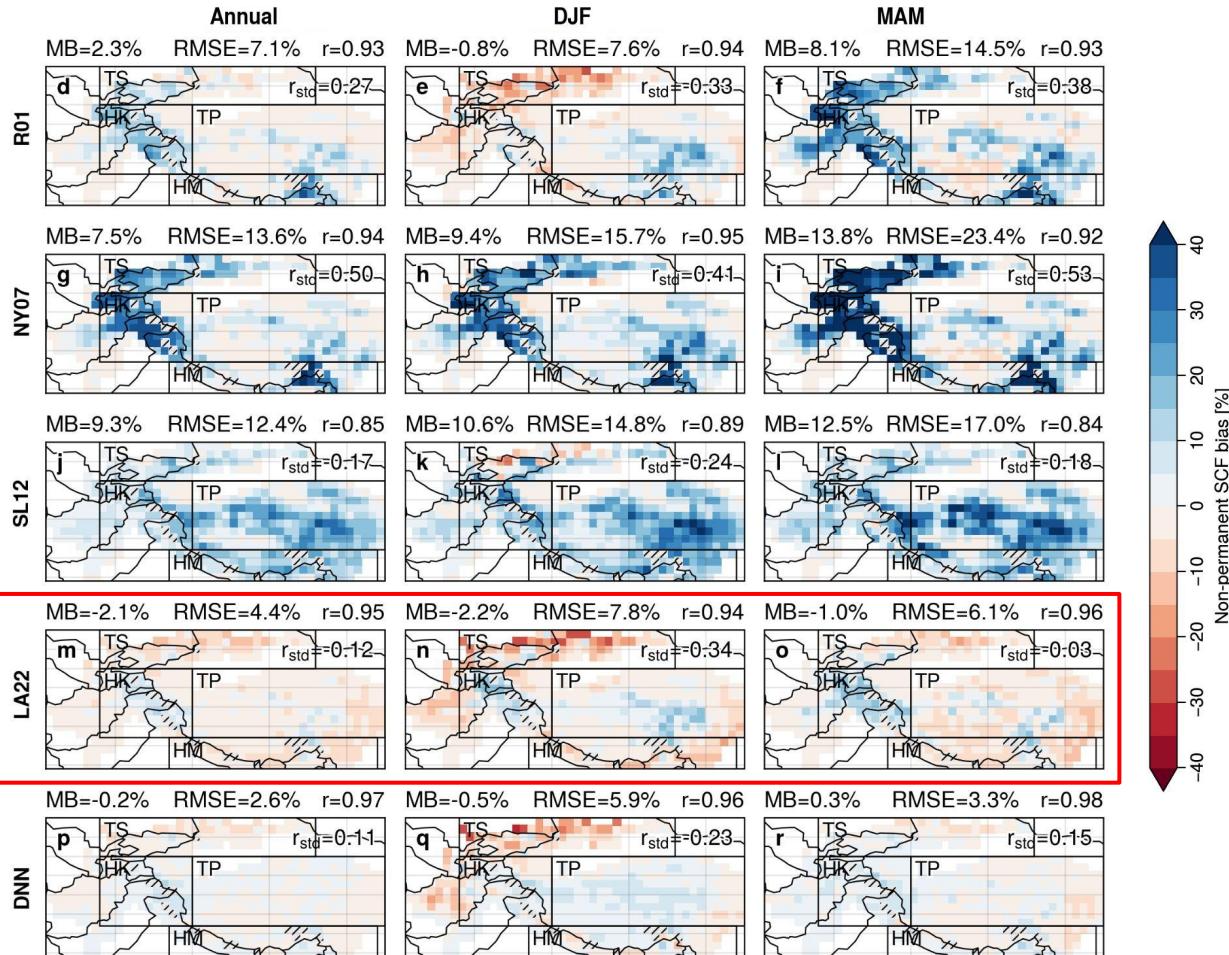
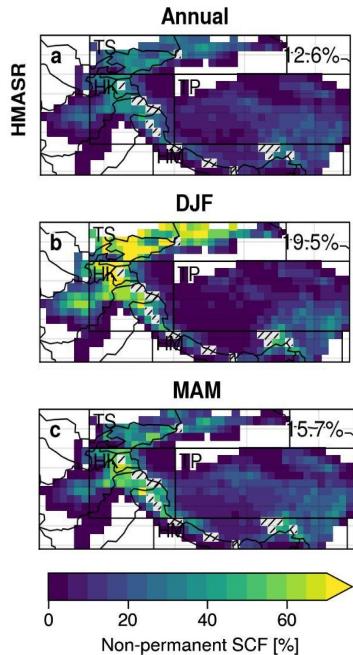
HMASR -> snow cover parameterizations



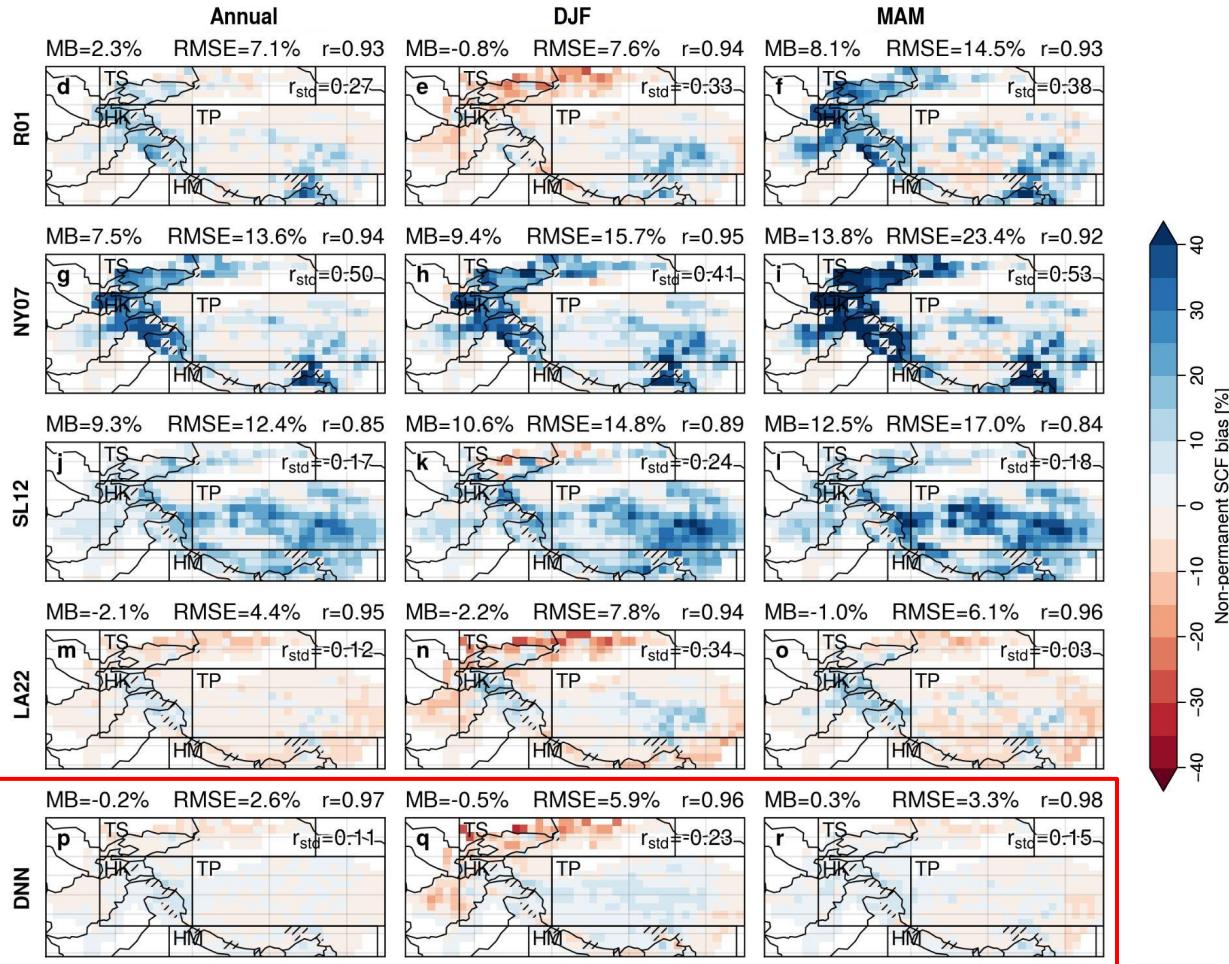
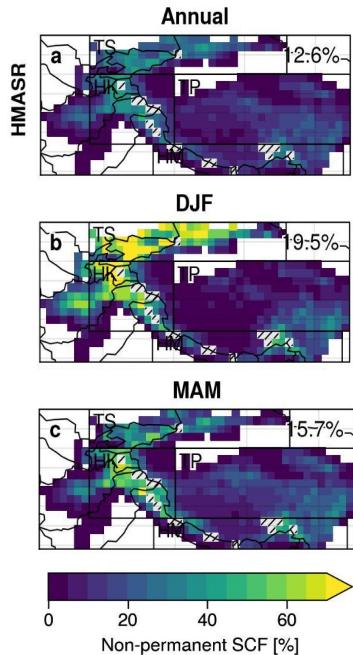
HMASR -> snow cover parameterizations



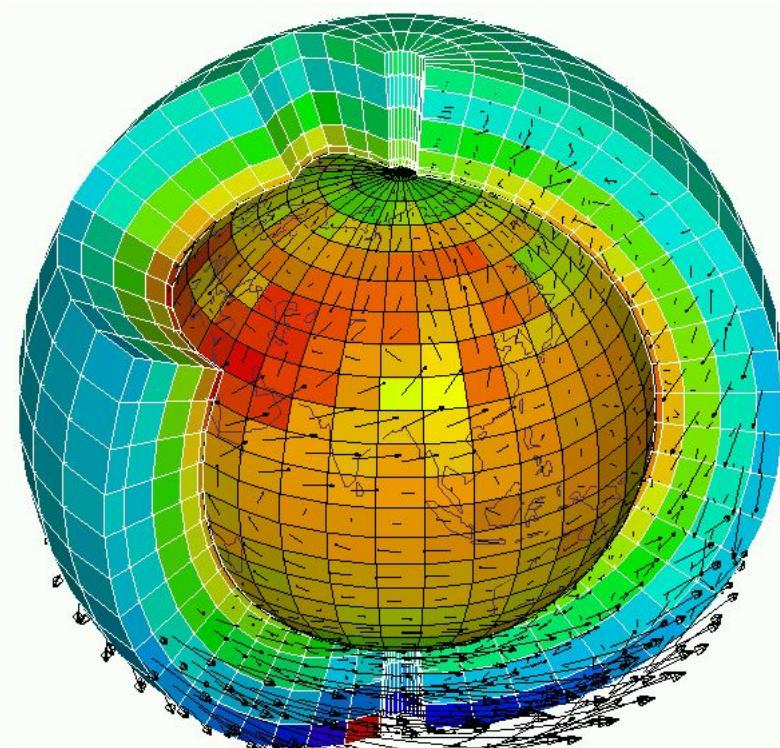
HMASR -> snow cover parameterizations



HMASR -> snow cover parameterizations



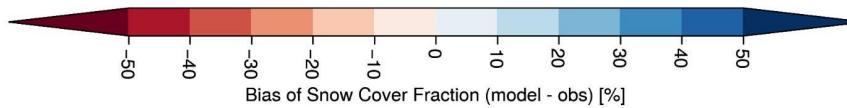
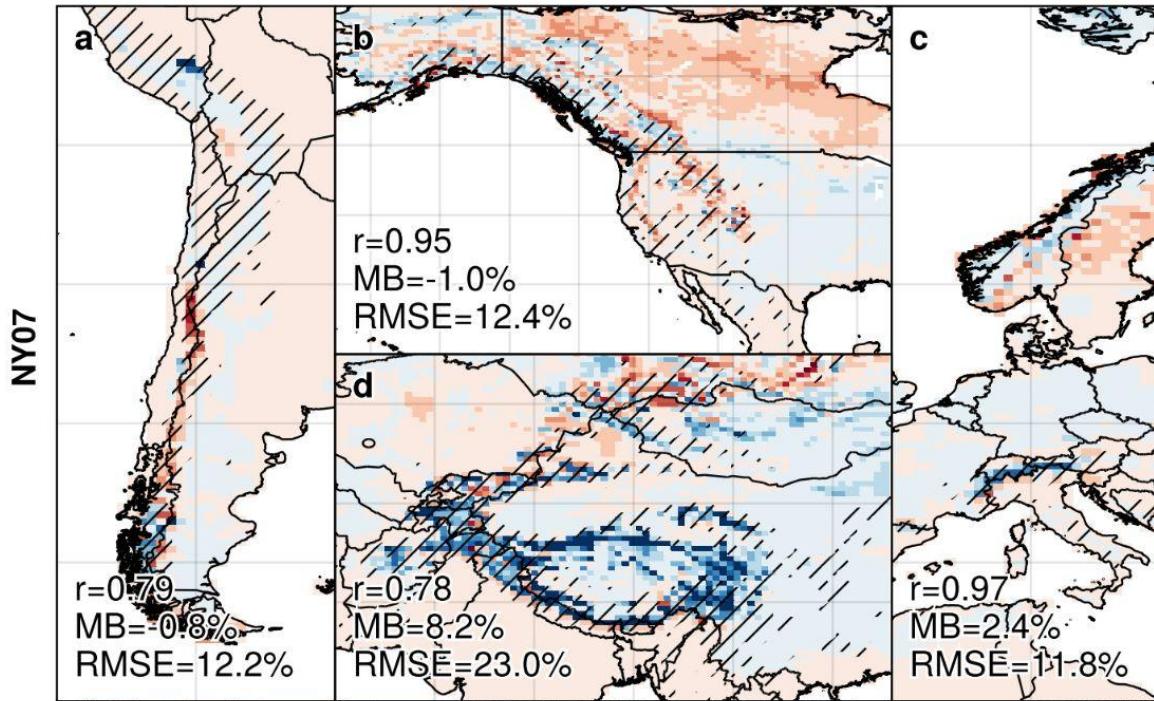
Application in GCM (LMDZ/ORCHIDEE)



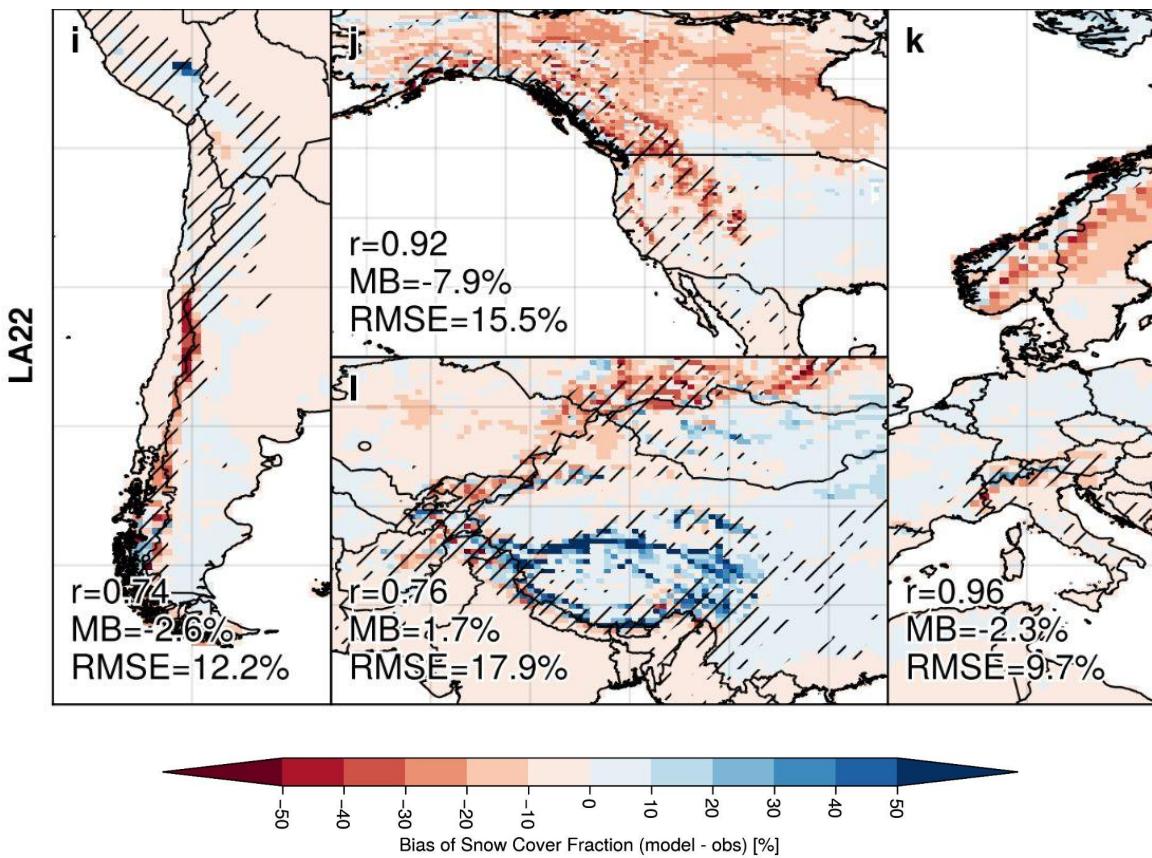
- Nudged land-atmosphere coupled simulations (LMDZ/ORCHIDEE)
- 2 resolutions:
 - LR 144x142 (~100/200 km)
 - HR 512x360 (~50 km)
- 2005-2008 (2004 spin-up)
- NY07, LA22, and SL2 parameterizations
- Snow CCI MODIS observational reference

Application in GCM (LMDZ/ORCHIDEE)

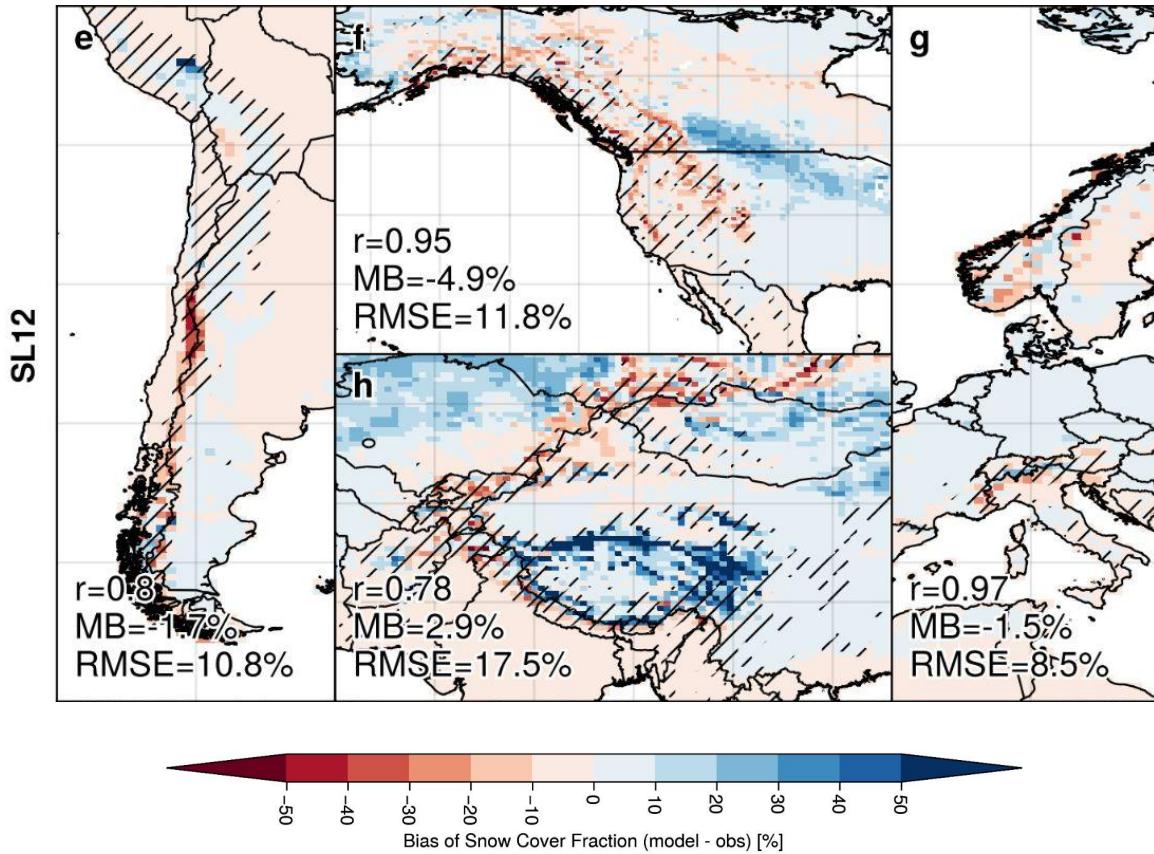
MAM (SON) SCF bias at HR (512x360) 2005-2008



Application in GCM (LMDZ/ORCHIDEE)



Application in GCM (LMDZ/ORCHIDEE)



Discussion

- Evaluating **SCF parameterizations** is not easy in GCMs because **depends on correct snowfall / SD / SWE estimates**
- These later snow related parameters (snowfall / SD / SWE) does not necessarily take into account **subgrid topography**:
 - ↳ subgrid parameterization of snowfall, snow distribution with elevation, surface energy budget, small scale orographic drag?
- Hard to evaluate!
 - ↳ Crucial need of snowfall, SD/SWE observations over mountainous areas!



Conclusion

- Taking into account the **sub-grid topography** in **SCF parameterization** seems essential over **mountainous areas** (Swenson and Lawrence, [2012](#); Miao et al., [2022](#); Lalande et al., in prep)
- **Other processes** might be involved in current **biases over HMA**:
 - precipitation (orographic drag; e.g, Wang et al., [2020](#)) / aerosol deposition on snow (e.g., Usha et al., [2020](#)) / boundary layer (e.g., Serafin et al., [2020](#)) / tropospheric cold bias, etc.
- Further **calibration** -> **other regions / datasets** (+ other variables, forested areas?, etc.)
- Limitation over **permanent snow** areas? (glaciers, etc.)
 - elevation bands (e.g., Walland and Simmonds, [1996](#); Younas et al., [2017](#))
- Other parameterizations not tested, e.g.: Liston ([2004](#)), Helbig et al. ([2021](#)), etc.
- **Deep learning** very **promising** for such parameterizations (+ help to test the influence of other parameters)



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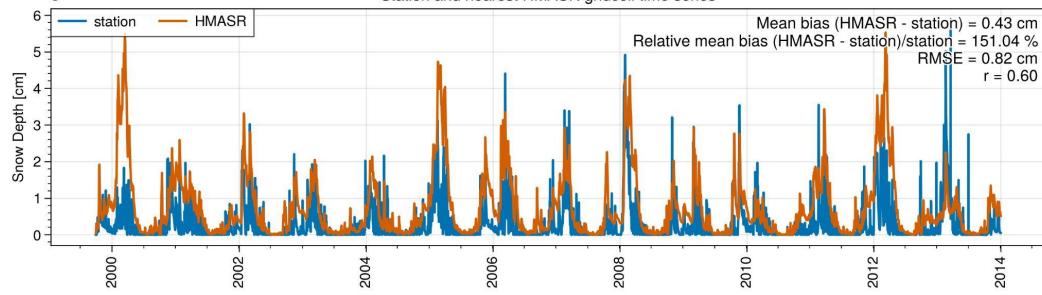
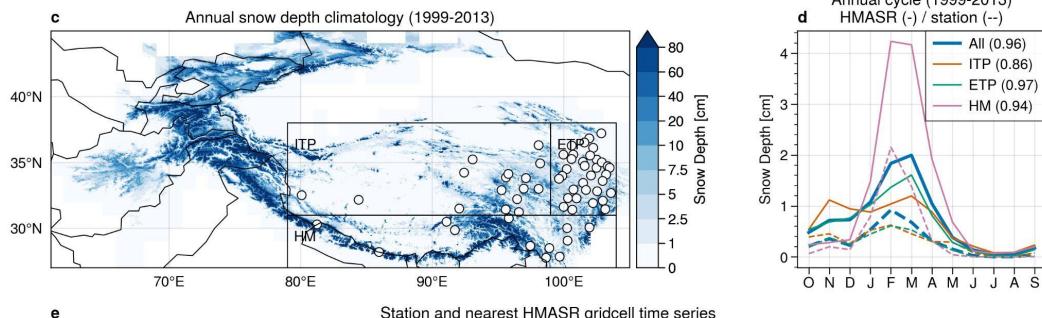
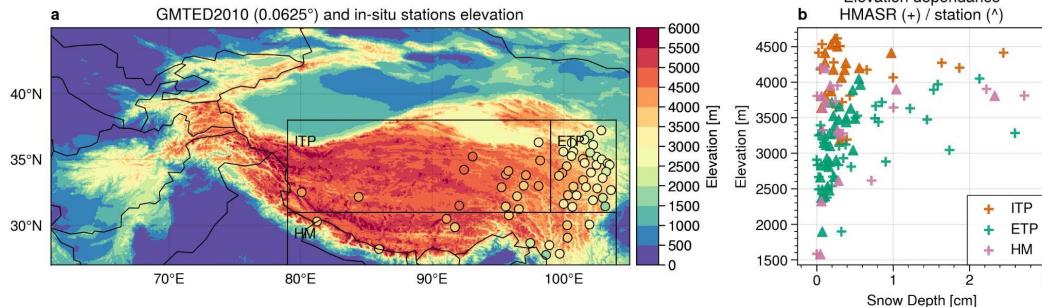
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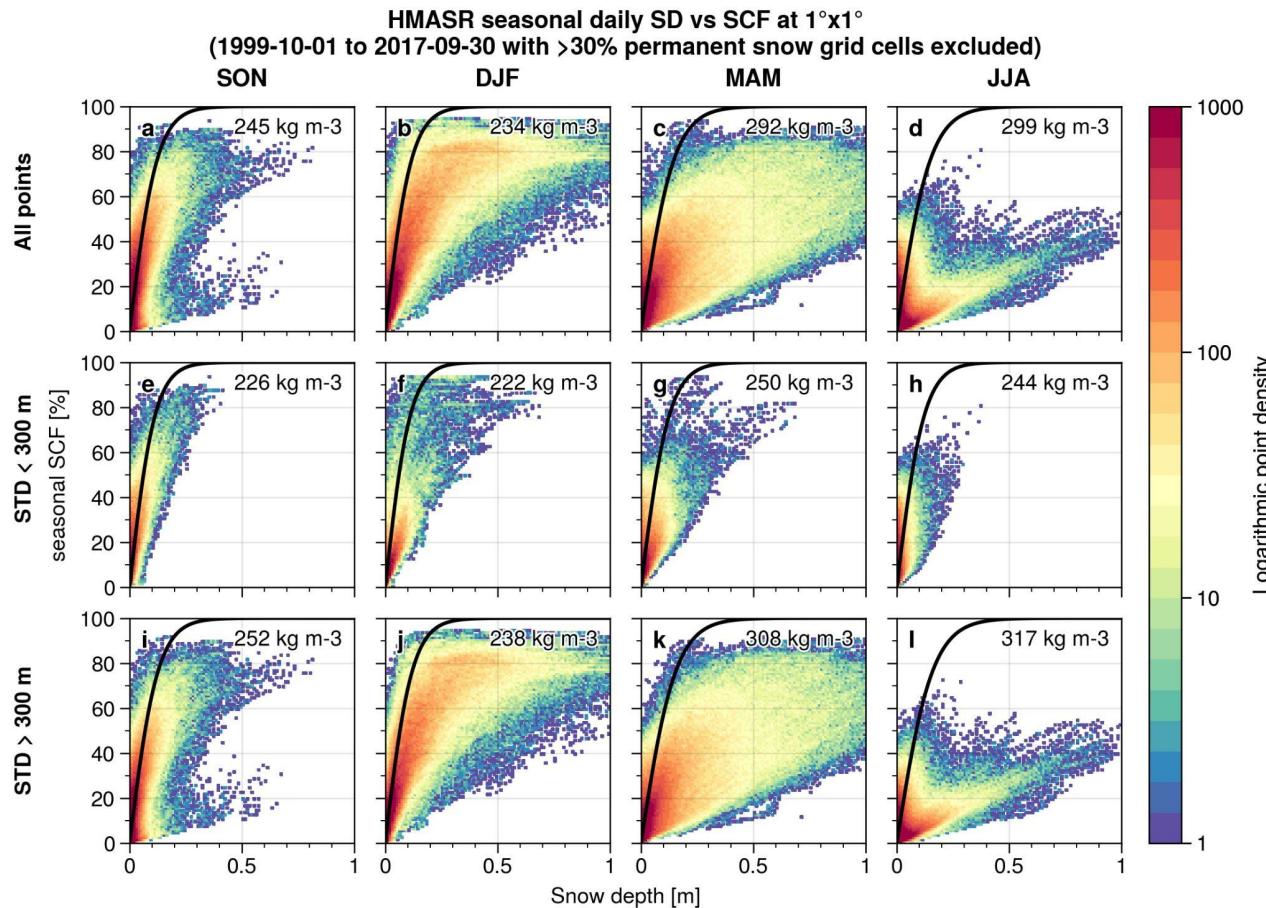
Complementary Slides

High Mountain Asia UCLA Daily Snow Reanalysis ([HMASR](#))

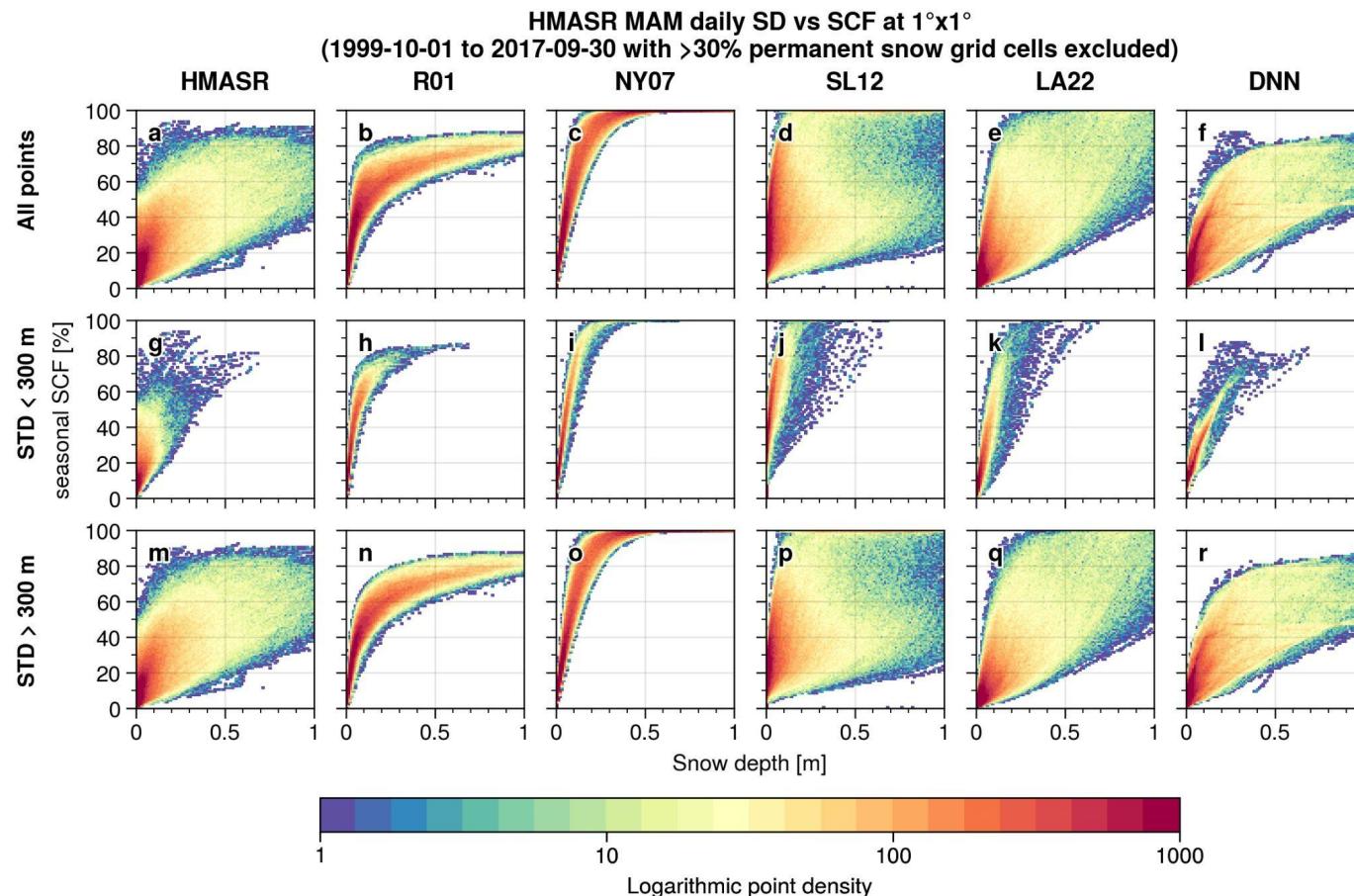
Comparison HMASR and in-situ station 1999-2013 (>90% temporal coverage and >1mm SD in winter DJFMA)



High Mountain Asia UCLA Daily Snow Reanalysis



High Mountain Asia UCLA Daily Snow Reanalysis

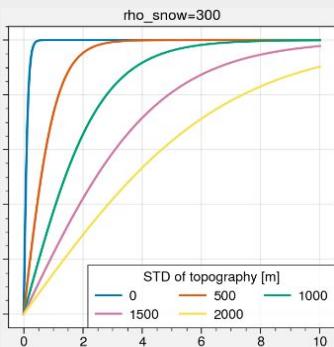


Other snow cover parameterizations

Niu and Yang (2007) custom

$$F = \tanh\left(\frac{d}{2.5z_0g(\rho_{snow}/\rho_{new})^m}\right)$$

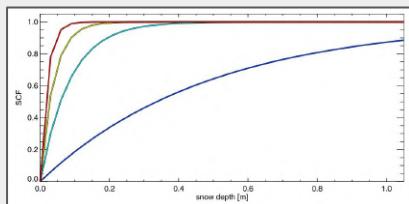
STD topo



Swenson and Lawrence (2012)

Accumulation

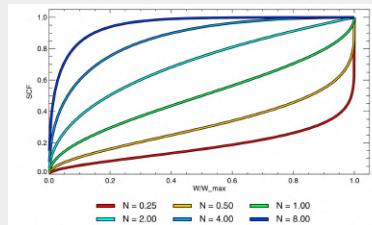
$$F_{N+1} = 1 - (p_{N+1})(p_N) = 1 - (1 - s_{N+1})(1 - F_N)$$



Depletion

$$F = 1 - \left[\frac{1}{\pi} \arccos\left(2 \frac{W}{W_{max}} - 1 \right) \right]^{N_{melt}}$$

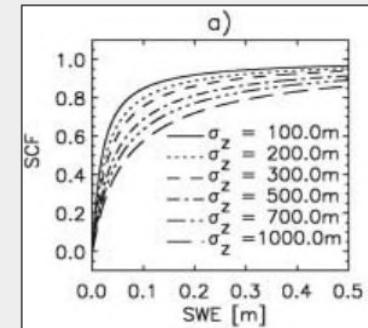
$$N_{melt} = \frac{200}{\sigma_{topo}}$$



Roesch et al. (2001)

Mountainous areas

$$f_s = 0.95 \cdot \tanh(100 \cdot S_n) \sqrt{\frac{1000 \cdot S_n}{1000 \cdot S_n + \epsilon + 0.15\sigma_z}}$$



Depends only on SWE so no hysteresis