Modélisation de la variabilité climatique et de ses liens avec la cryosphère dans les Hautes Montagnes d'Asie

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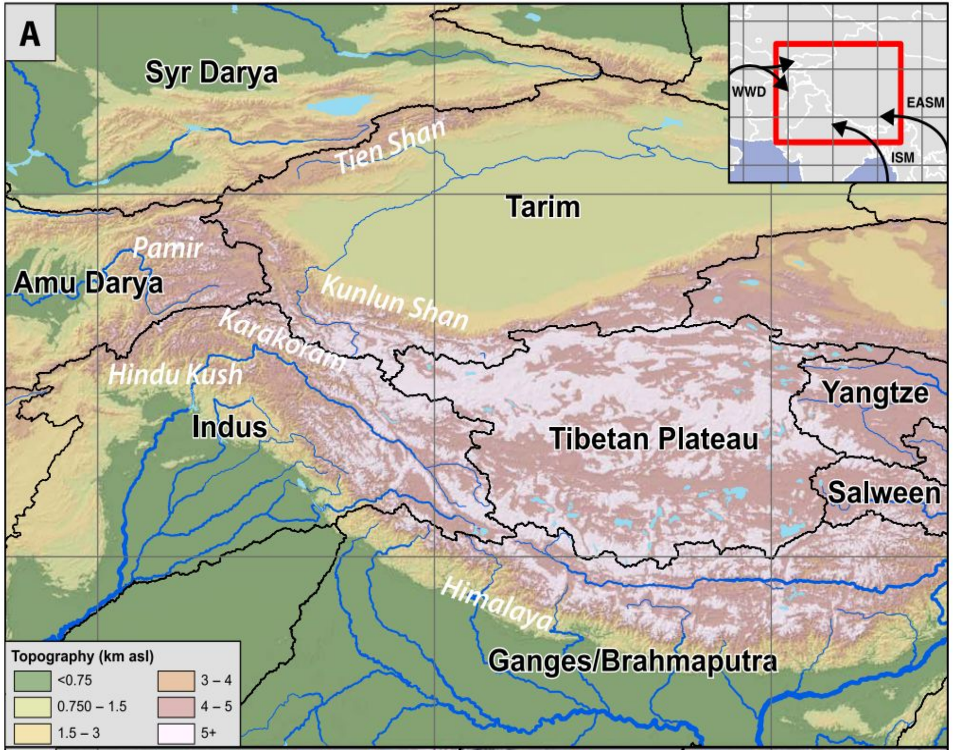
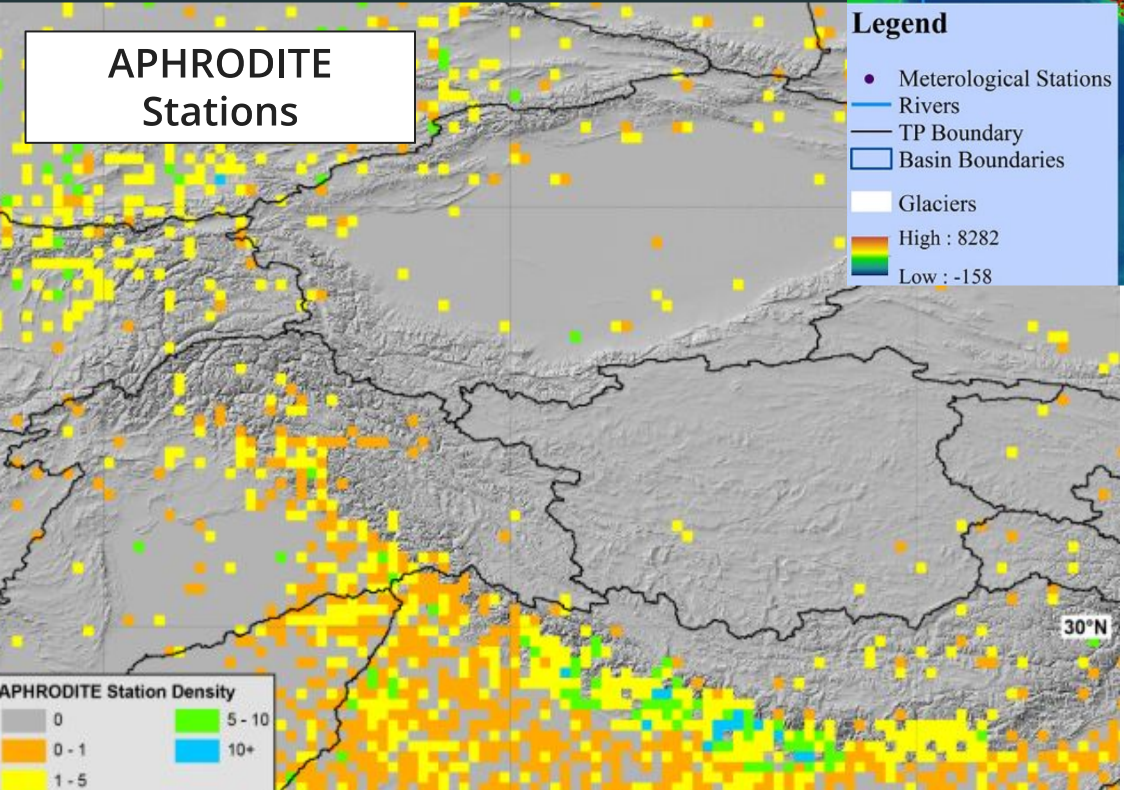
High Mountain Asia (HMA): Introduction

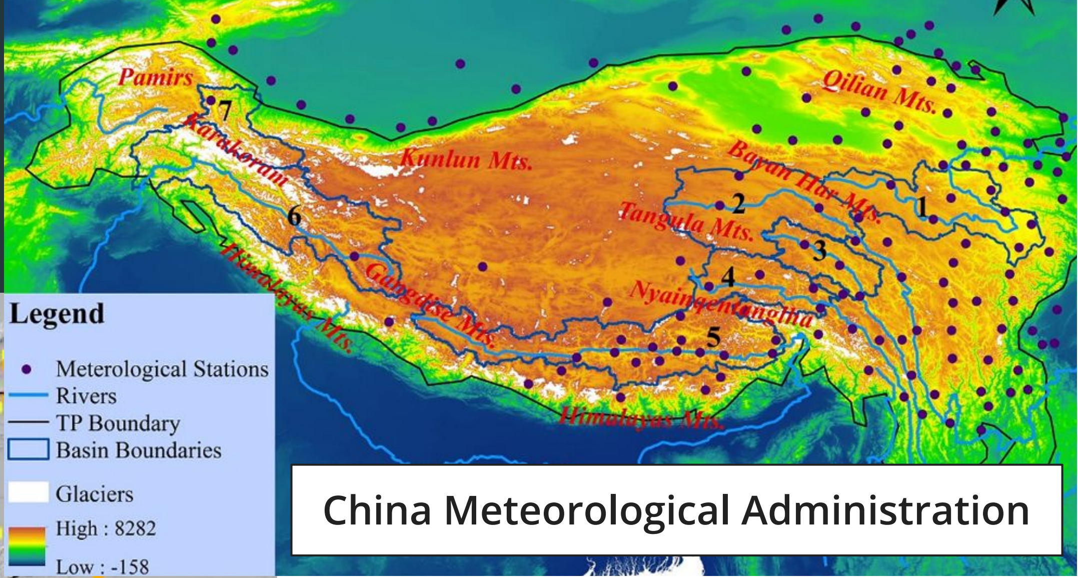
- The Tibetan Plateau (TP) region is the world's highest plateau (average elevation 4000m) ➝ considerable influence on regional and global climate. (Orsolini et al., 2019)
- Directly sustain the livelihoods of 240 million people in the mountain and hills of the Hindu Kush Himalaya. (Sharma et al., 2019)
- Two distinct climatic regimes:
  - winter westerly disturbances ➝ 50 % of the precipitation over the western Himalaya and Hindu Kush mountains
  - central and eastern Himalayan mountains receiving major part (up to 80%) of annual precipitation during the Indian summer monsoon months (June-September). (Bookhagen and Burbank, 2010)



Smith and Bookhagen (2018), Fig. 1A

High Mountain Asia (HMA): station observations





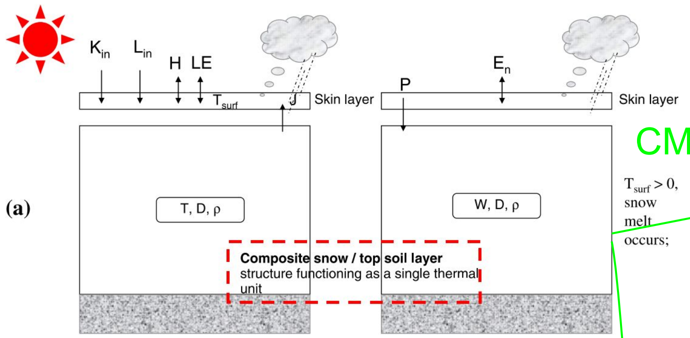
Li et al. (2018), Fig. 1

- Illustrates the low station density in the core of HMA (Tibetan Plateau)
- The highest elevations are severely under-represented
- Almost exclusively measure rainfall (there exist very few snow monitoring stations in HMA)

Smith and Bookhagen (2018), Fig. S1

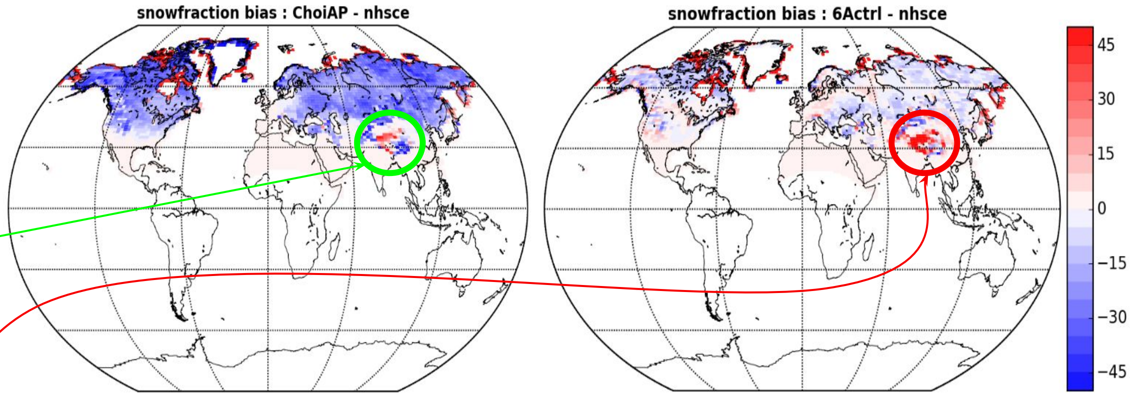
Snow bias in IPSL model CMIP5 versus CMIP6

WANG ET AL.: ORCHIDEE SNOW MODEL EVALUATION



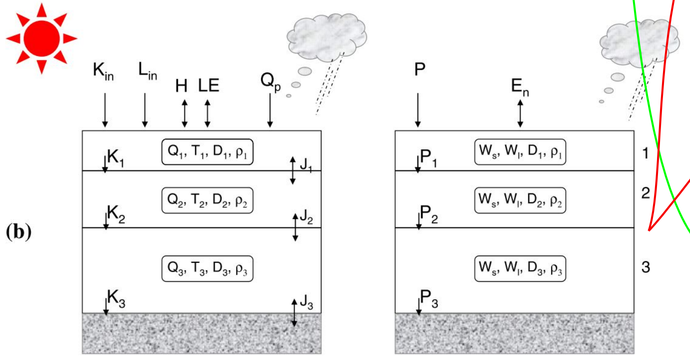
K_{in} (short wave radiation), **L_{in}** (longwave radiation), **H** (sensible heat flux), **LE**(latent heat flux), **J** (conduction heat flux), **W** (SWE), **D** (snow depth), **ρ** (fixed snow density 330) , **P** (precipitation), **E_n** (evaporation), **T**(snow temperature), **Tsurf**(skin layer temperature)

CMIP5



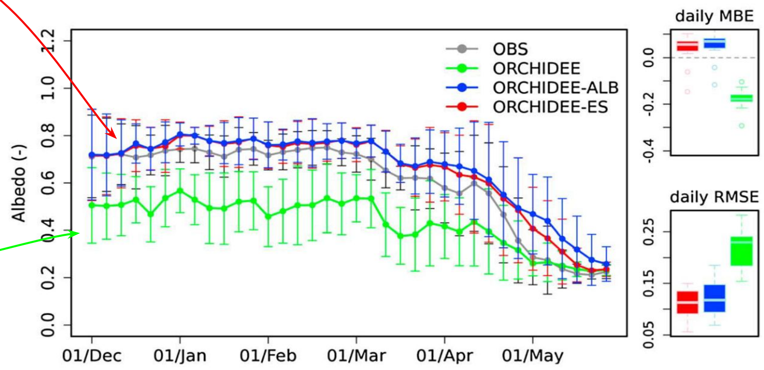
Cheruy et al. (submitted), Fig. 6

CMIP6



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)

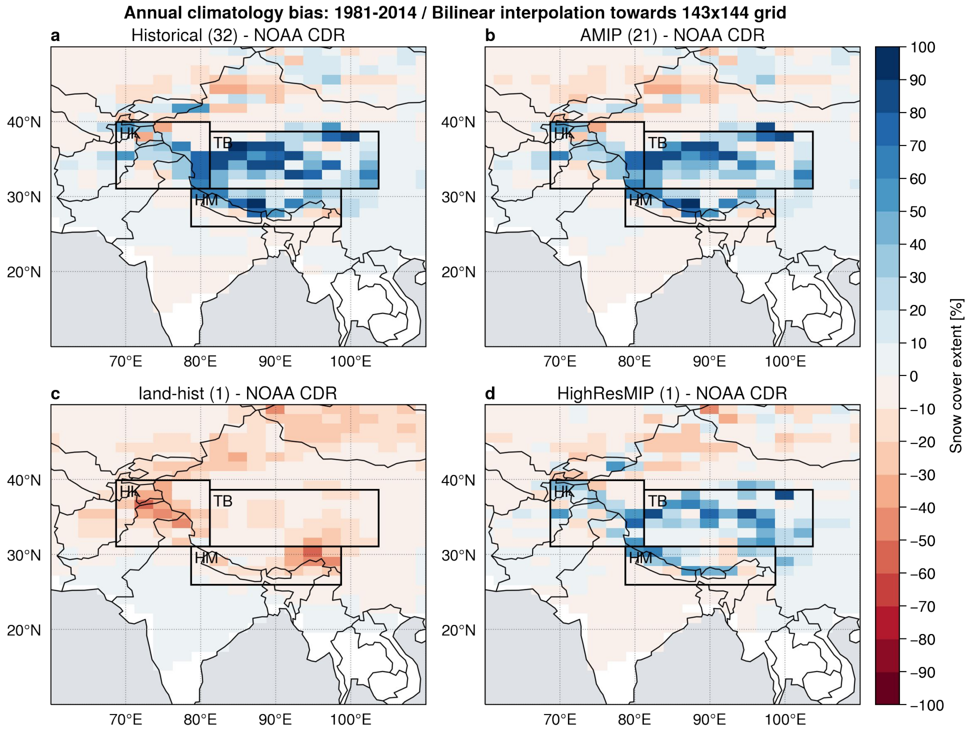
Wang et al. (2013), Fig. 1



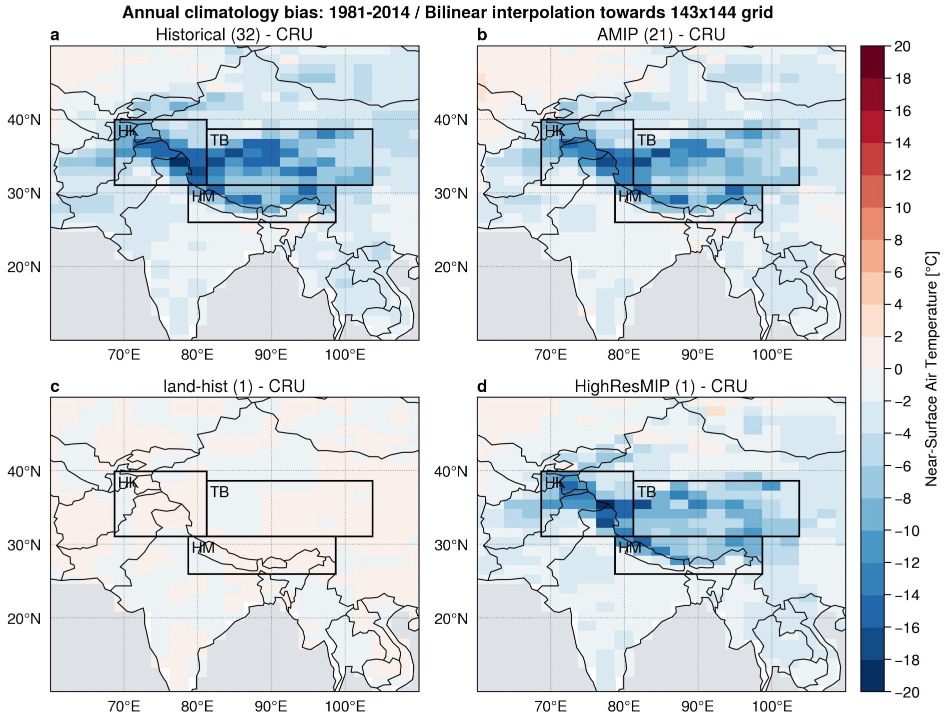
Wang et al. (2013), Fig. 5

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

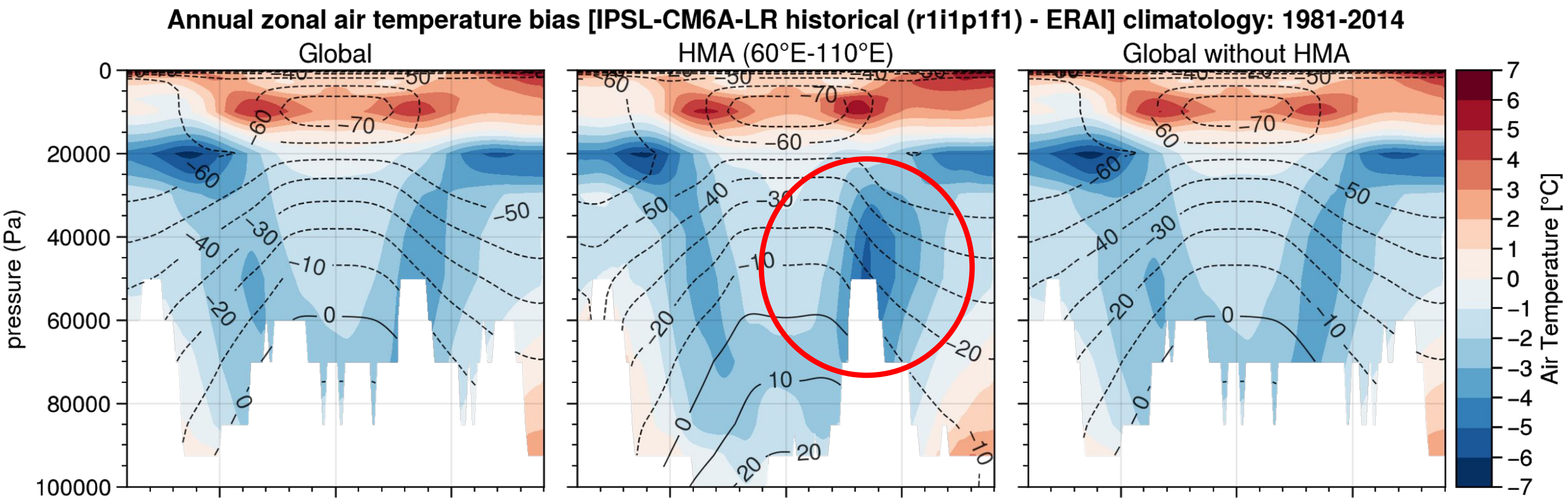
Snow cover bias



Temperature bias



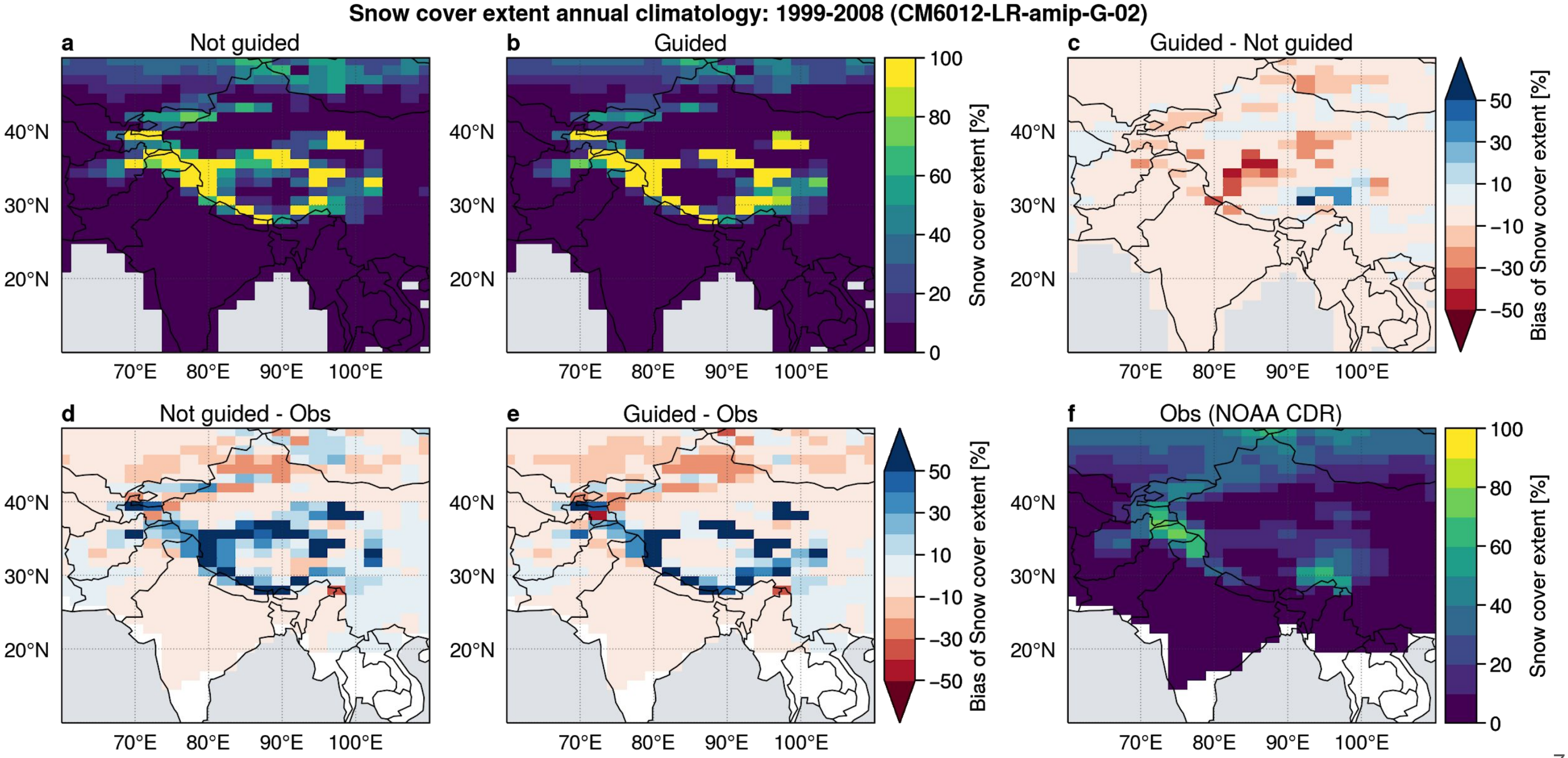
Air Temperature zonal means bias global versus HMA



- 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

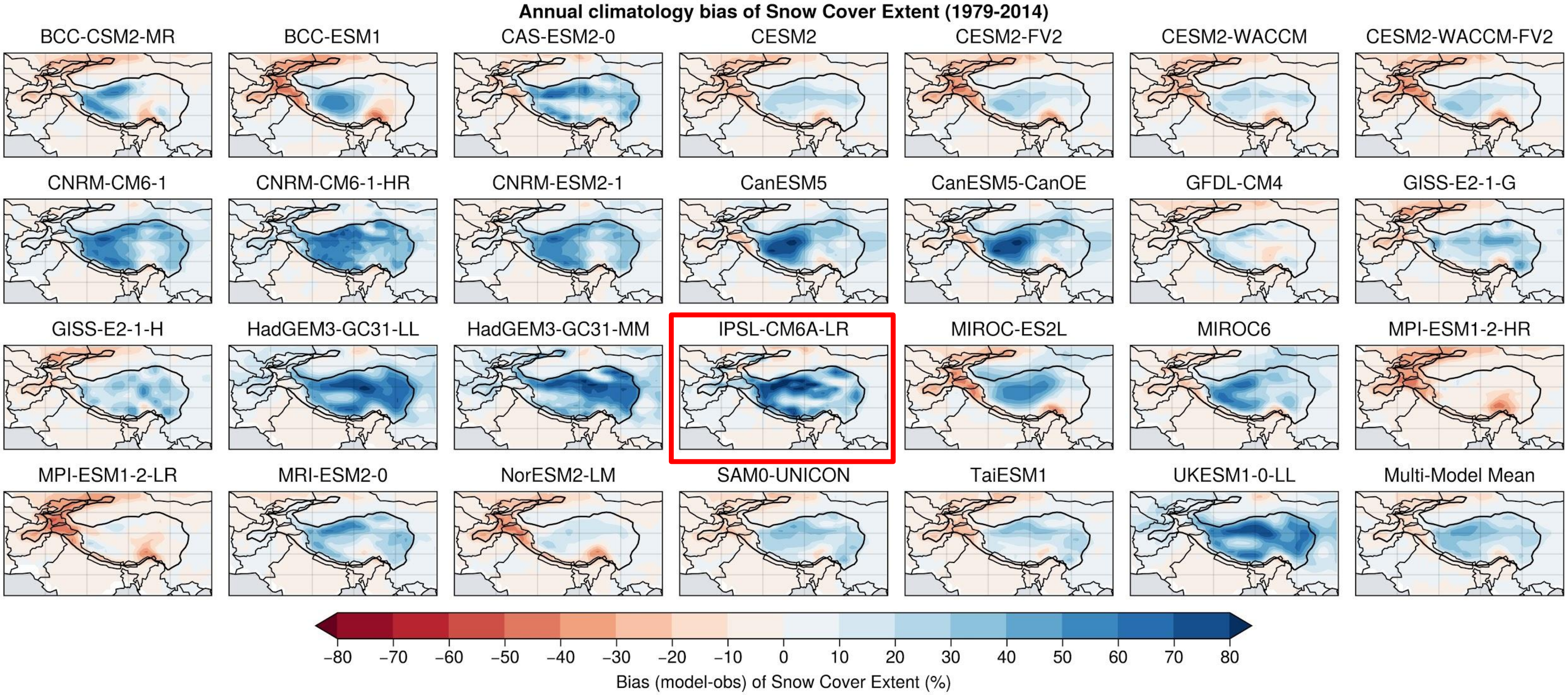
Adapted from from Boucher et al., Fig. 3 (submitted)

Nudged versus not nudged: snow cover*

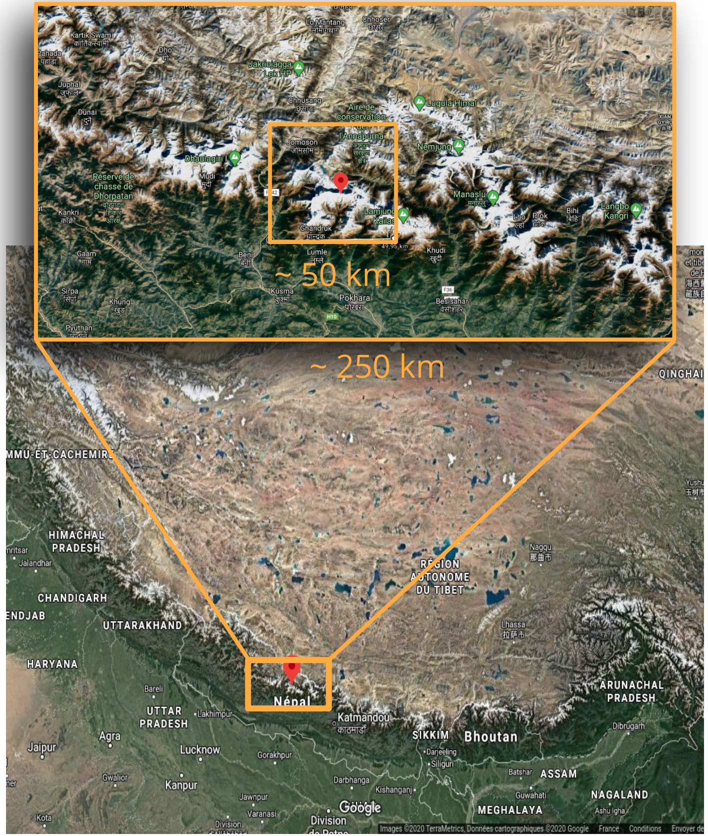


* Simulation: Frédérique Cheruy

CMIP6 other models: snow cover bias



SCF parameterization



Swenson and Lawrence (2012)

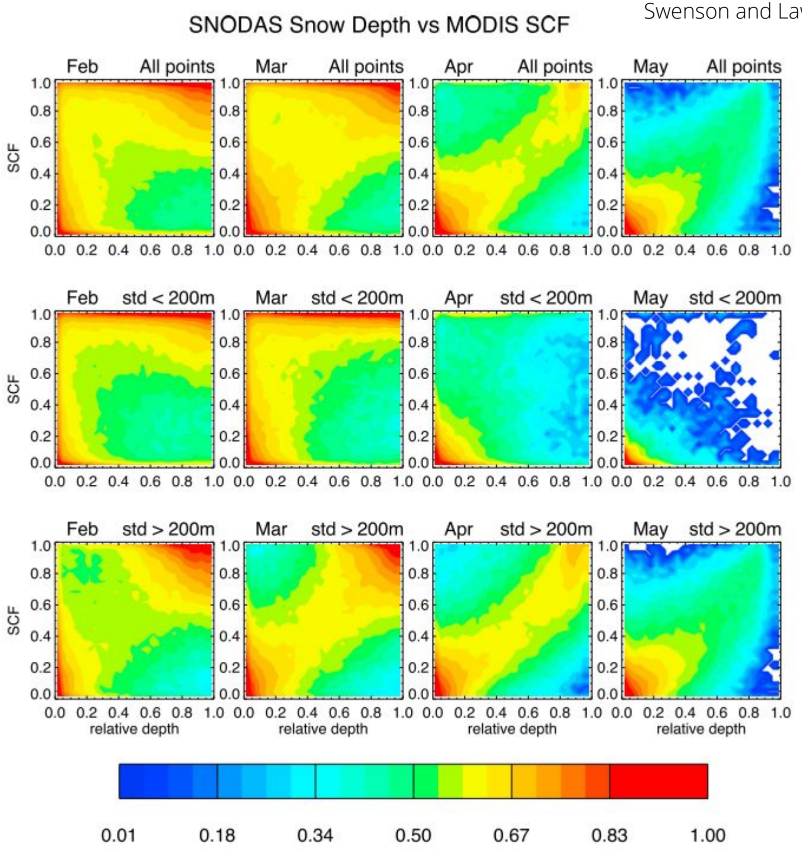


Figure 8. Histograms of relative depth and SCF based on SNODAS snow depth data and MODIS SCF data. Contours represent logarithm of number of points. (top) Histograms based on all points. (middle) Histogram based on points having low topographic variability ($\sigma \leq 200$ m). (bottom) Histogram based on points having high topographic variability ($\sigma \geq 200$ m).

SCF parameterization: preliminary results

- Niu and Yang (2007)
-> actual version in
Orchidée (reference)

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

- Niu and Yang (2007)
modified

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

σtopo

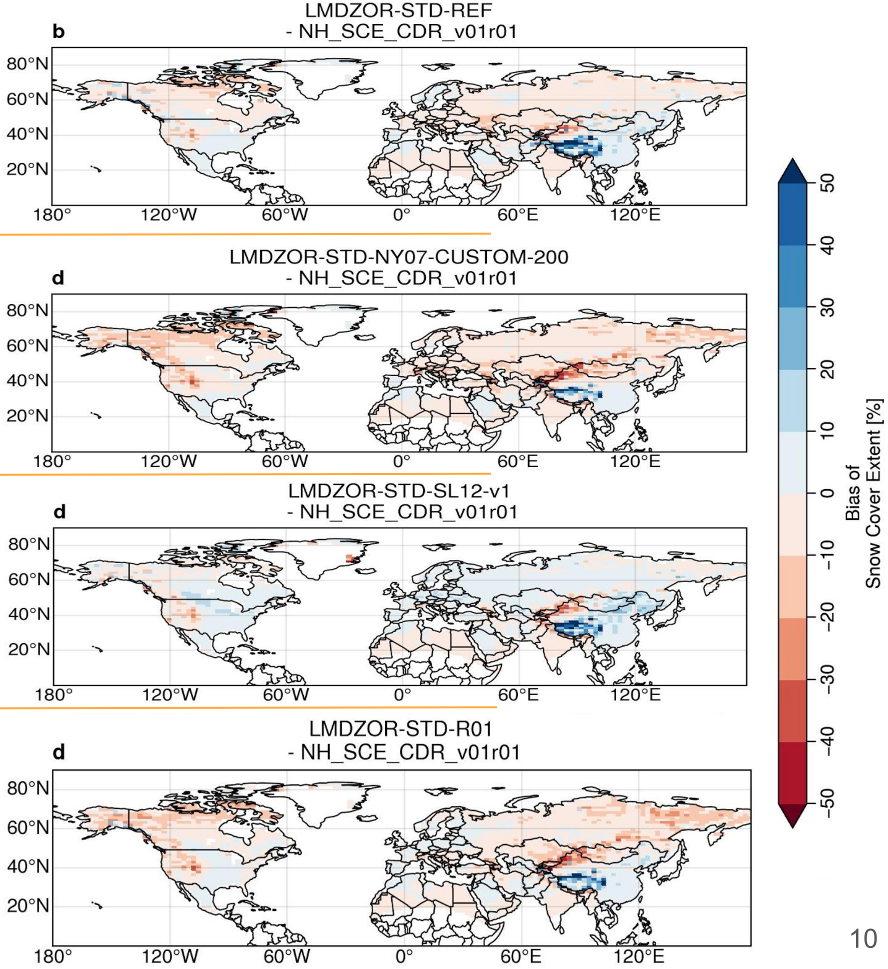
- Swenson and
Lawrence (2012)

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

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

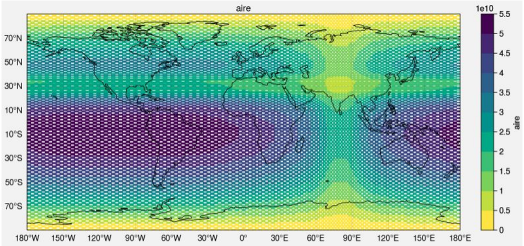
- Roesch et al. (2001)

$$f_s = 0.95 \cdot tanh(100 \cdot S_n)\sqrt{\frac{1000 \cdot S_n}{1000 \cdot S_n + \epsilon + 0.1\boxed{5\sigma_z}}}$$



La suite...

- Tuner les paramétrisation sous-maille + ajouter d’autres variables ? (ex : isotherme 0°C)
- Papier multimodèle (CMIP6) en incluant les projections
- Simulation zoomée (voire guidée) pour une validation avec les observations GLACIOCLIM et envisager des simulations longues (1850-2100)



Exemple de grille zoomée

- Etudier les expériences DAMIP déjà a disposition pour étudier l’impact des forçages
- Appliquer la méthode des analogues décrite dans Deser et al. (2016) afin de détecter des changements dans la région des HMA et de les attribuer à des changements dynamiques ou thermodynamiques de l’atmosphère

Objectif final : essayer de détecter les changements futur en HMA et les attribuer à des changements dynamique / thermodynamique et/ou aux changements anthropiques (CO2, aérosols, etc.)

Conclusions

- Larger **snow cover bias** in CMIP6 IPSL GCM than CMIP5 over **HMA**
- land-hist: no bias / AMIP: bias -> **coupled with the atmosphere**
- Possible link with the **cold bias in the troposphere**
- Bias reduced with nudge / higher resolution / dynamico
- Other possible source of the bias:
  - precipitation, albedo, cloud cover, aerosols, boundary layer, surface energy budget

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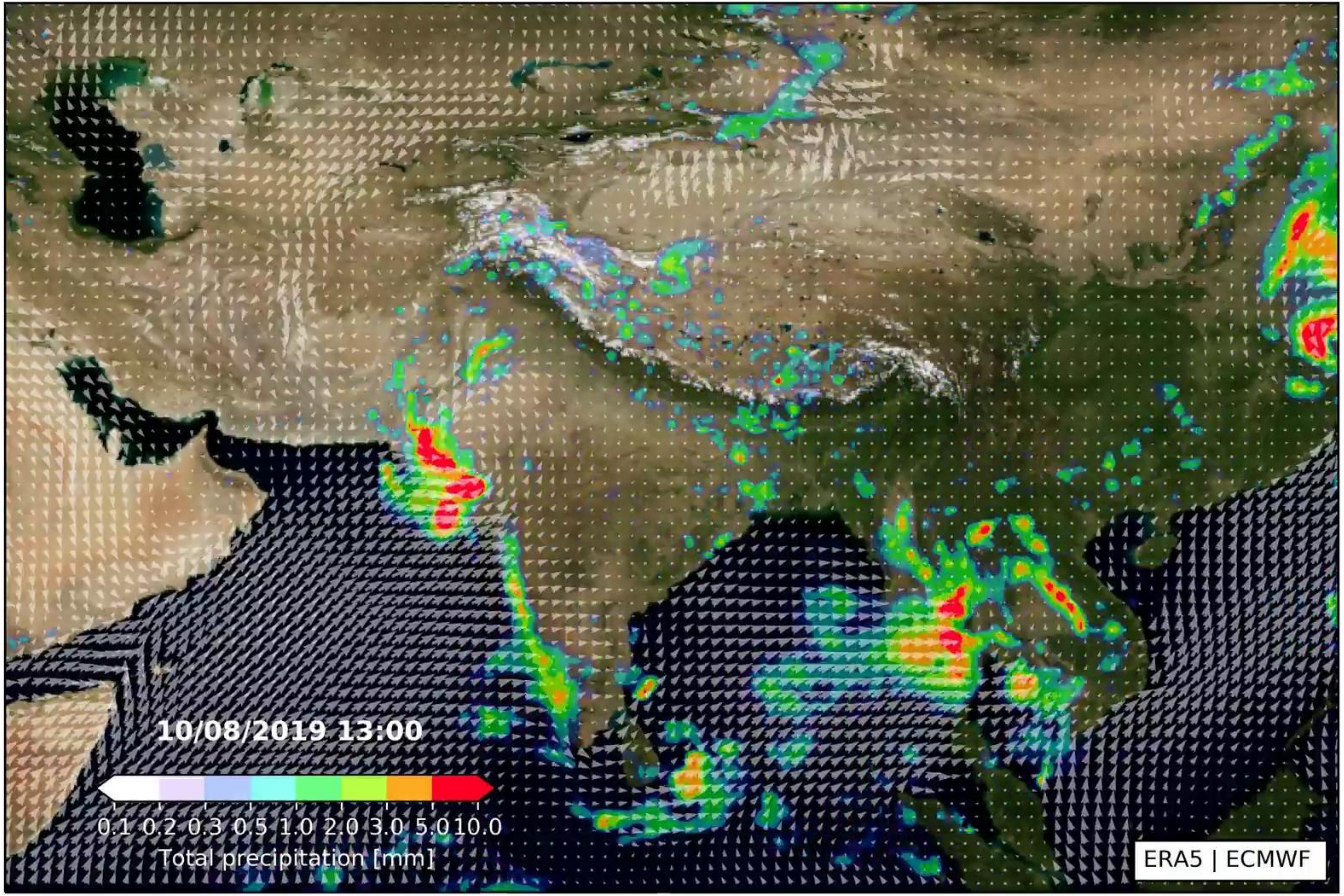
- MC-Toolkit: exchange about numerical tools!

Conclusions



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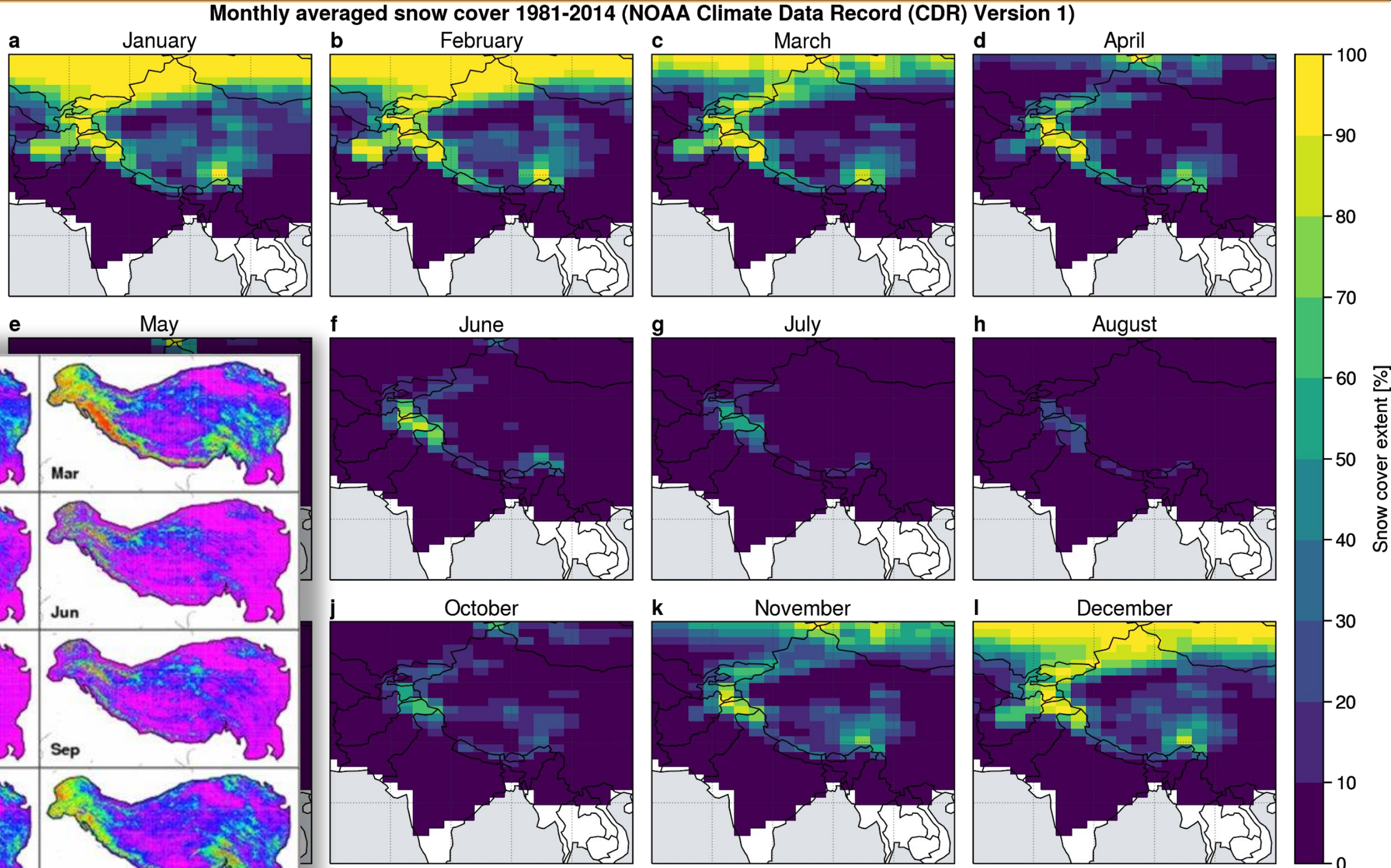
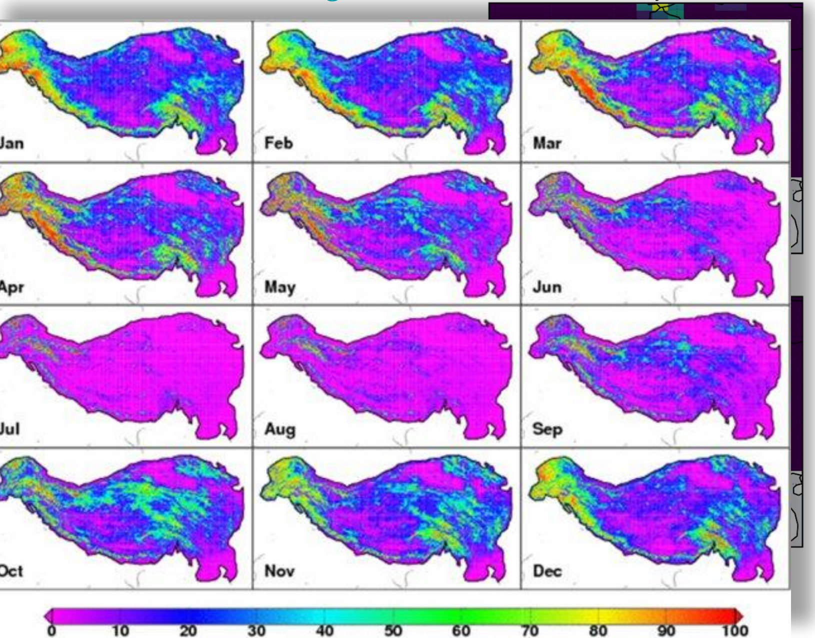
Monthly snow cover climatologies (from satellite observations)

[NOAA Climate Data Record (CDR) of Northern Hemisphere (NH) Snow Cover Extent (SCE), Version 1](#) (1981-2014)

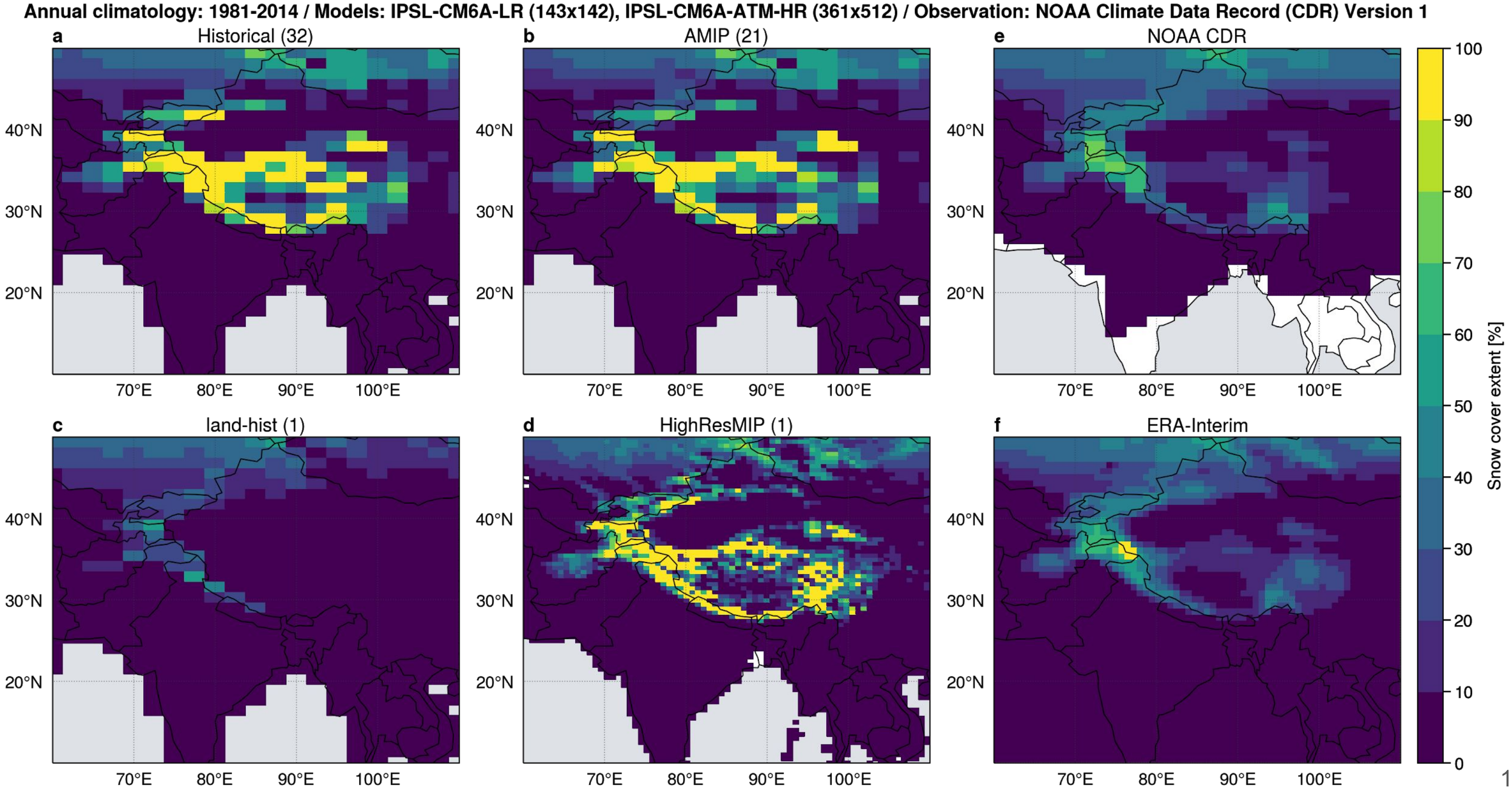
[MODIS/Terra Snow Cover 8-Day L3 Global 0.05Deg CMG, Version 6](#) (2001-2014)

Li et al. ([2018](#)), [Fig. 2](#)

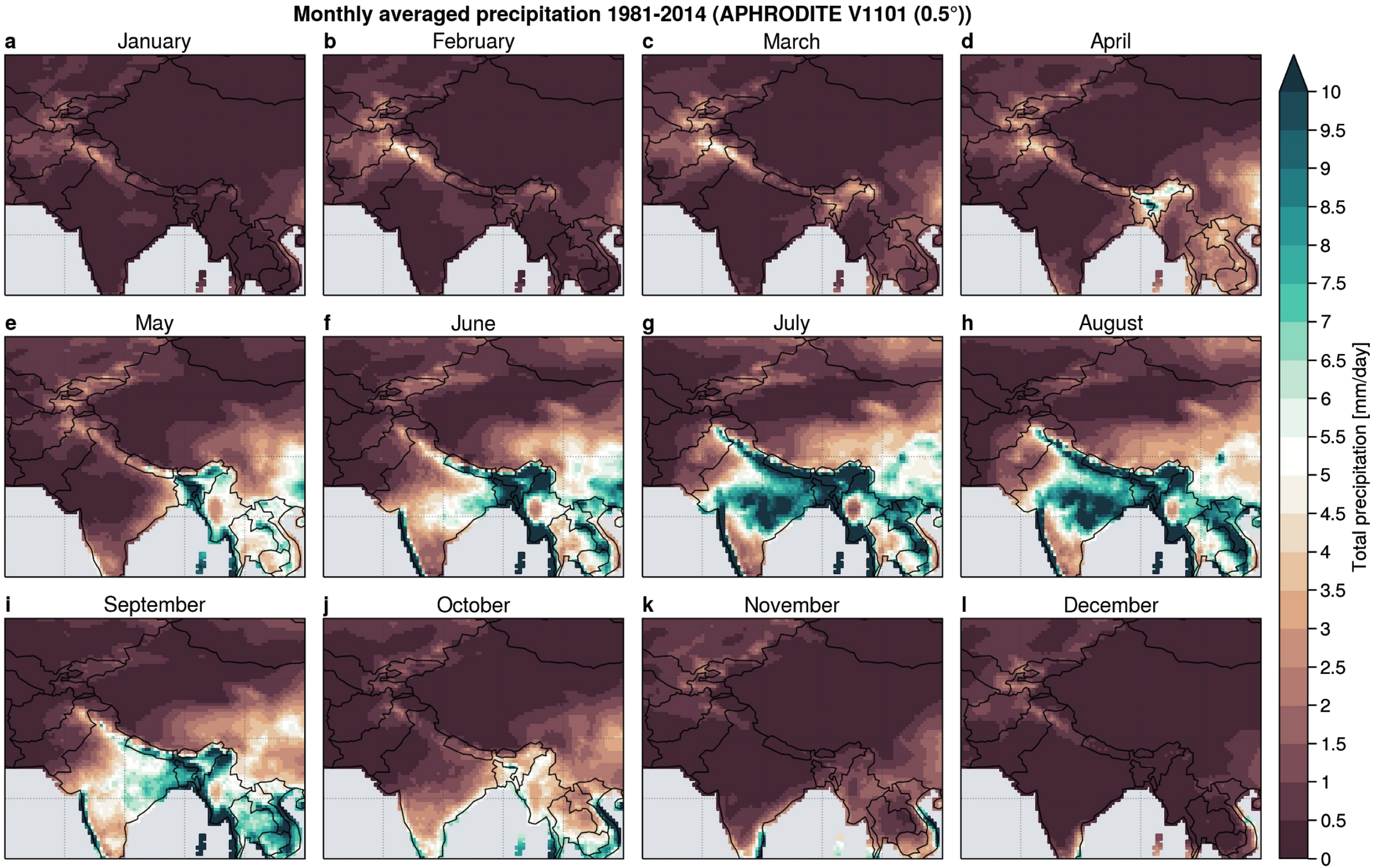




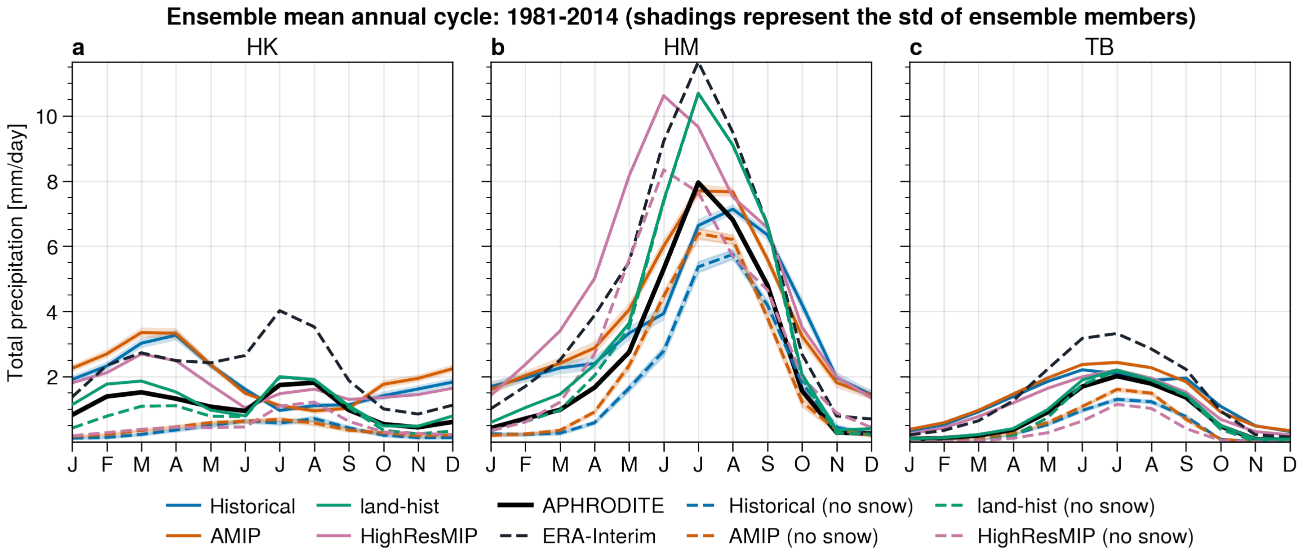
Snow cover climatology (1981-20014)



Precipitation climatologies (APHRODITE)



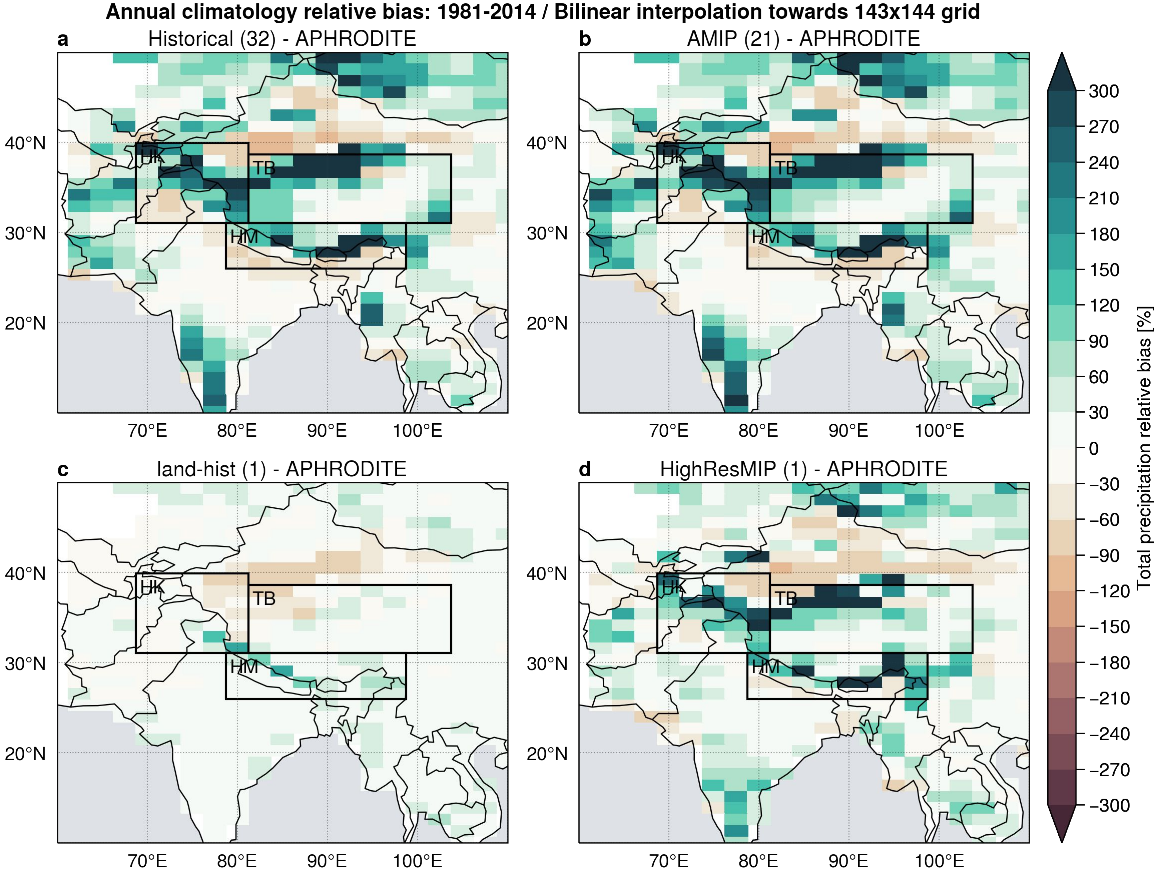
Precipitation: annual cycles



*"**ERA-Interim strongly overestimates precipitation** compared to the other data sets, and so does EC-Earth in the HKK domain, probably owing to the fact that both **ERA-Interim and EC-Earth provide total precipitation while the in situ station and satellite data, as well as their combinations, have difficulties in detecting the snow component of precipitation**. The analysis of liquid-only precipitation in ERA-Interim and EC-Earth generally gives results closer to the observations."*

(Palazzi et al., 2013)

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



Total precipitation **relative** bias

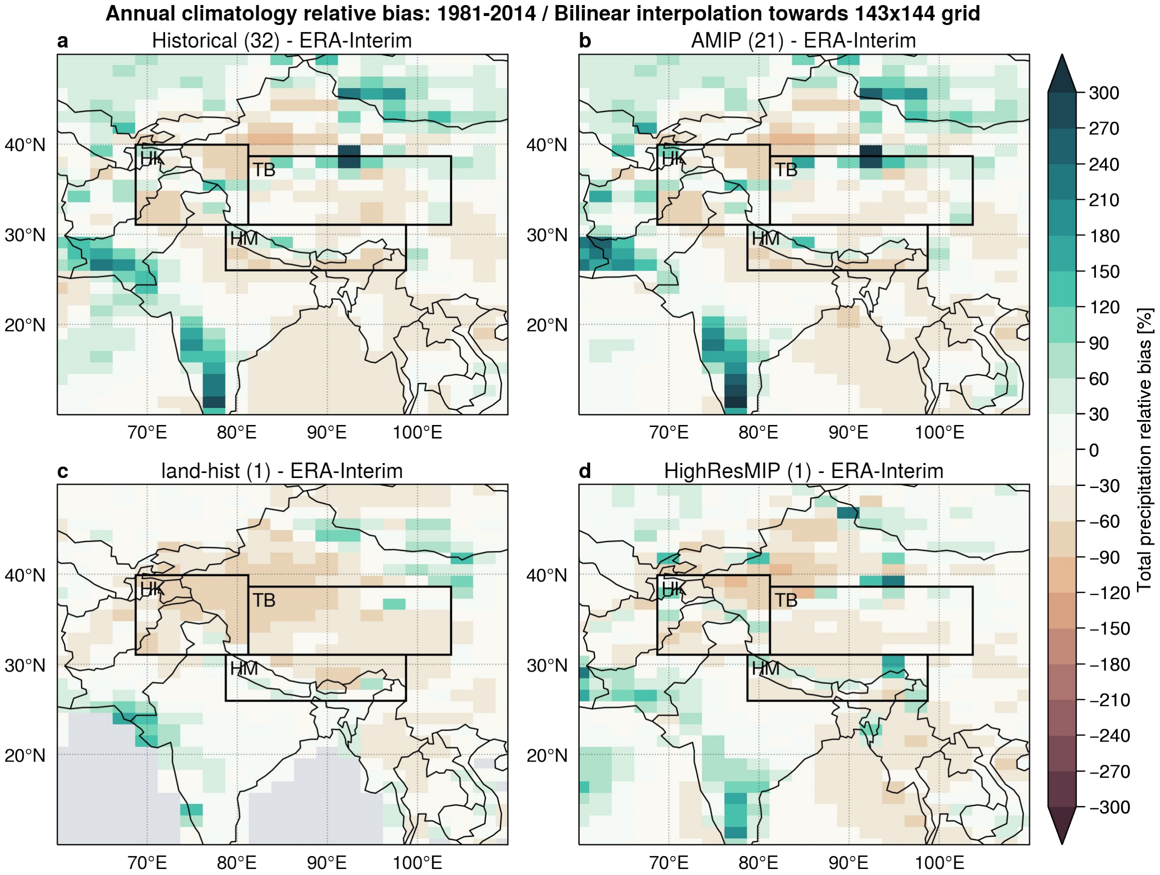
(versus stations observations)

BUT… (see ERAI)

All in situ stations and satellite data tends to underestimate the snow component!

- The in situ station and satellite data, as well as their combinations, have difficulties in detecting the snow component of precipitation. (Palazzi et al., 2013)
- An independent validation with observed river flow confirms that the water balance can indeed only be closed when the high altitude precipitation on average is more than twice as high and in extreme cases up to a factor of 10 higher than previously thought. (Immerzeel et al., 2015)

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



Total precipitation **relative** bias

(versus reanalysis)

BUT…

"ERA-Interim strongly overestimates precipitation compared to the other data sets, and so does EC-Earth in the HKK domain, probably owing to the fact that both ERA-Interim and EC-Earth provide total precipitation while the in situ station and satellite data, as well as their combinations, have difficulties in detecting the snow component of precipitation. The analysis of liquid-only precipitation in ERA-Interim and EC-Earth generally gives results closer to the observations." (Palazzi et al., 2013)

Back

“Cold bias” over Tibetan Plateau

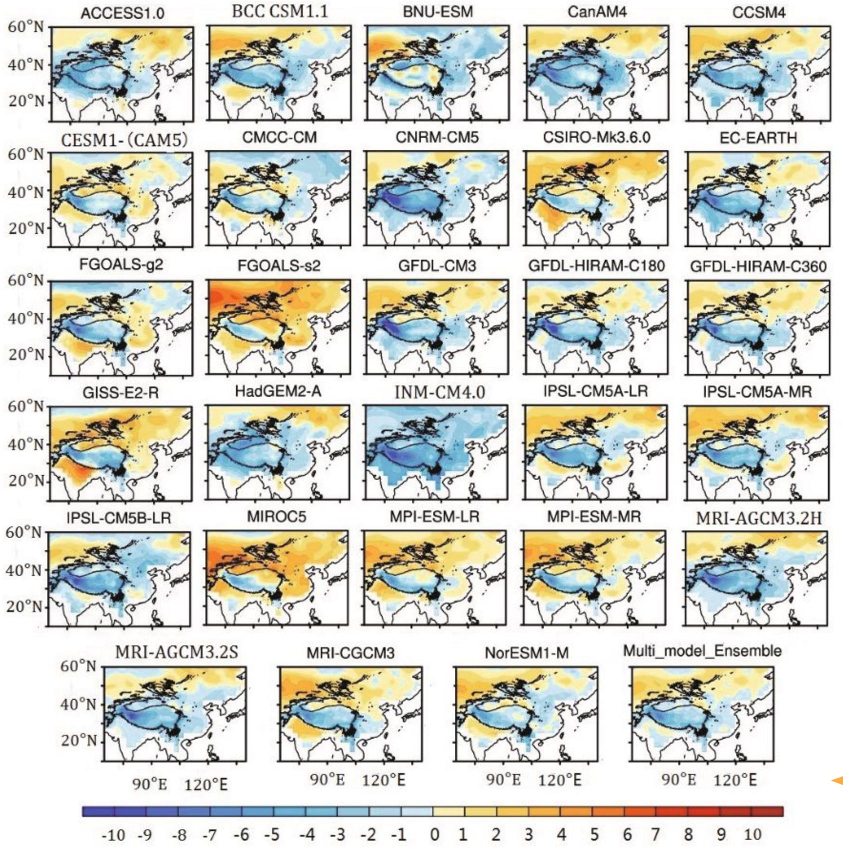


Fig. 2. Annual mean T_{as} (°C) differences between various models and CRU data averaged during 1979–2005. All air temperature values in the models have been corrected to real elevation at a resolution of 2.5° × 2.5°.

- The large cold biases are located in the mountainous areas, such as the Rocky Mountains, the Tibetan Plateau, the Andes, Greenland, and Antarctica, and seem to be proportional to the topographic height. (Mao and Robock, 1998 — First AMIP experiments)
- These cold biases are partly attributable to the simulation of excess precipitation in these regions (Lee & Suh, 2000). The lack of high-elevation observation stations in the CRU data may also be partly responsible for the apparent cold bias of the model (Gu et al., 2012). (Wang et al., 2013 — regional climate model RegCM)
- This feature may imply a common deficiency in the representation of snow–ice albedo in the diverse models. It appears that the systematic bias and the significant problems over the mountain regions (e.g., the Tibetan Plateau) still remain in the CMIP5 models. (Su et al., 2013)
- GCMs show predominant cold biases in T500, which may be caused by penetration of dry and cold air from the deserts of western Asia due to an overly smoothed representation of topography west of the TP (Boos and Hurley, 2013). (Xu et al., 2017 — CMIP5)
- The results suggest that improvements in the parameterization of the area of snow cover, as well as the boundary layer, and hence surface turbulent fluxes, may help to reduce the cold bias over the TP in the models. (Chen et al., 2017 — surface energy budget CMIP5)
- Others: Salunke et al. (2019)., etc.

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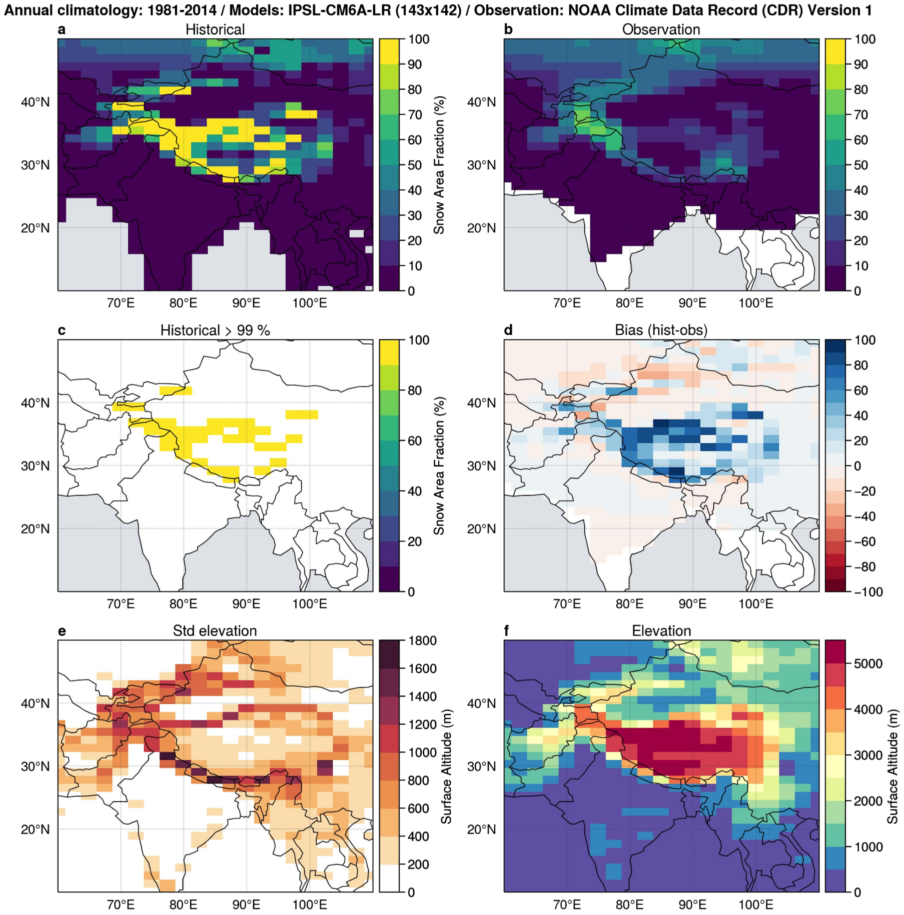
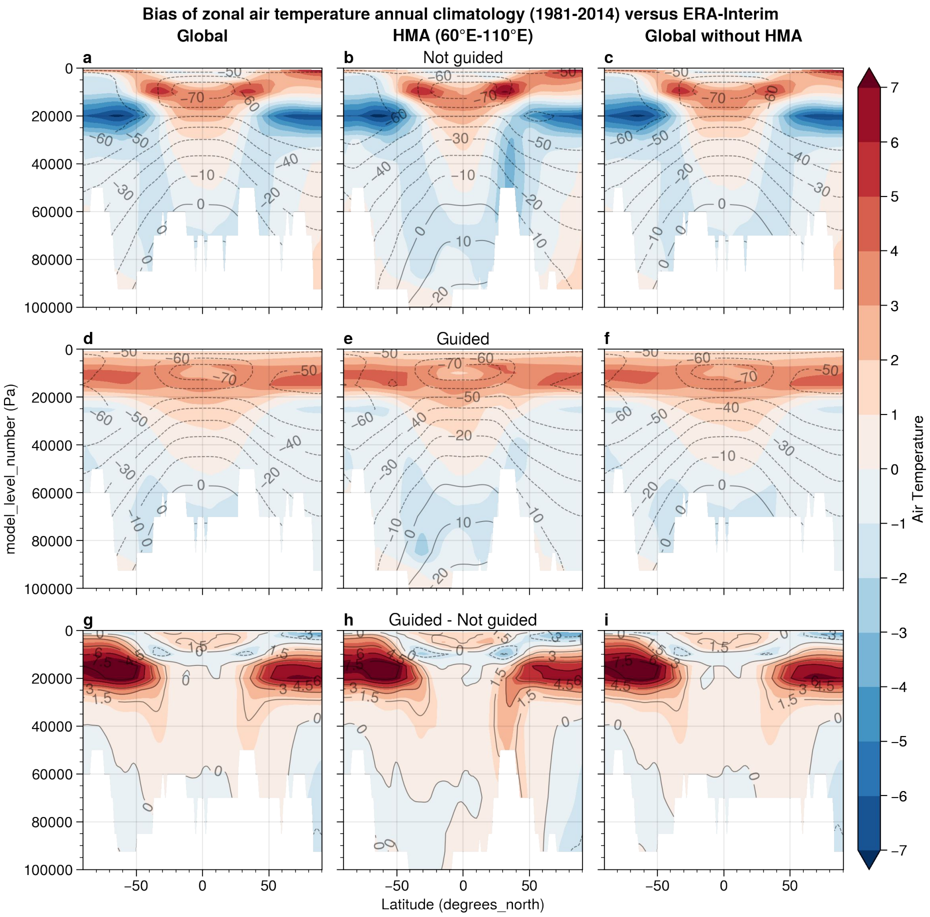
Link with orography?



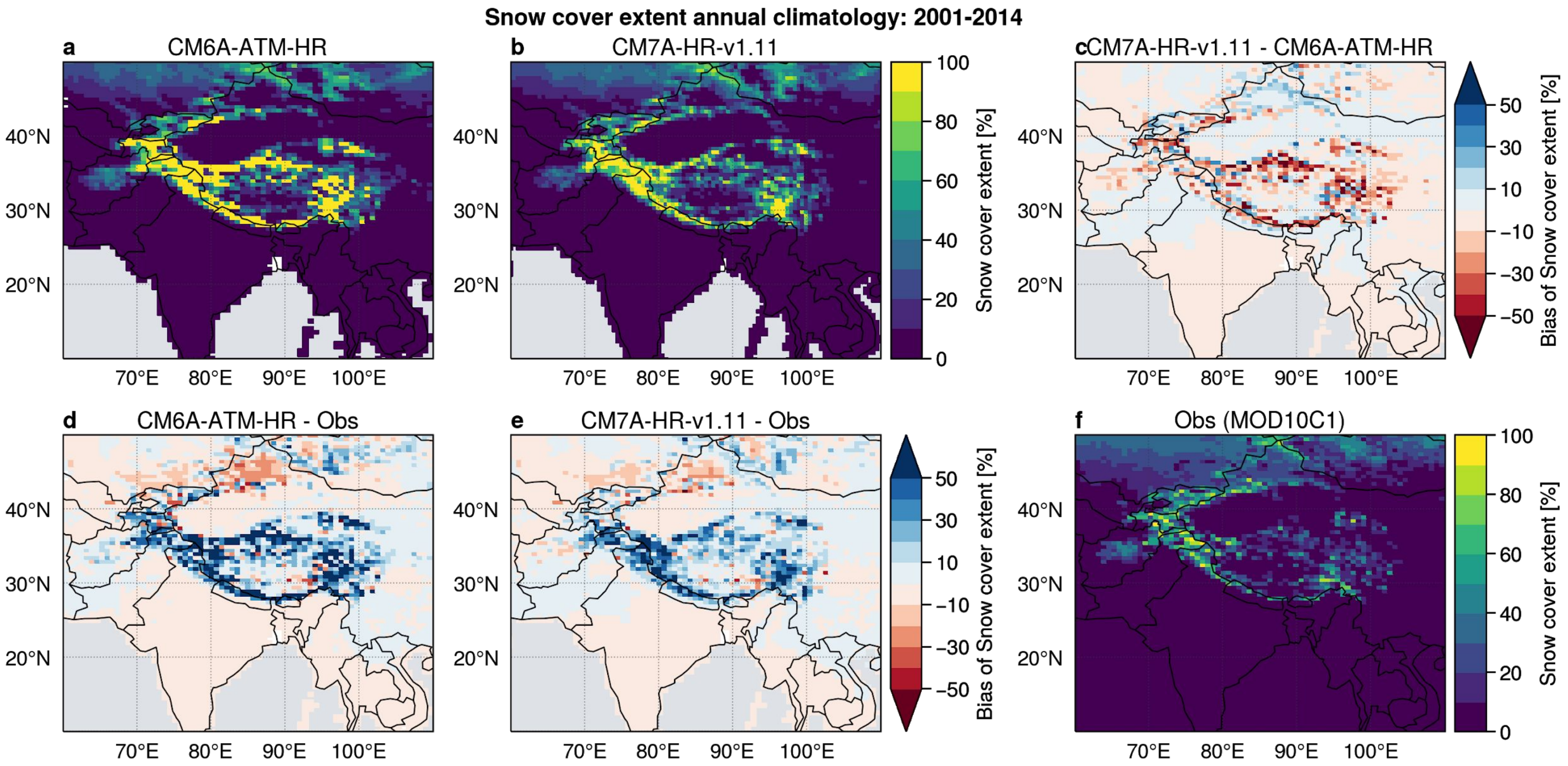
- Some cells stays at 100% of snow cover all the time!
- Seems related with elevation
- No obvious link with the standard deviation of elevation… maybe more for higher resolution

Nudged versus not nudged



More:
https://docs.google.com/document/d/1SphVviaGEyB9KQbkgC4U2hC-qraRfaE-ojLayZcDGPU/edit?usp=sharing

Dynamico



More: https://docs.google.com/document/d/1ClllEB5U824pH9O3Tshlajc1djtttlWfU4reDSbAV4c/edit?usp=sharing