ORCHIDEE DEV meeting — 26th September 2023

Reducing the High Mountain Asia cold bias in GCMs by adapting snow cover parameterization to complex topography areas

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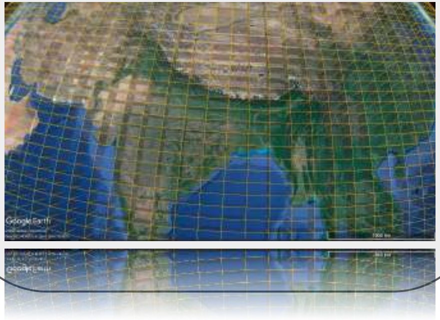
Objective and presentation outline

Objective: Improving the representation of snow cover in mountain regions in CMGs.

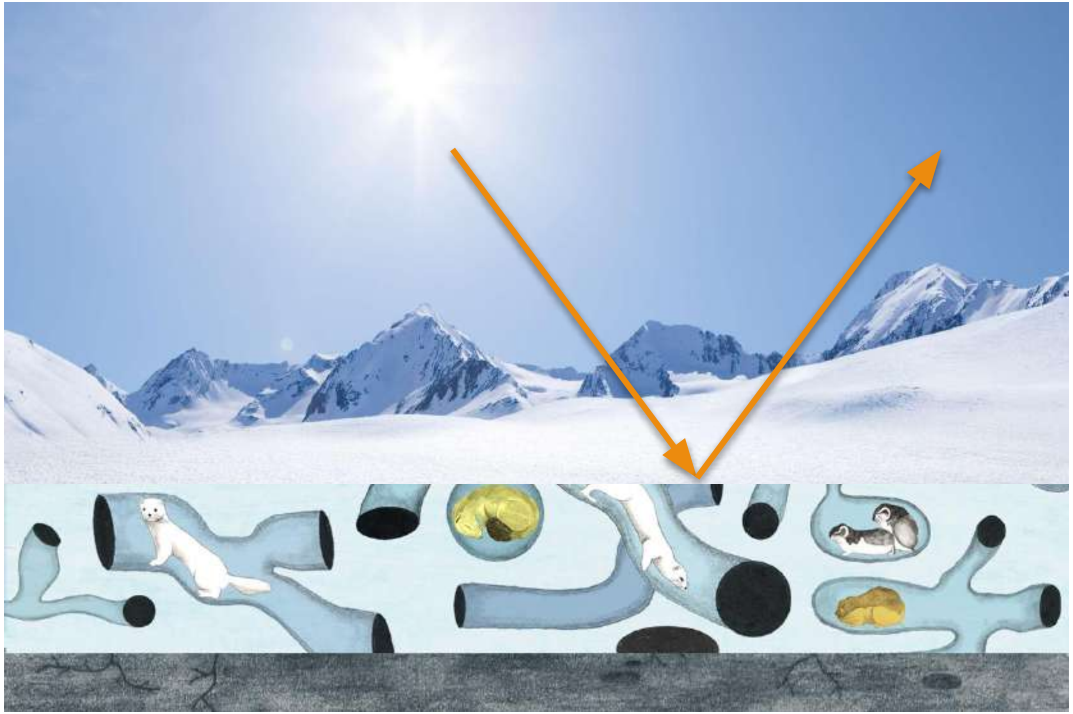
#1 Description and evaluation of the IPSL model in HMA



#2 Parameterization of snow cover in mountain regions

#3 Technical and practical information

Context: what is snow?



Context: snow bias in IPSL model CMIP5 versus CMIP6

Bias of the snow cover fraction
(i.e., simulated - observed snow fraction)

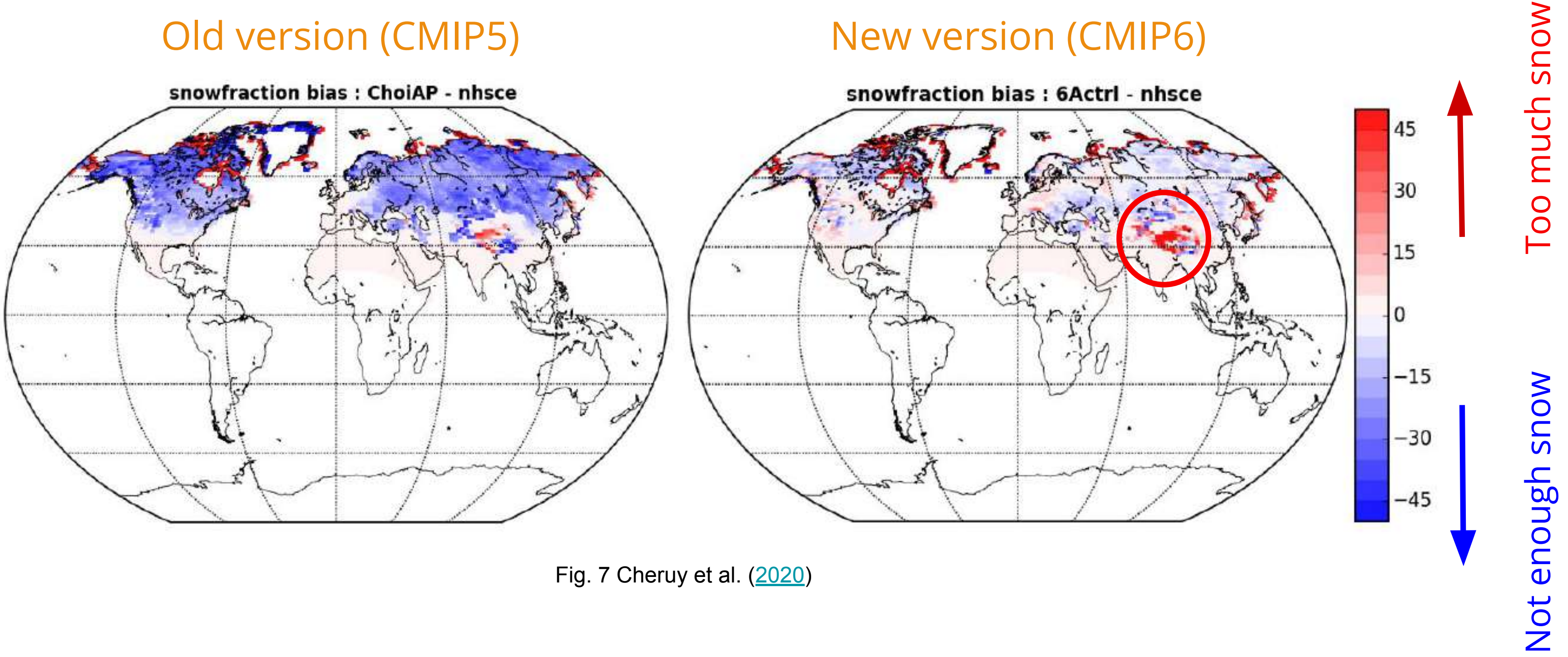
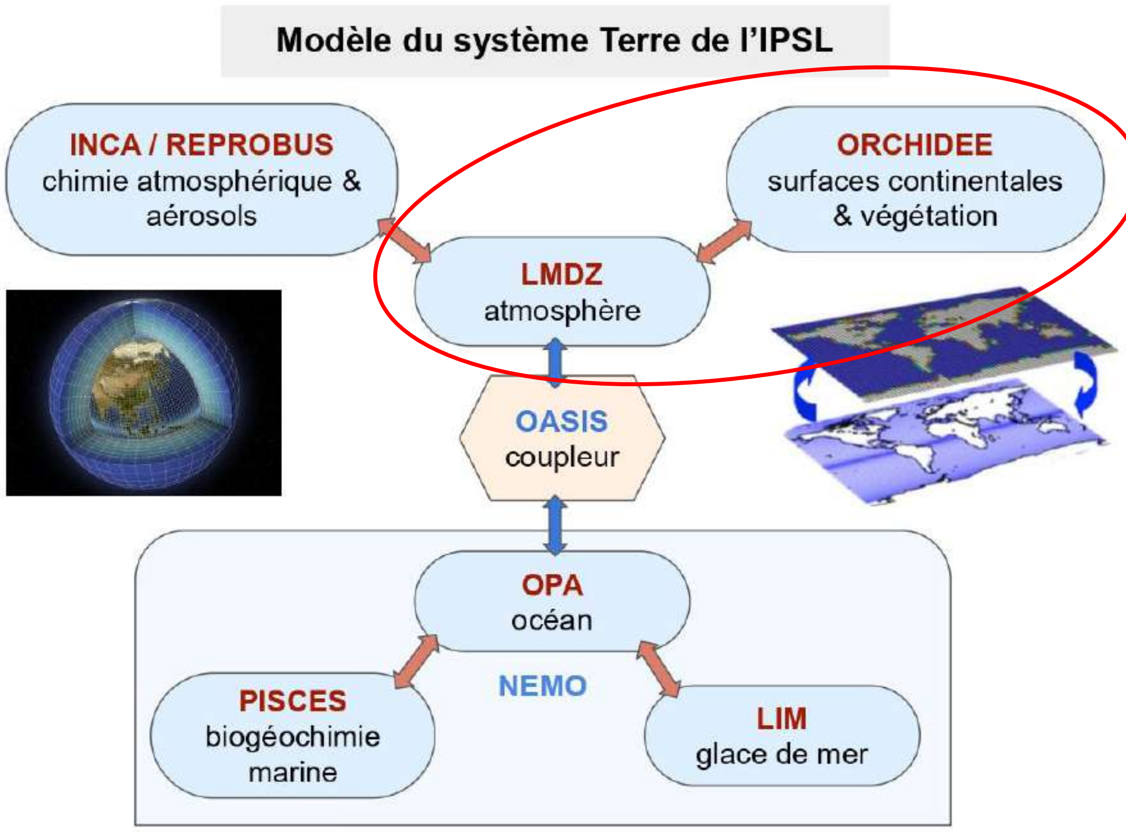


Fig. 7 Cheruy et al. (2020)

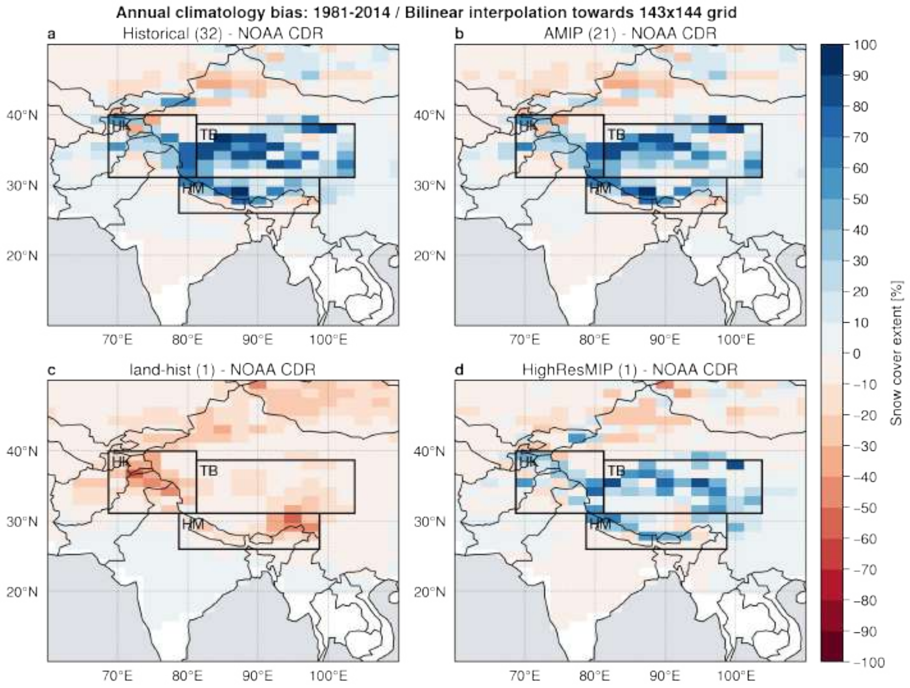
IPSL Earth System Model



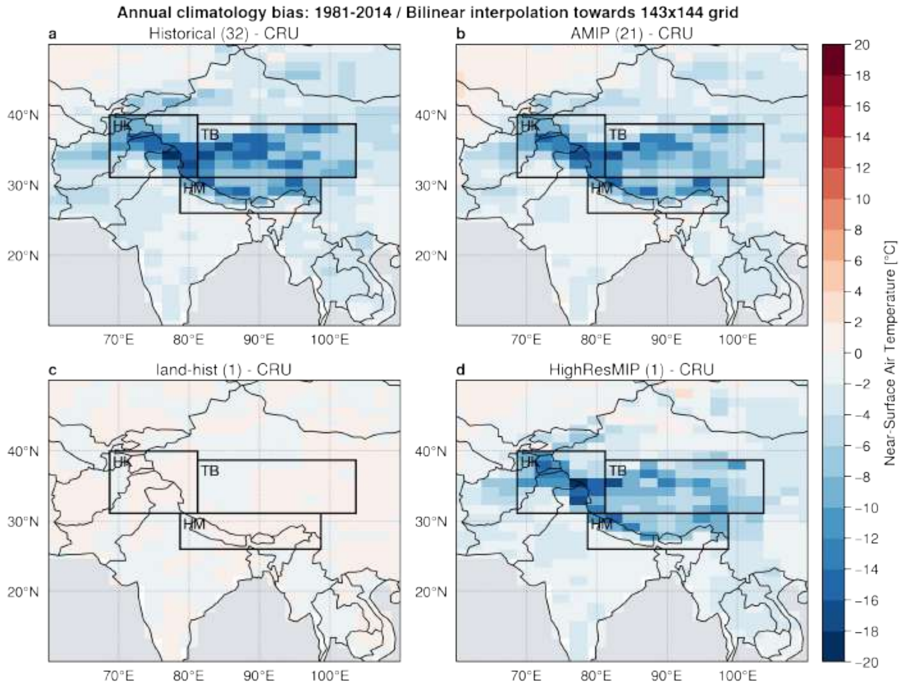
- Version 6A-LR (CMIP6):
  - 144 x 142 (grid points lon / lat)
  - ~ 2,5° x 1,25°
  - 79 vertical layers (up to ~80 km altitude)
  - time step of the physics: 15 min
- Version 6A-HR (CMIP6):
  - 360 x 180 (grid points lon / lat)
  - ~ 0,5° x 0,5°
  - time step of the physics: 3,75 min

IPSL-CM6A-LR: Historical, AMIP, land-hist / IPSL-CM6A-ATM-HR bias

Snow cover bias

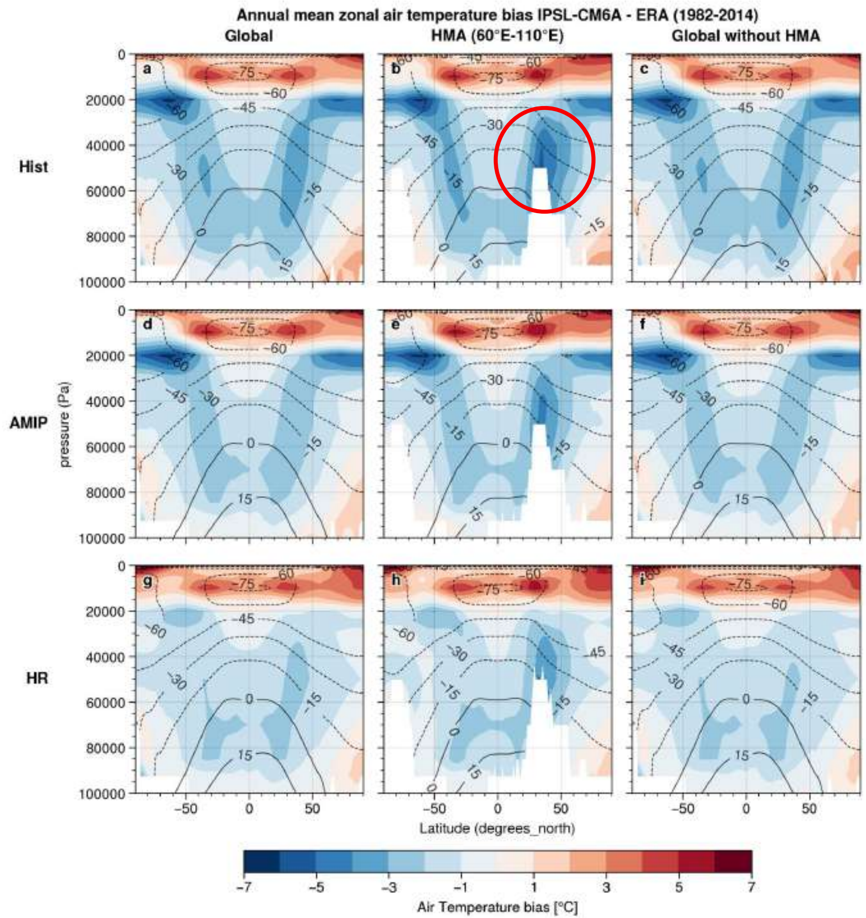


Temperature bias



- Large cold bias (up to -20 °C) and excess of snow cover (> 50 %) mainly located on the Tibetan Plateau
- Historical / AMIP similar and reduced biases in HighResMIP
- land-hist slightly underestimate the snow cover (/!\ poor quality of atmospheric forcing? /!\)

Air Temperature zonal means bias global versus HMA



- Cold bias in troposphere and hot bias in stratosphere
- Cold bias of air temperature not restricted to HMA!
  - HMA seems to amplify this bias
  - The bias is reduced in HighResMIP

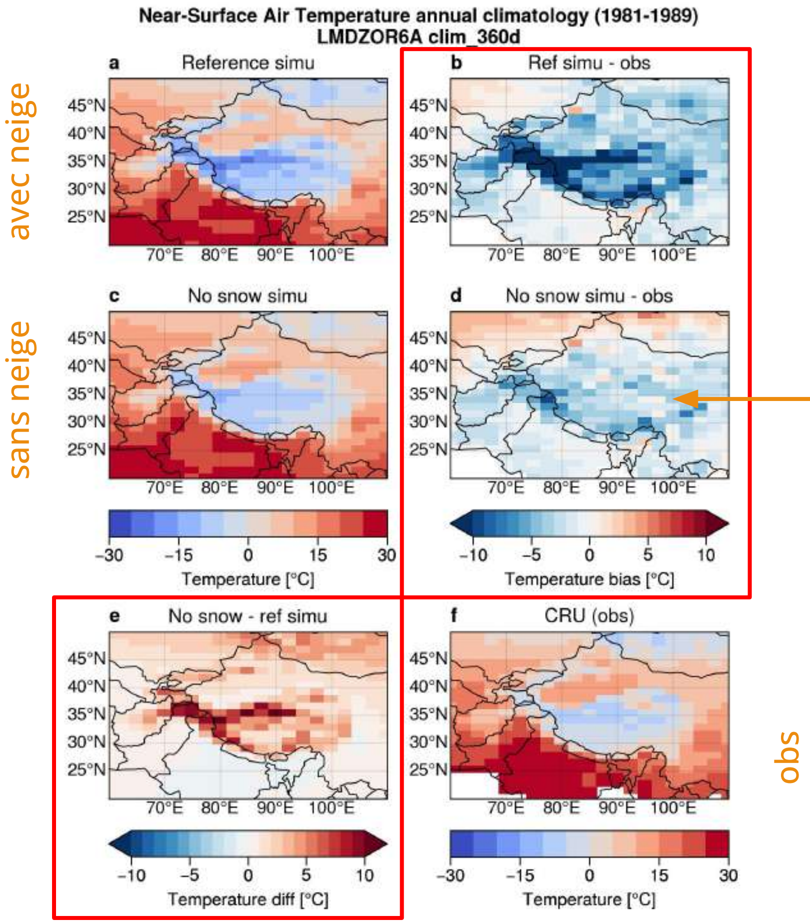
Questions

1. Does the surface biases trigger tropospheric biases?
2. Are the tropospheric biases responsible of surface biases?

Experiments

1. Experience without snow
2. Nudged experiments (temperature and wind)

Impact of the surface: experiment without snow

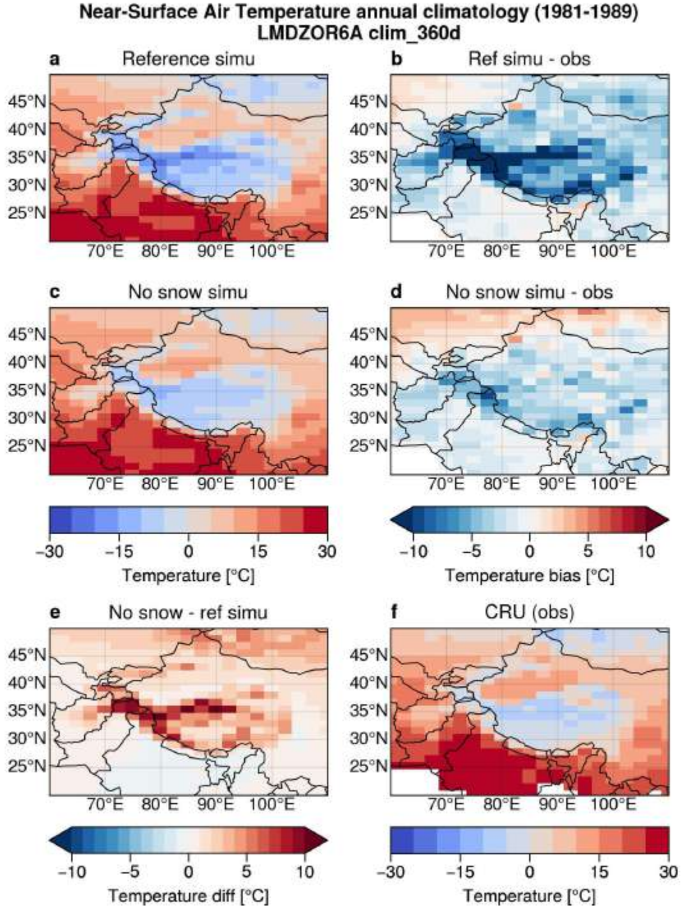


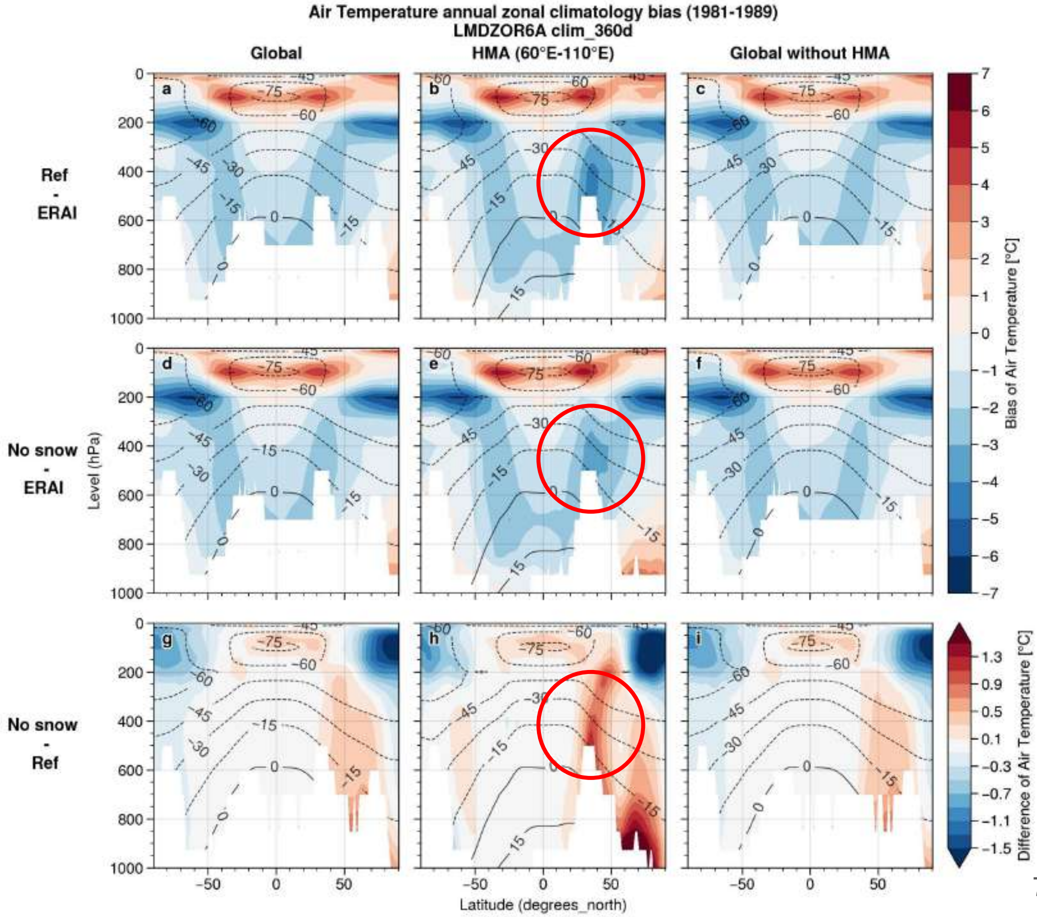
bias froid persistant même sans neige!

Impact of the surface: experiment without snow

avec neige

sans neige





Tropospheric bias reduction: nudged experiments

6h u, v

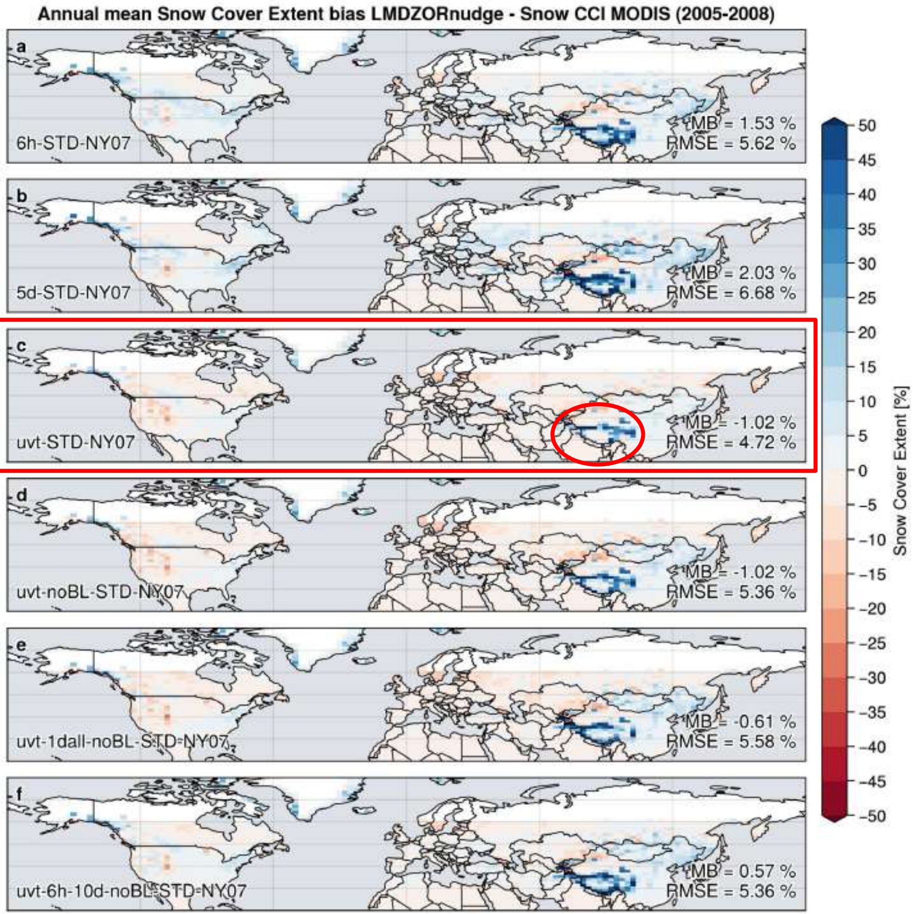
5j u, v

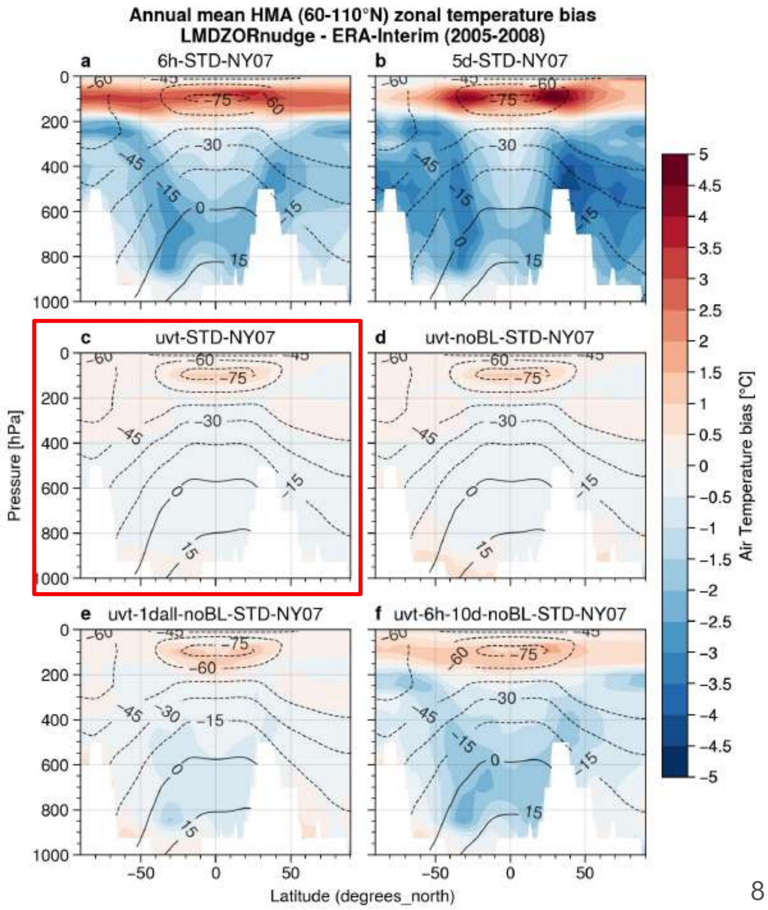
3h u, v, T

3h u, v, T NoBL

1j u, v, T NoBL

6h u, v, 10j T NoBL





Take home messages

- Surface biases don’t seem to be the source of the tropospheric biases

Take home messages

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- Snow cover biases seem partly related to the topography

Take home messages

- Surface biases don't seem to be the source of the tropospheric biases
- Tropospheric biases amplify surface biases
- Surface biases seem to have distinct cause of the tropospheric biases

- Snow cover biases seem partly related to the topography

- Other important possible causes (not investigated):
cloud cover, albedo, aerosols, boundary layer processes, etc.

Part #2

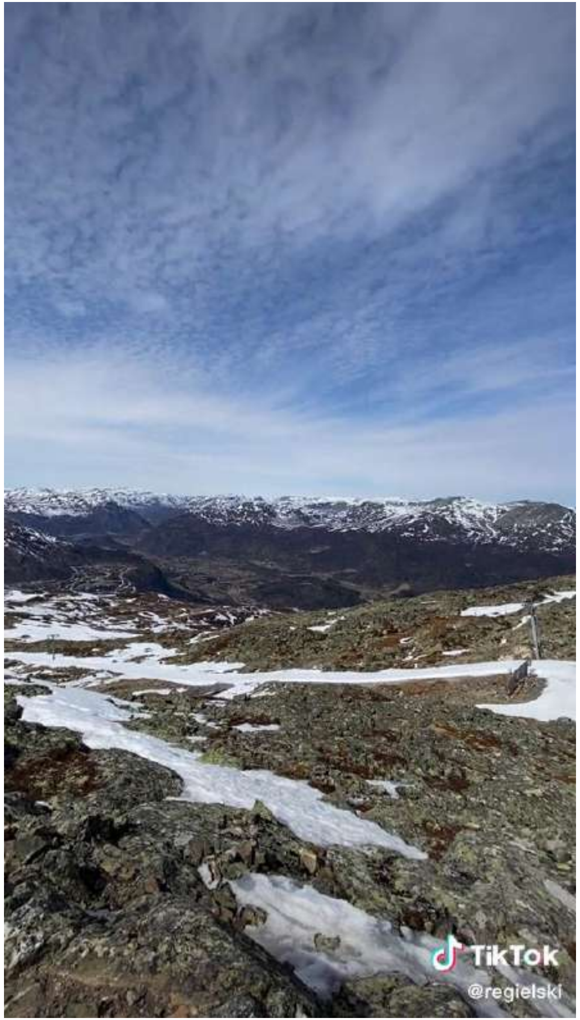
Parameterization of snow cover in mountain regions


TikTok
@regielski


TikTok
@regielski

TikTok
@regielski


TikTok
@regielski

TikTok
@regielski

TikTok
@regielski

Snow cover over mountainous areas in global climate models

IPSL-CM6A

HOW DO WE COMPUTE THE

SNOW COVER FRACTION (SCF)

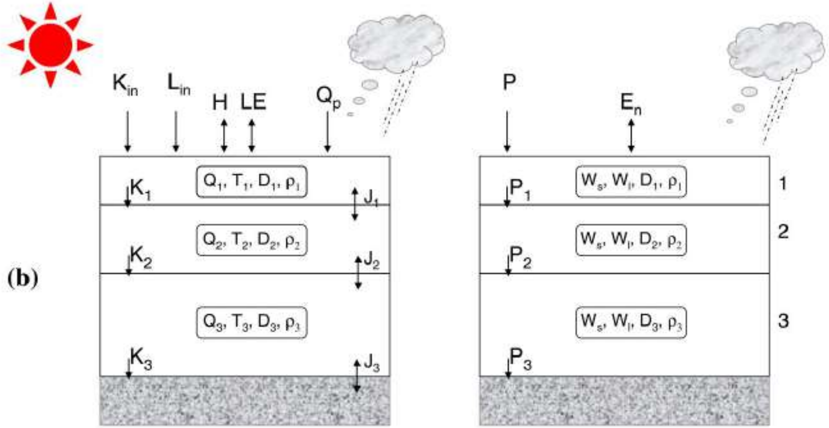
IN GLOBAL CLIMATE MODELS?

&

HOW DOES THE SCF EVOLVES

OVER MOUNTAINOUS AREAS?

(b)



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

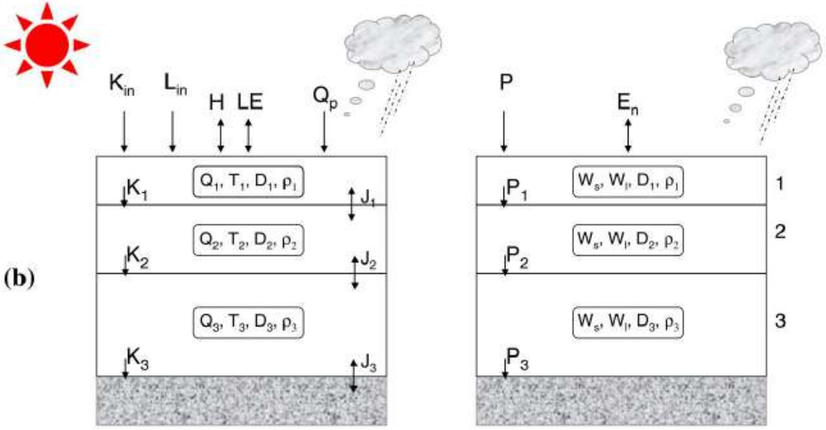
snow scheme in the ORCHIDEE land surface model (Wang et al., 2013)

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**(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)

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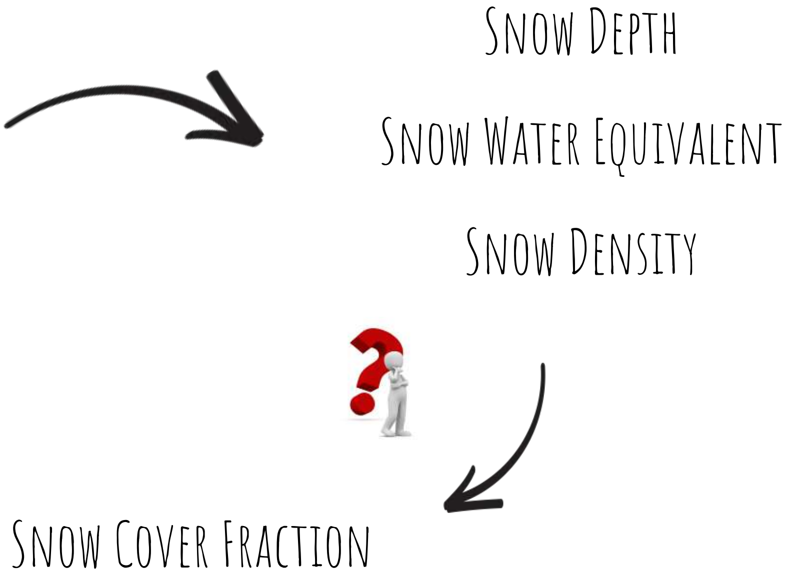


Snow cover parameterizations

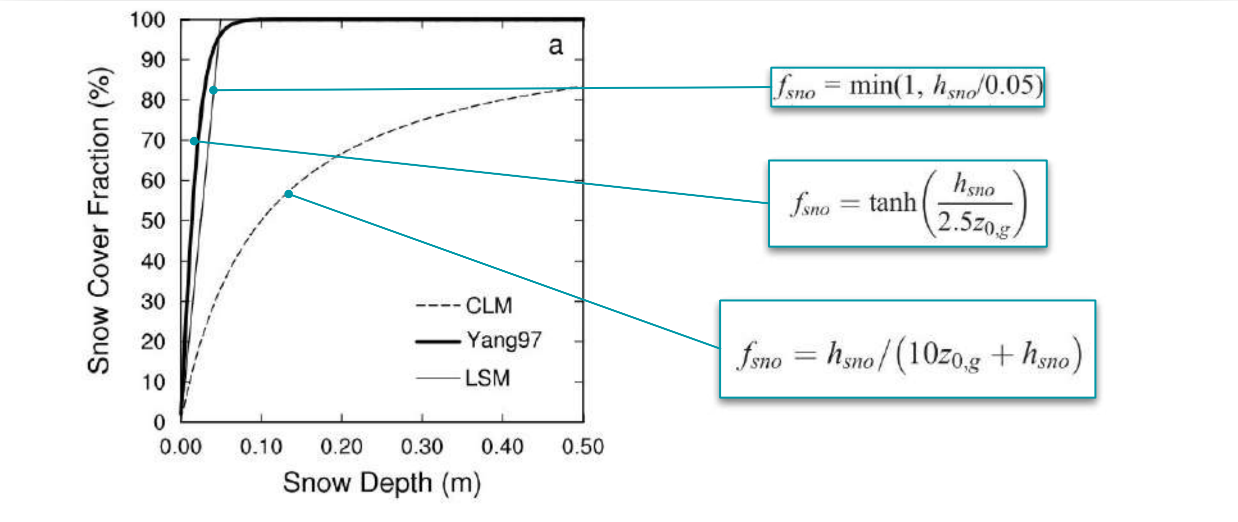


Figure 1. (a) SCF (or f_{sno}) computed from equation (2) (used in the default CLM and BATS), equation (3) of *Yang et al.* [1997], and a formulation used in the NCAR LSM1.0, $f_{sno} = \min(1, h_{sno}/0.05)$, where h_{sno} is snow depth (m) and (b) SCF as a function of ground surface roughness, snow depth, and snow density computed from equation (4) with new snow density 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 parameterization: Niu and Yang (2007) - NY07

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

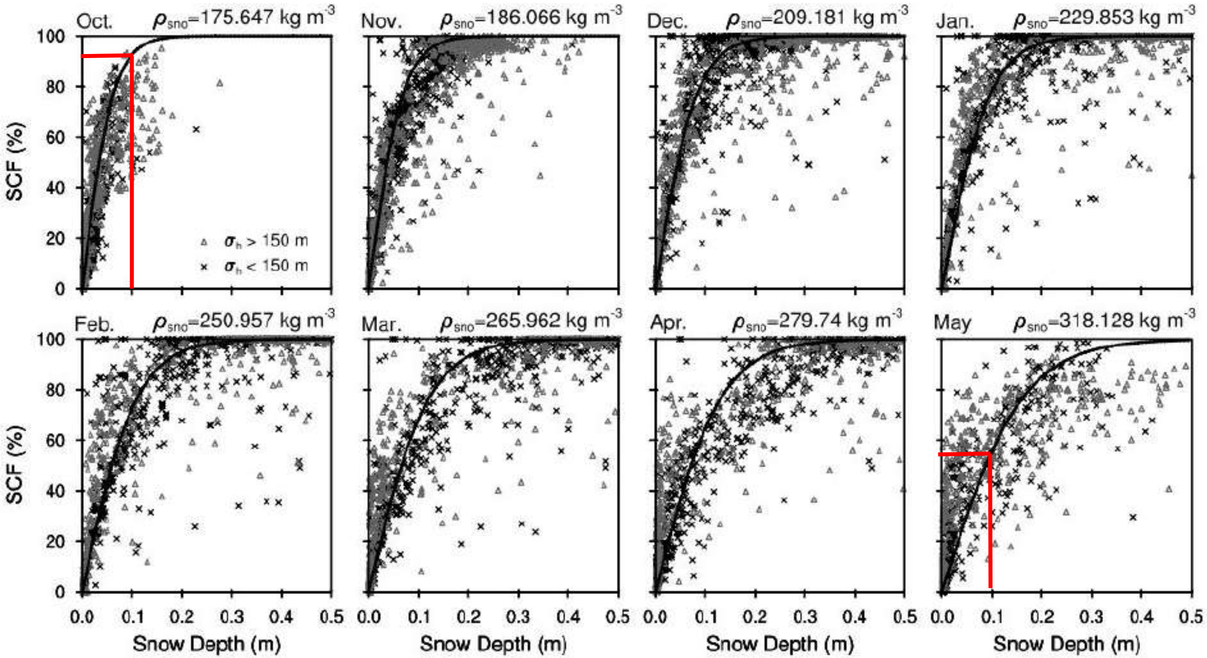
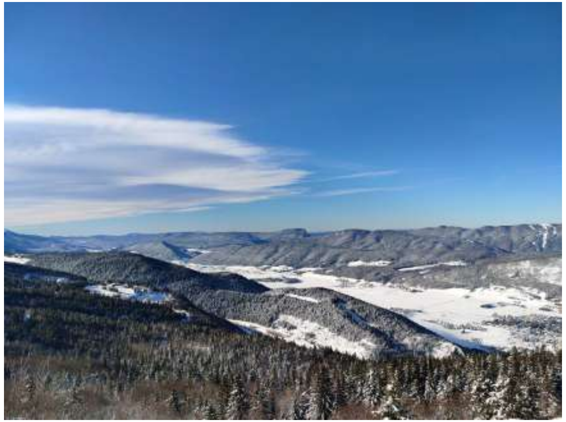


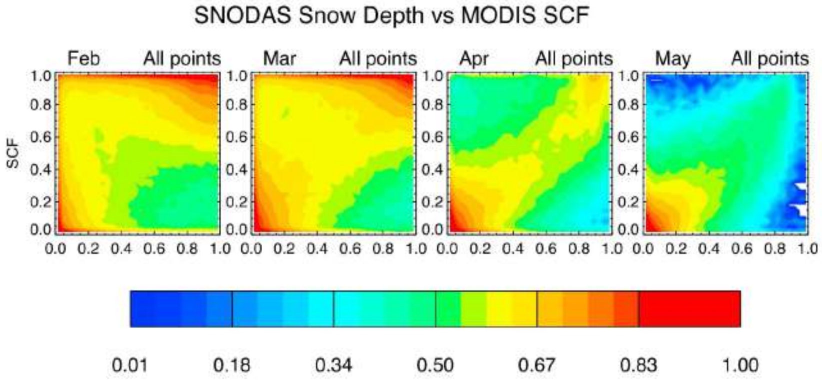
Figure 2. Relationship between AVHRR SCF (%) and CMC snow depth (m) in 1° × 1° grid cells of major NA river basins including the Mackenzie, Yukon, Churchill, Fraser, St. Lawrence, Columbia, Colorado, and Mississippi from October to May. The darker crosses stand for 1° × 1° grid cells where the standard deviation of topography σ_h < 150 m, and the lighter triangles stand for 1° × 1° grid cells where σ_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 micro to macro

Snow cover micro to macro

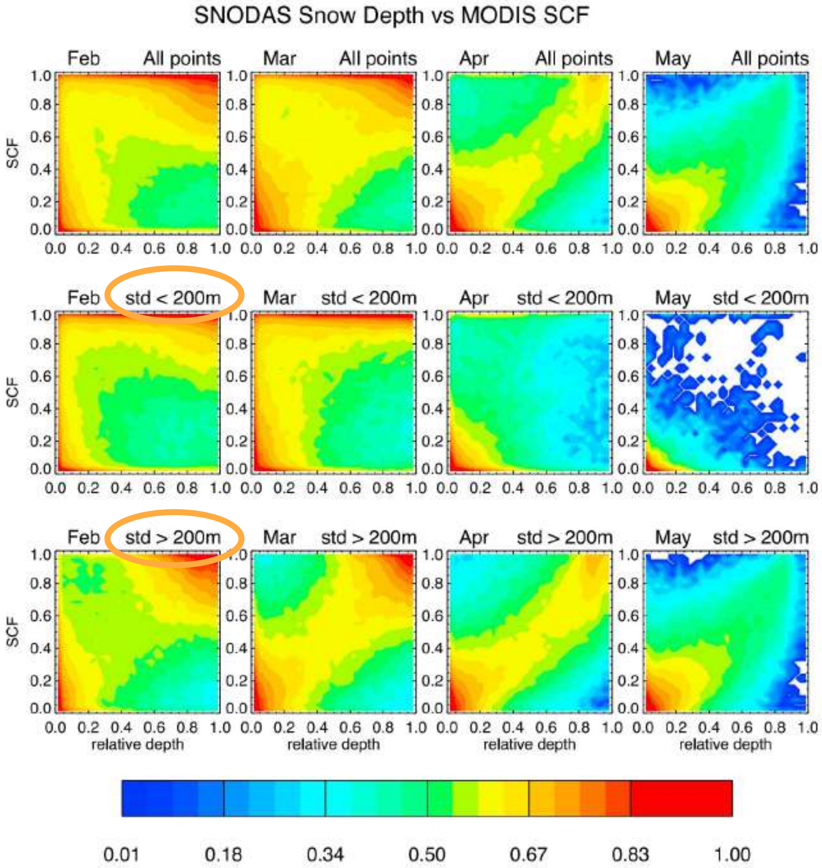


Snow cover in mountainous area: Swenson & Lawrence (2012) - SL12



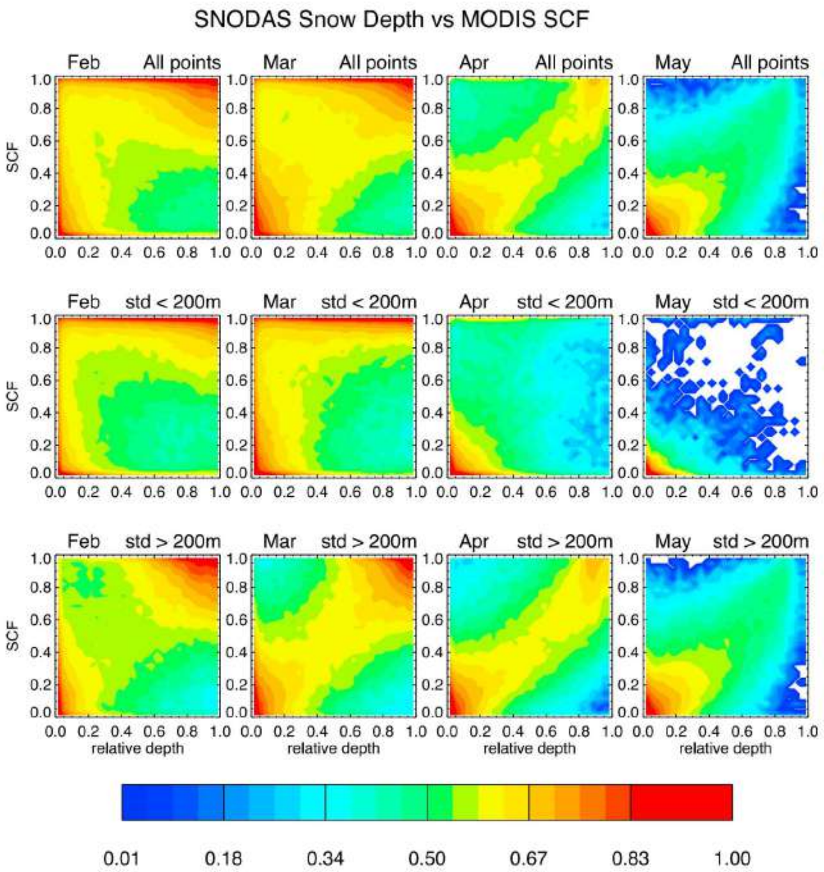
Relative snow depth

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



Swenson & Lawrence (2012)

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



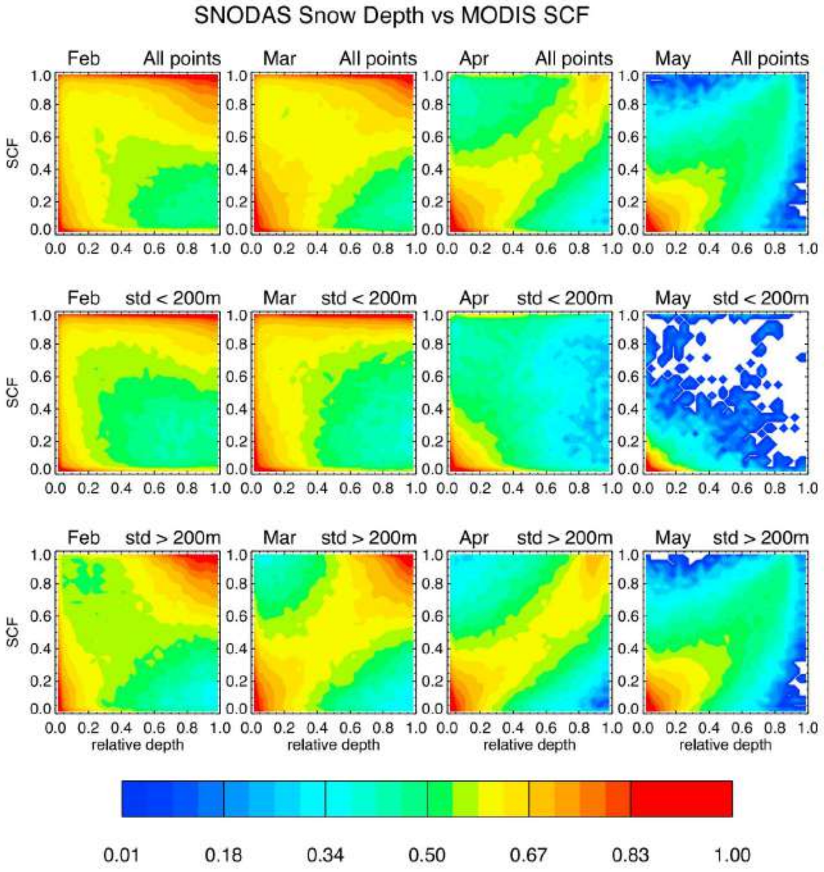
Swenson & Lawrence (2012)

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

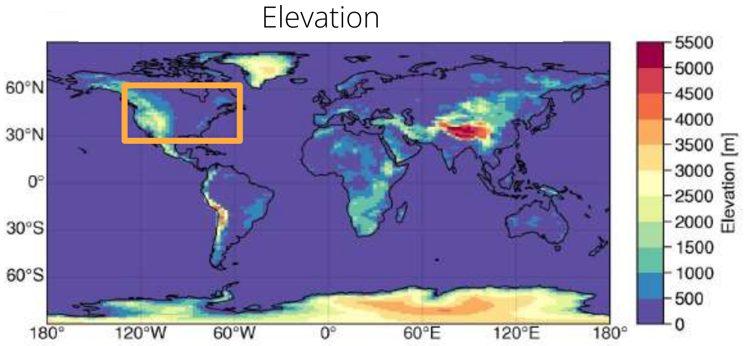
$$SCF = 1 - \left[\frac{1}{\pi}\operatorname{acos}\left(2\frac{SWE}{SWE_{max}} - 1\right)\right]^{N_{melt}}$$

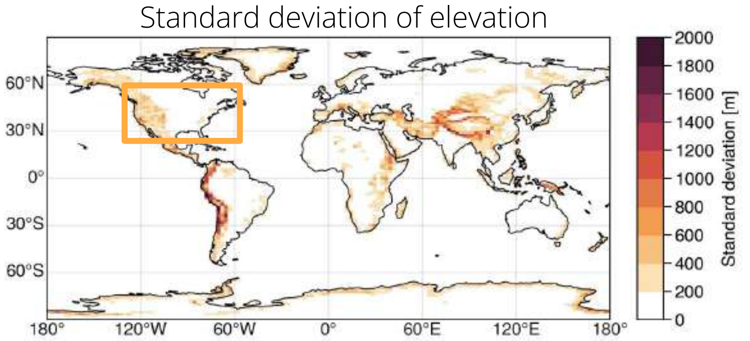
$$N_{melt} = \frac{200}{\max(30, \sigma_{topo})}$$

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

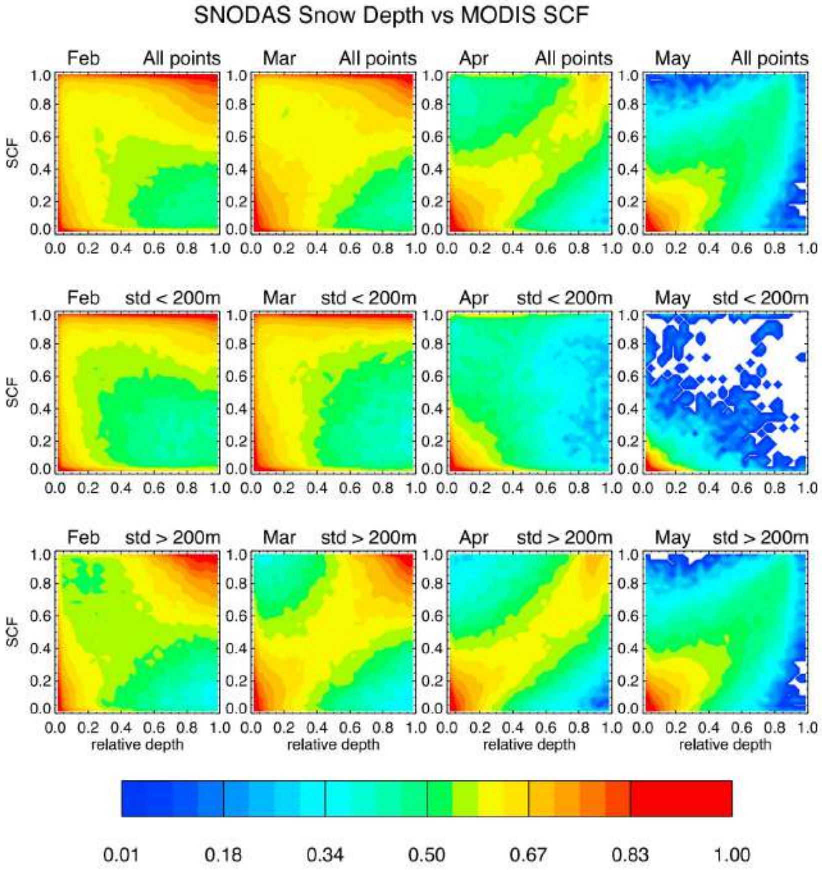


Swenson & Lawrence (2012)

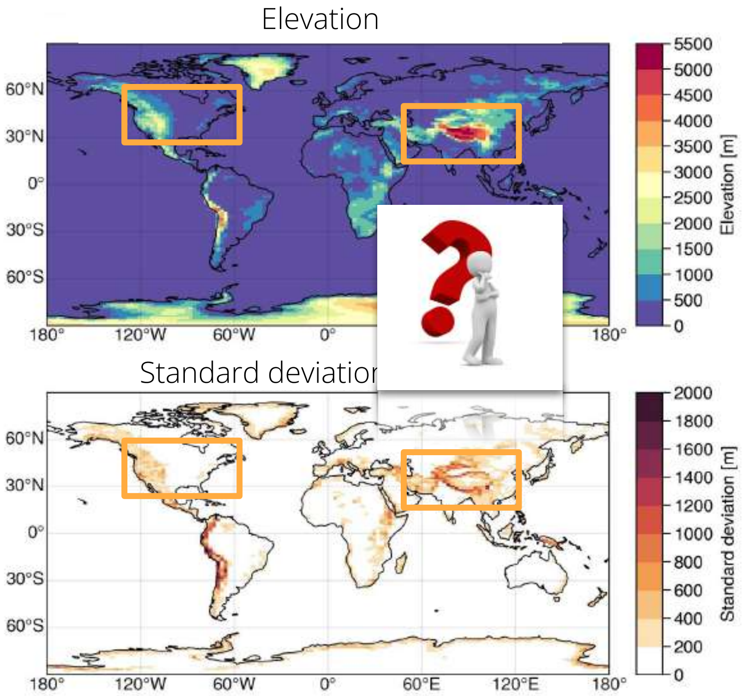




Snow cover in mountainous area: Swenson & Lawrence (2012)



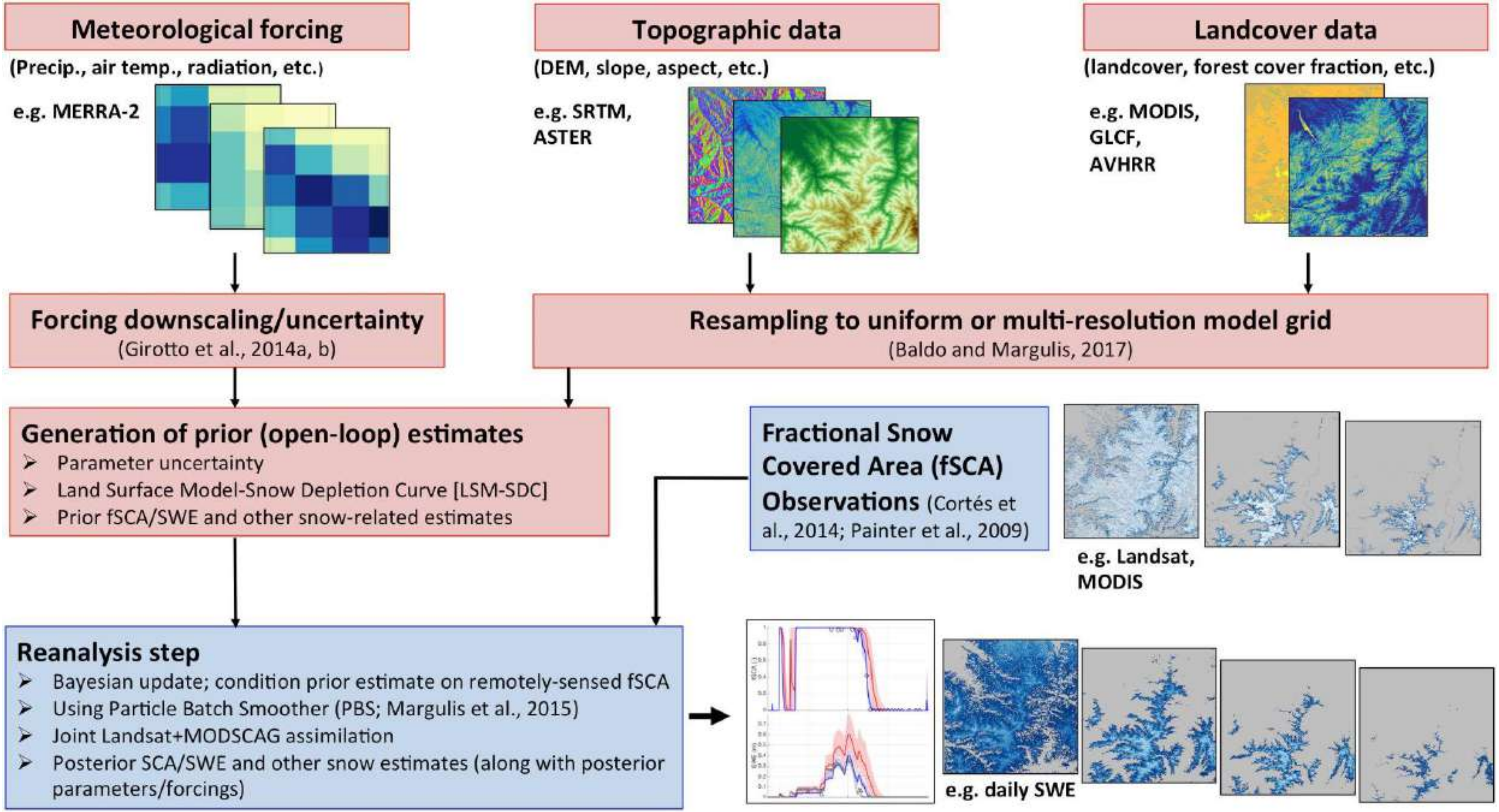
Swenson & Lawrence (2012)



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

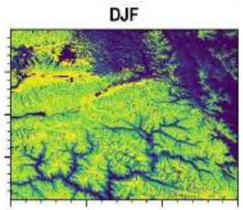
Dozier et al. (2016)

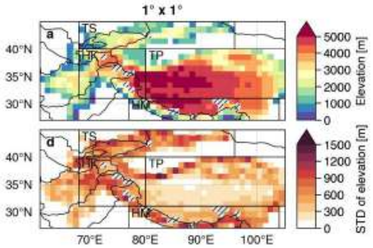
High Mountain Asia UCLA Daily Snow Reanalysis (HMASR)



Margulis et al. (2019)

HMASR -> snow cover parameterizations

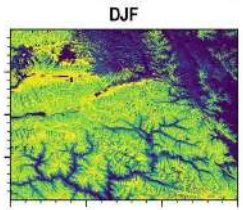


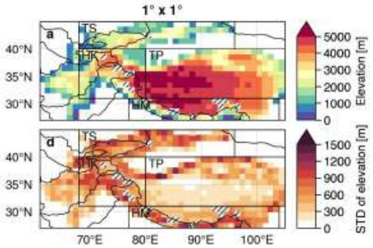


HMASR
SD / SWE / density
+ STD topo
at 1°x1°

SCF

HMASR -> snow cover parameterizations





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)

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

+ σ_{topo} (LA23)

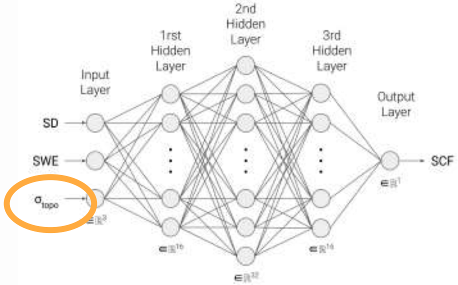
SL12 (Swenson and Lawrence, 2012)

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

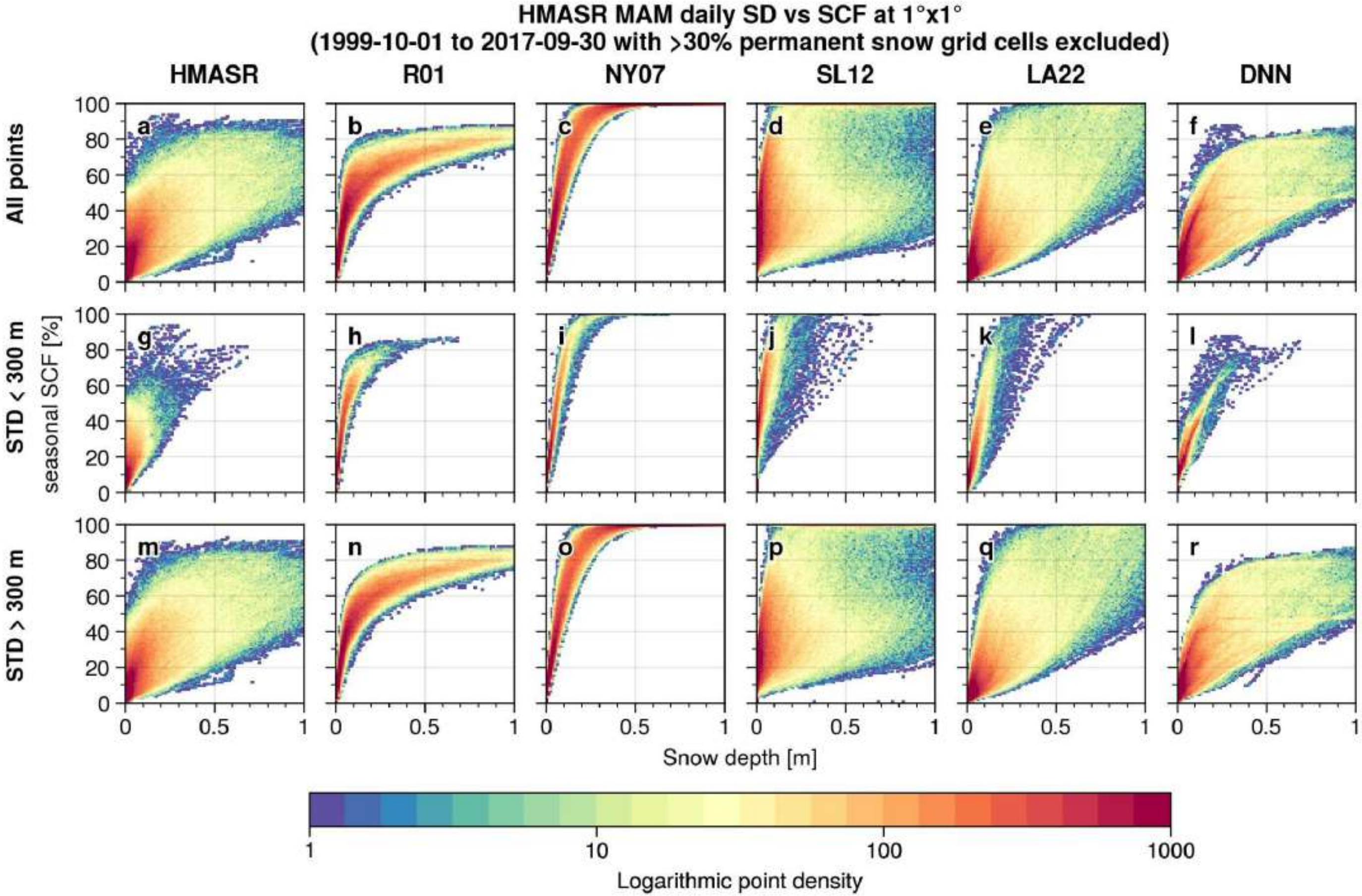
$$N_{\mathrm{melt}} = \frac{200}{\max(30, \sigma_{\mathrm{topo}})}$$

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

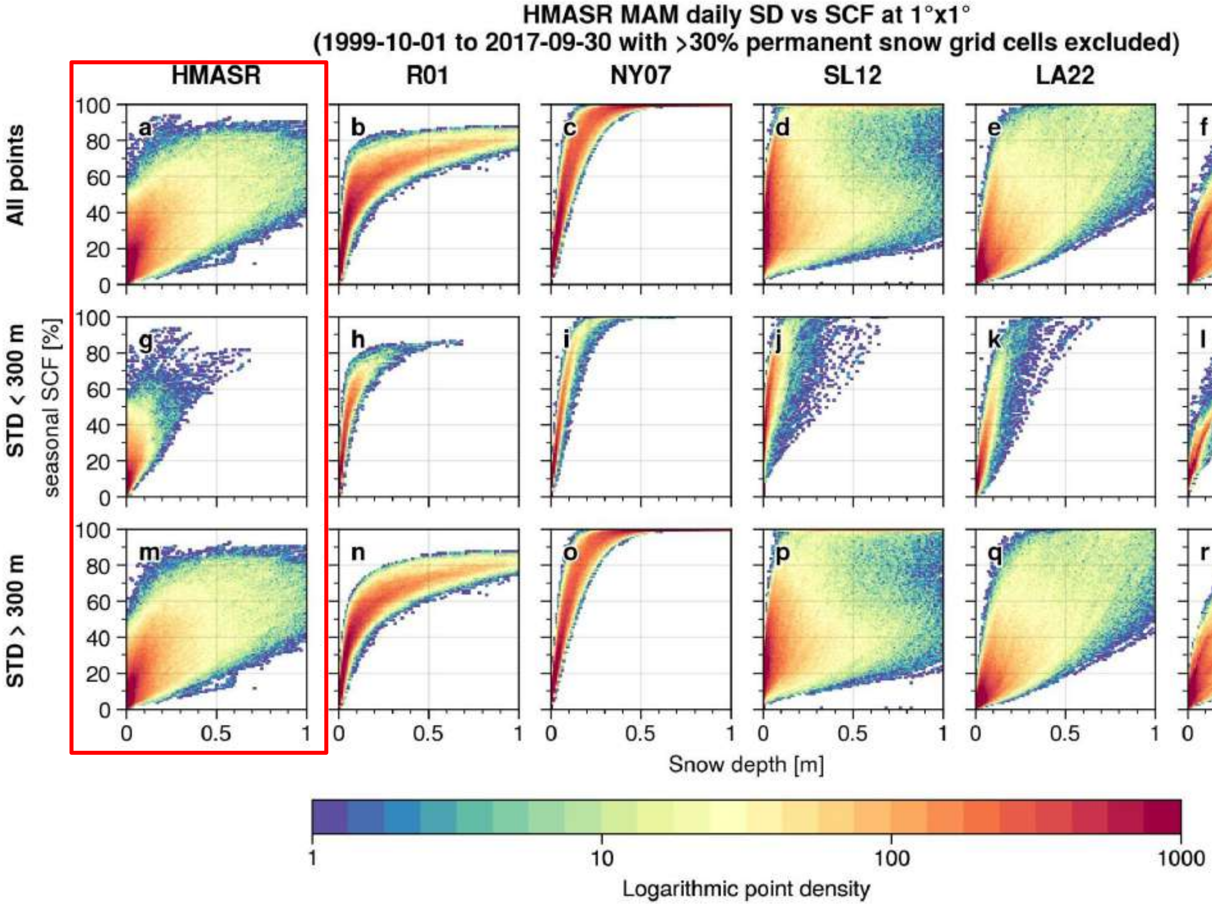
DNN (deep neural network)



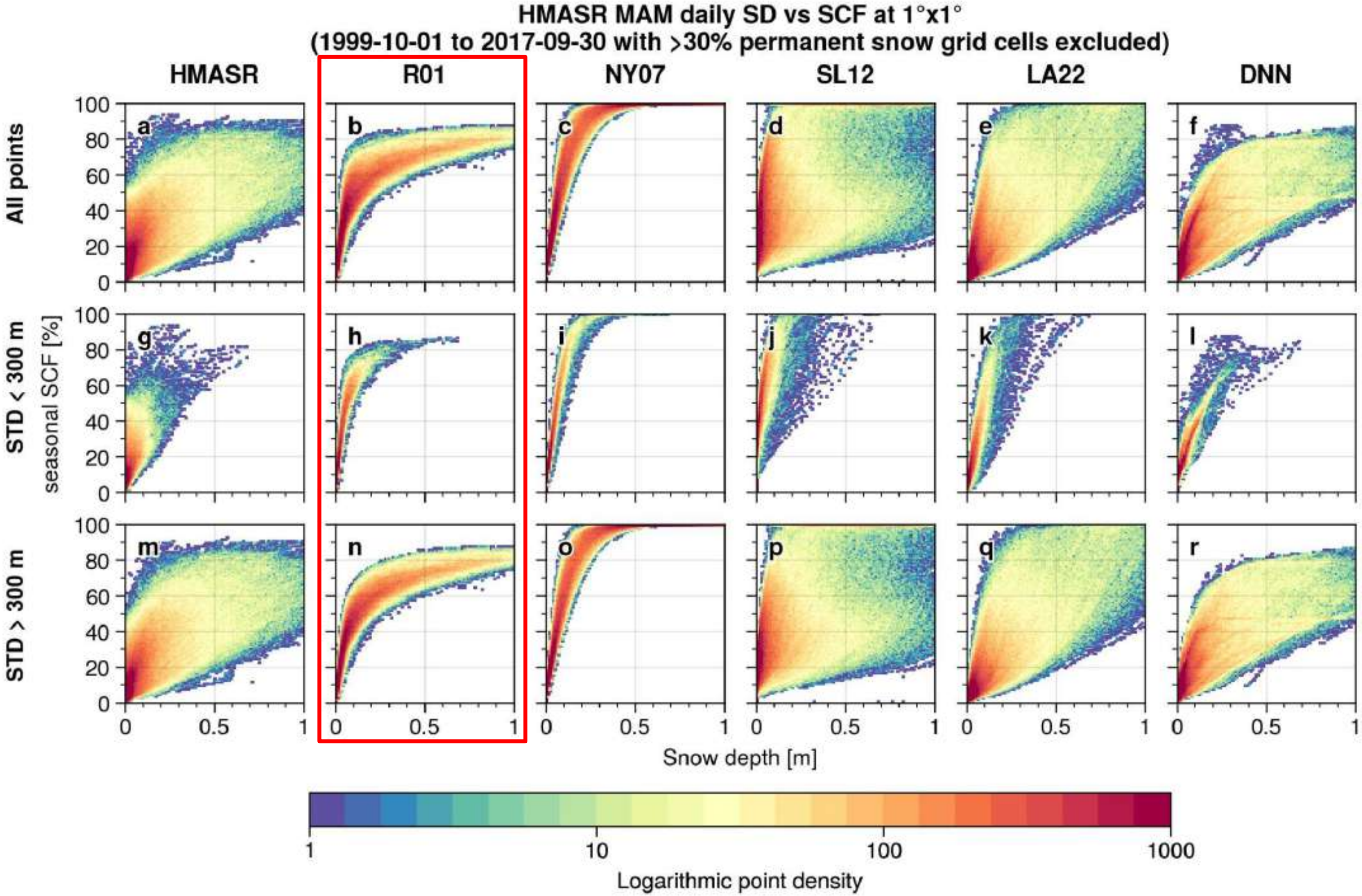
Histograms of the daily HMASR seasonal SCF and SD



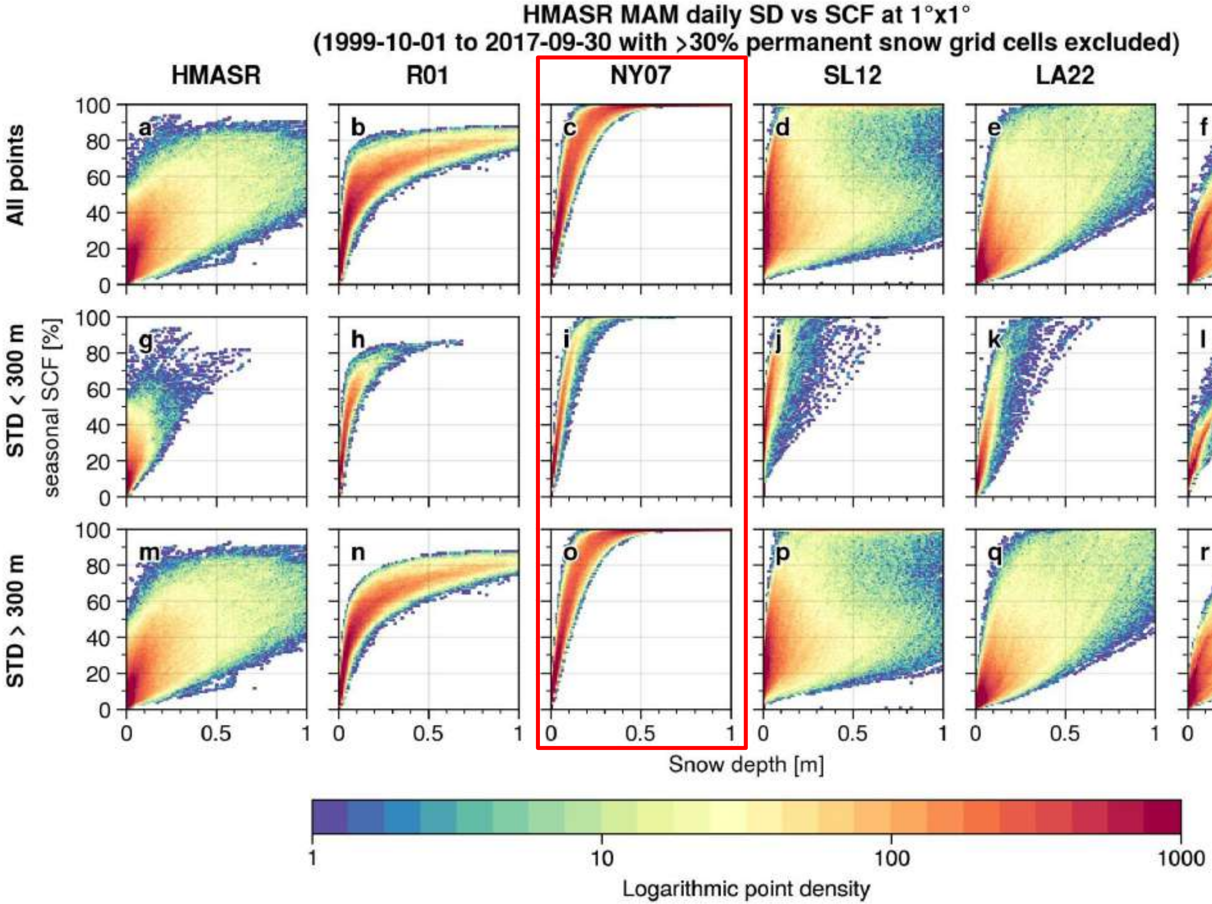
Histograms of the daily HMASR seasonal SCF and SD



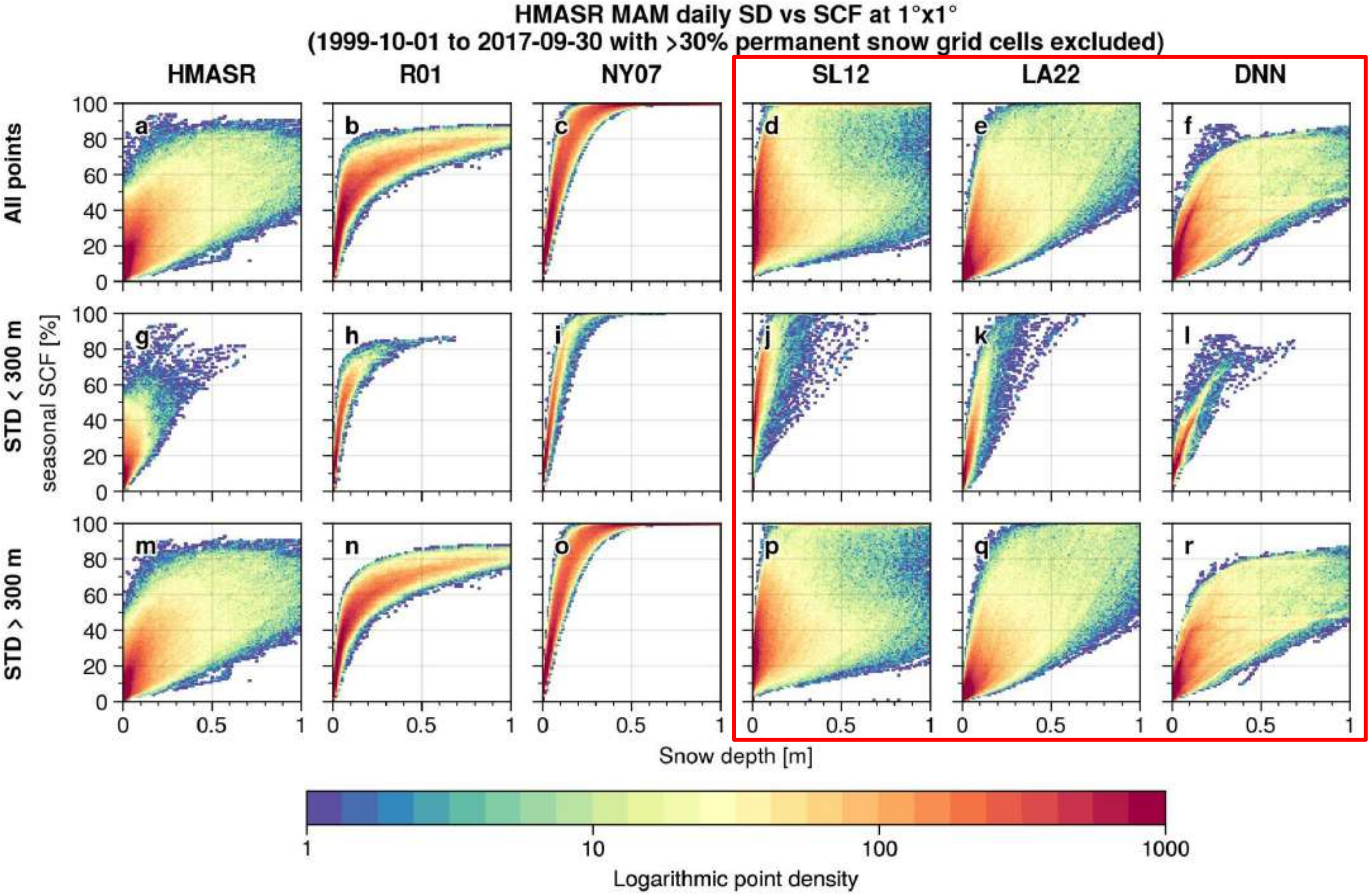
Histograms of the daily HMASR seasonal SCF and SD



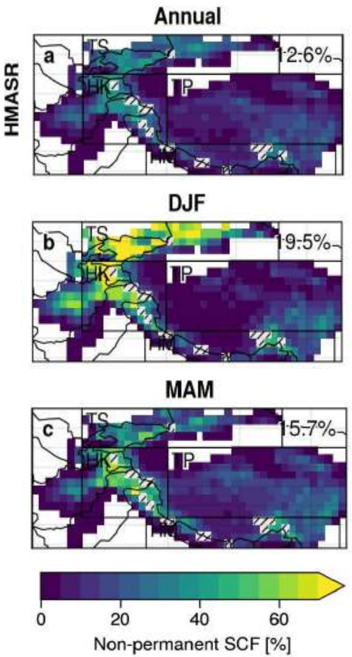
Histograms[#3] of the daily HMASR seasonal SCF and SD

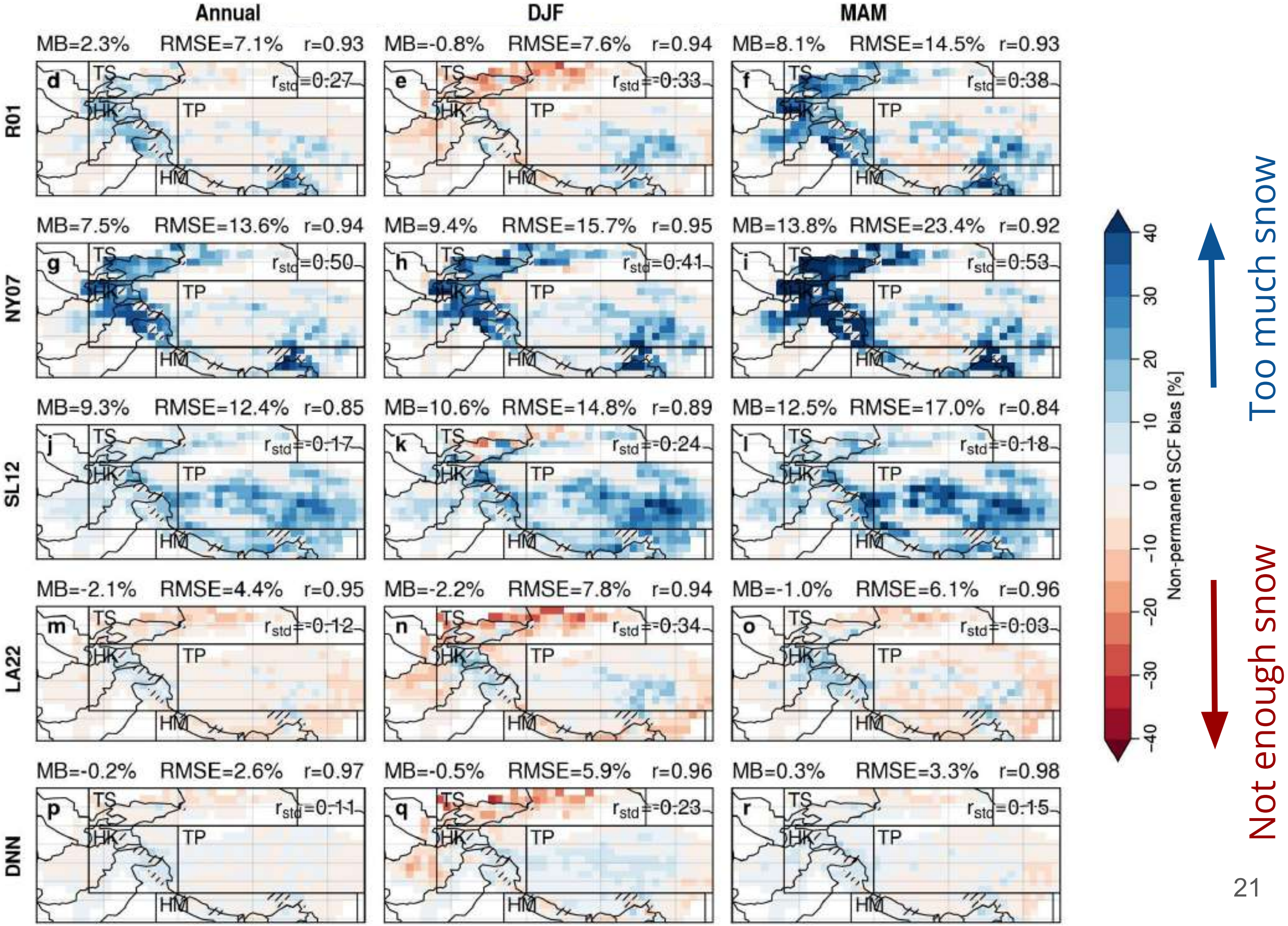


Histograms of the daily HMASR seasonal SCF and SD

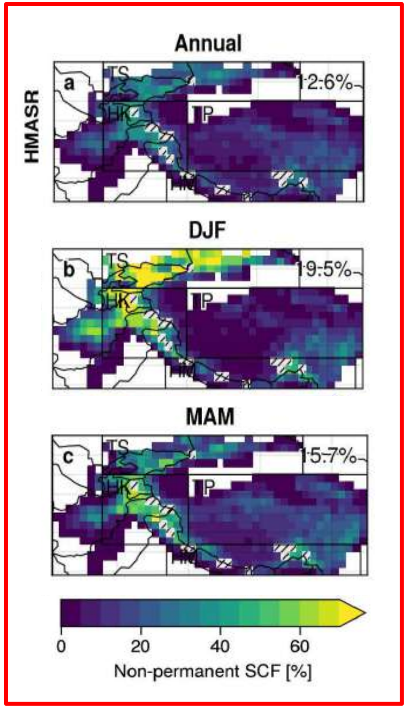


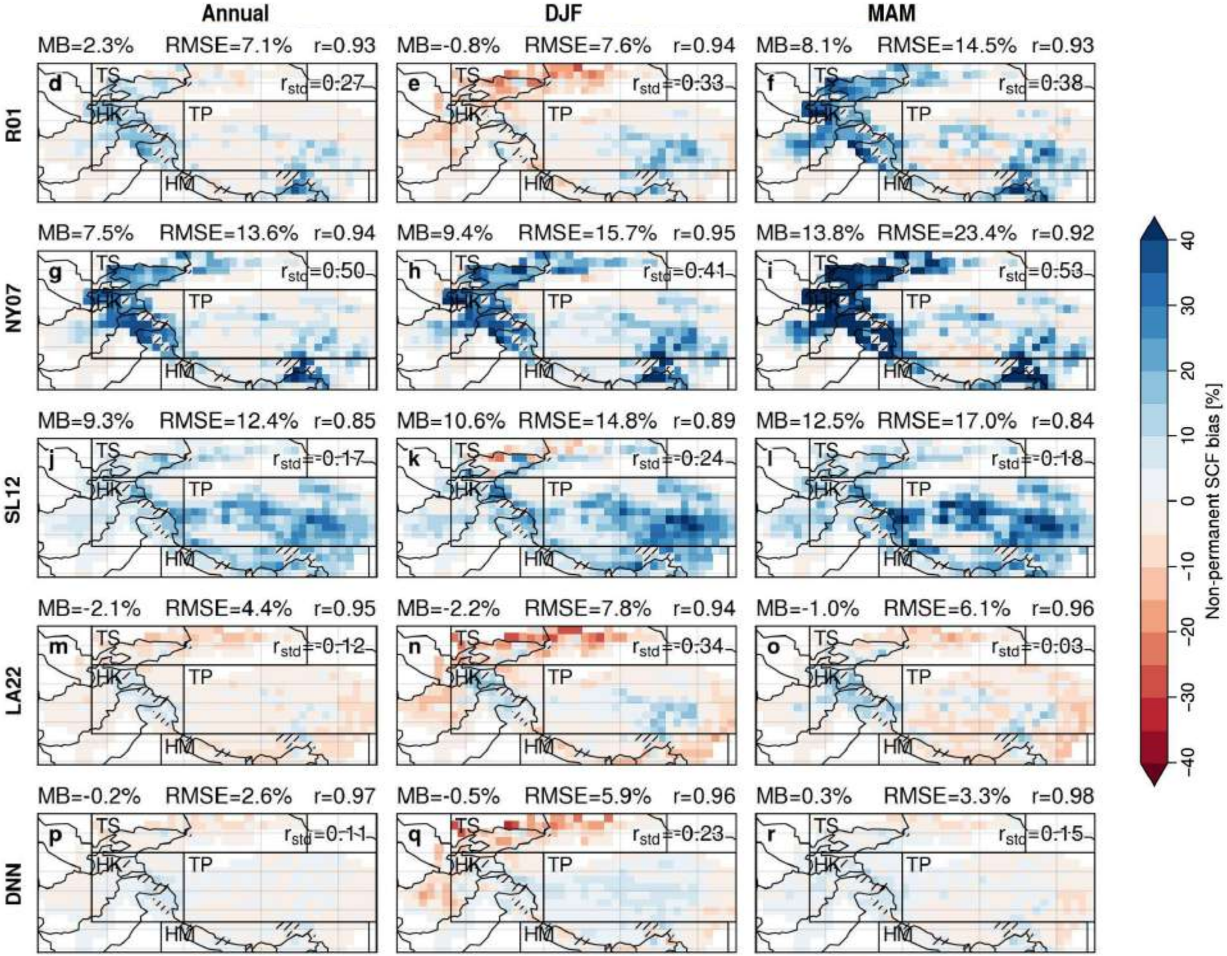
HMASR -> snow cover parameterizations





HMASR -> snow cover parameterizations

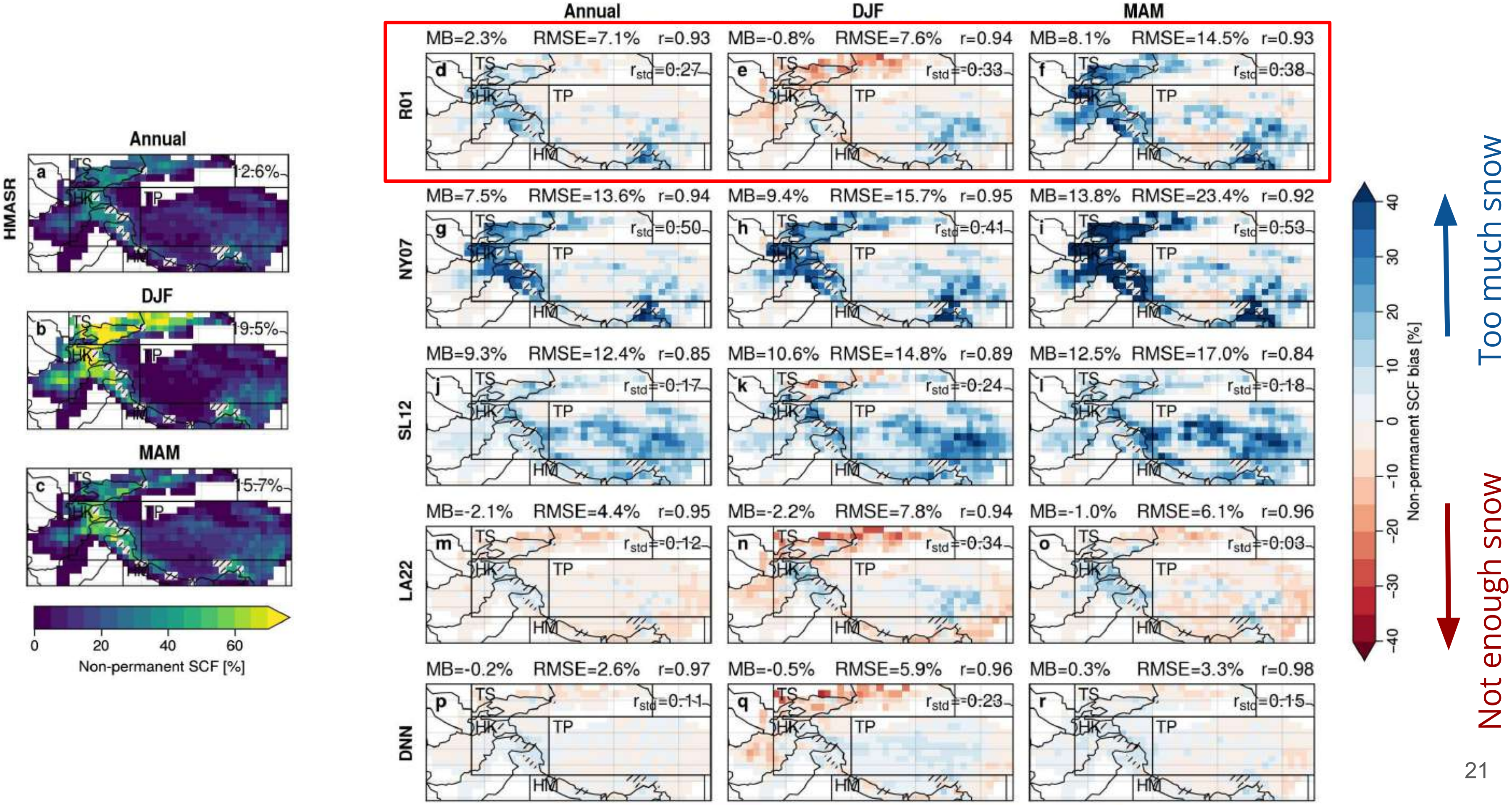




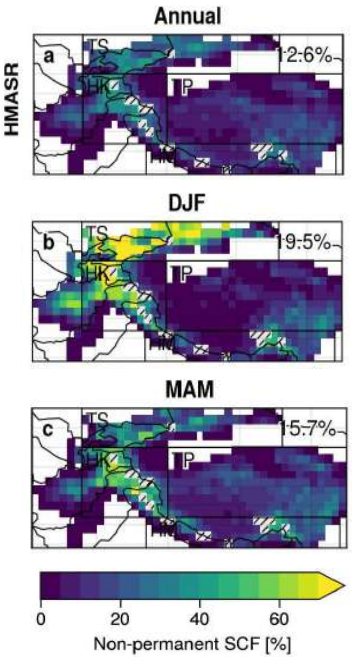
Too much snow

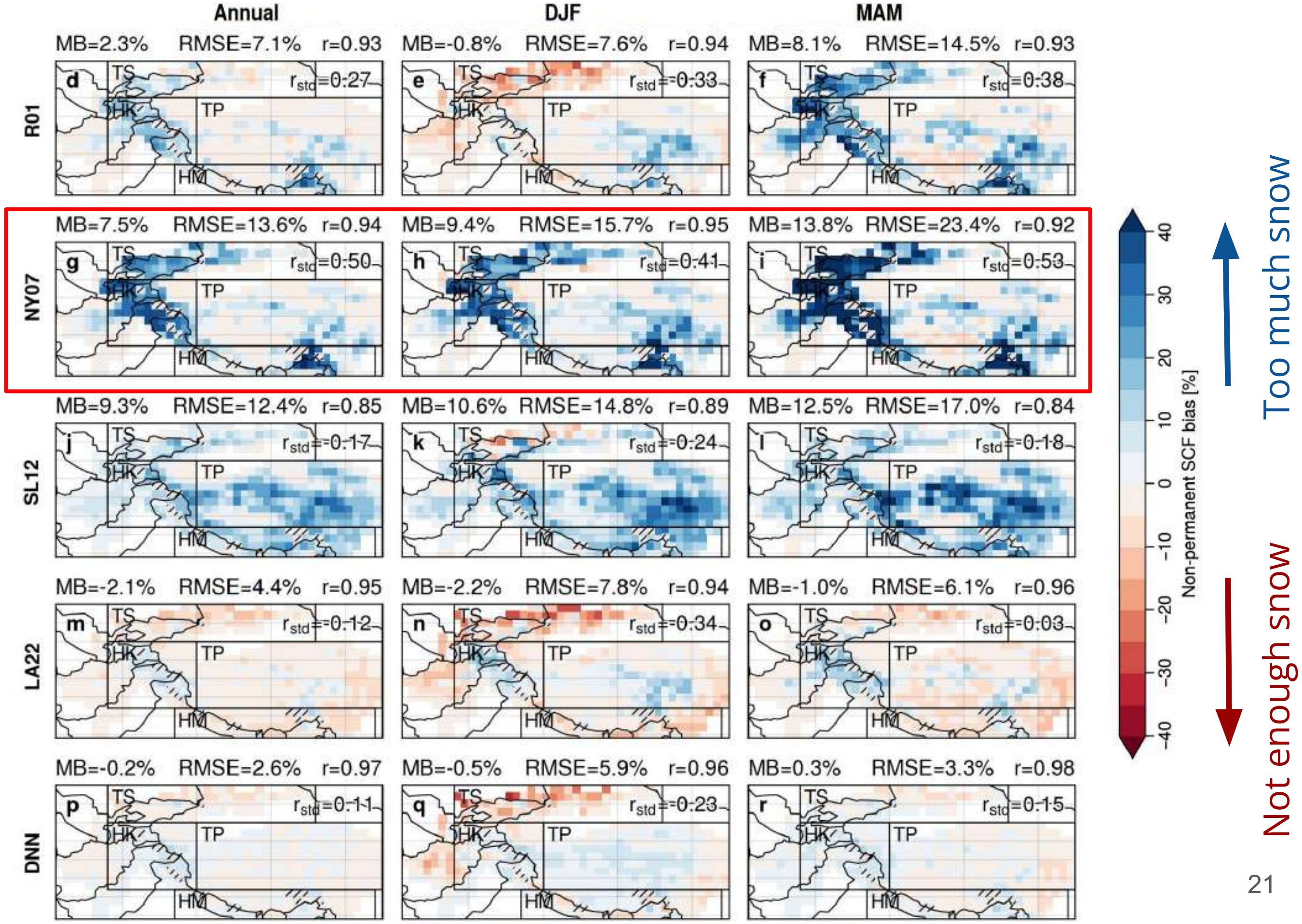
Not enough snow

HMASR -> snow cover parameterizations

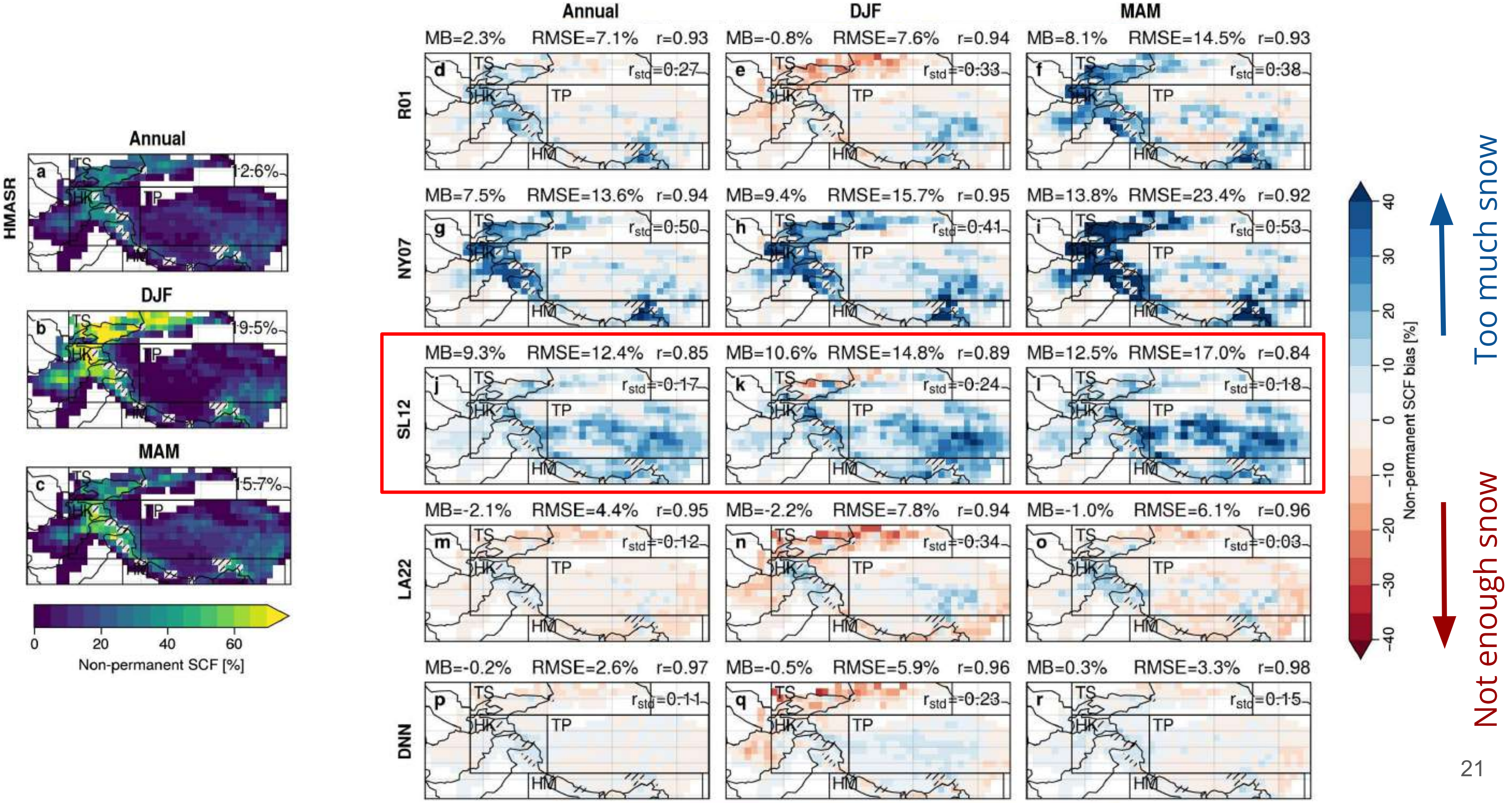


HMASR -> snow cover parameterizations

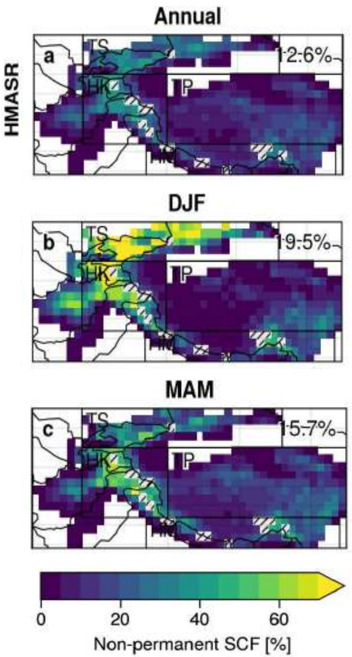


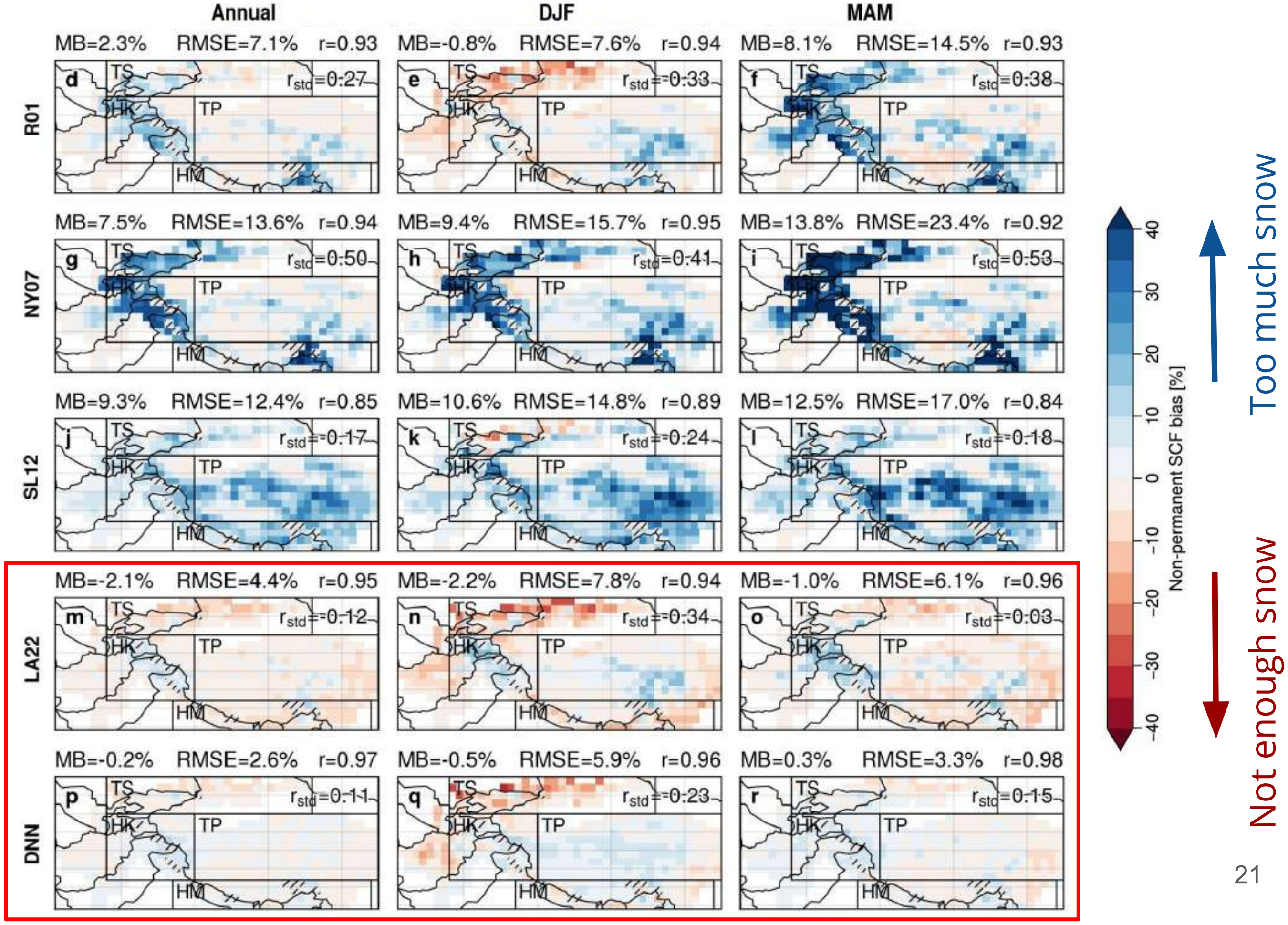


HMASR -> snow cover parameterizations

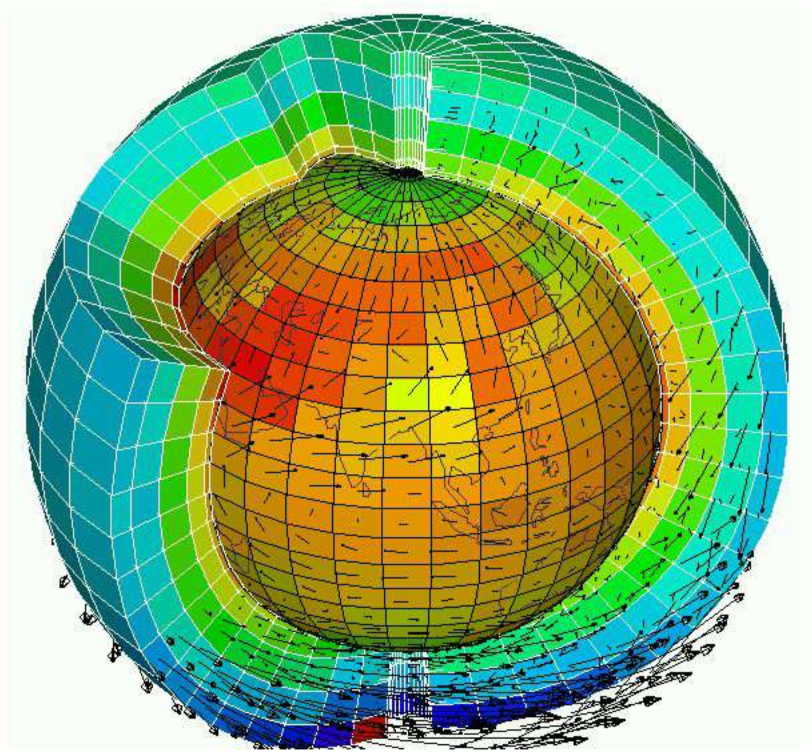


HMASR -> snow cover parameterizations





Application in GCM (LMDZ/ORCHIDEE)

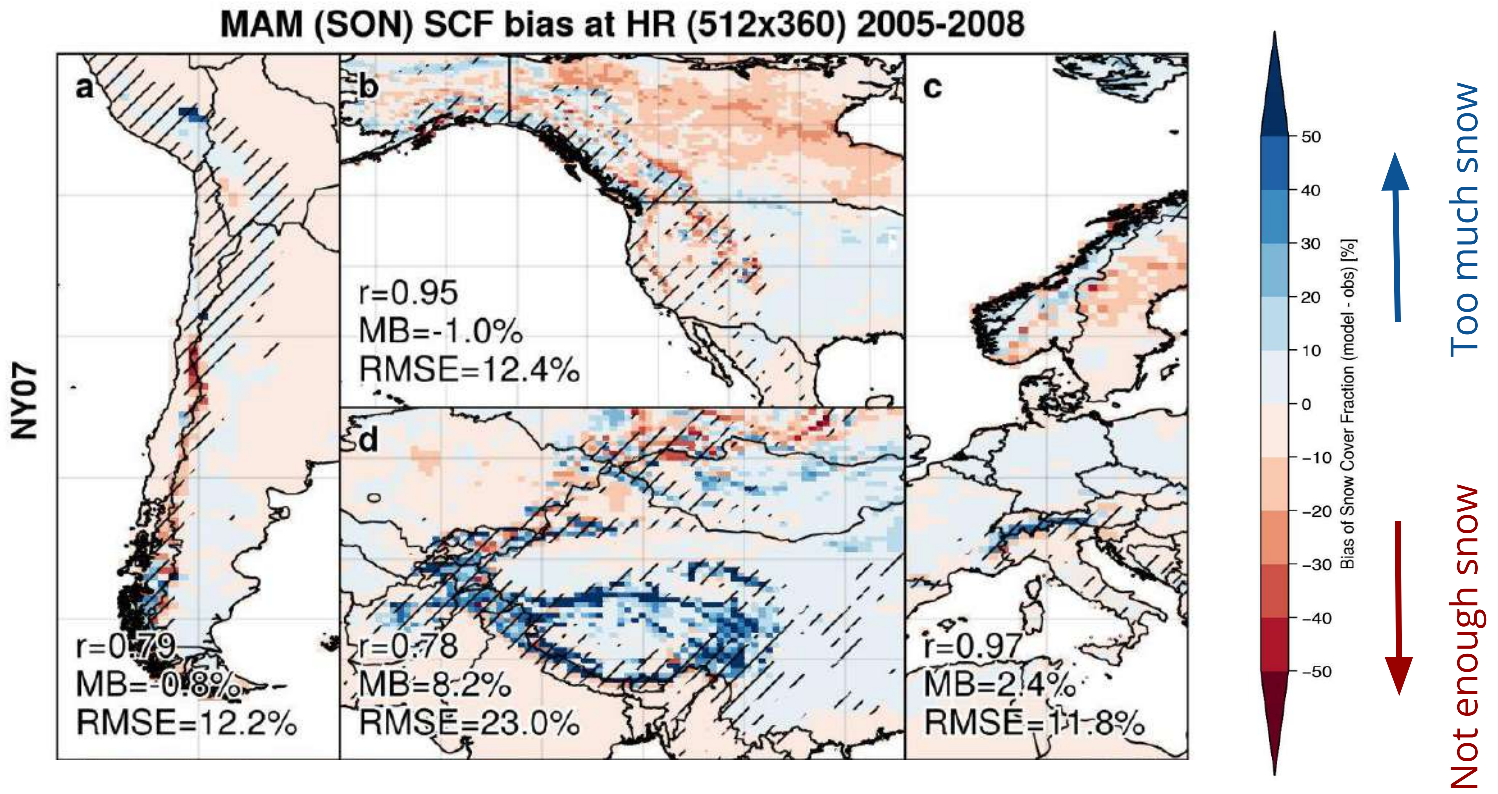


- Nudged land-atmosphere coupled simulations (LMDZ/ORCHIDEE)
- 2 resolutions:
  - LR 144x142 (~100/200 km)
  - HR 512x360 (~50 km)
- 2005-2008 (2004 spin-up)
- NY07, LA23, and SL12 parameterizations
- Snow CCI MODIS observational reference

Application in GCM (LMDZ/ORCHIDEE)

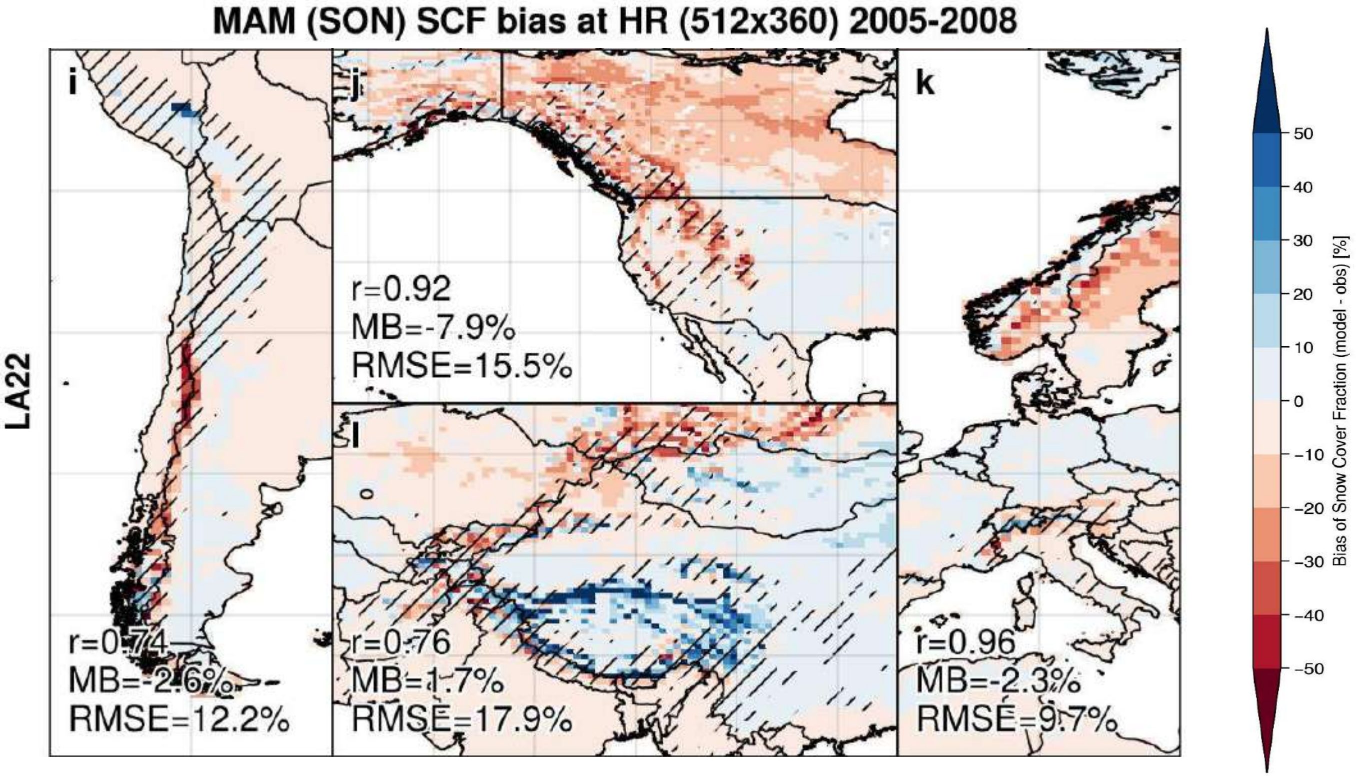
Spring snow cover bias

Reference
(Niu and Yang, 2007)



Spring snow cover bias

New LA23
(based on NY07)



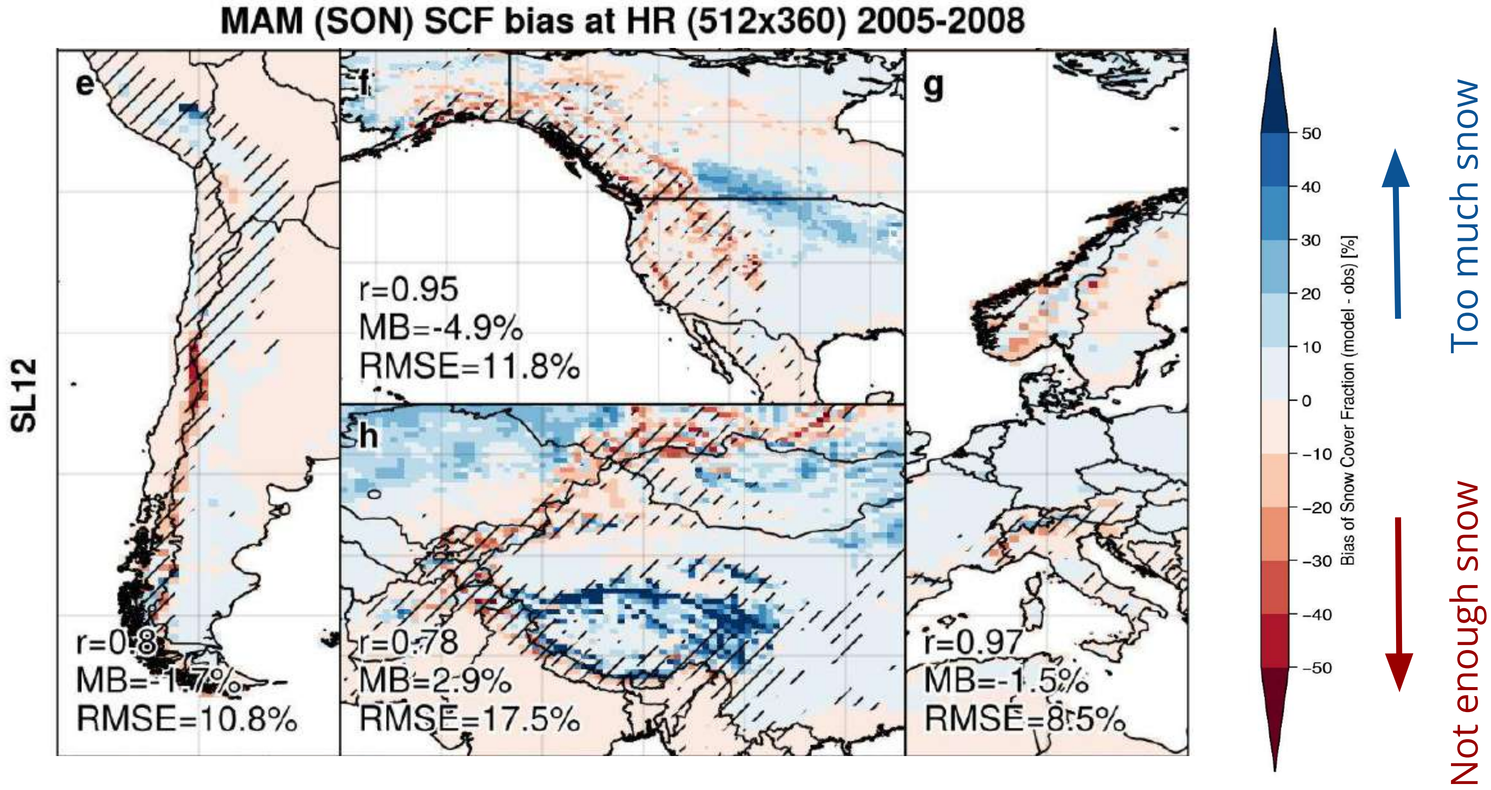
Too much snow

Not enough snow

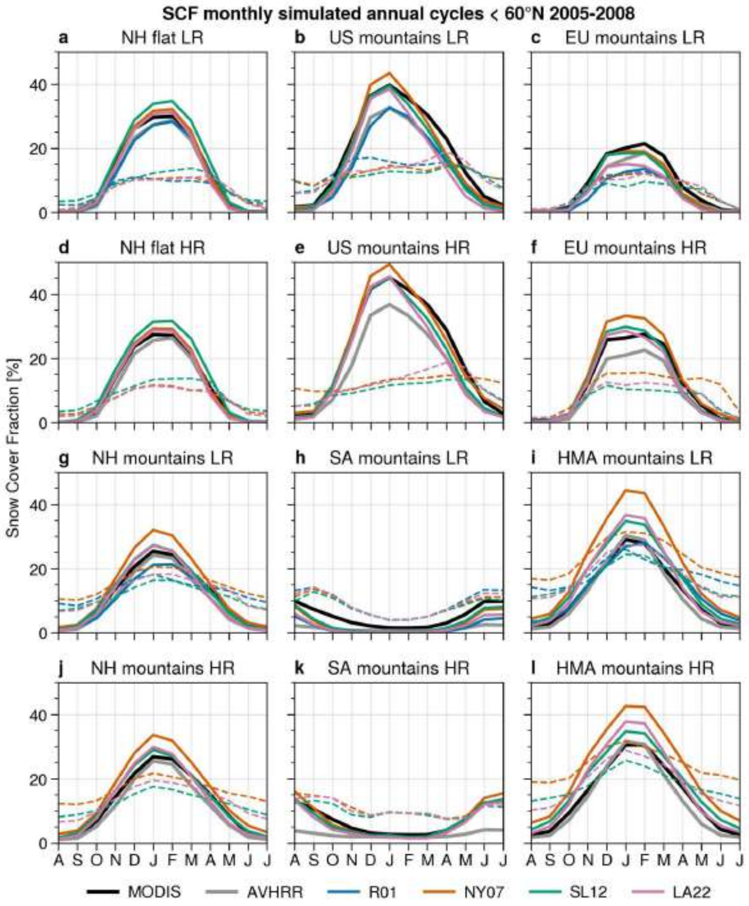
Application in GCM (LMDZ/ORCHIDEE)

Spring snow cover bias

New SL12
(Swenson and Lawrence, 2012)



Application in GCM (LMDZ/ORCHIDEE)



- Contrasting results depending on the location
- Snow cover overestimation in mountain areas is reduced by about 5 to 10 % (when including a dependency on the subgrid topography in the SCF parameterizations)
- No deterioration over flat areas (in average) and no increase of the spatial RMSE
- Surface cold bias decrease from −1.8 °C to about −1 °C in the High Mountain Asia (HMA) region
- Increasing the resolution improves the simulated SCF in certain areas (e.g., Alps)

Conclusion and general outlook

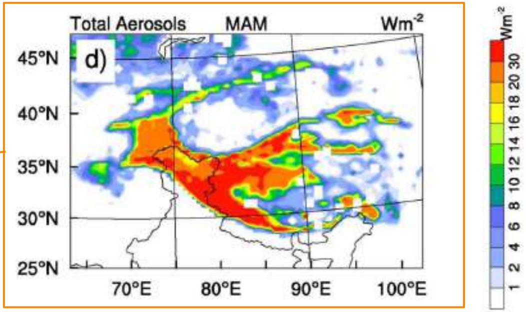
Take home messages

- 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.) +
  ⤷Crucial need of snowfall, SD/SWE observations over mountainous areas!
- 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)

Perspectives : conseils SCF CMIP6 -> CMIP7 LMDZ/ORCHIDEE

- Amélioration de la représentation de l'albédo de la neige incluant le dépôt d'aérosols (ex., Warren and Wiscombe, 1980; Kokhanovsky and Zege, 2004; Wang et al., 2020b)

Fig. 7 Usha et al. (2020)



Le sable du Sahara a partiellement recouvert le manteau neigeux de plusieurs stations des Pyrénées, comme ici à la station de Piau (Hautes-Pyrénées), le 15 mars 2022. | BASTIEN ARBERET / AFP

Perspectives : conseils SCF CMIP6 -> CMIP7 LMDZ/ORCHIDEE

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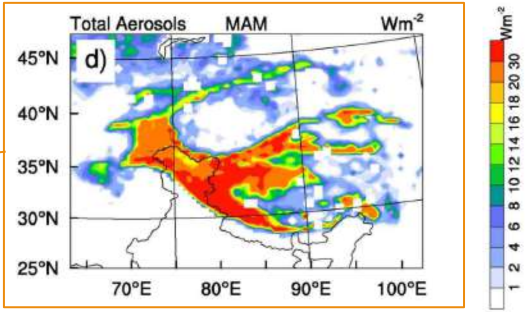
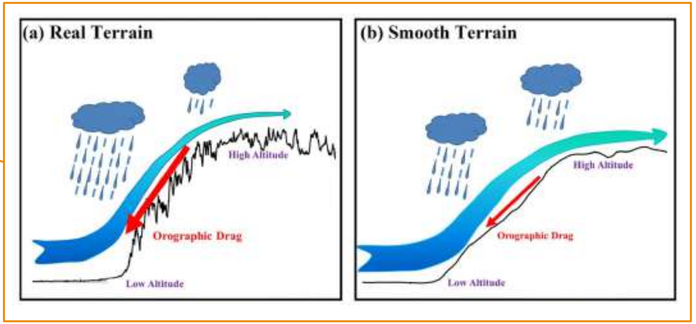


- Trainée orographique de petite échelle

Fig. 5 Wang et al. (2020)



Perspectives : conseils SCF CMIP6 -> CMIP7 LMDZ/ORCHIDEE

- Amélioration de la représentation de l'albédo de la neige incluant le dépôt d'aérosols (ex., Warren and Wiscombe, 1980; Kokhanovsky and Zege, 2004; Wang et al., 2020b)

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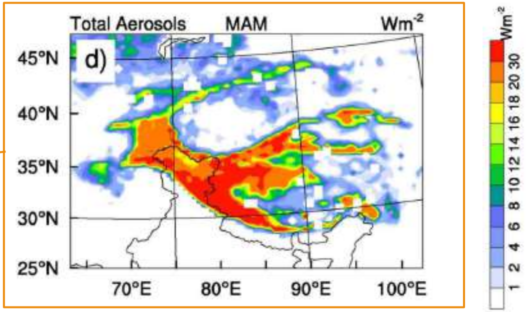

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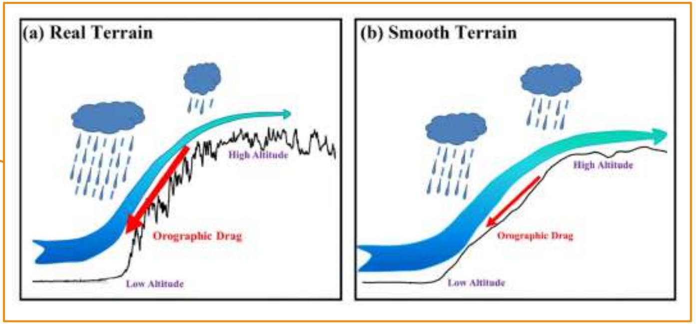
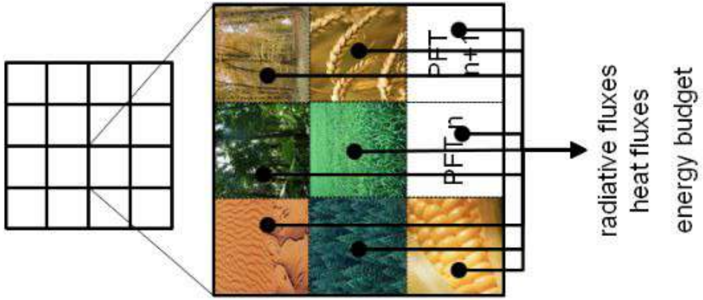


- Amélioration du calcul du bilan d'énergie de surface



Perspectives : conseils SCF CMIP6 -> CMIP7 LMDZ/ORCHIDEE

- Amélioration de la représentation de l'albédo de la neige incluant le dépôt d'aérosols (ex., Warren and Wiscombe, 1980; Kokhanovsky and Zege, 2004; Wang et al., 2020b)

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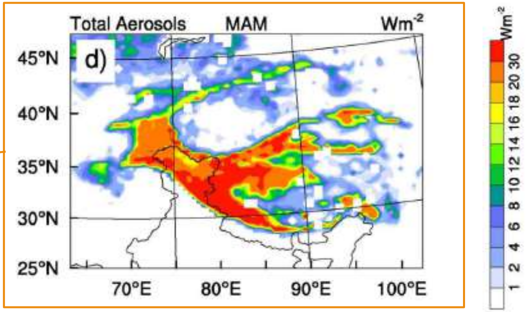
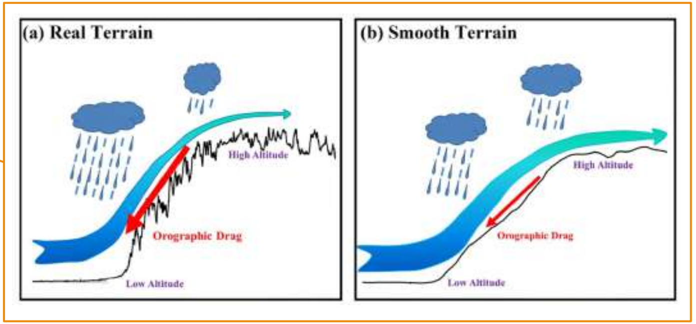


- Trainée orographique de petite échelle

Fig. 5 Wang et al. (2020)



- Amélioration du calcul du bilan d'énergie de surface

- Bandes d'altitudes et couplage neige-glace

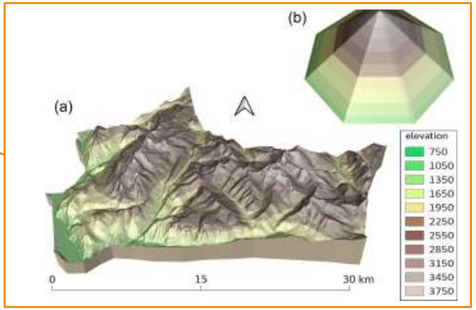
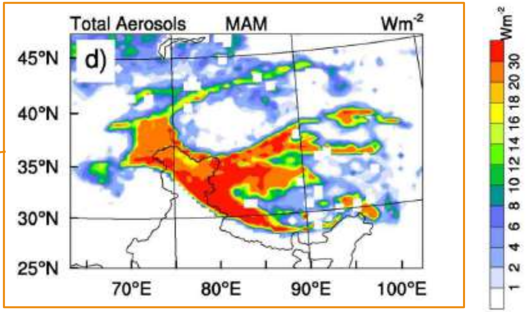


Fig. 3 Vernay et al. (2022)

Perspectives : conseils SCF CMIP6 -> CMIP7 LMDZ/ORCHIDEE

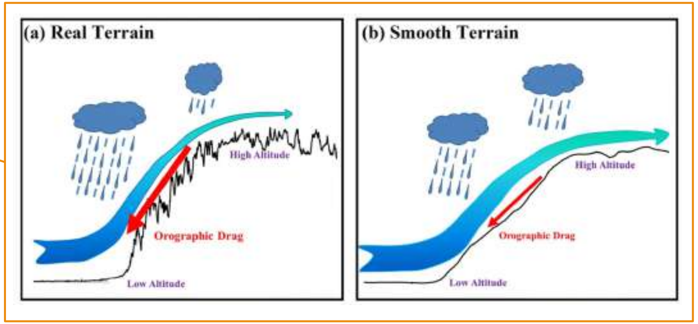
- Amélioration de la représentation de l'albédo de la neige incluant le dépôt d'aérosols (ex., Warren and Wiscombe, 1980; Kokhanovsky and Zege, 2004; Wang et al., 2020b)

Fig. 7 Usha et al. (2020)



- Trainée orographique de petite échelle

Fig. 5 Wang et al. (2020)



- Amélioration du calcul du bilan d'énergie de surface

- Bandes d'altitudes et couplage neige-glace

- Couche limite en zone de montagne (Wekker and Kossmann, 2015; Serafin et al., 2020)

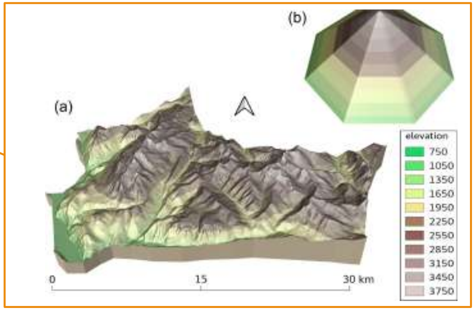


Fig. 3 Vernay et al. (2022)

Part #3

Technical and practical information

Get the topography not smoothed

ce0l.F90

Purpose: **Initial states and boundary conditions files creation**:

- start.nc for dynamics (using etat0dyn routine)
- **startphy**.nc for physics (using etat0phys routine)
- limit.nc for forced runs (using limit_netcdf routine)

CALL etat0phys_netcdf(masque,phis)

etat0phys_netcdf.F90

Purpose: Create physical initial state using atmospheric fields from a database of atmospheric to initialize the model.

etat0phys_netcdf routine can access to NetCDF data through subroutines:

- "start_init_phys" for variables contained in file "ECPHY.nc":
  - 'ST' : Surface temperature
  - 'CDSW' : Soil moisture
- **"start_init_orog"** for variables contained in file **"Relief.nc"**:
  - 'RELIEF' : High resolution orography

Add zmea0_not_filtered and zstd0_not_filtered (dynamics grid)

USE phys_state_var_mod, ONLY: **zmea, zstd**, zmea_not_filtered, zstd_not_filtered, ...

USE grid_noro_m, ONLY: **grid_noro**, read_noro

phys_state_var_mod.F90

Variables saved in startphy.nc

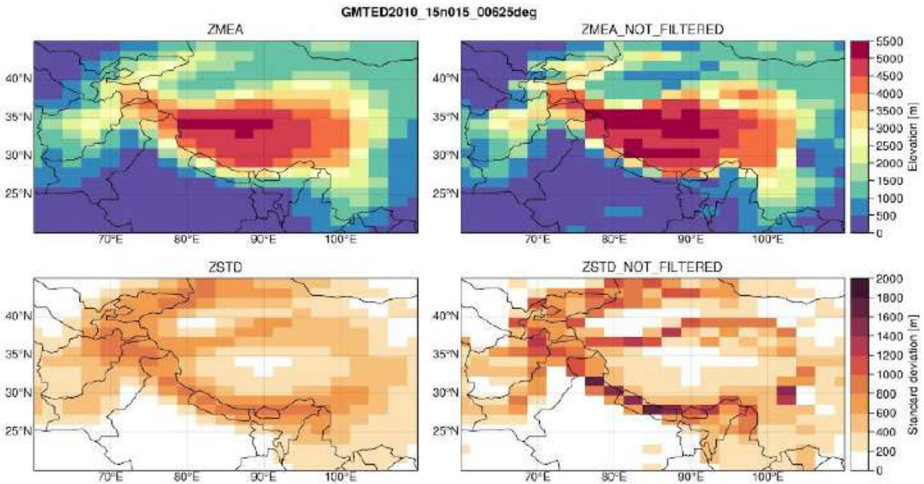
Add zmea_not_filtered and zstd_not_filtered

(physics grid)

grid_noro_m.F90

Purpose: Compute the Parameters of the SSO scheme as described in LOTT & MILLER (1997) and LOTT(1999).

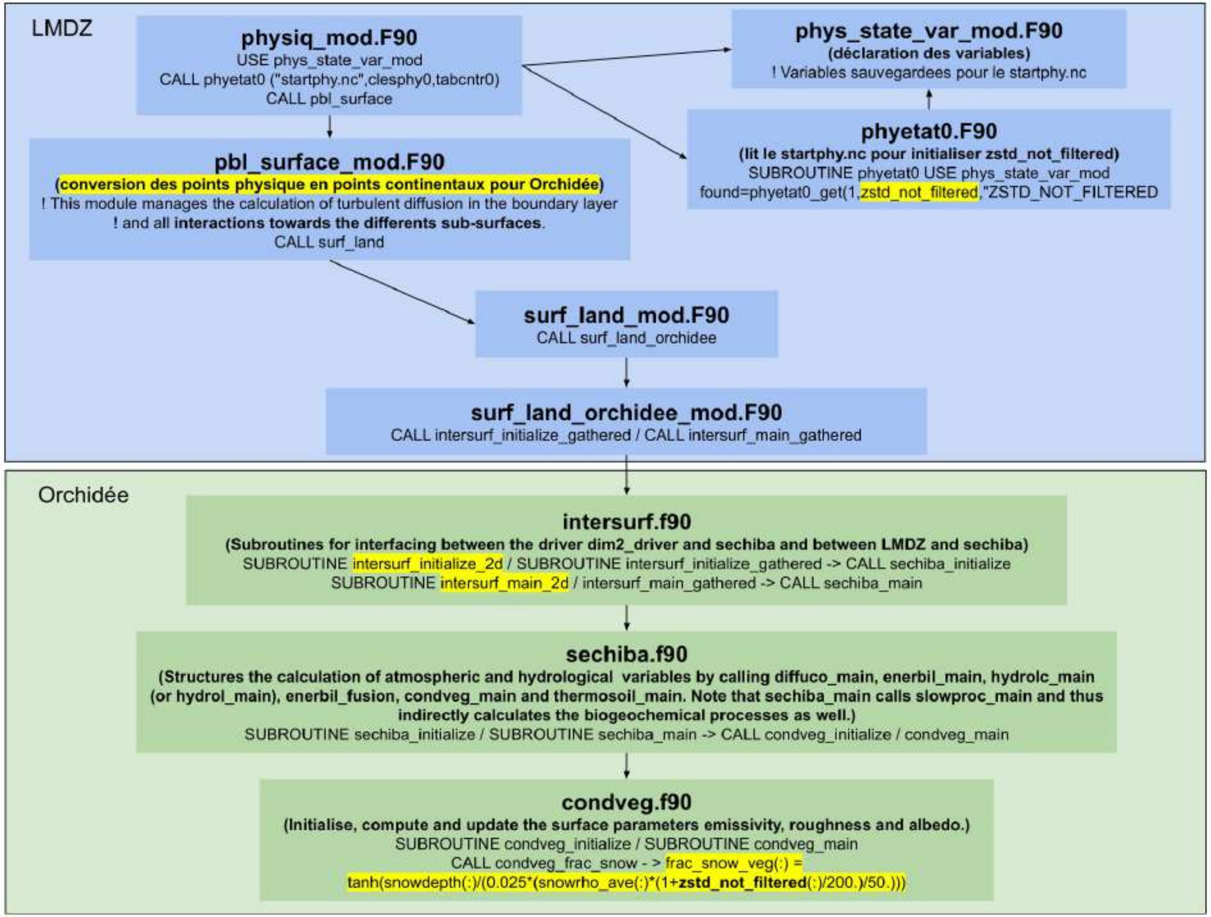
Add zmea_not_filtered and zstd_not_filtered (dynamics grid)




```
!=== FILTERS TO SMOOTH OUT FIELDS FOR INPUT INTO SSO SCHEME.
!--- FIRST FILTER, MOVING AVERAGE OVER 9 POINTS.
!-------------------------------------------------------------------------------
  zphi(:,:)=zmea(:,:)                        ! GK211005 (CG) UNSMOOTH
  zmea_not_filtered(:,:)=zmea(:,:)
  zstd_not_filtered(:,:)=zstd(:,:)

  CALL MVA9(zmea);  CALL MVA9(zstd);  CALL MVA9(zpic);  CALL MVA9(zval)
  CALL MVA9(zxtzx); CALL MVA9(zxtzy); CALL MVA9(zytzy)
```

LMDZ to ORCHIDEE



https://docs.google.com/document/d/1gK69TtH3feRFu4q0MjmuouC8xG6Gcth6Qe9cbeY5vIM/edit?usp=sharing

Parameterizations

```
!! Calculate snow cover fraction for both total vegetated and total non-vegetative surfaces.
IF (ok_explicitsnow) THEN
   snowdepth=sum(snowdz,2)
   snowrho_snowdz=sum(snowrho*snowdz,2)
   WHERE(snowdepth(:) .LT. min_sechiba)
      frac_snow_veg(:) = 0.
   ELSEWHERE
      snowrho_ave(:)=snowrho_snowdz(:)/snowdepth(:)

      ! LMDZOR-STD-NY07
      frac_snow_veg(:) = tanh(snowdepth(:)/(0.025*(snowrho_ave(:)/50.)))

      ! LMDZOR-STD-LA22
      ! frac_snow_veg(:) = tanh(snowdepth(:)/( 0.025*(snowrho_ave(:)/50.) + 3e-6*zstd_not_filtered(:)*(snowrho_ave(:)/50.)**3 ))

      ! LMDZOR-STD-NY07-CUSTOM-200
      ! frac_snow_veg(:) = tanh(snowdepth(:)/(0.025*(snowrho_ave(:)*(1+zstd_not_filtered(:)/200.)/50.)))

      ! LMDZOR-STD-NY07-opti
      ! frac_snow_veg(:) = tanh(snowdepth(:)/(0.6*0.01*(snowrho_ave(:)/50.)**2.5))

      !!!!!!!!!!!!!!!!!!!!!!!!
      ! Roesch et al. (2001) !
      !!!!!!!!!!!!!!!!!!!!!!!!
      ! https://link.springer.com/article/10.1007/s003820100153

      ! LMDZOR-STD-R01
      ! swe(:) = (snowdepth(:) * snowrho_ave(:)) / 1000. ! to get swe in meter as in R01 paper
      ! frac_snow_veg(:) = 0.95 * TANH( 100. * swe(:) ) * SQRT( 1000.*swe(:) / (1000.*swe(:) + 1e-6 + 0.15 * zstd_not_filtered(:)) )
```

https://github.com/mickaellalande/SCA_parameterization/blob/R01/modipsl/modeles/ORCHIDEE/src_sechiba/condveg .f90

Perspectives : conseils SCF CMIP6 -> CMIP7 LMDZ/ORCHIDEE

- Implémenter SL12 et LA23 (en plus de NY07) et conserver un switch pour passer d'une version à l'autre pour déterminer la meilleure en fonction des configurations (+ ML sur du long terme).
- Envisager une calibration directement dans le modèle (dès lors que l'on pas — encore — d'obs fiables sur les régions montagneuses).
  ⤷ /!\ compensations de biais ≠ couplé ou non /!\
- Lorsque + de jeux de données revenir sur une calibration + physique
- Approfondir simulations ORCHIDEE offline pour déterminer les incertitudes liées aux jeux de forçages
- Regarder ce qu'il se passe dans les zones de forêt
- En couplé : /!\ biais tropo /!\ -> impact sur l'ensemble des surfaces continentales

Merci à tous pour votre attention !

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Preprint. Discussion started: 24 July 2023

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Reducing the High Mountain Asia cold bias in GCMs by adapting snow cover parameterization to complex topography areas

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Annex B: Climate Change Initiative Fellowship Project Proposal

Project (2 years) : **Snow cover heterogeneity and its impact on the Climate and Carbon cycle of Arctic regions (SnowC^2)**

Objectives : **Improving snow model in CLASSIC** (SCF, multi-layer snow scheme, blowing snow sublimation) and **assessment of these improvements over the Arctic**

Location : **Trois-Rivières, QC, UQTR / GLACIOLAB / RIVES (Canada)**

Supervision : **Christophe Kinnard** (+ Alexandre Roy / Environnement Canada)

GLACIOLAB

RESEARCH FELLOWSHIP SCHEME 2022

climate.esa.int

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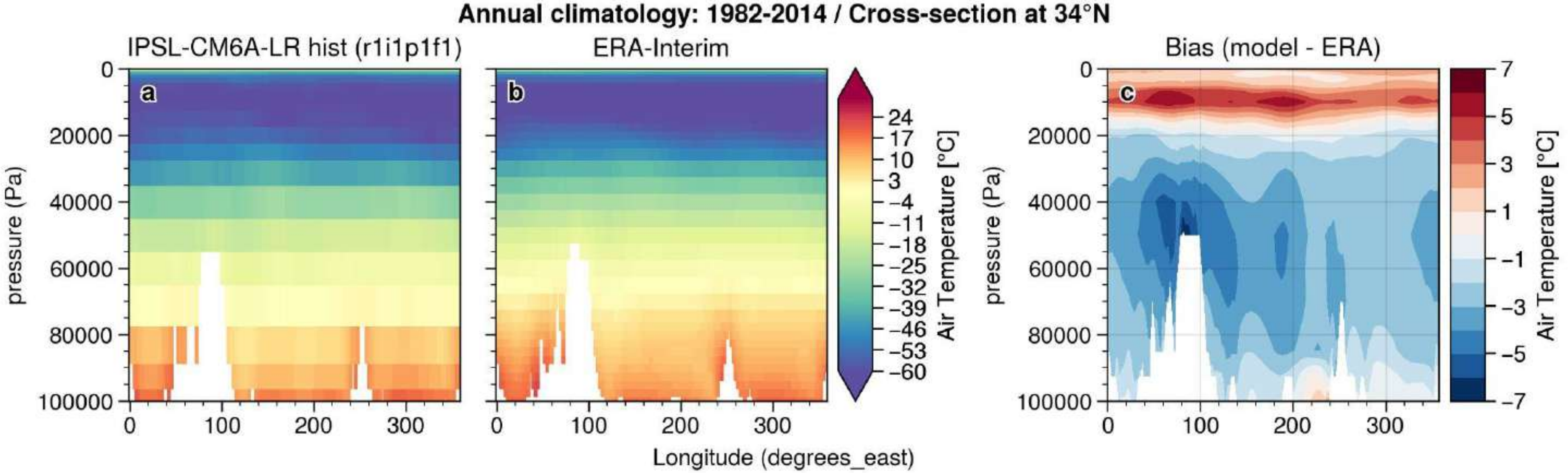
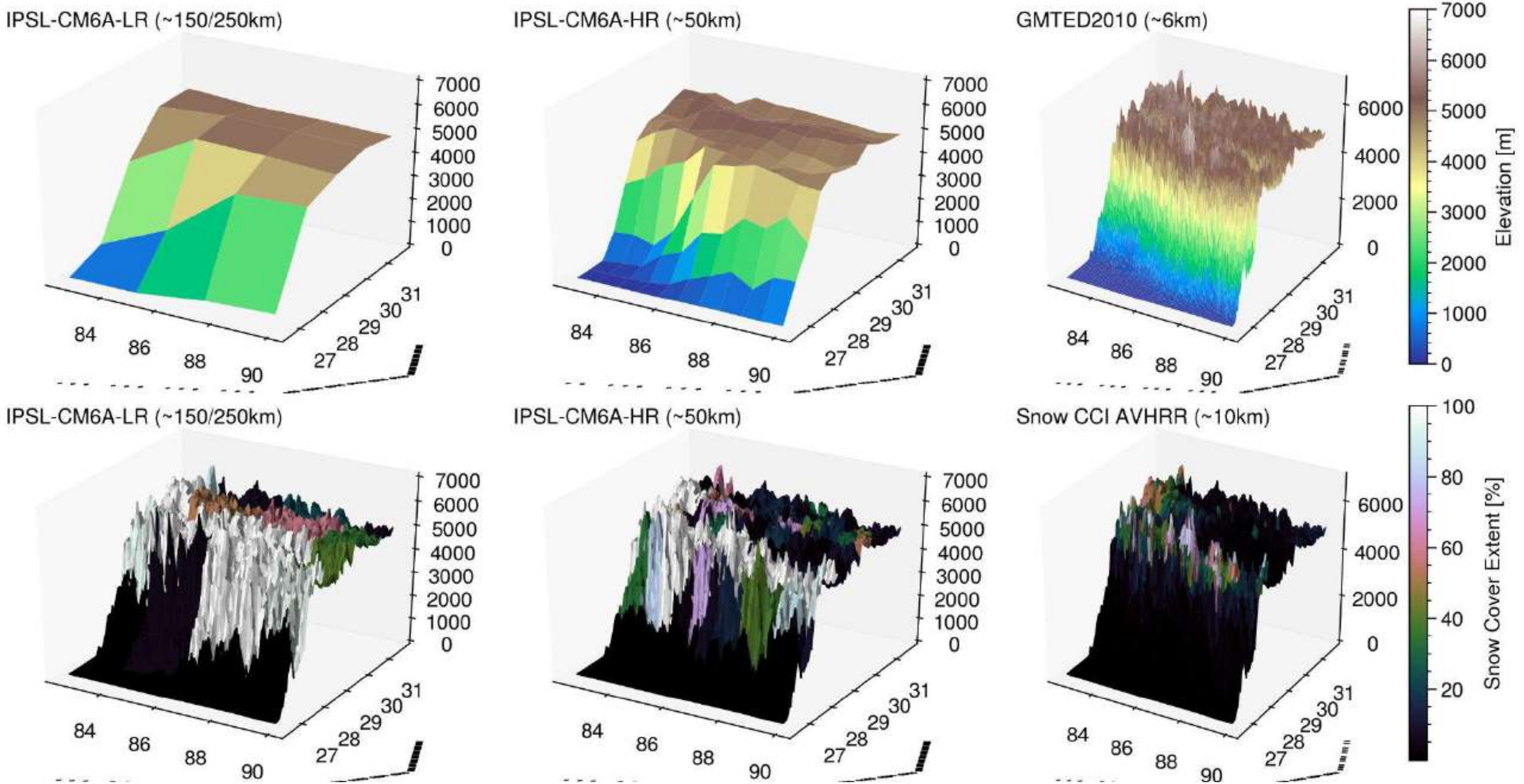
Supplementary materials

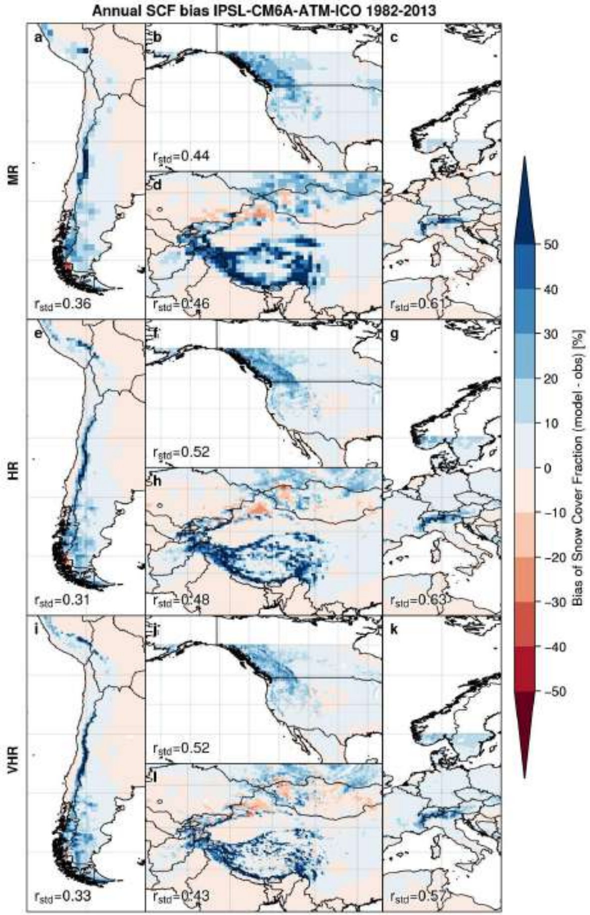
Air Temperature meridional cross-section means bias

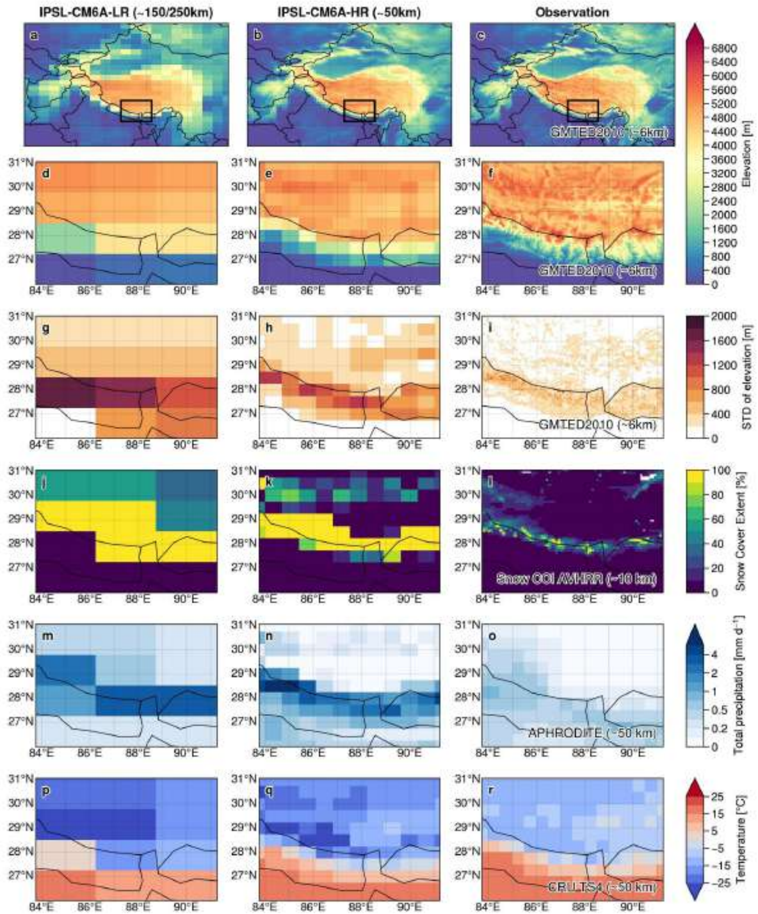


Lien avec la topographie ?

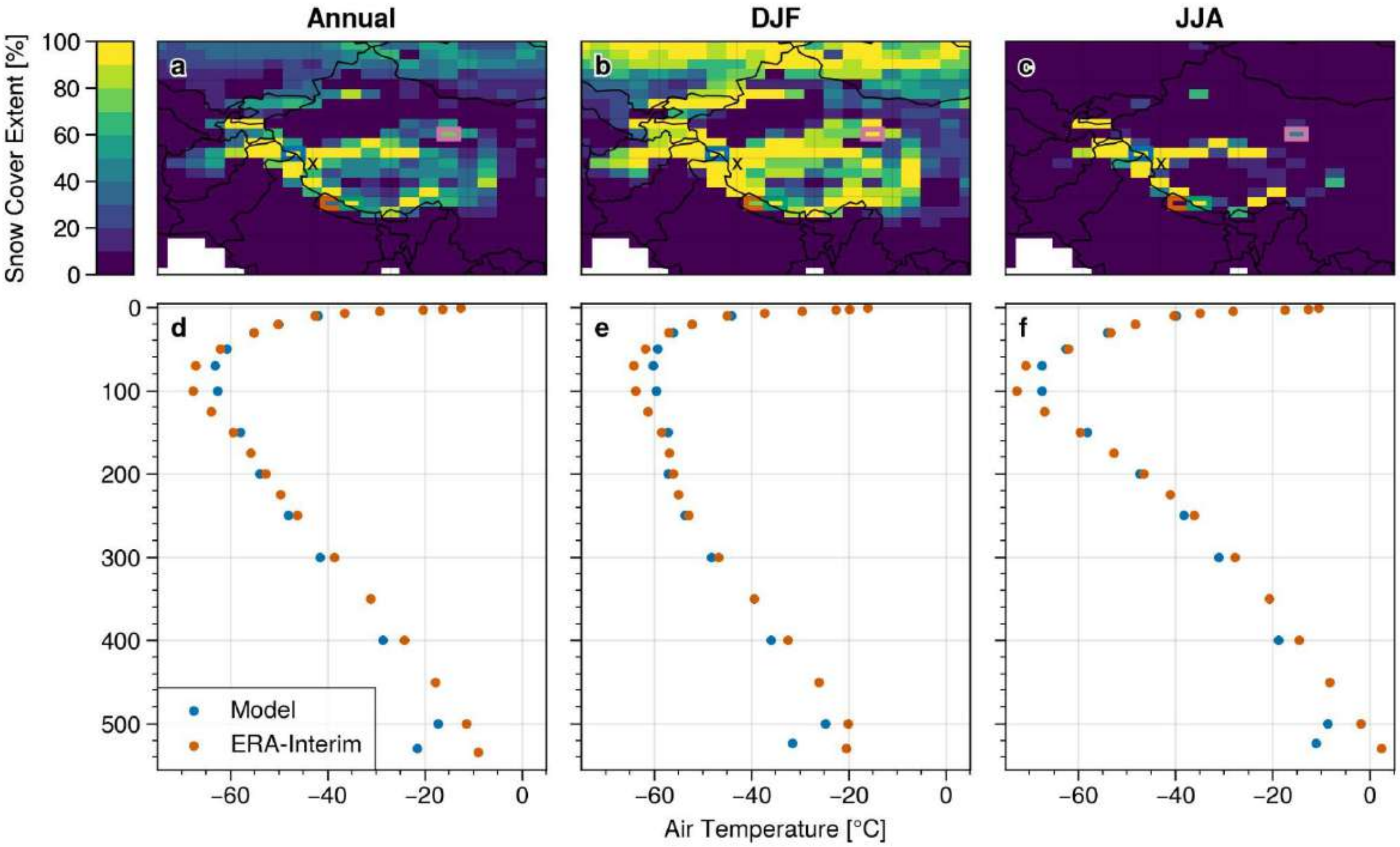


Influence de la résolution





Neige permanente



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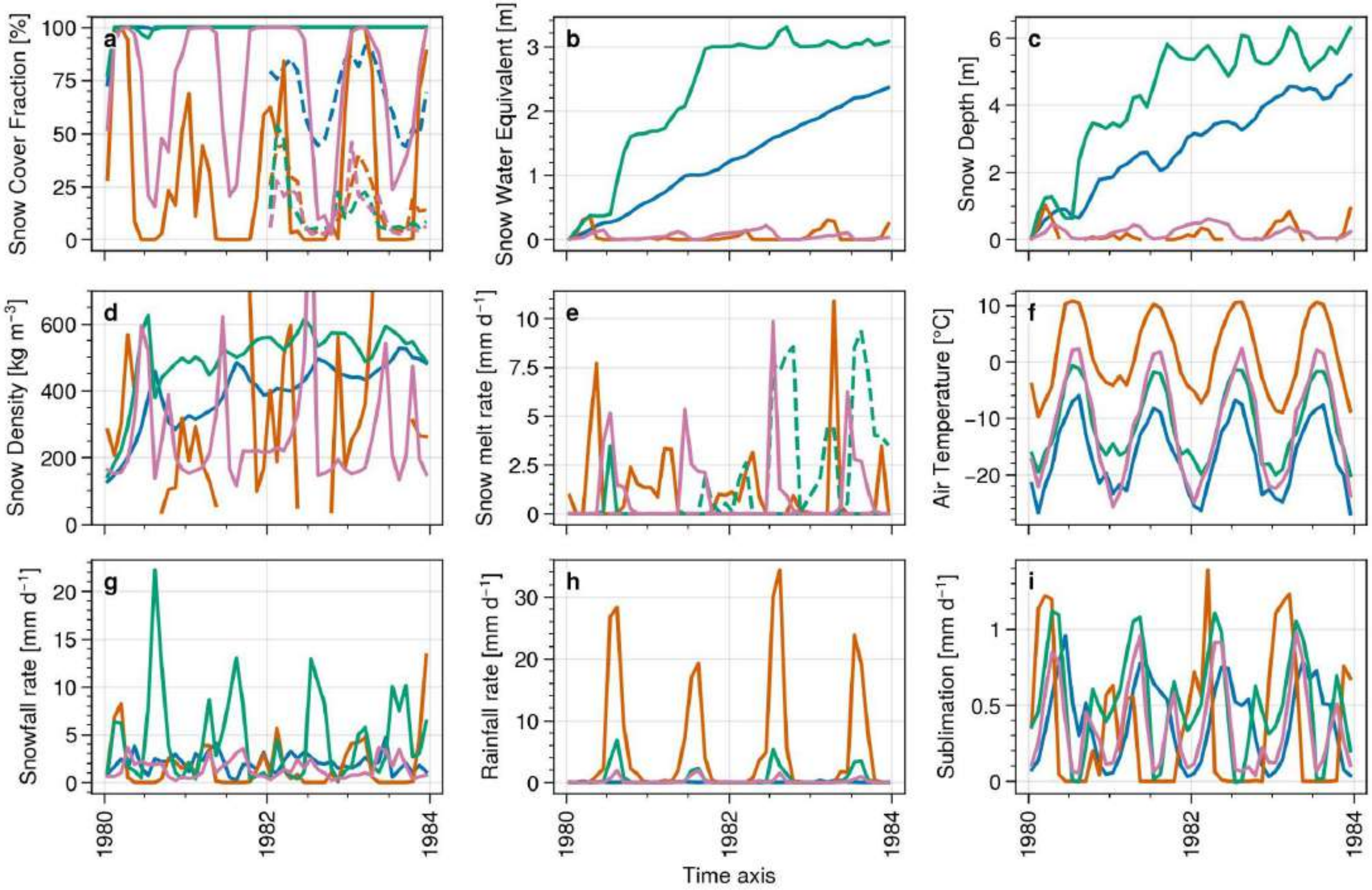
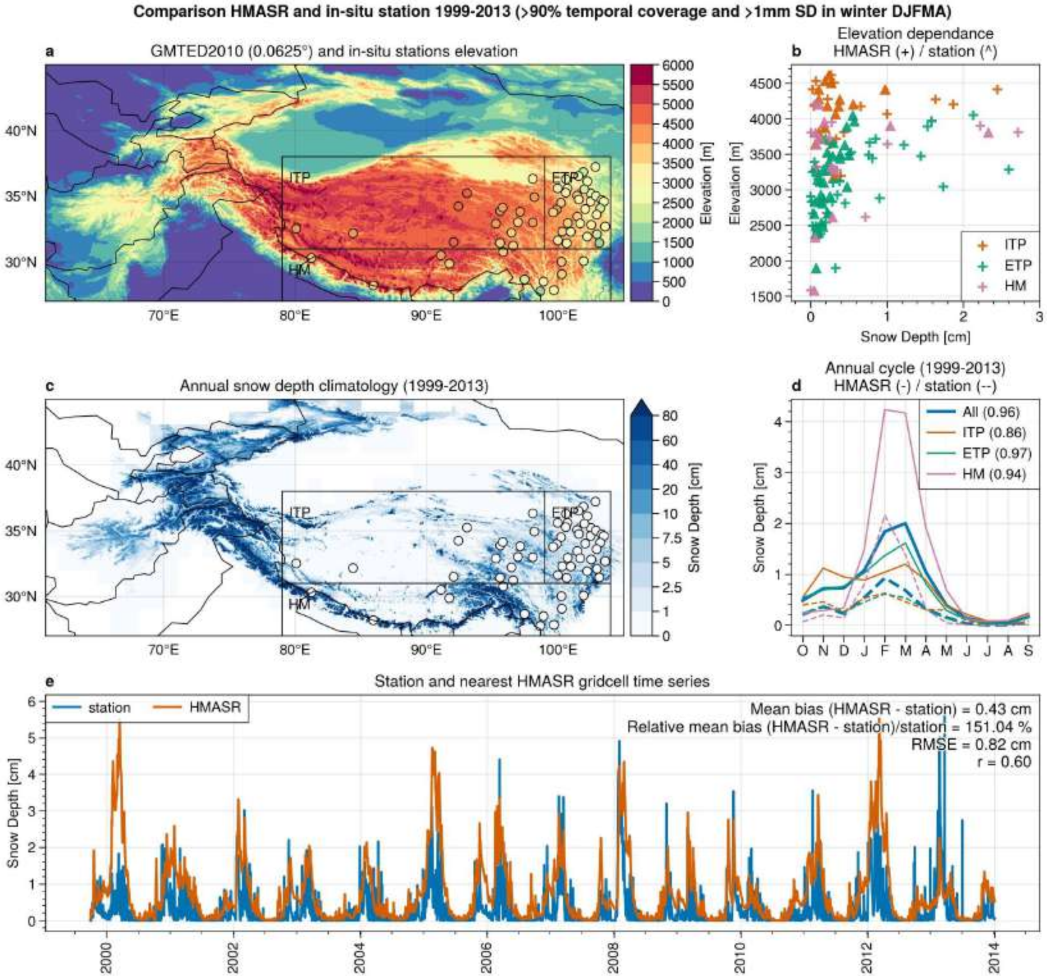


High Mountain Asia UCLA Daily Snow Reanalysis (HMASR)



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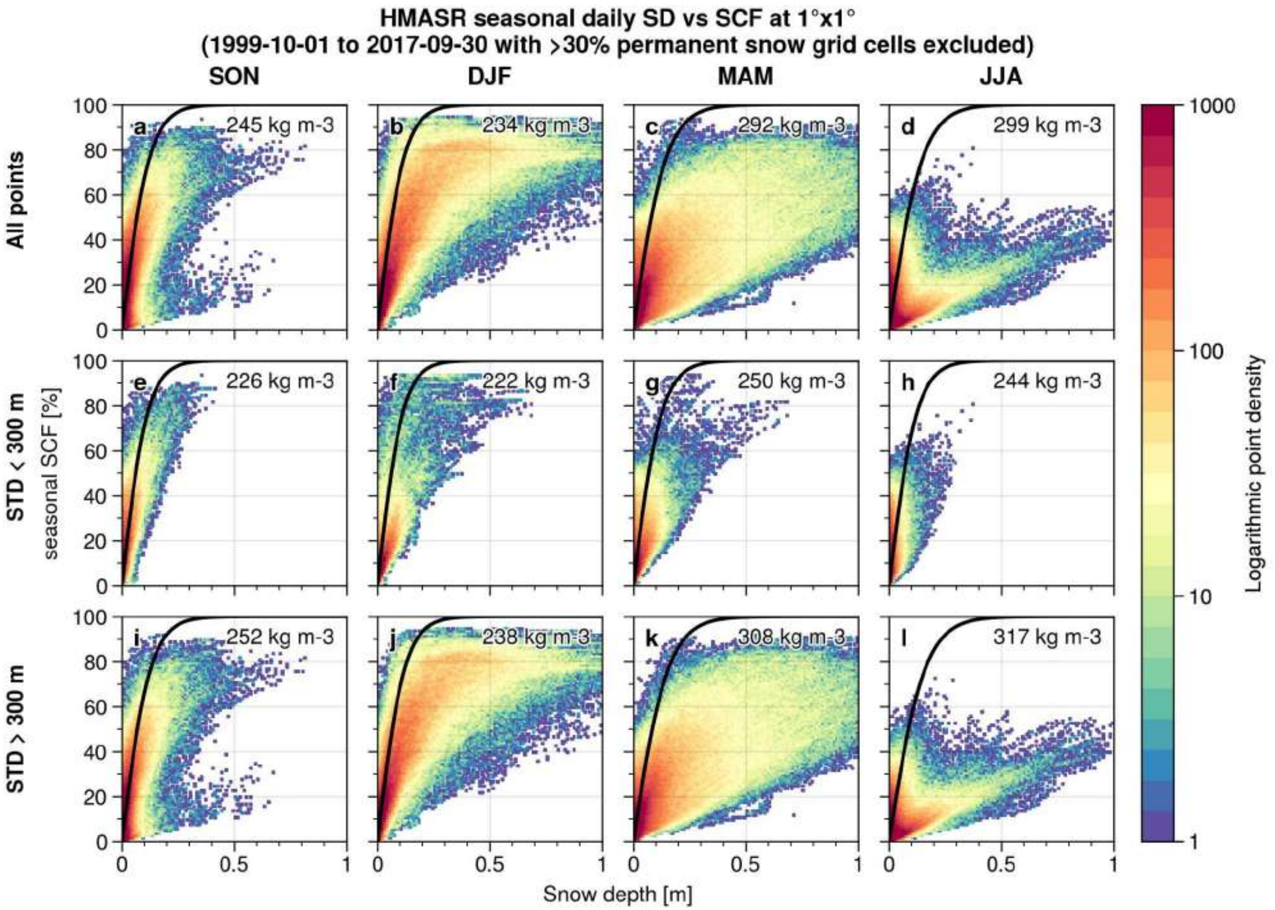
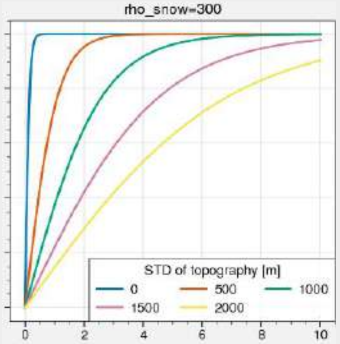


Other snow cover parameterizations

Niu and Yang (2007) custom

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

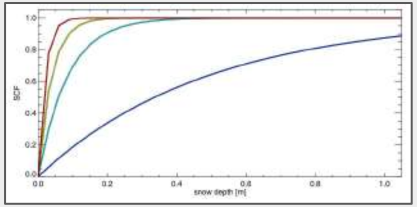
STD topo



Swenson and Lawrence (2012)

Accumulation

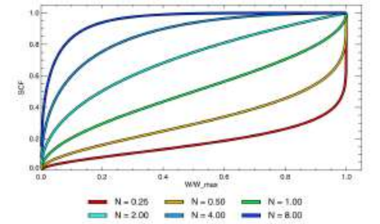
$$F_{N+1} = 1 - (p_{N+1})(p_N) = 1 - (1 - s_{N+1})(1 - F_N)$$



Depletion

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

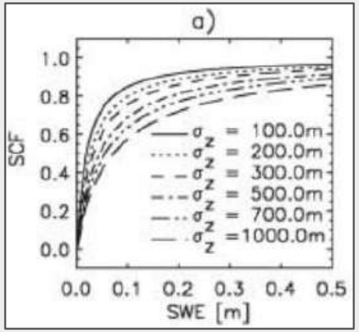
$$N_{melt} = \frac{200}{\sigma_{topo}}$$



Roesch et al. (2001)

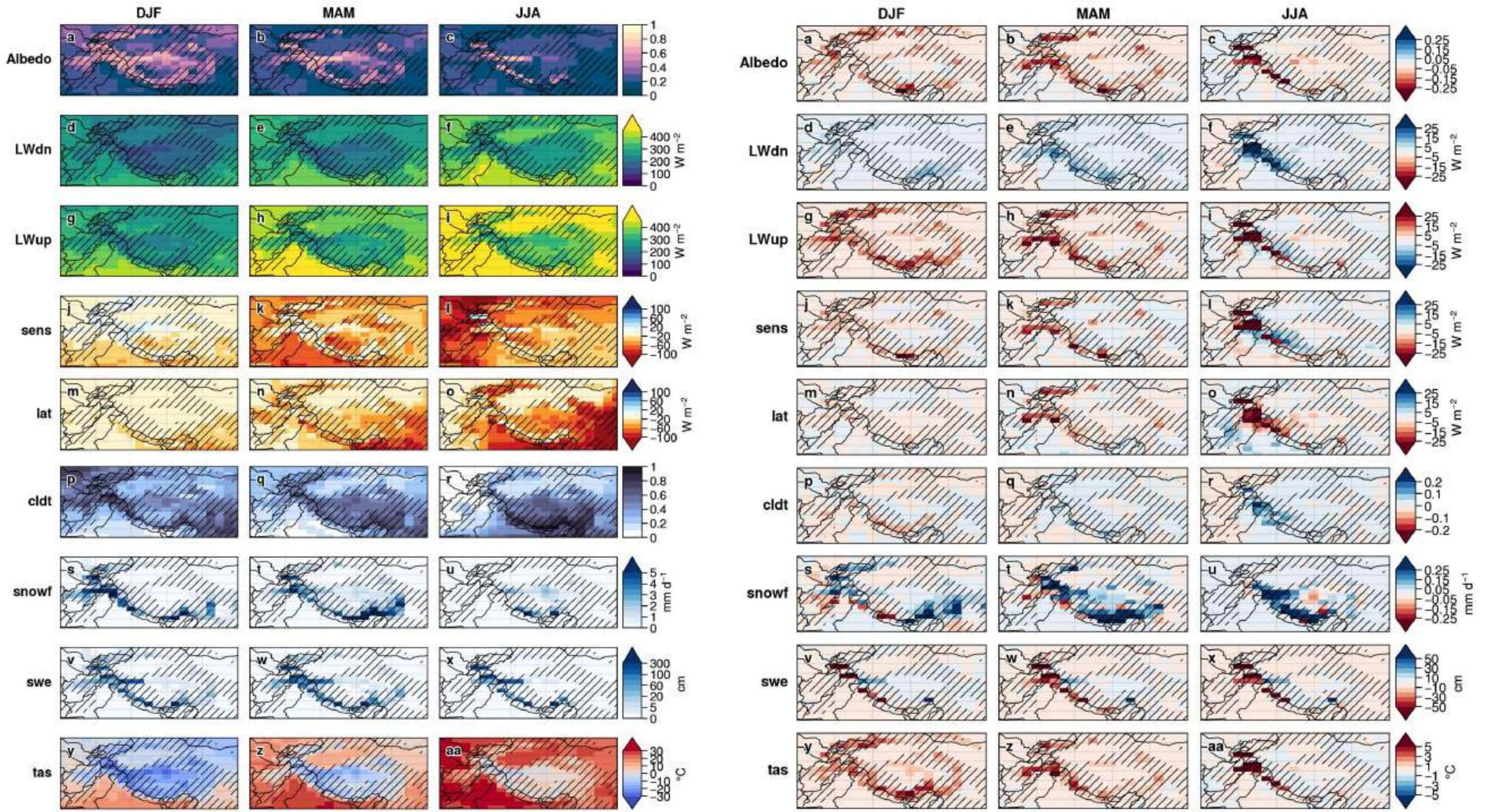
Mountainous areas

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

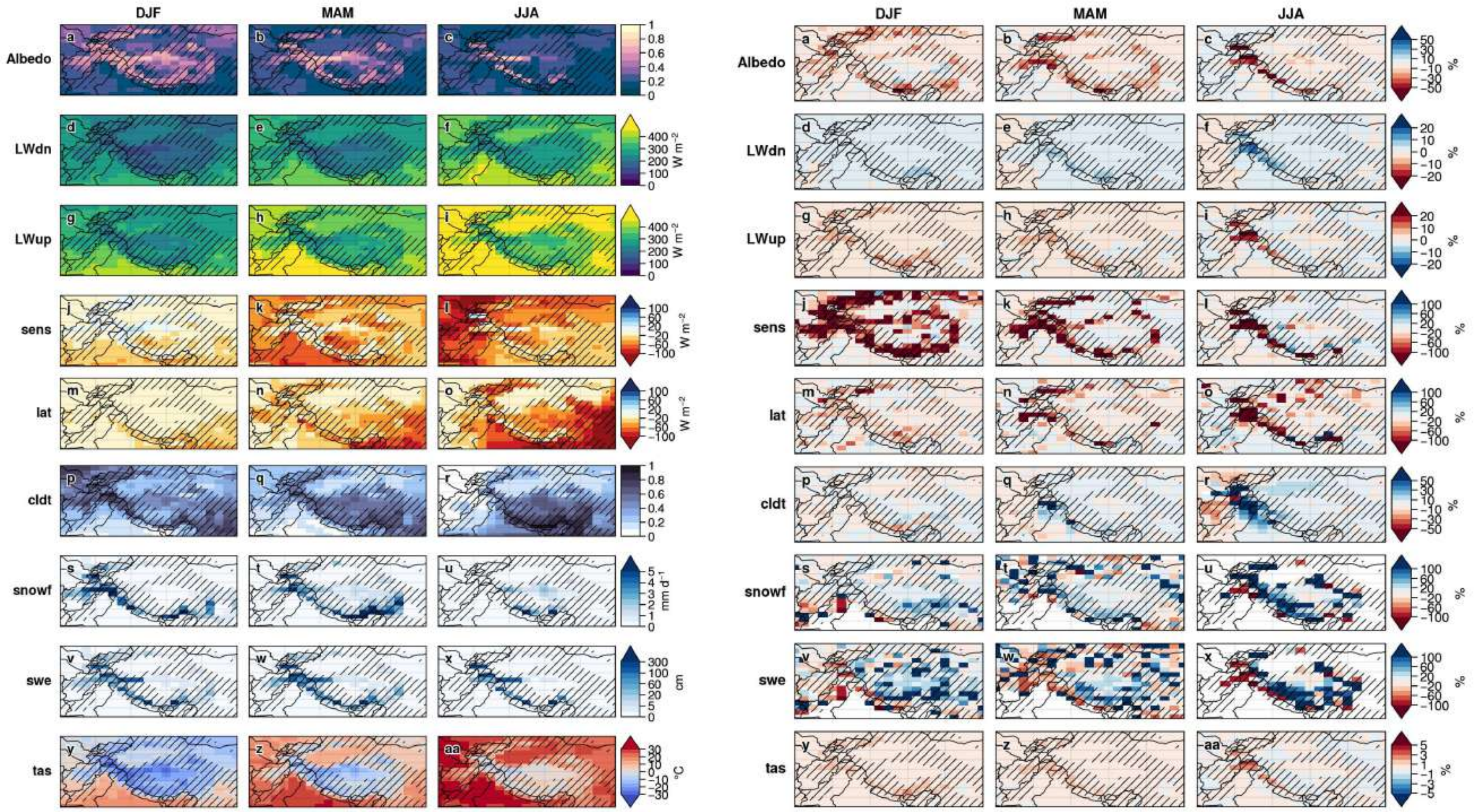


Depends only on SWE so no hysteresis

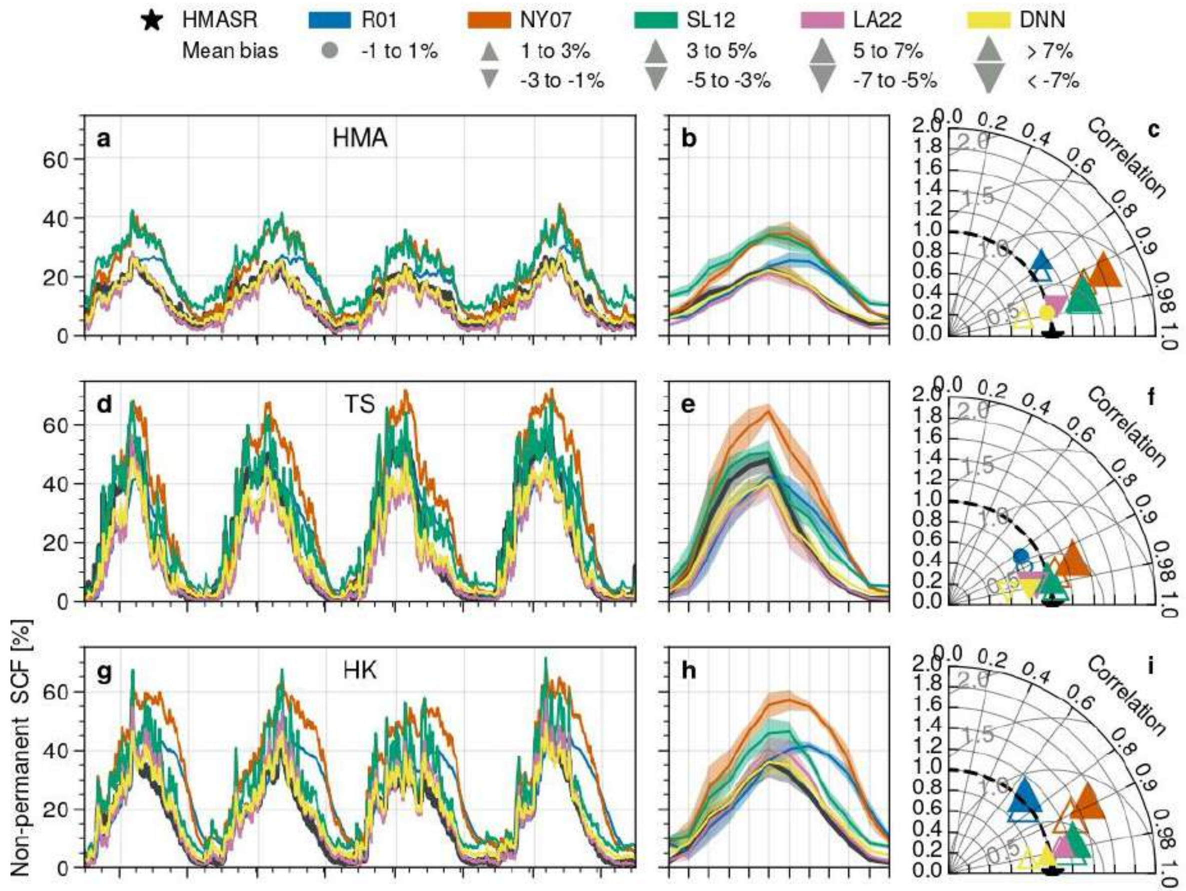
Feedbacks (LA23 - NY07)



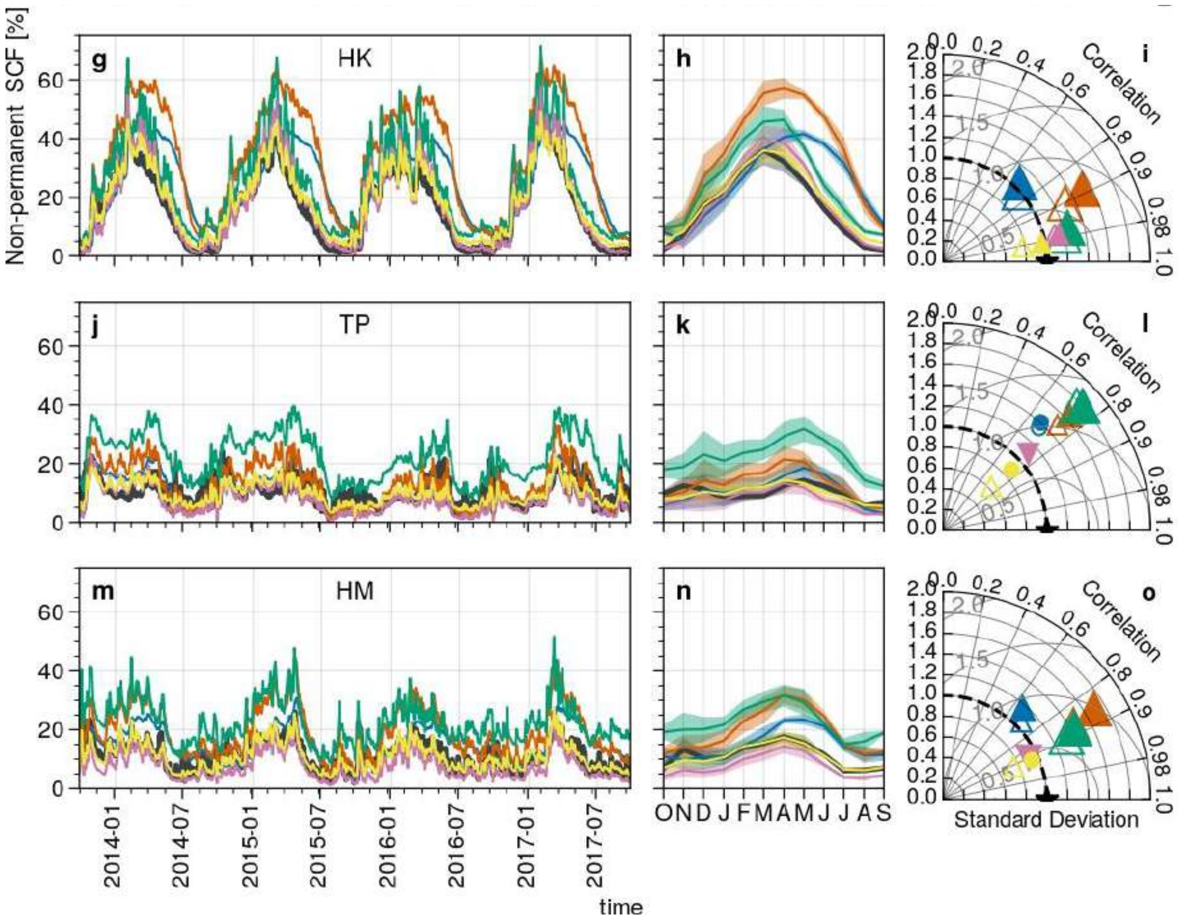
Feedbacks (LA23 - NY07)/NY07



Time series


HMASR
R01
NY07
SL12
LA22
DNN
Mean bias
-1 to 1%
1 to 3%
-3 to -1%
3 to 5%
-5 to -3%
5 to 7%
-7 to -5%
> 7%
< -7%
a
HMA
b
c
Correlation
d
TS
e
f
g
HK
h
i
Non-permanent SCF [%]

Time series



Non-permanent SCF [%]
g
HK
h
i
Correlation
j
TP
k
l
m
HM
n
o
Standard Deviation
2014-01
2014-07
2015-01
2015-07
2016-01
2016-07
2017-01
2017-07
time
O N D J F M A M J J A S