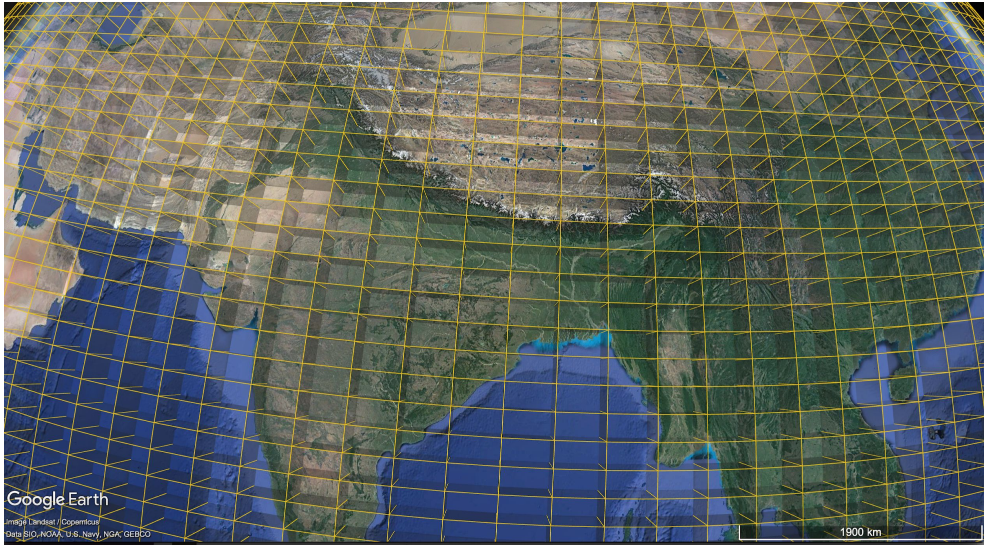
Adaptation of a snow cover scheme for complex topography areas:

regional calibration over High Mountain Asia and application in global models



This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

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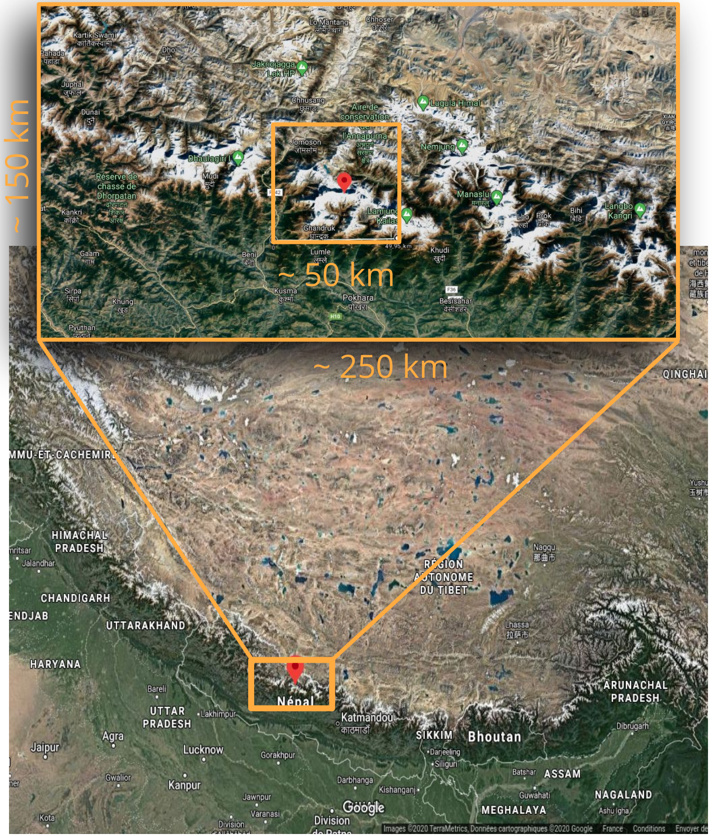
EGU22-615 | Presentations | CR3.1 — 24/05/2022

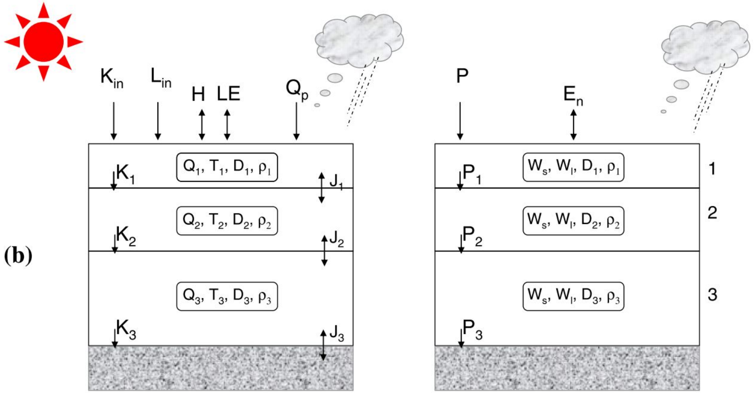
IPSL-CM6A

How does the snow cover fraction (SCF) evolves over mountainous areas?

Snow cover parameterization in global models



IPSL-CM6A

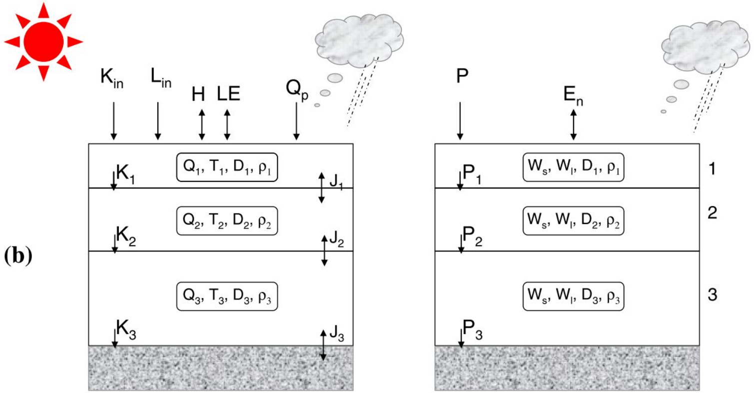


K_{in} (short wave radiation), **L_{in}** (longwave radiation), **H** (sensible heat flux), **LE**(latent heat flux), **J** (conduction heat flux), **Q** (snow layer heat content), **Q_p**(advective heat from rain and snow), **W** (snow layer SWE), **W_l** (snow layer liquid water content), **D** (snow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

snow scheme in the ORCHIDEE land surface model (Wang et al., 2013)

Snow cover parameterization in global models

IPSL-CM6A



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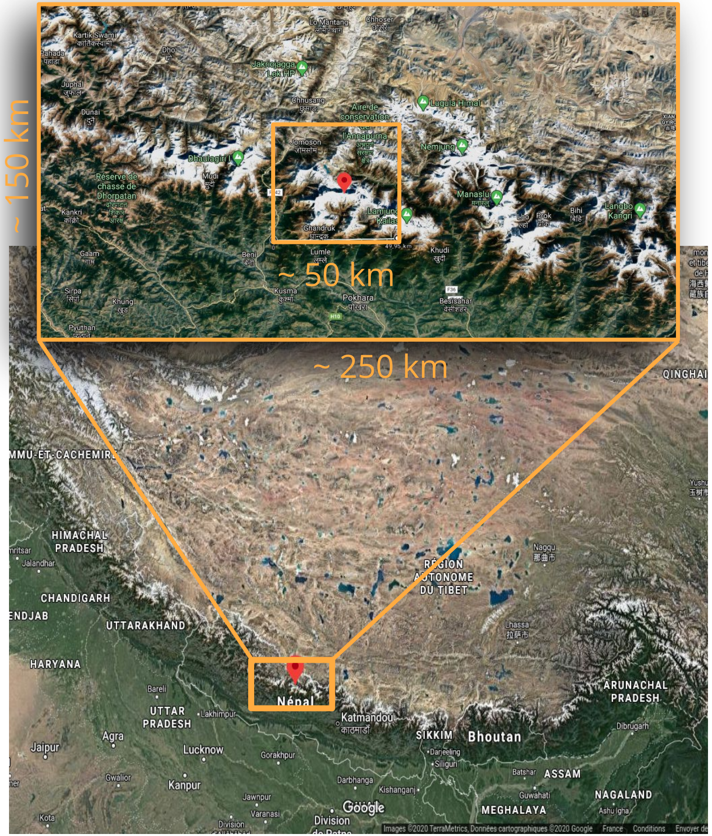
snow scheme in the ORCHIDEE land surface model
(Wang et al., 2013)

Snow Depth

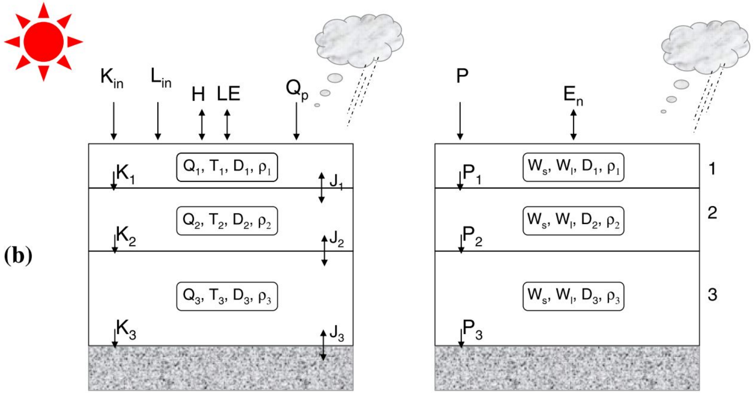
Snow Water Equivalent

Snow Density

Snow cover parameterization in global models



IPSL-CM6A



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**(advective 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 Cover Fraction

Snow Density

Snow cover real world vs global models

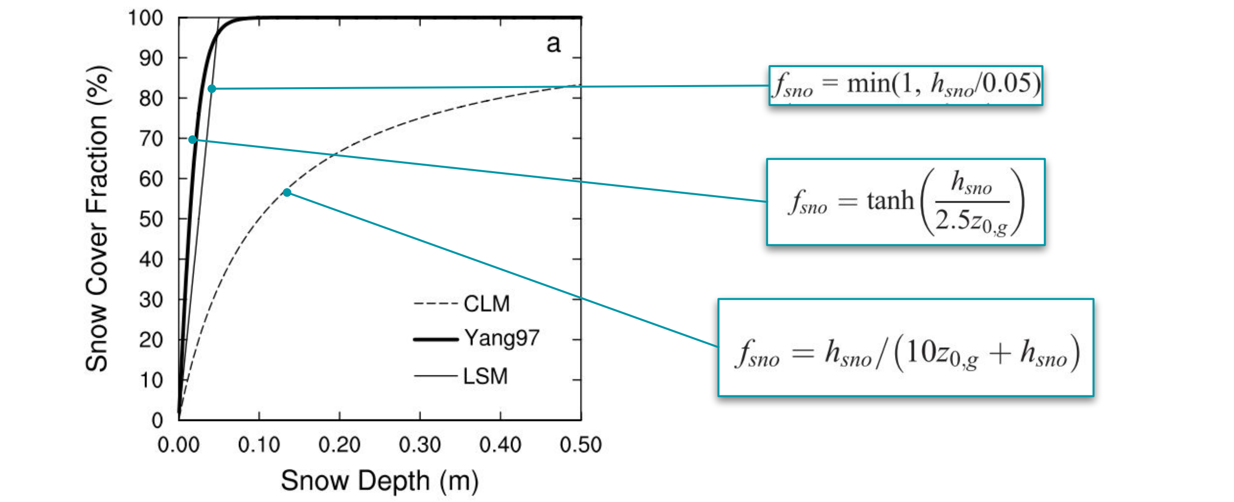
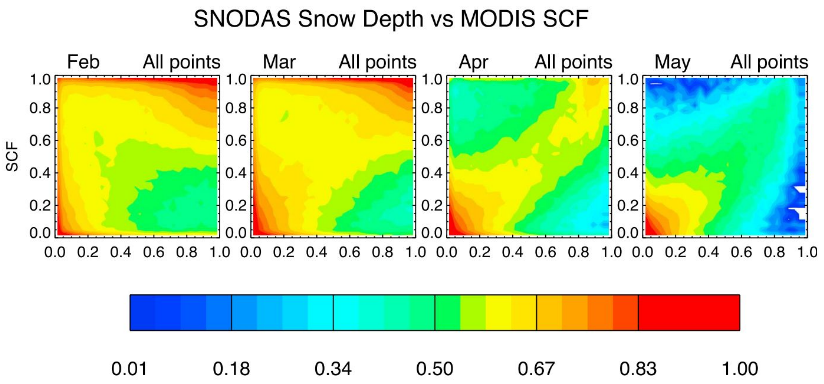


Figure 1. (a) SCF (or f_{sno}) computed from equation (2) (used in the default CLM and BATS), equation (3) of *Yang et al.* [1997], and a formulation used in the NCAR LSM1.0, $f_{sno} = \min(1, h_{sno}/0.05)$, where h_{sno} is snow depth (m) and (b) SCF as a function of ground surface roughness, snow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

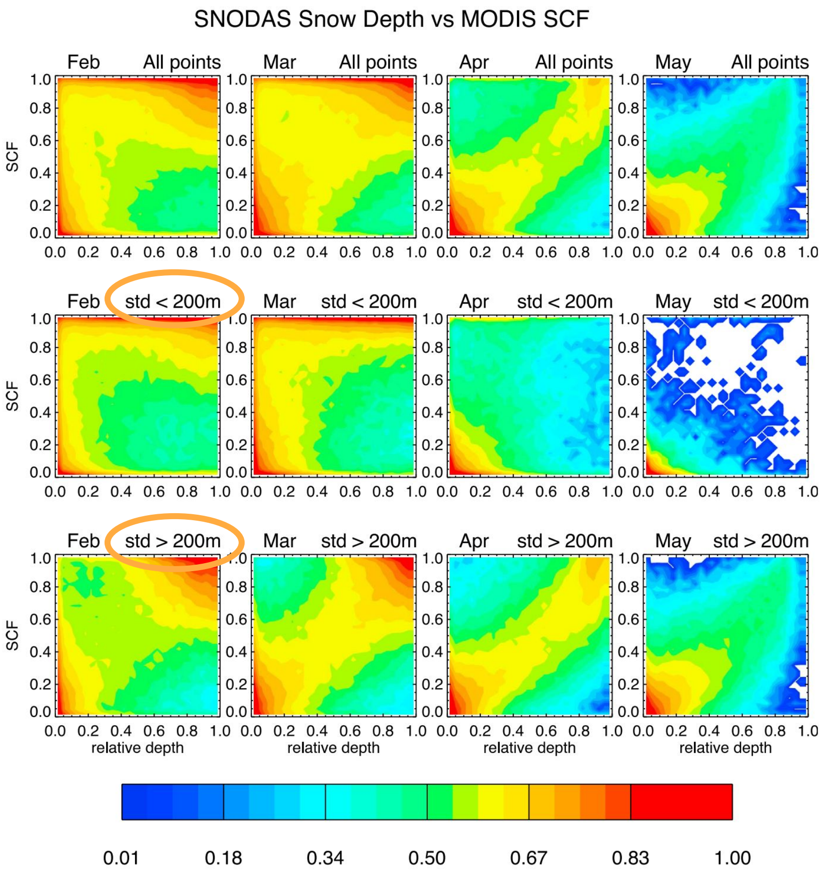
Niu and Yang (2007)

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



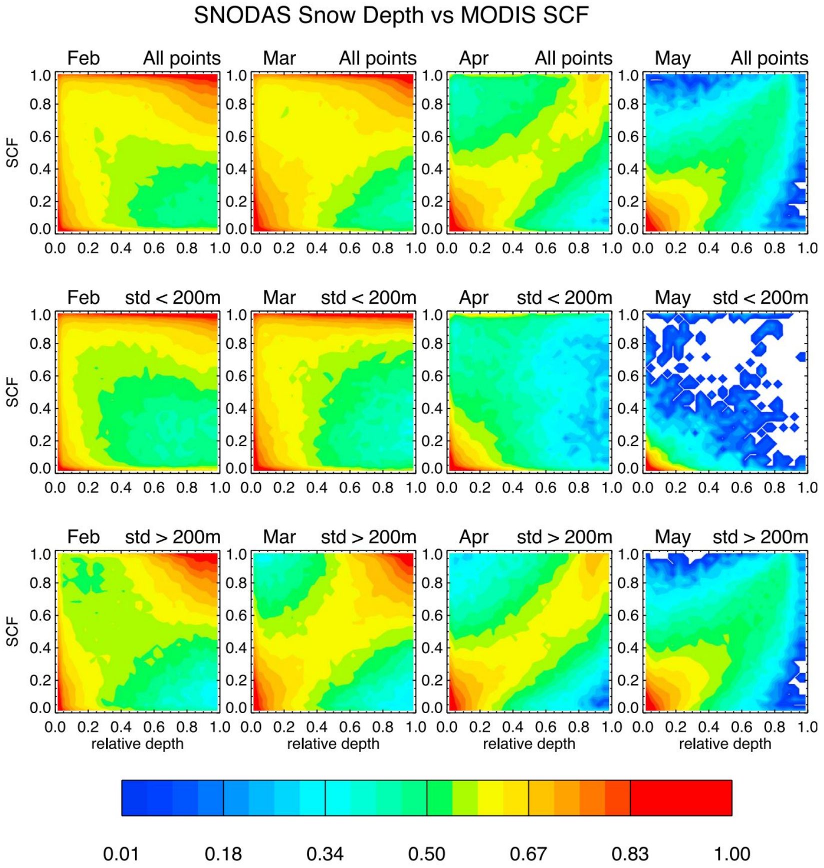
Swenson & Lawrence (2012)

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



Swenson & Lawrence (2012)

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



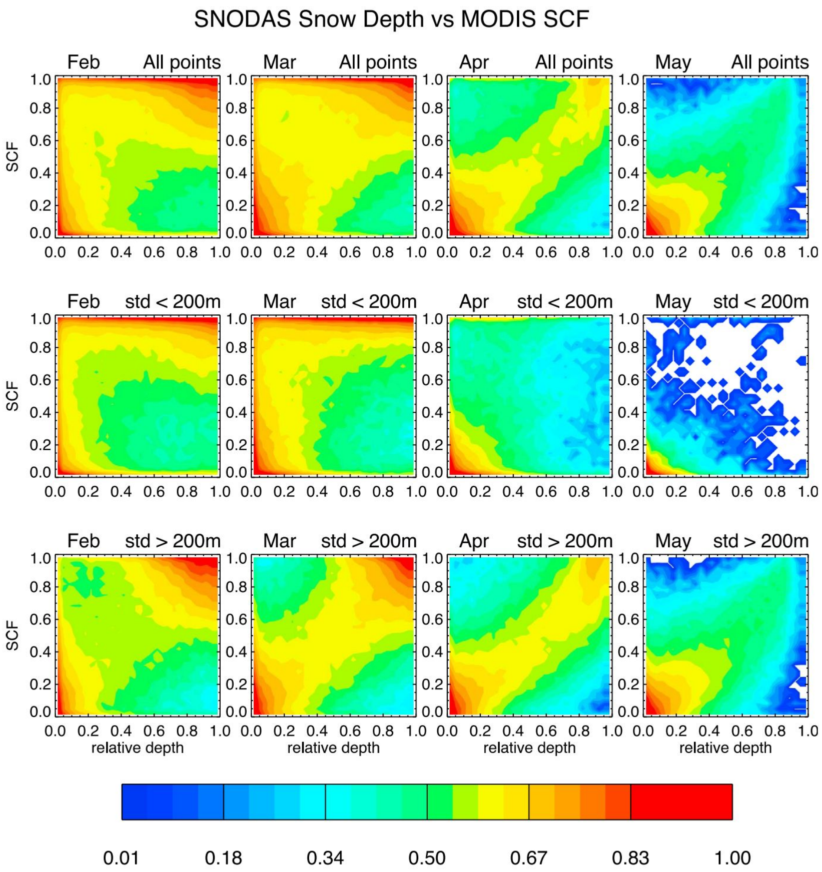
Swenson & Lawrence (2012)

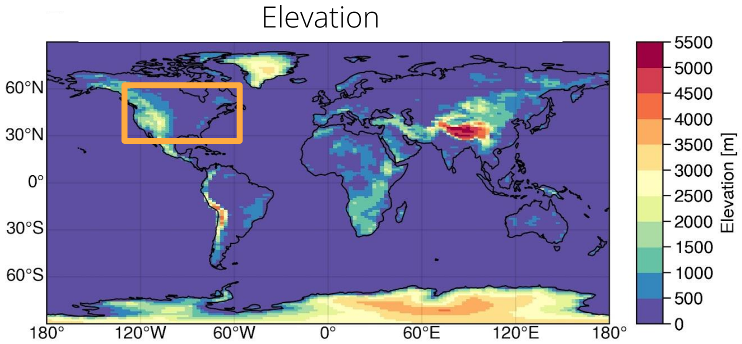
Standard deviation of topography (σ_{topo}) in SCF parameterization first introduced by Douville et al. (1995), then Roesch et al. (2001), etc.

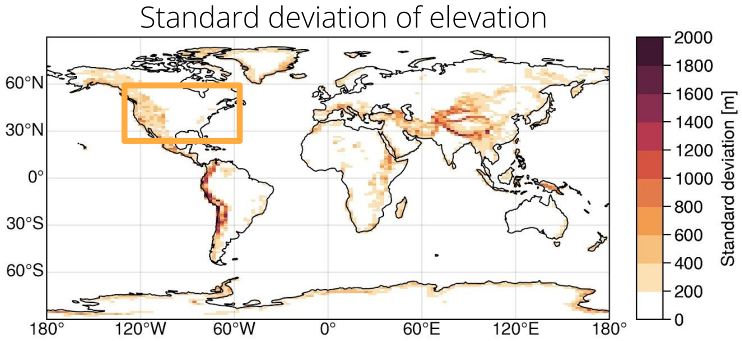
$$\mathrm{SCF} = 1 - \left[\frac{1}{\pi}\mathrm{acos}\left(2\frac{\mathrm{SWE}}{\mathrm{SWE_{max}}} - 1\right)\right]^{N_{\mathrm{melt}}}$$

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

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

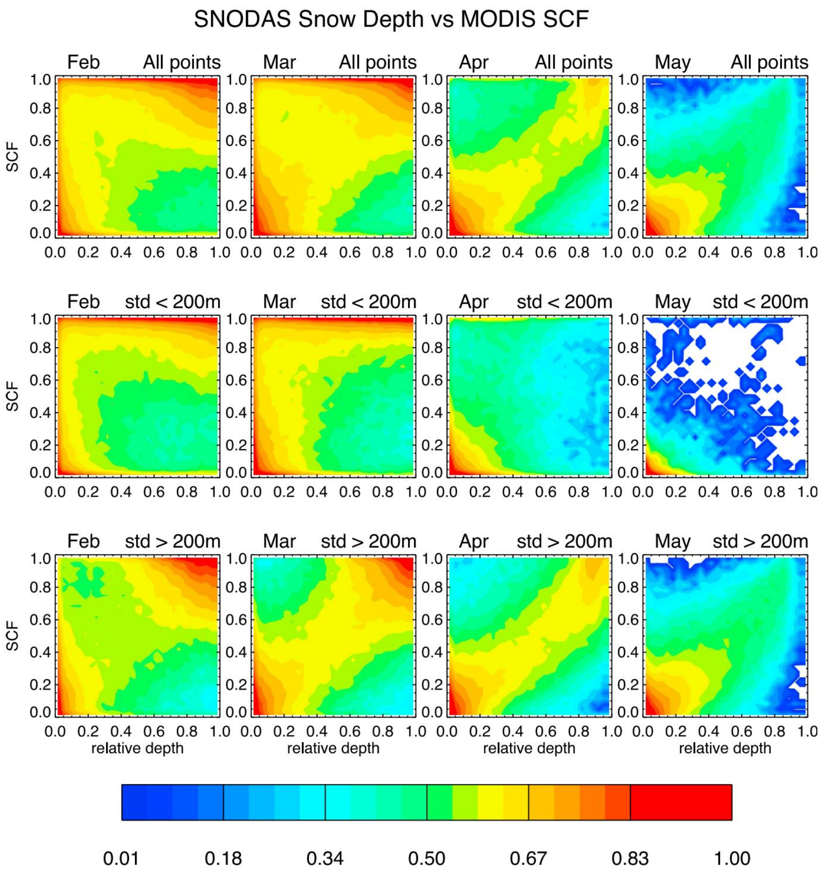




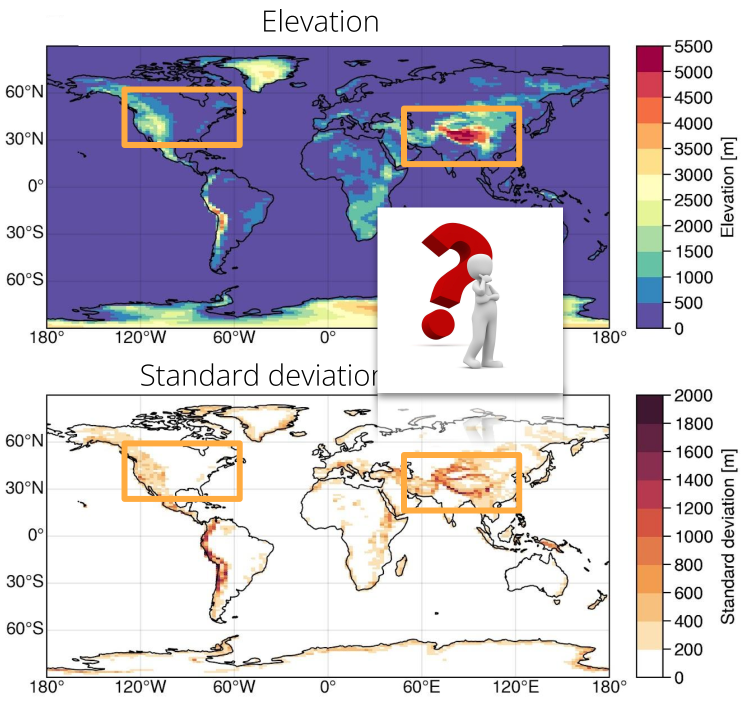


Swenson & Lawrence (2012)

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



Swenson & Lawrence (2012)



High Mountain Asia UCLA Daily Snow Reanalysis (HMASR)

- **Problem**:
  - No global reliable product of SD/SWE over mountainous areas
  - To better test/calibrate SCF param -> need SD and SWE (or density)
- **New snow reanalysis over HMA**: HMASR
  - downscale meteorological forcing + topo/landcover -> prior SCF/SWE
  - assimilate Landsat/MODIS -> posterior SCF/SWE
  - provides daily SCF/SWE at 500 m
  - not validated over HMA / Sierra Nevada (Margulis et al., 2016) and Andes (Cortés and Margulis, 2017)

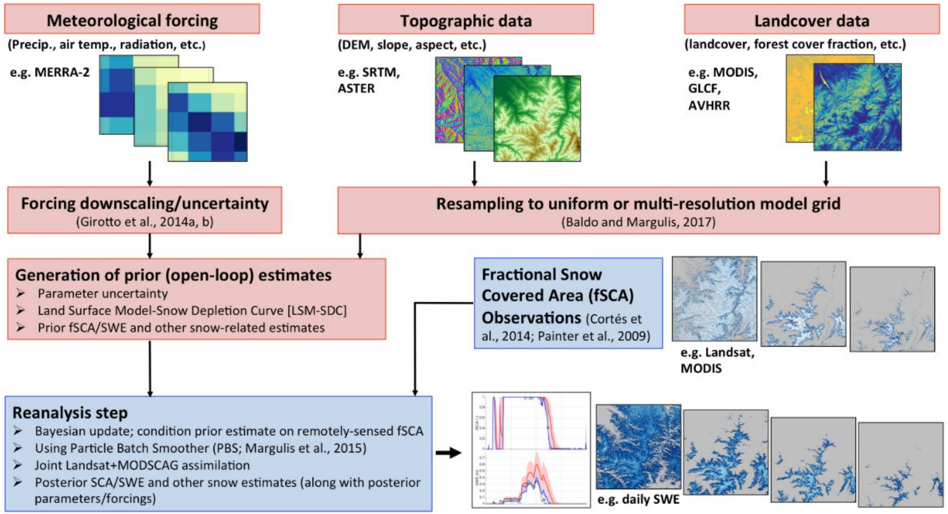
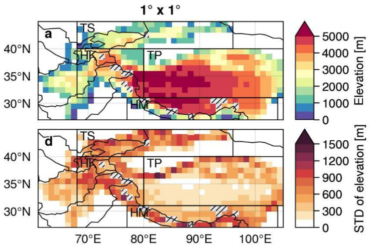
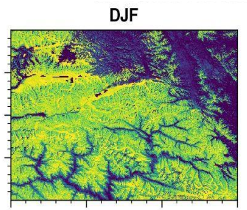


FIGURE 2 | Schematic representation of the Bayesian snow reanalysis framework that consists of an ensemble-based prior modeling system (red boxes) and a posterior update component for assimilating remotely sensed fractional snow covered area (SCA) data from Landsat and MODIS (blue boxes).

Margulis et al. (2019)

Calibration with new snow reanalysis HMASR

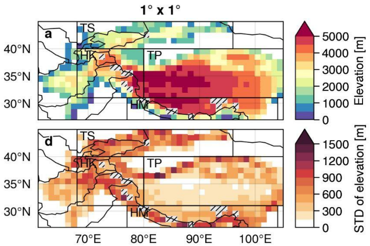


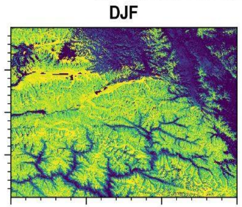


HMASR
SD / SWE / density
+ STD topo
at 1°x1°

SCF

Calibration with new snow reanalysis HMASR





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

→

→

SCF

R01 (Roesch et al., 2001)

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

NY07 (Niu and Yang, 2007)

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

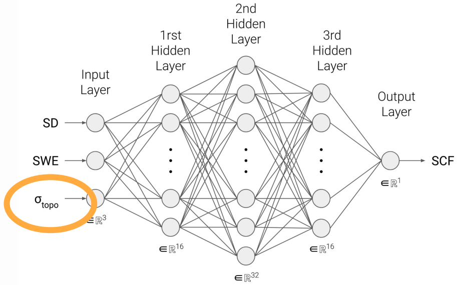
SL12 (Swenson and Lawrence, 2012)

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

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

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

DNN (deep neural network)

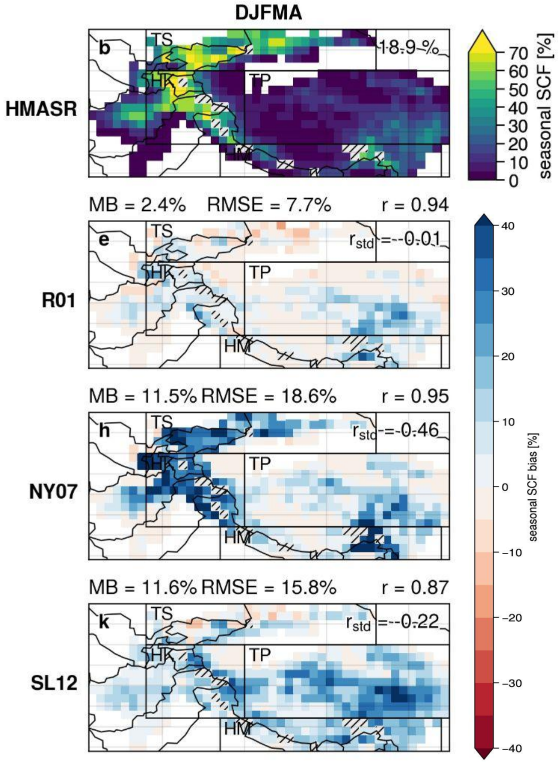


Calibration with new snow reanalysis HMASR

HMASR winter SCF

SCF Bias

(param - HMASR)

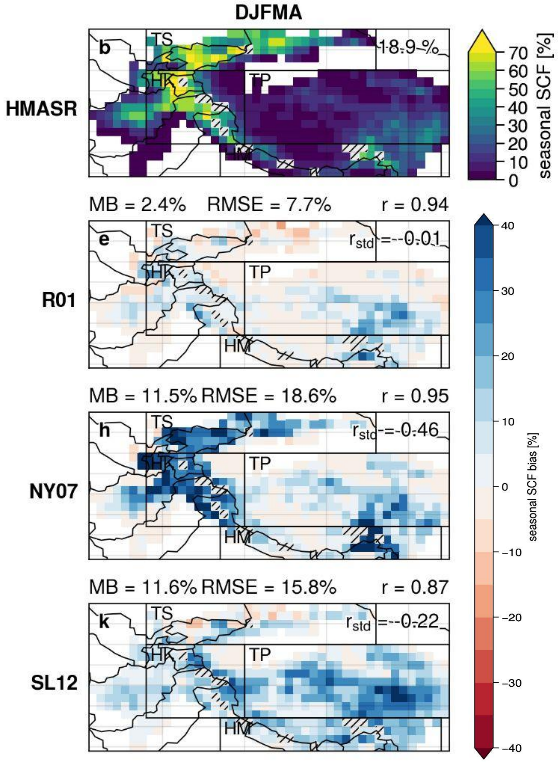


Calibration with new snow reanalysis HMASR

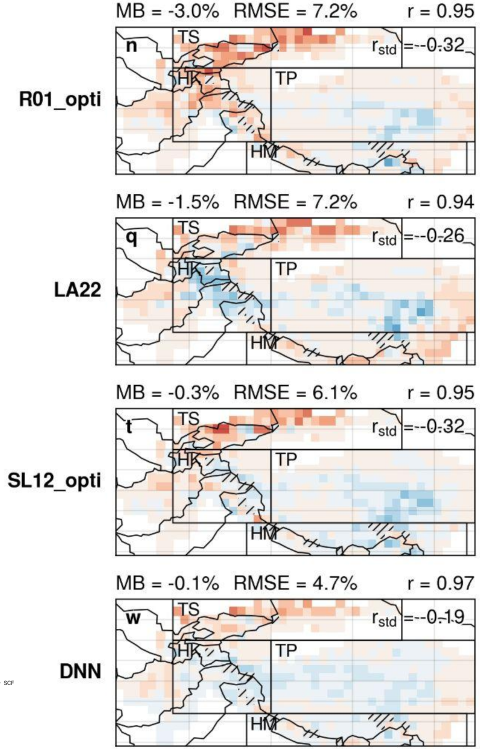
HMASR winter SCF

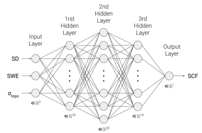
SCF Bias

(param - HMASR)



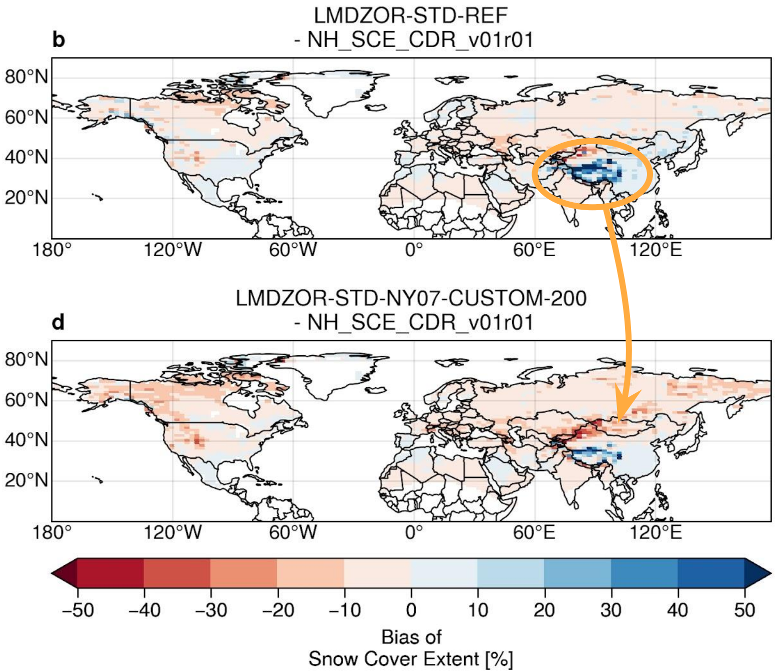
Optimization



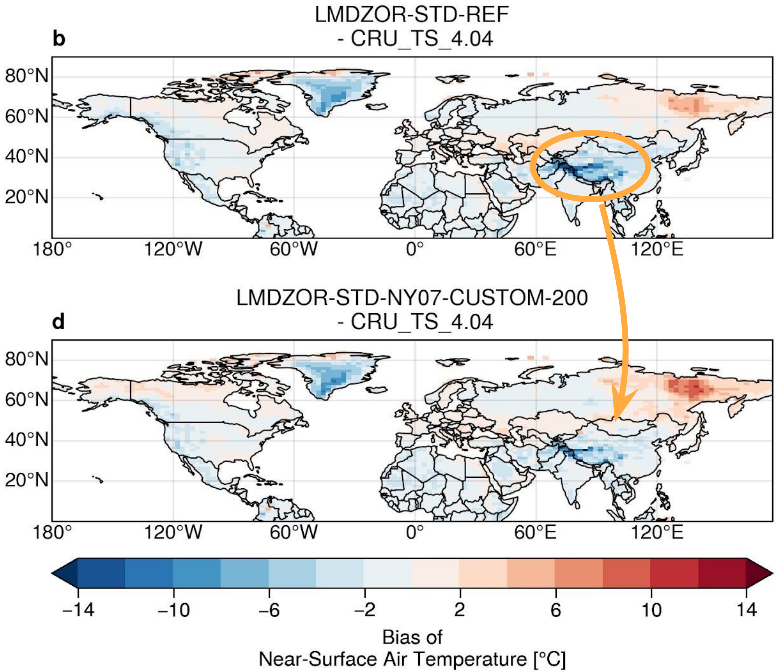


Application in GCM (LMDZ/ORCHIDEE)

Bias of Snow Cover Fraction



Bias of Temperature



Perspectives / Discussion / Conclusion

- Taking into account the sub-grid topography in SCF parameterization is essential for mountainous areas
- 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 (+ 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 to replace such parameterization (+ test the influence of other parameters)

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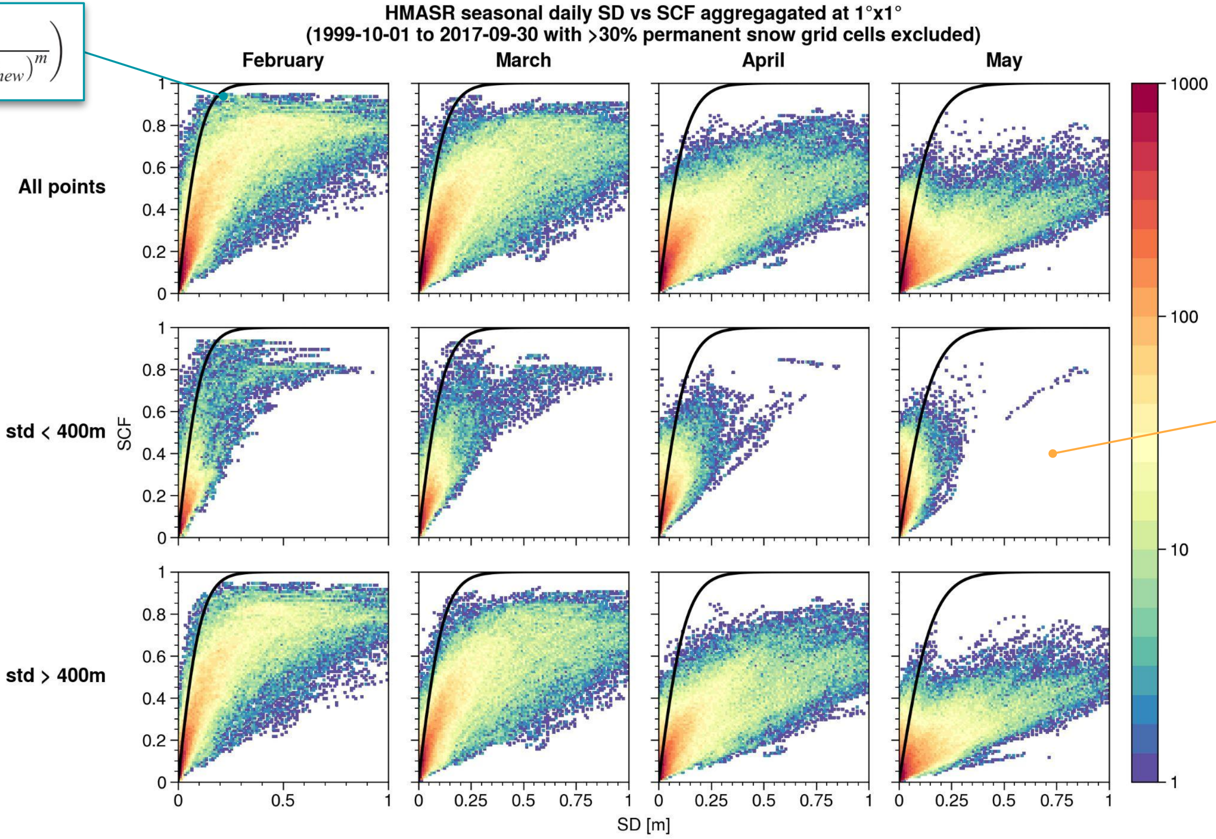
Complementary Slides

Snow cover in mountainous area: HMASR

$$f_{sno} = \tanh\left(\frac{h_{sno}}{2.5 z_{0g} (\rho_{sno}/\rho_{new})^m}\right)$$



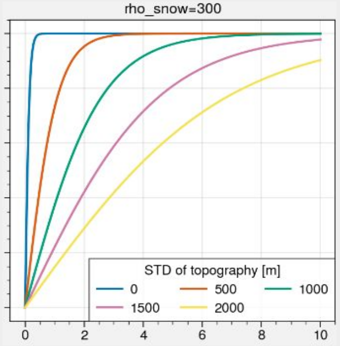
HMASR might be not representative of flat areas (TP mostly have STD >200m and dry)

Other snow cover parameterizations

Niu and Yang (2007) custom

$$F = \tanh\left(\frac{d}{2.5 z_{0g} \left(\rho_{snow}/\rho_{new}\right)^{m}}\right)$$

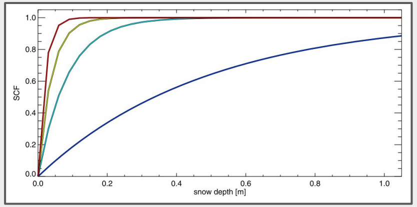
STD topo



Swenson and Lawrence (2012)

Accumulation

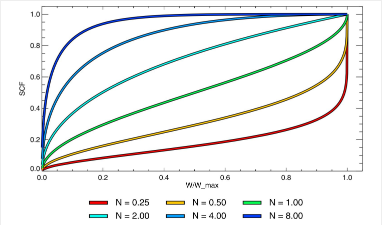
$$F_{N+1} = 1 - (p_{N+1})(p_N) = 1 - (1 - s_{N+1})(1 - F_N)$$



Depletion

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

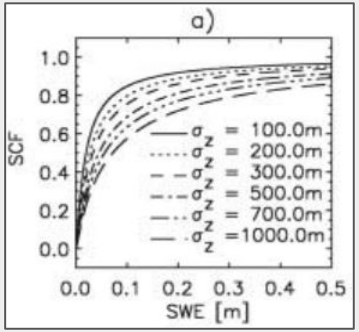
$$N_{melt} = \frac{200}{\sigma_{topo}}$$



Roesch et al. (2001)

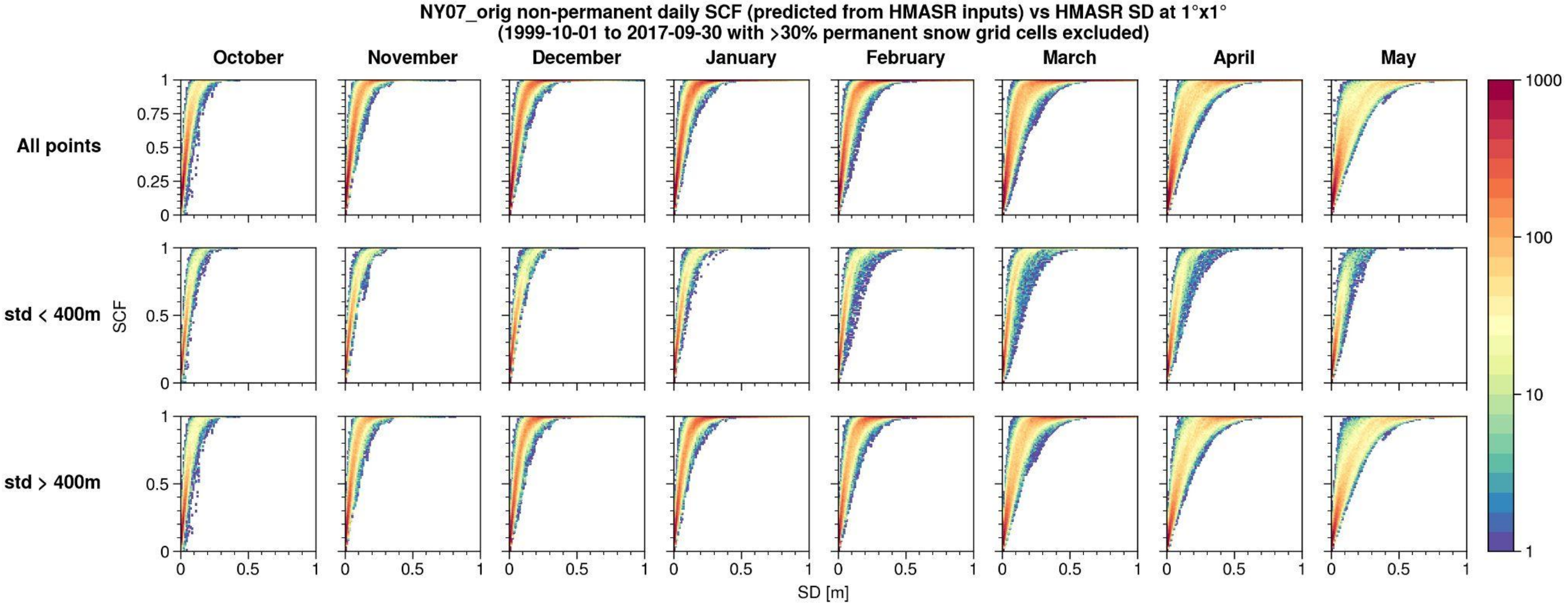
Mountainous areas

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

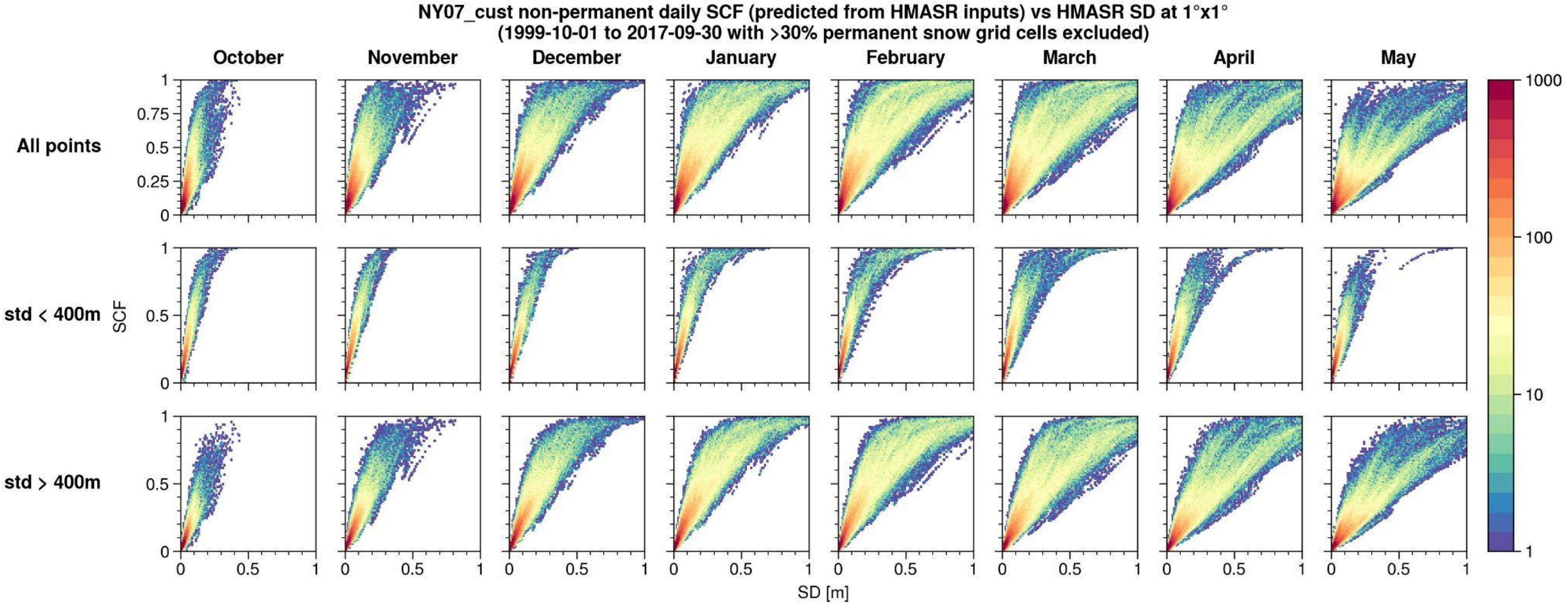


Depends only on SWE so no hysteresis

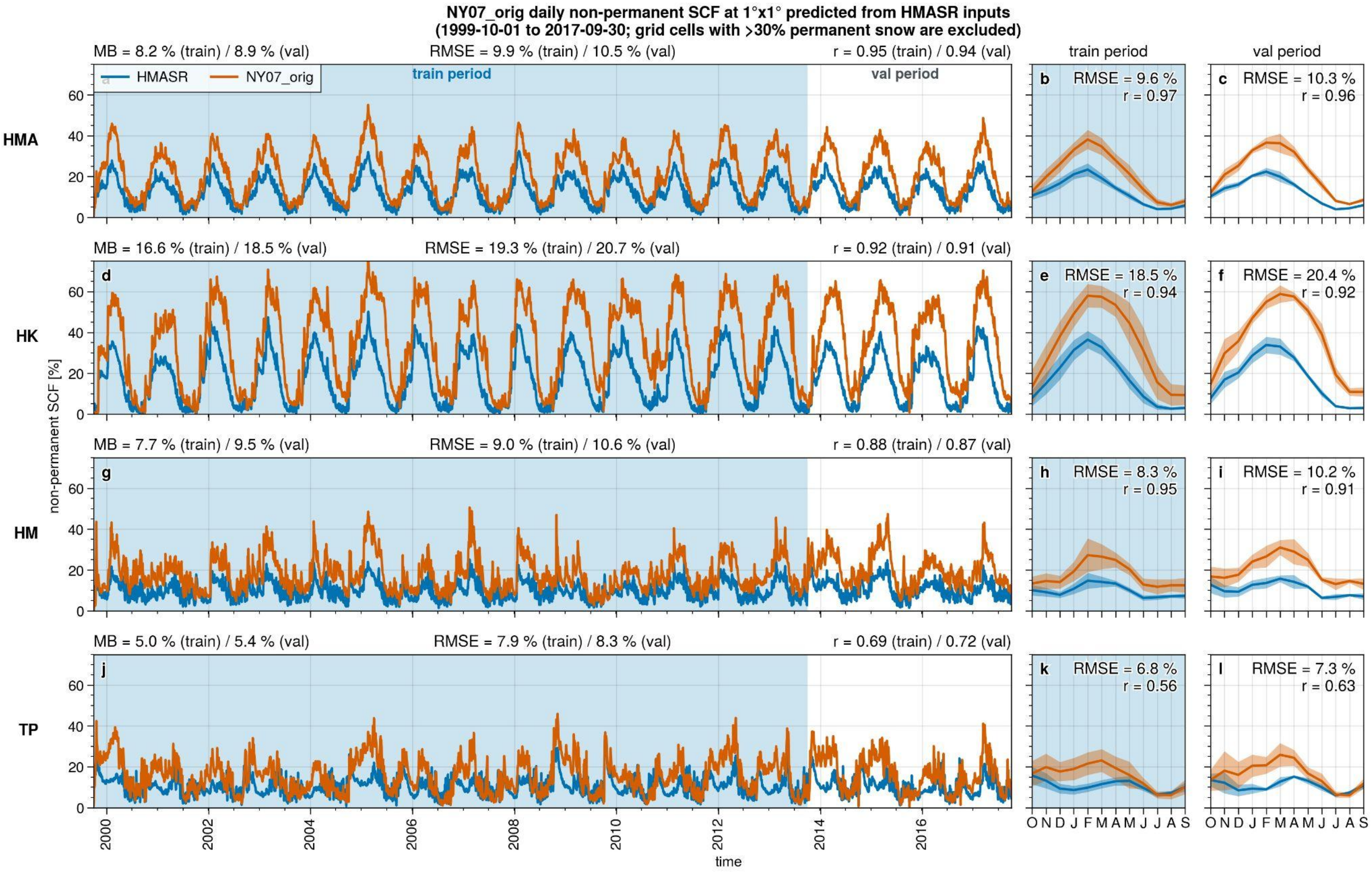
High Mountain Asia UCLA Daily Snow Reanalysis



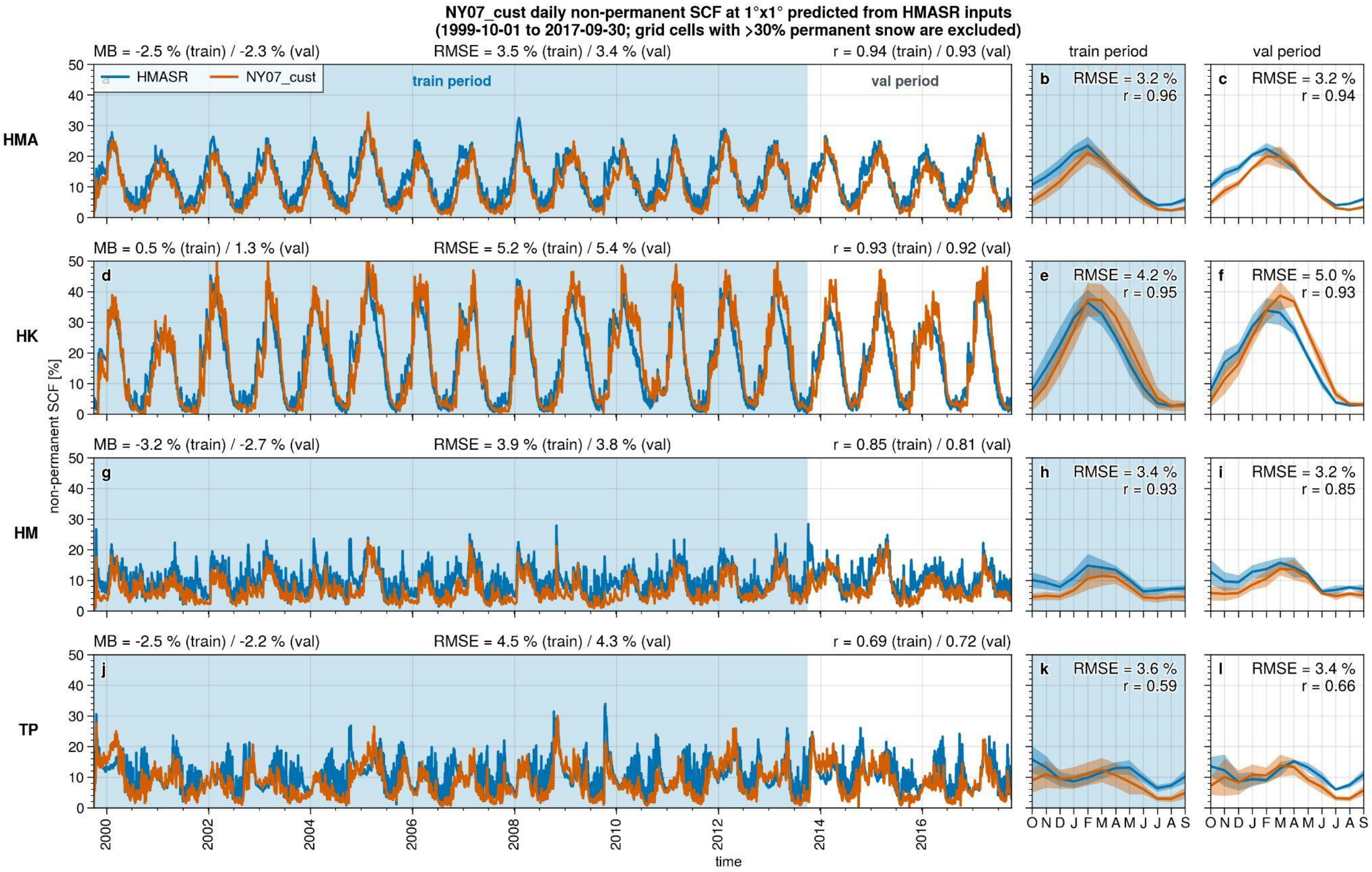
High Mountain Asia UCLA Daily Snow Reanalysis



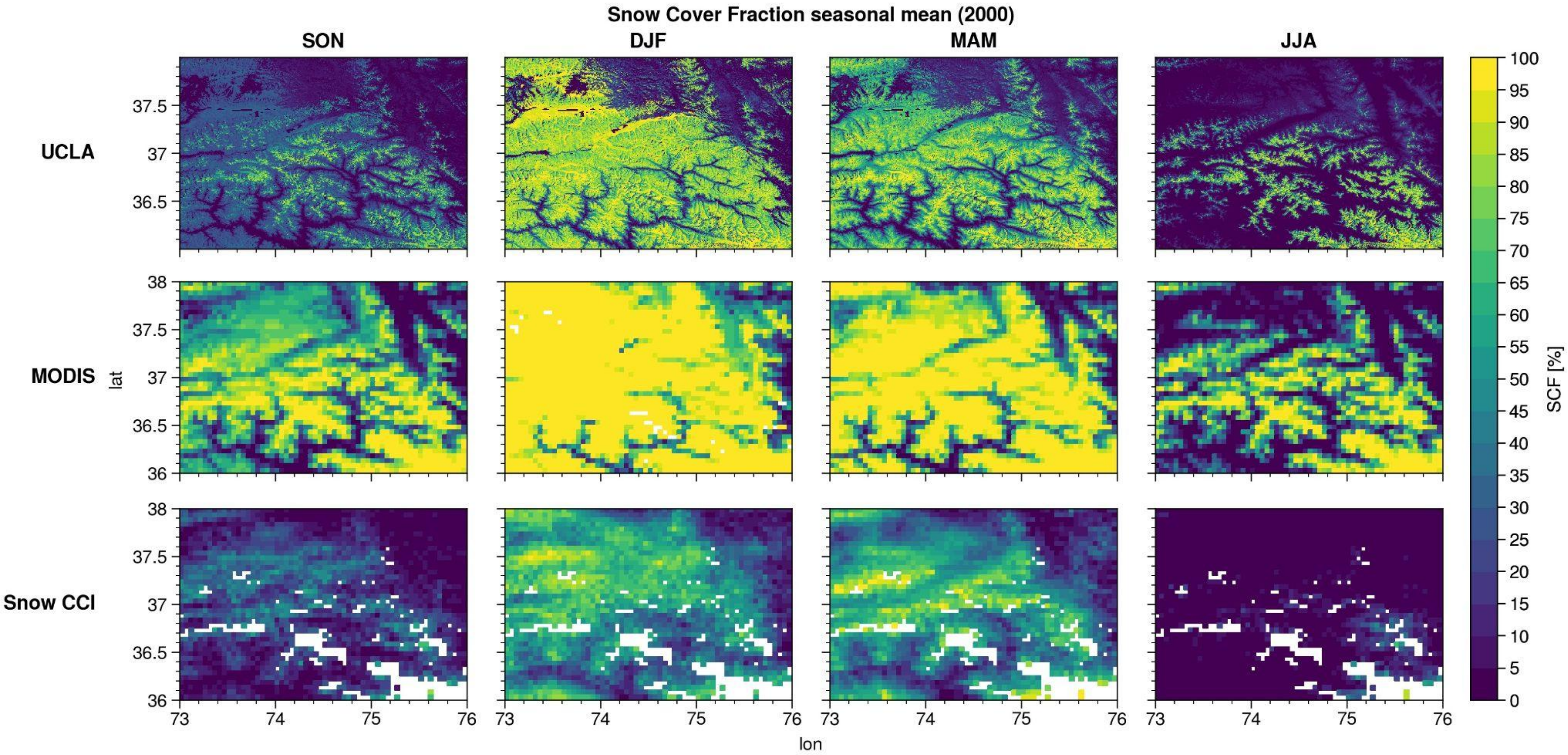
High Mountain Asia UCLA Daily Snow Reanalysis



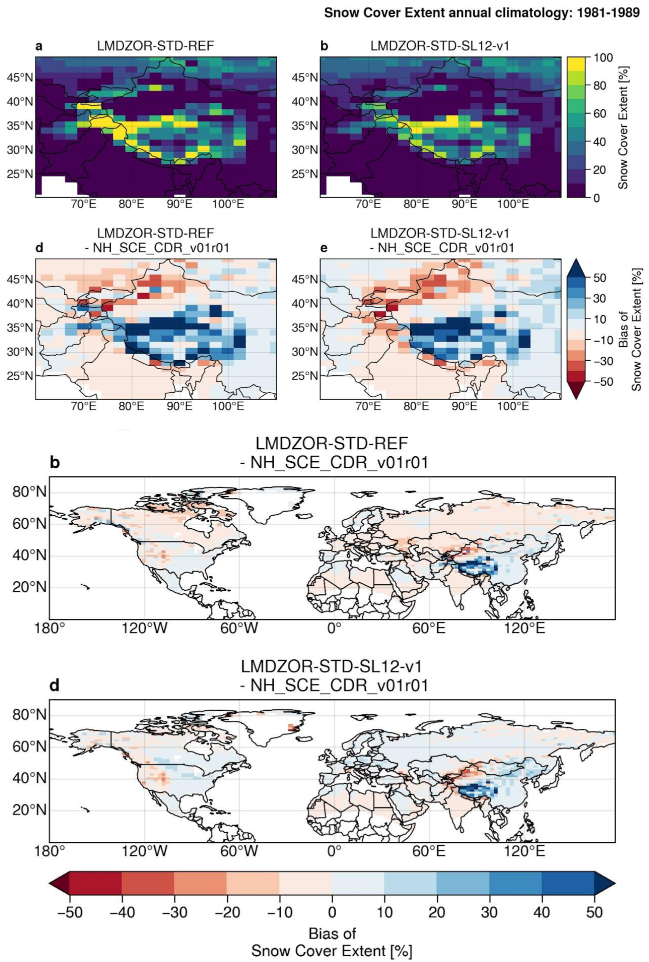
High Mountain Asia UCLA Daily Snow Reanalysis

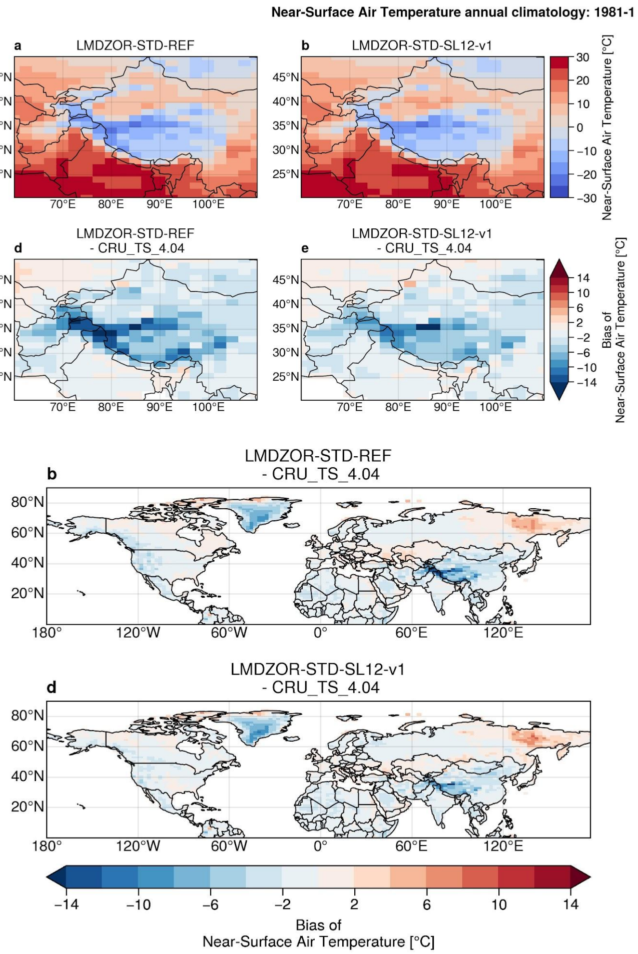


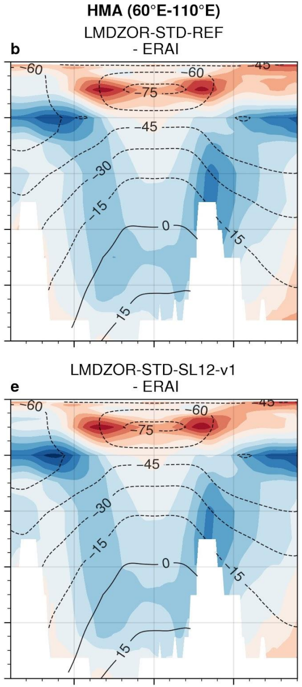
High Mountain Asia UCLA Daily Snow Reanalysis



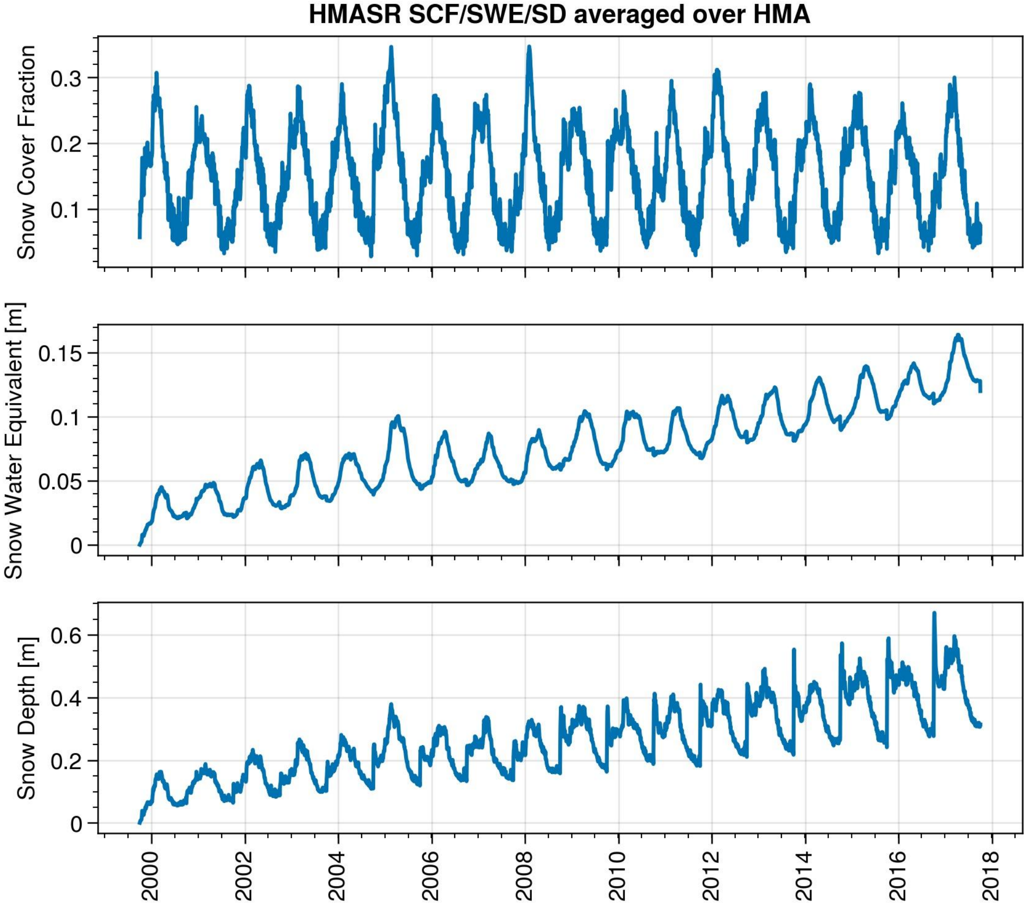
Swenson and Lawrence (2012): commits 1, 2, 3, 4, thredds



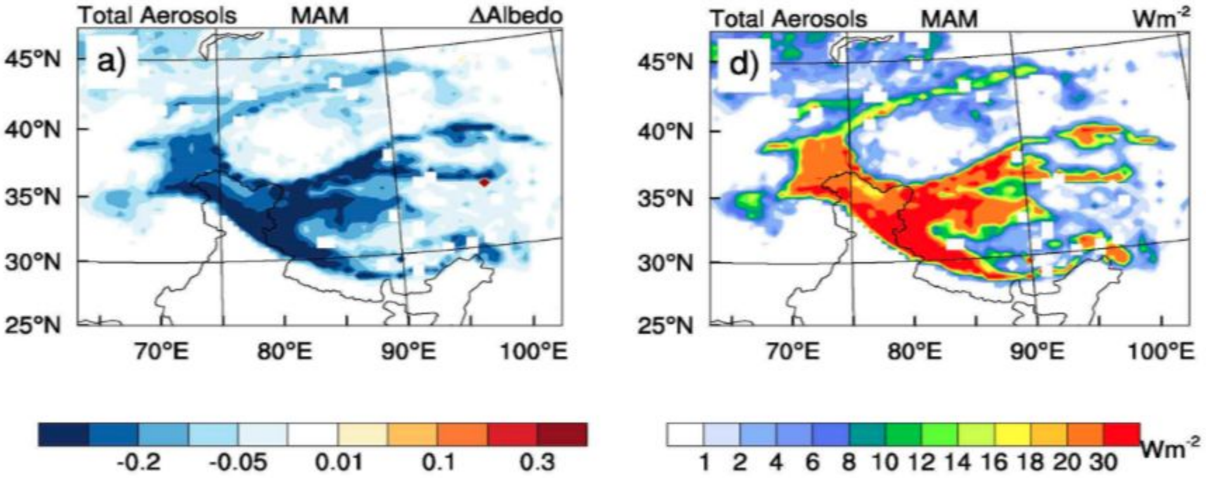


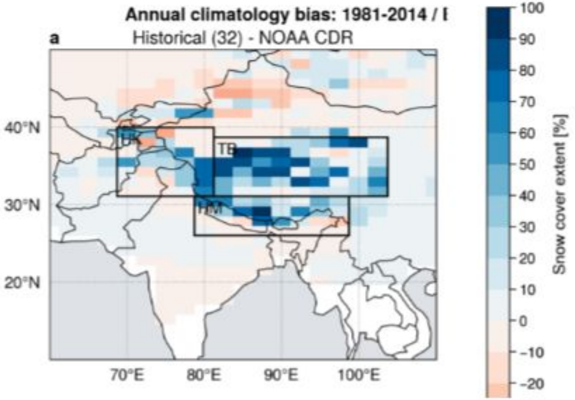


Permanent snow area: problem?



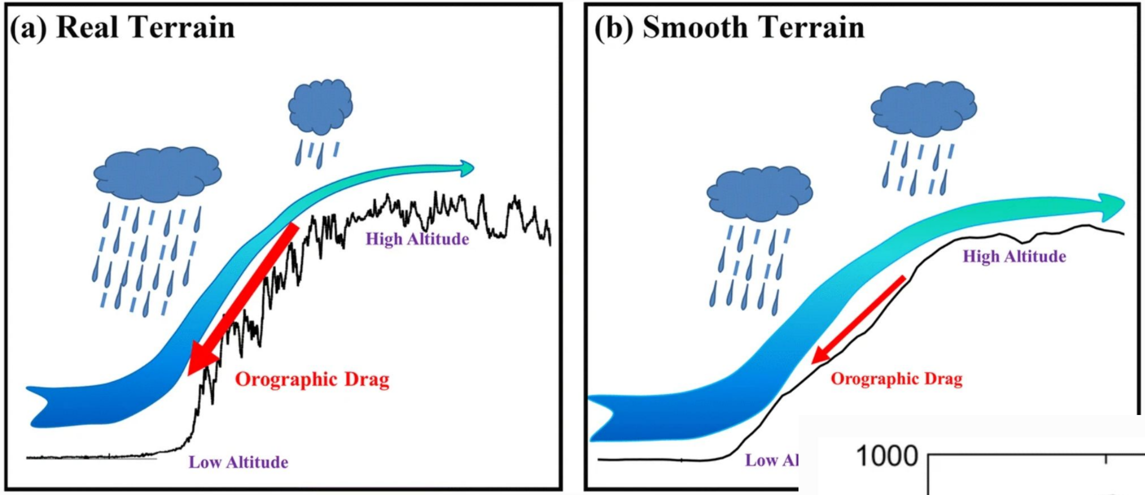
Dépôt aérosols





Usha et al., (2020, Fig 7)

TOFD



Wang et al., (2020, Fig 5 & 9)