



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

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PhD Student 2019-2022

Encadrants : Martin Ménégoz et Gerhard Krinner

Membres du comité : Frédérique Cheruy (référent HDR) et Isabelle Gouttevin

Institut des Géosciences de l'Environnement (IGE, Grenoble, France)

Comité de thèse 1ère année — 10/09/2020

1. Mon début de thèse
2. Introduction High Mountain of Asia
3. Analyse des biais dans LMDZ (CMIP6)
4. Analyse multi-modèle CMIP6
5. Paramétrisation sous-maille de la topographie
6. Autres prospectives
7. Conclusions sur le déroulement de la thèse

Mon début de thèse

Cursus universitaire

Expériences personnelles

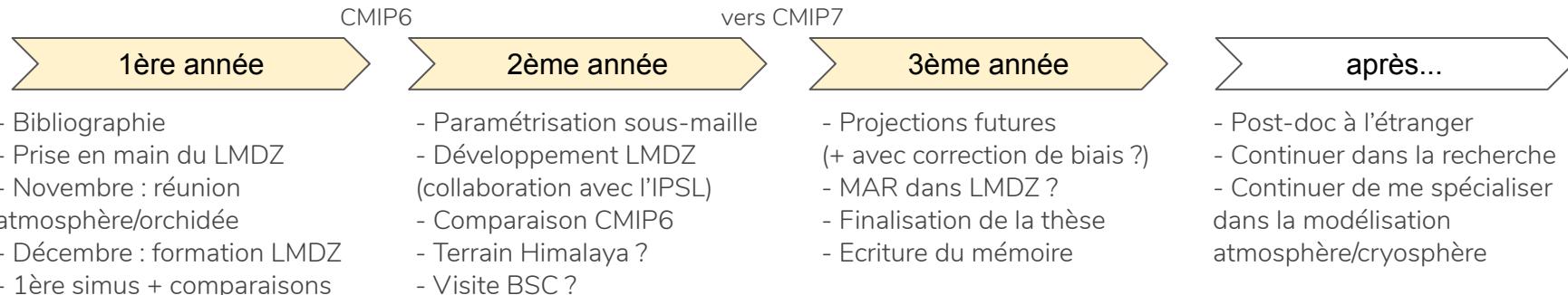
3 mois en Nouvelle-Zélande
1 an en VVT au Japon
→ Anglais
Auto-entreprise développement web → programmation
Passion pour la Science et l'Environnement

Prépa PCSI/PSI
L3 STPE/Physique
-> recherche plus fondamentale
Master ACSC
→ atmosphère / cryosphère / modélisation

Expériences professionnelles

Supméca Paris → ~~ingénieur~~
Stages glaciologie + astrophysique
Stage atmosphère
Stage océan + machine learning
→ complémentaire à ma formation
→ soumission d'un papier

Projet de thèse autour de la **modélisation atmosphère/cryosphère et du réchauffement climatique**



Trainings and Meetings



Formations Fortran : documentation

Fortran_Base : "Fortran : notions de base" (1er niveau) :

- Support de cours :
 - Version française
- Exemples du cours (source des programmes) :
 - Exemples du support
- Travaux pratiques :
 - Travaux pratiques avec solutions

Fortran_Avancé : "Fortran : apports des normes 90 et 95 avec quelques aspects de la norme 2003" (2ème niveau) :

- Support de cours :
 - Version française
- Travaux pratiques :
 - Travaux pratiques avec solutions

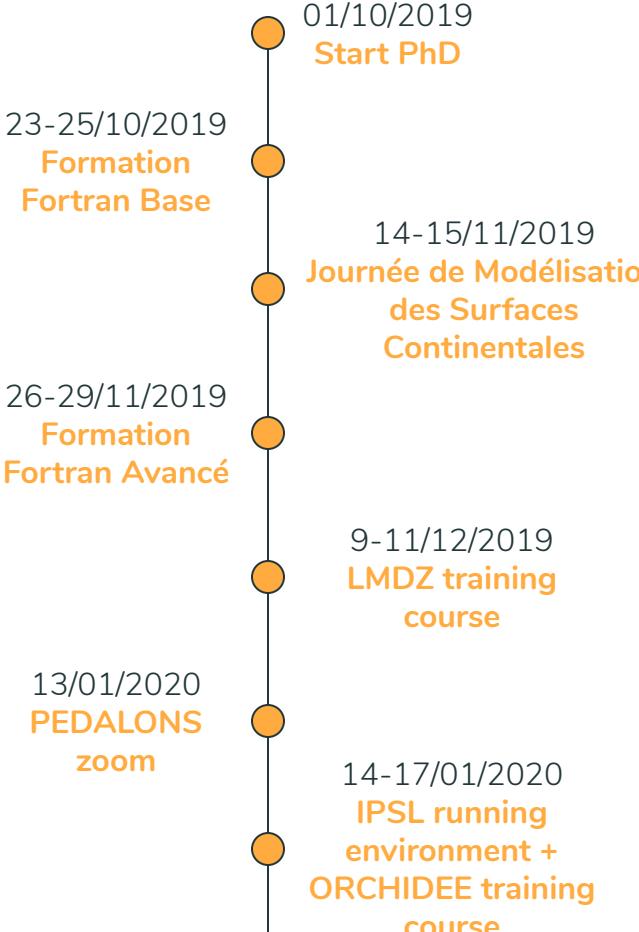


Accueil Le projet LMDZ Pour utiliser LMDZ Le coin des développeurs Communication Membres

Vous êtes ici : Accueil / Le coin des développeurs / Réunions PEDALONS / 2020/01/13

2020/01/13

Réunion PEDALONS du 13 janvier 2020. Utilisation du zoom pour l'étude des climats régionaux



JMSC-2019 : Journées de Modélisation des Surfaces Continentales, 14-15 novembre 2019



JMSC-2019 : 3èmes Journées de Modélisation des Surfaces Continentales
14 -15 Novembre 2019, Paris

LMDZ training course : 9th, 10th, 11th of december 2019

LMDZ training course, december 2019
corridor 45-55, 2nd floor, room 201 / Laplace
Sorbonne Université
Faculté des Sciences et Ingénierie
4 place Jussieu 75005 Paris, France



ORCHIDEE training course

Next session

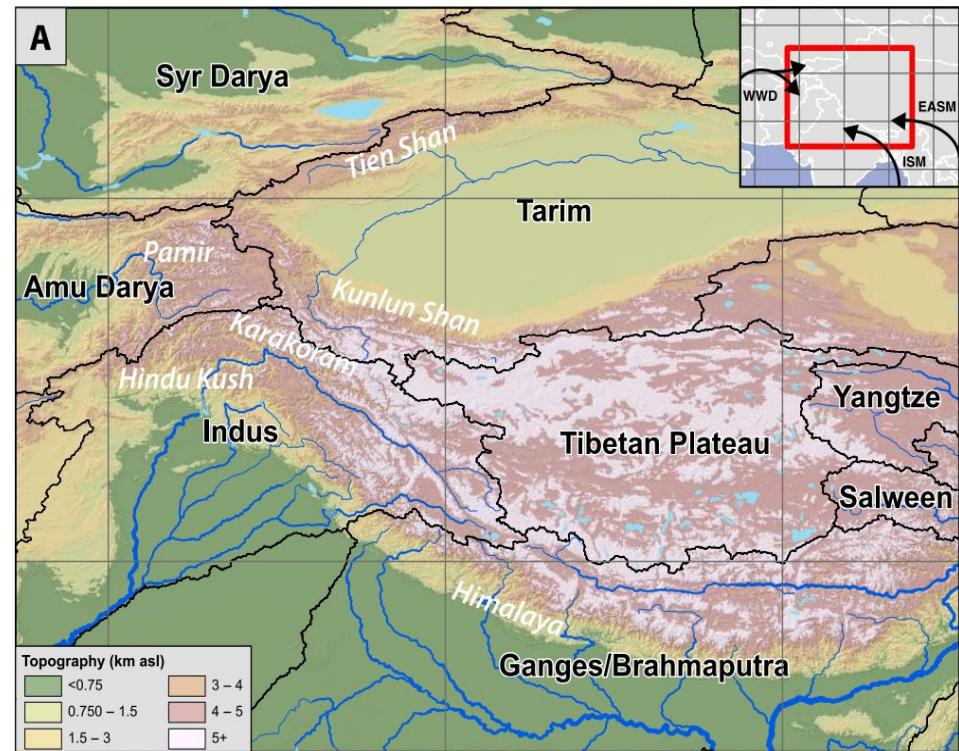
• Training course 16th-17th January 2020, at IDRIS
Next training session will take place on the 16th-17th January 2020 at IDRIS in Orsay outside Paris. See here how to reach IDRIS: <http://www.idris.fr>
The training will be held in english and includes lecture and hands on sessions. The hands on sessions will be done on the IDRIS training computers
Don't forget to bring your ID-card each day for entrance in the IDRIS building !
The ORCHIDEE training is preceded by a 2-days training course in IPSL running environment for beginners the 14th-15th of January 2020.
Program for ORCHIDEE Training
Thursday 16th January 2020
09:30 - 10:00 - Welcome presentation (Philippe Peyré)
10:00 - 11:30 - Introduction to ORCHIDEE (Bertrand Guenard)
11:00 - 12:15 - Break
12:15 - 13:30 - Introduction to IPSL-HESS (Gilles Vincent)
13:30 - 14:30 - Lunch in the IDRIS "Caroline" employees restaurant
14:00 - 17:00 - Hands on session and technical presentations
Friday 17th January 2020
09:00 - 10:30 - Soil hydrology (Agnès Ducharne)
10:20 - 11:10 - Soil carbon (Bertrand Guenard)
11:10 - 11:30 - Break
11:30 - 12:30 - Land surface and soil freezing (Catherine Otté)
12:30 - 14:00 - Lunch in the IDRIS "Caroline" employees restaurant
14:00 - 17:00 - Hands on session and technical presentations



Introduction High Mountain of Asia

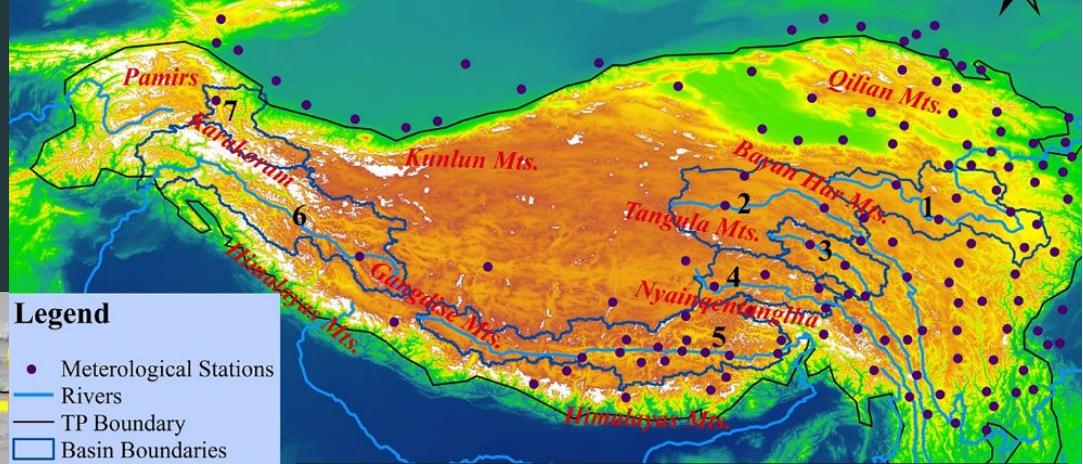
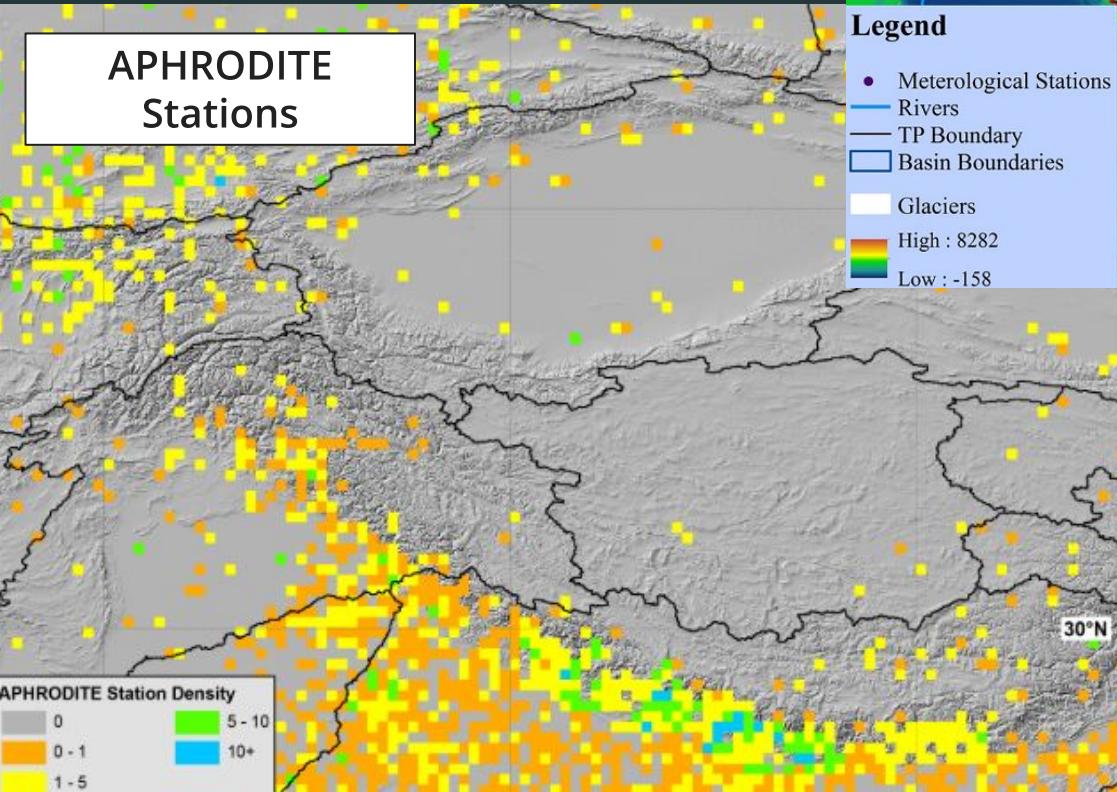
High Mountain Asia (HMA): Introduction

- 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



China Meteorological Administration

Li et al. (2018), Fig. 1

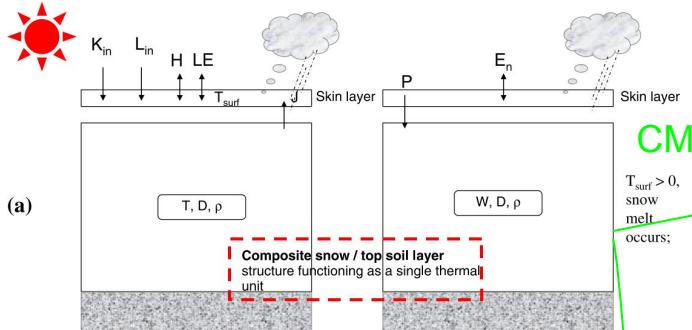
- Illustrates the **low station density** in the core of HMA (Tibetan Plateau)
- The **highest elevations are severely under-represented**
- **Almost exclusively measure rainfall** (there exist very few snow monitoring stations in HMA)

Smith and Bookhagen (2018), Fig. S1

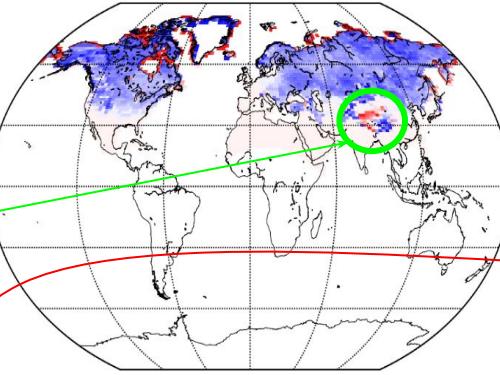
Analyse des biais dans LMDZ (CMIP6)

Snow bias in IPSL model CMIP5 versus CMIP6

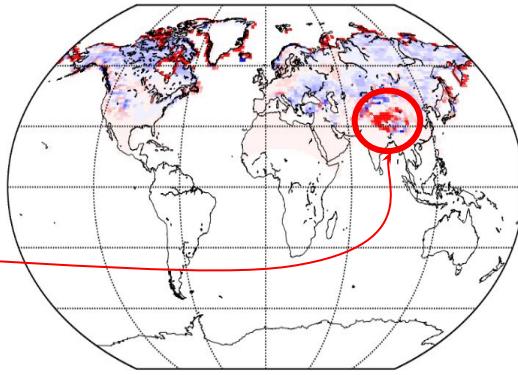
WANG ET AL.: ORCHIDEE SNOW MODEL EVALUATION



snowfraction bias : ChoiAP - nhsce

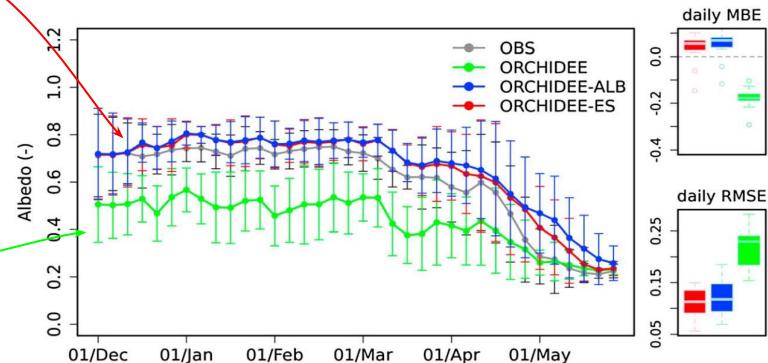
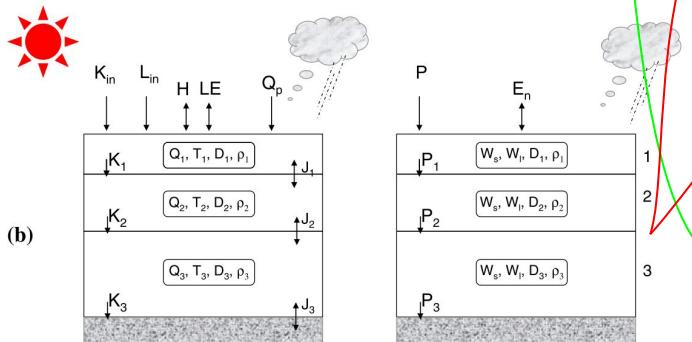


snowfraction bias : 6Actrl - nhsce



45
30
15
0
-15
-30
-45

Cheruy et al. (2020), Fig. 6

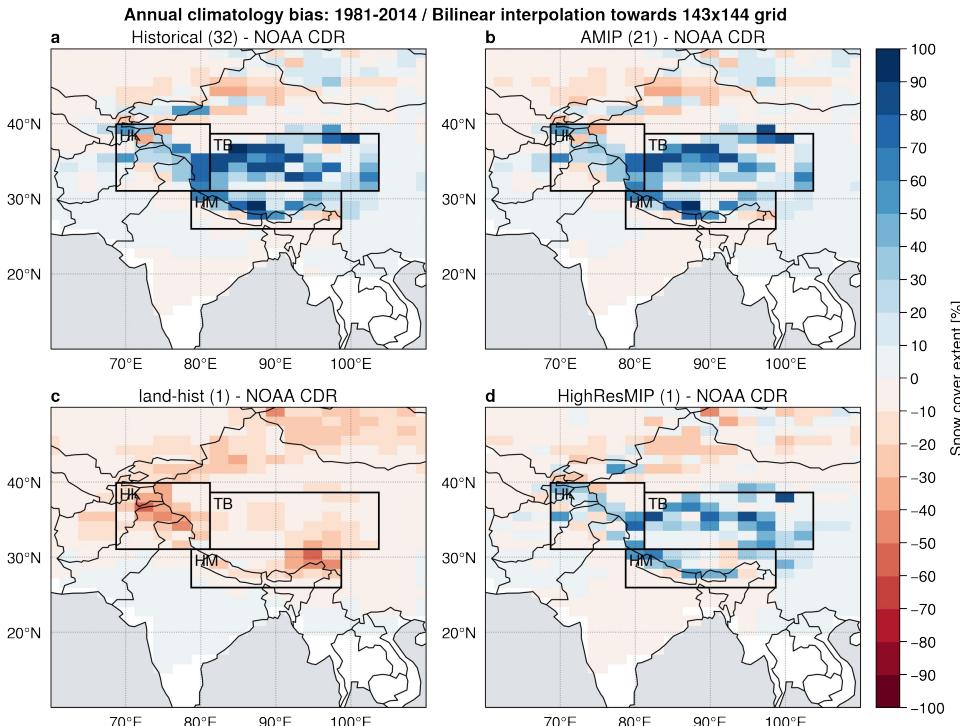


Wang et al. (2013), Fig. 1

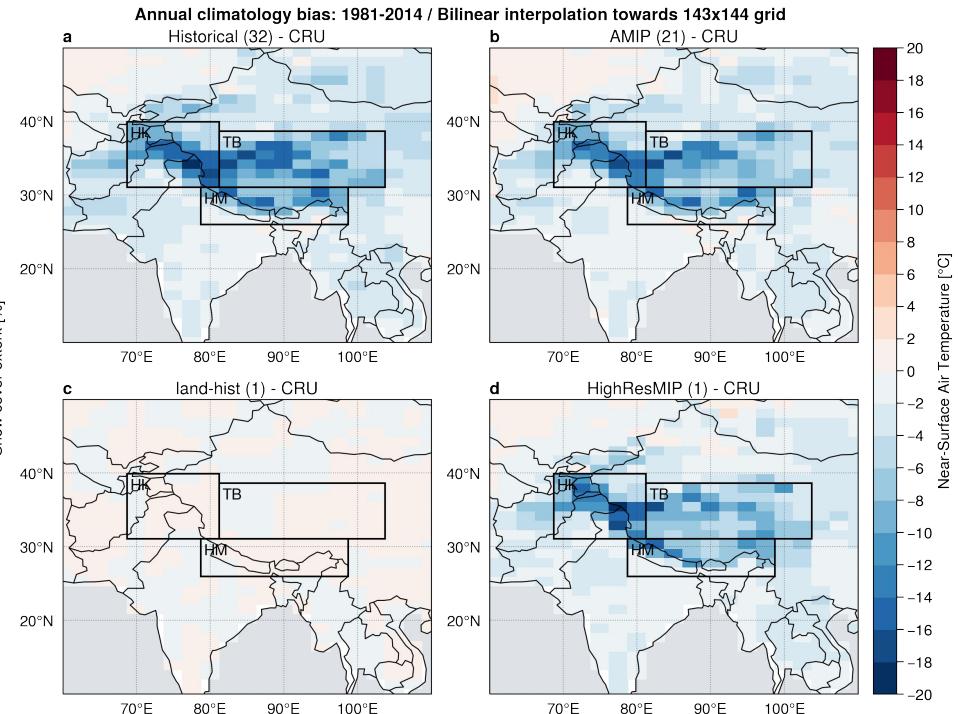
Wang et al. (2013), Fig. 5

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

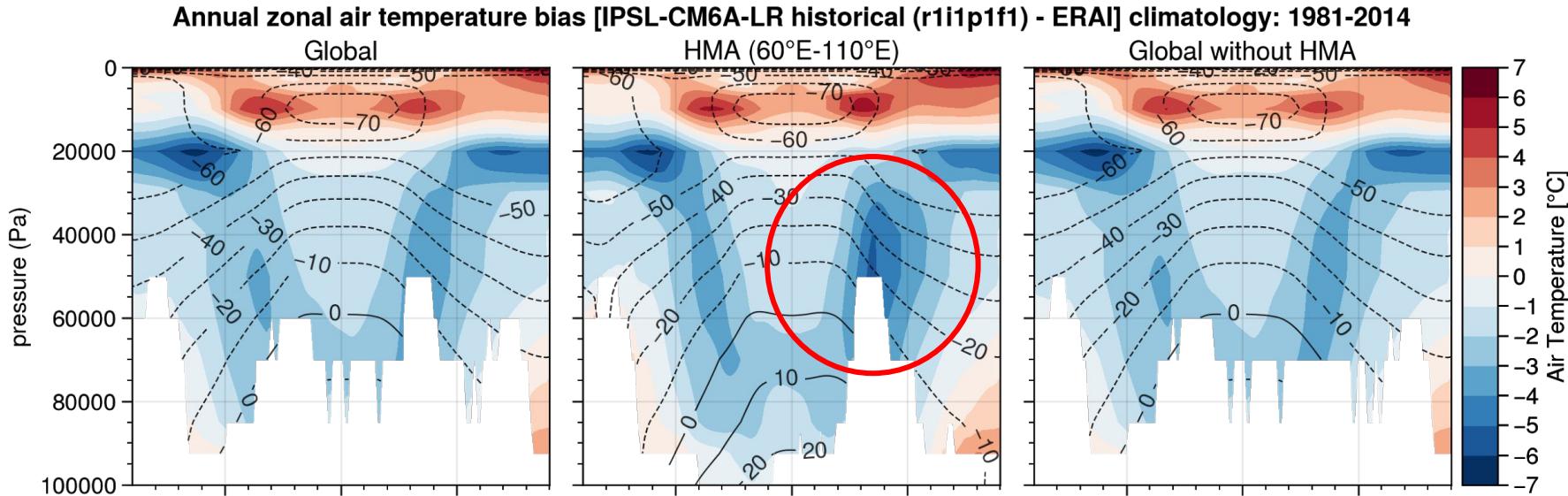
Snow cover bias



Temperature bias



Air Temperature zonal means bias global versus HMA

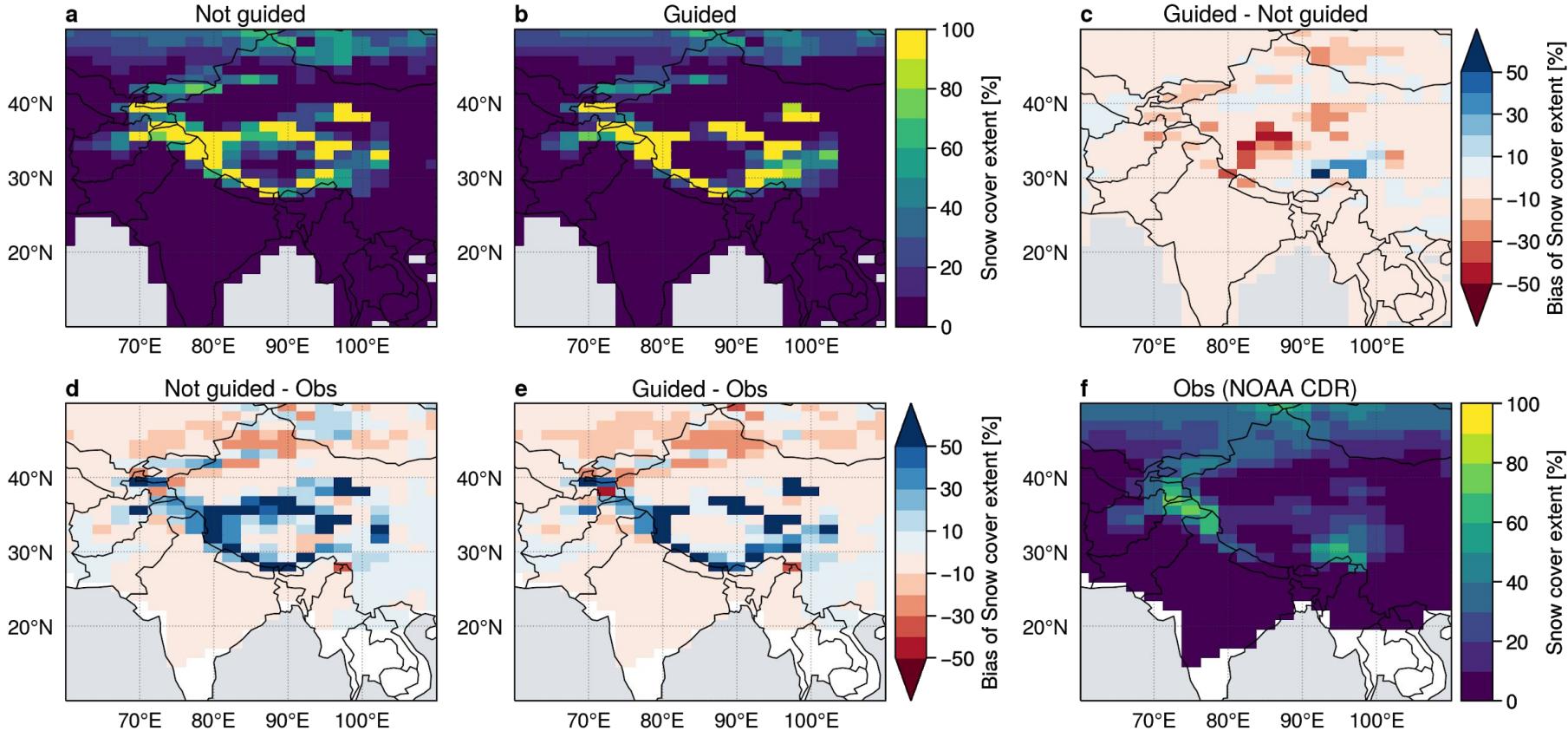


- Cold bias in troposphere and hot bias in stratosphere
- Cold bias of air temperature not restricted to HMA!
- HMA seems to amplify this bias
- The bias is reduced in HighResMIP

Adapted from Boucher et al., Fig. 3 ([2020](#))

Nudged versus not nudged: snow cover* ([tropo bias](#))

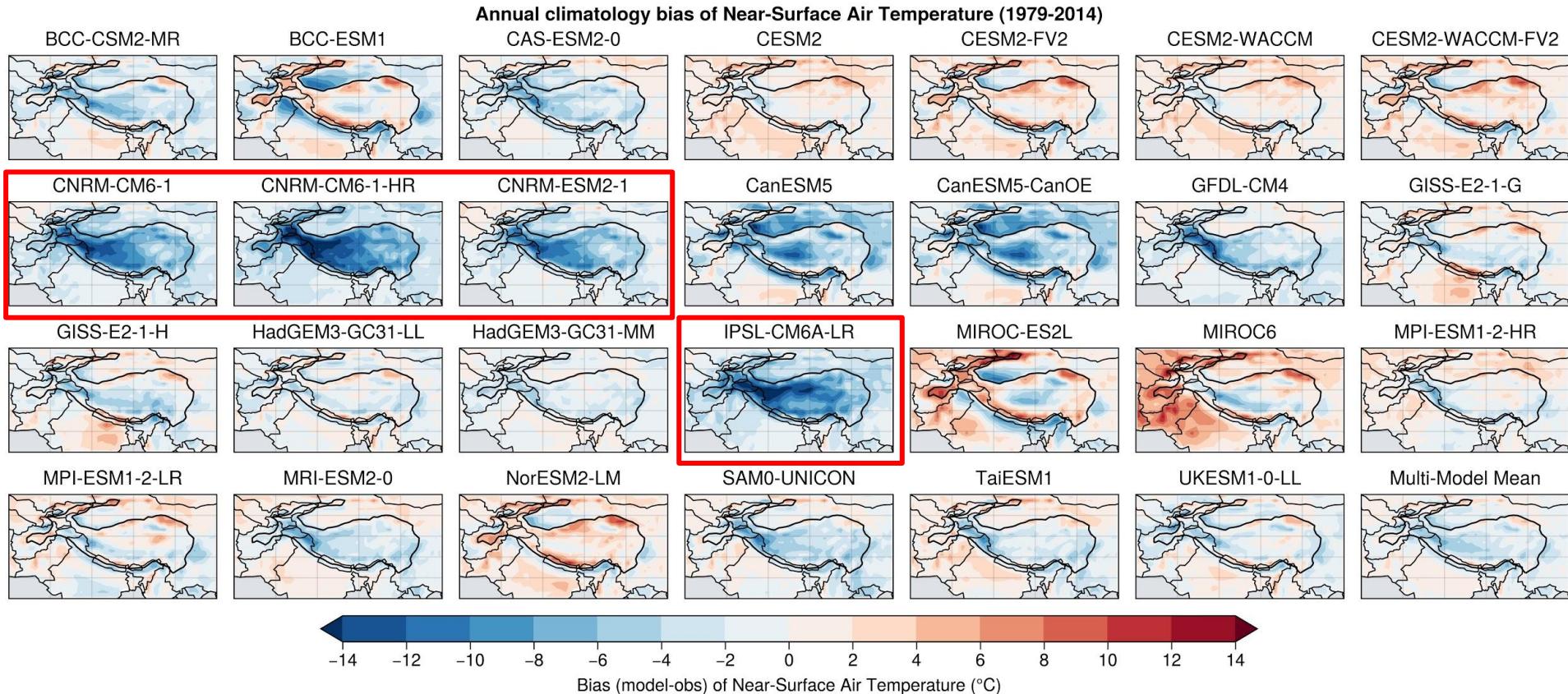
Snow cover extent annual climatology: 1999-2008 (CM6012-LR-amip-G-02)



* Simulation: Frédérique Cheruy

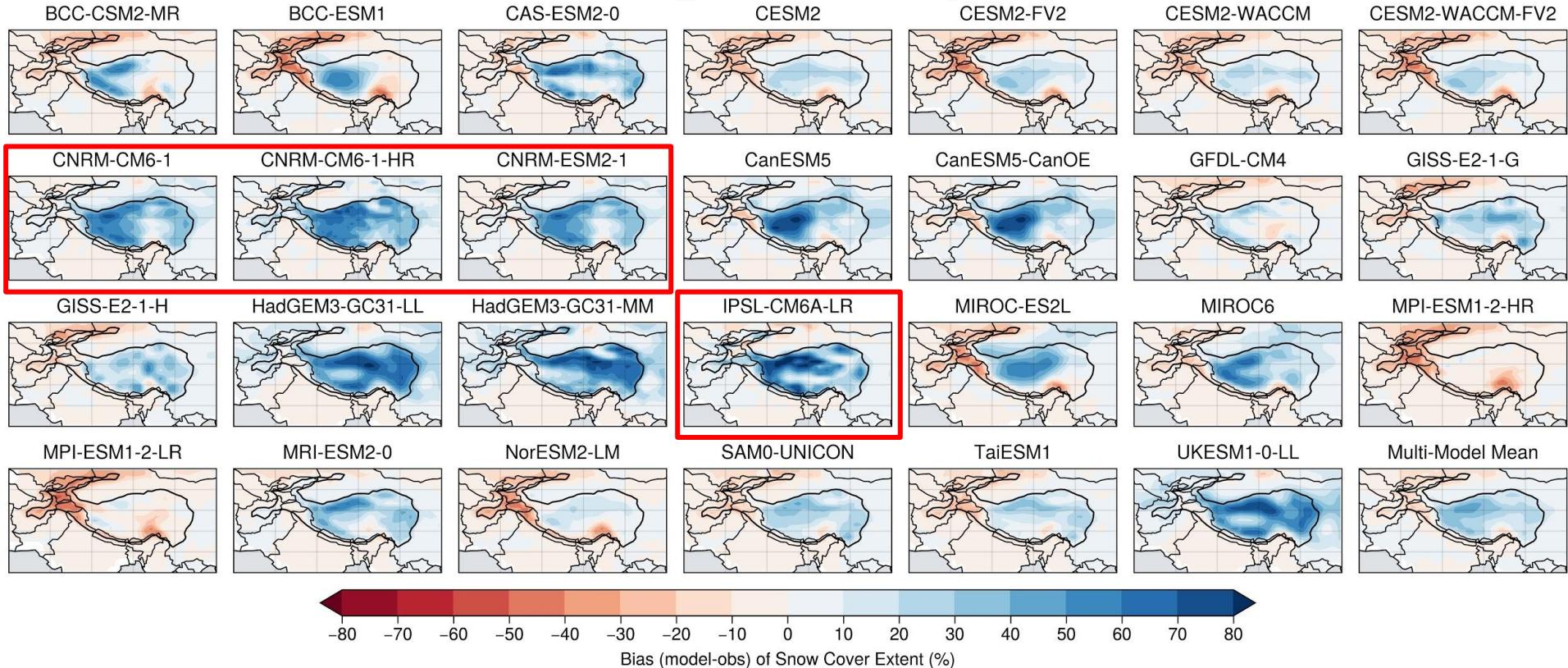
Analyse multi-modèle CMIP6

CMIP6 other models: Near-Surface Air Temperature bias



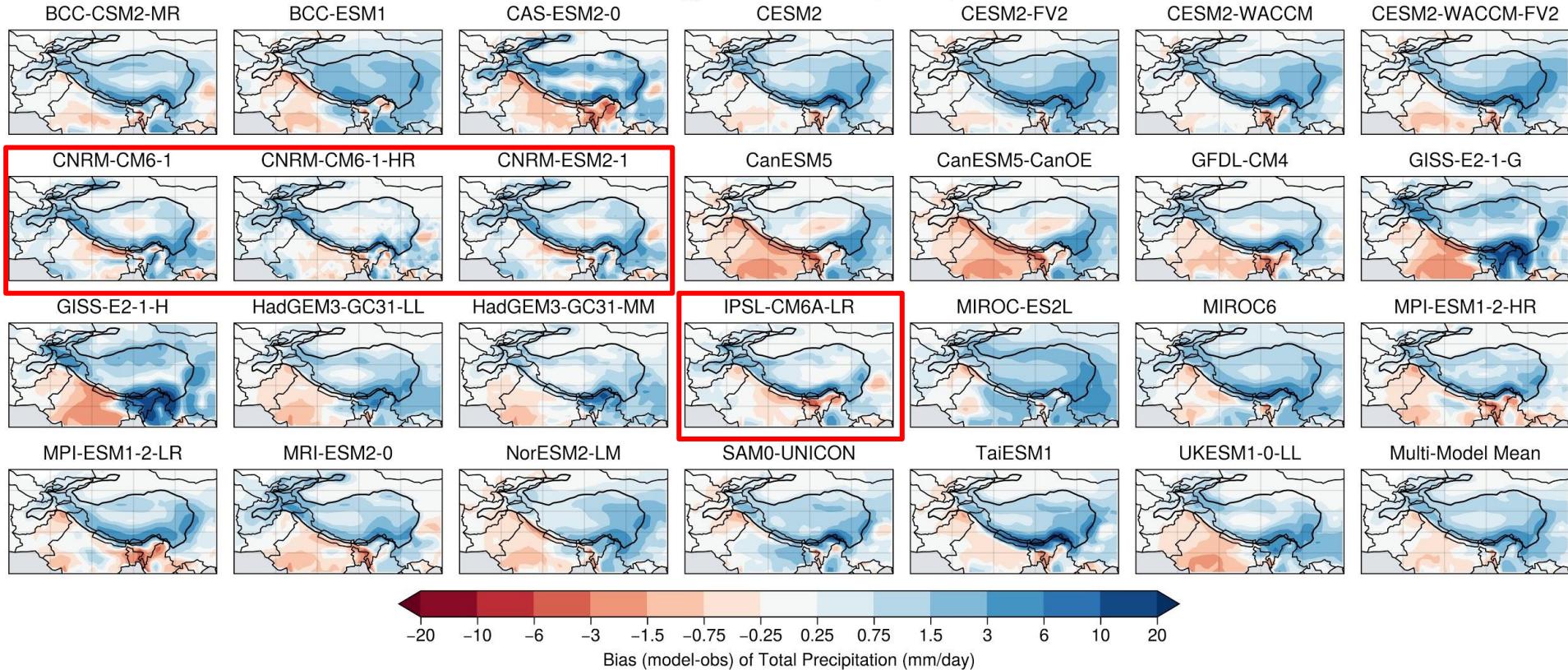
CMIP6 other models: Snow Cover bias

Annual climatology bias of Snow Cover Extent (1979-2014)



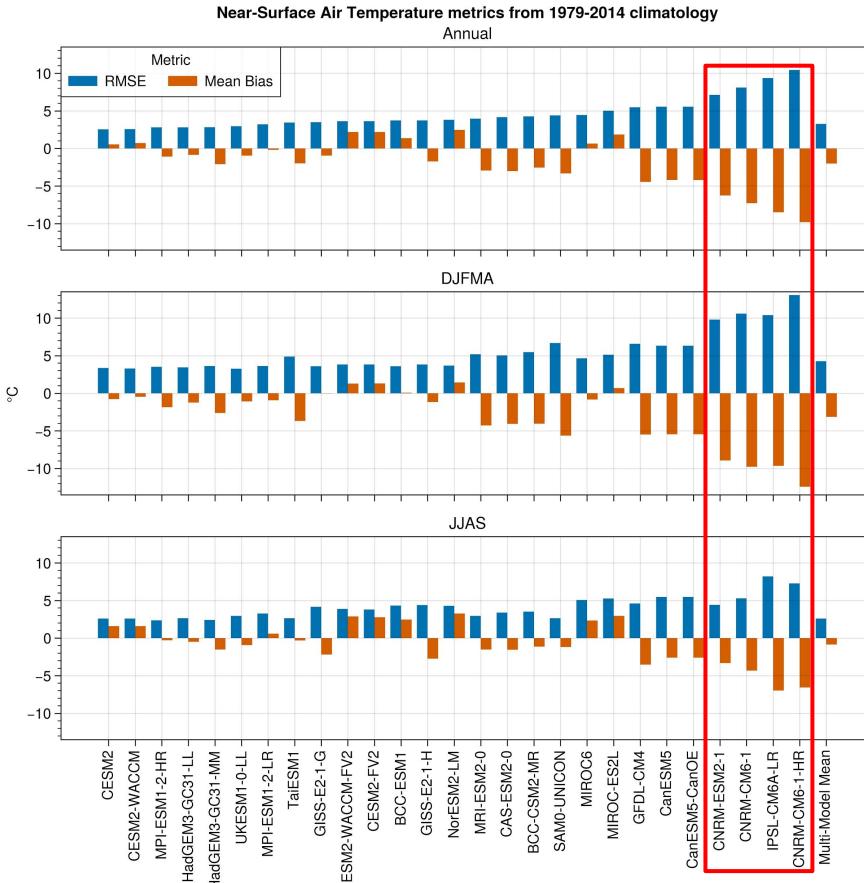
CMIP6 other models: Total Precipitation bias

Annual climatology bias of Total Precipitation (1979-2014)

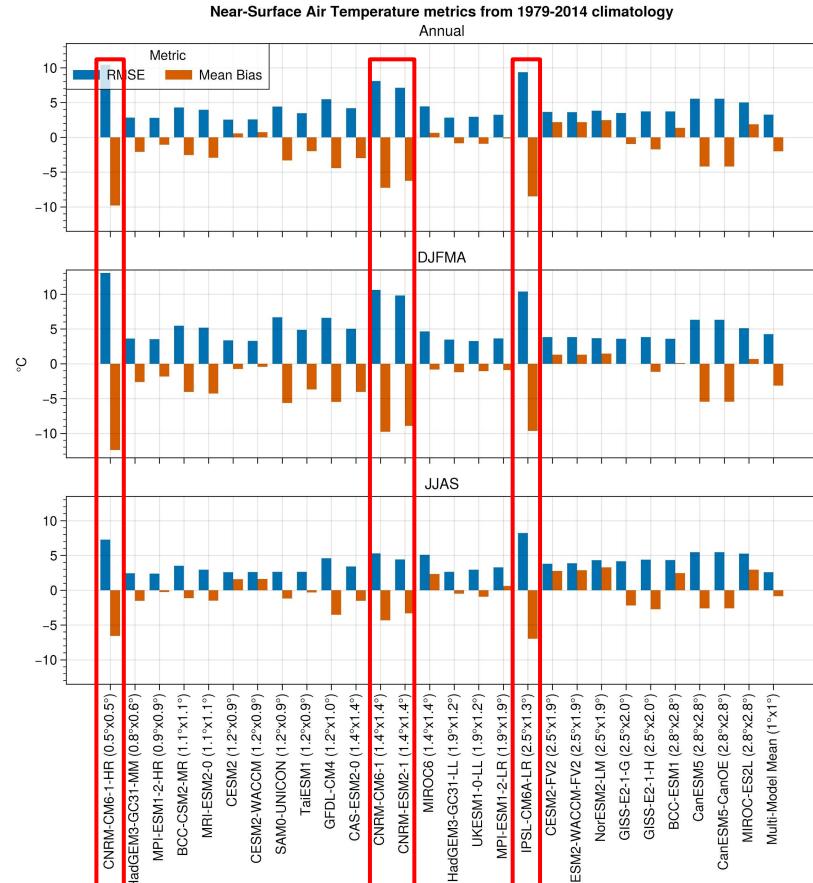


CMIP6 other models: Near-Surface Air Temperature metrics

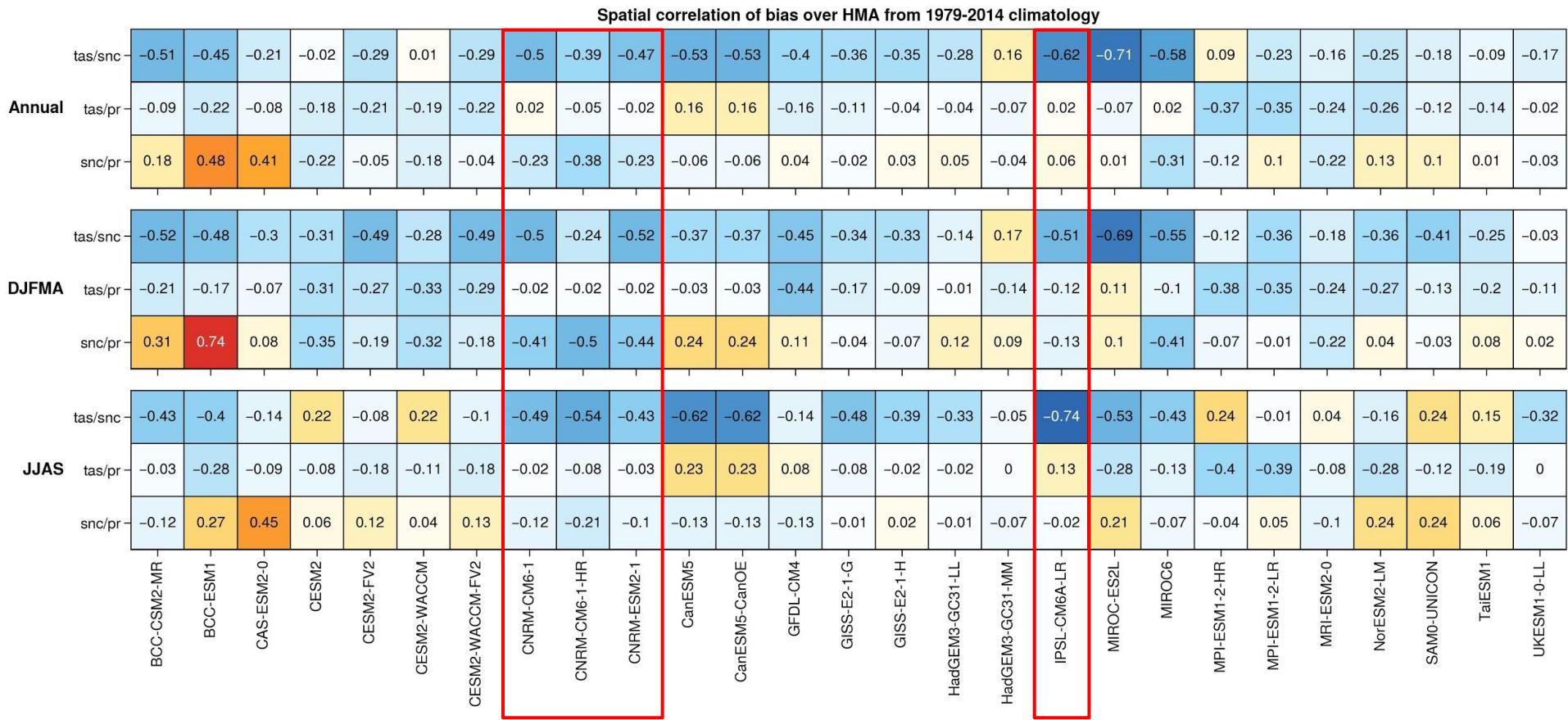
Sorted by annual RMSE



Sorted by resolution



CMIP6 other models: spatial correlations



“Cold bias” over Tibetan Plateau

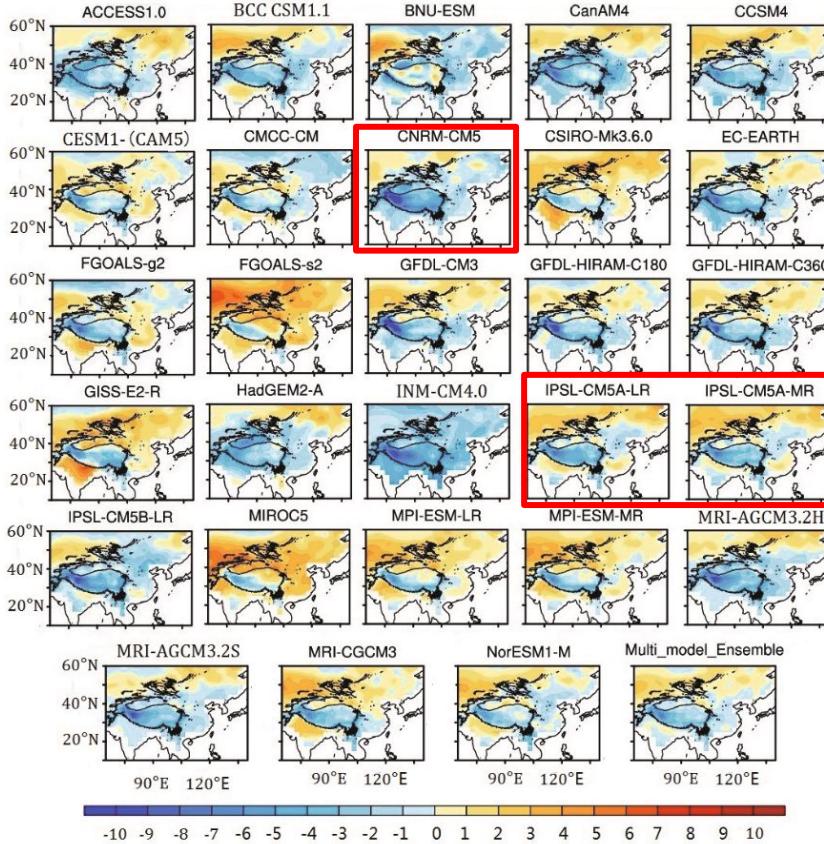
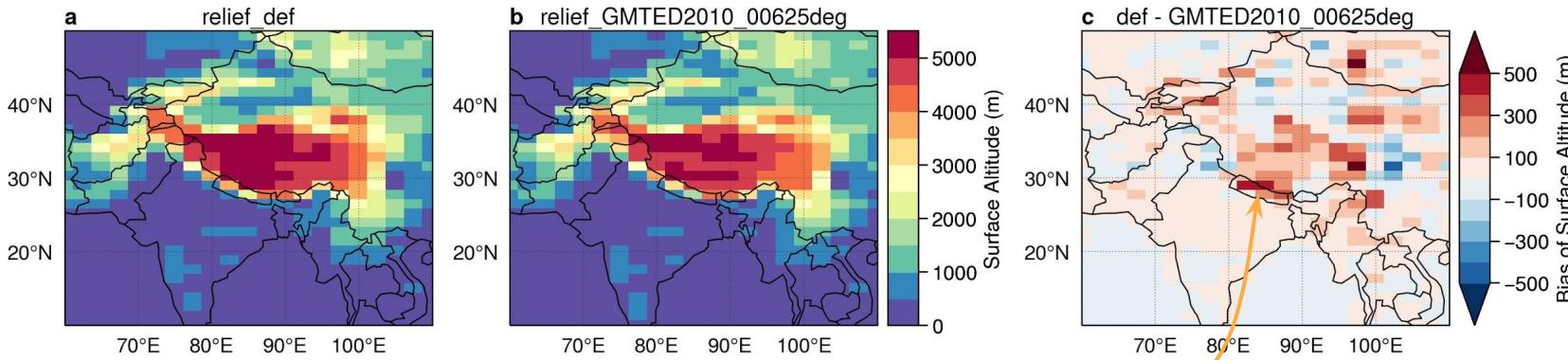


Fig. 2. Annual mean T_{as} ($^{\circ}\text{C}$) differences between various models and CRU data averaged during 1979–2005. All air temperature values in the models have been corrected to real elevation at a resolution of $2.5^{\circ} \times 2.5^{\circ}$.

- 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.

Paramétrisation sous-maille de la topographie

Problem with elevation?

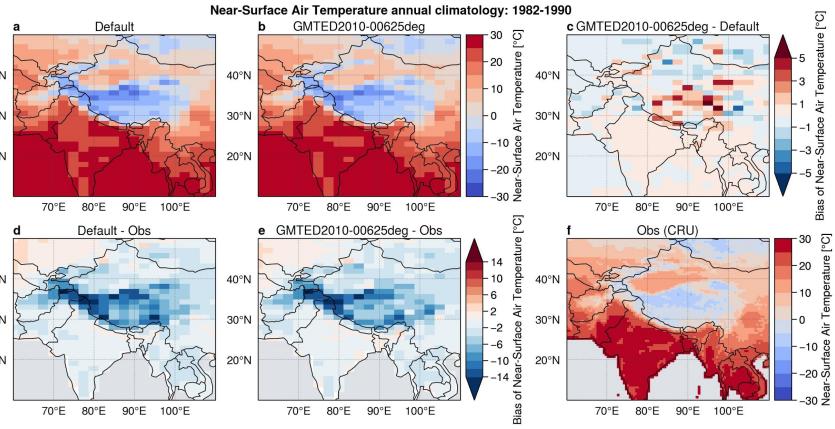
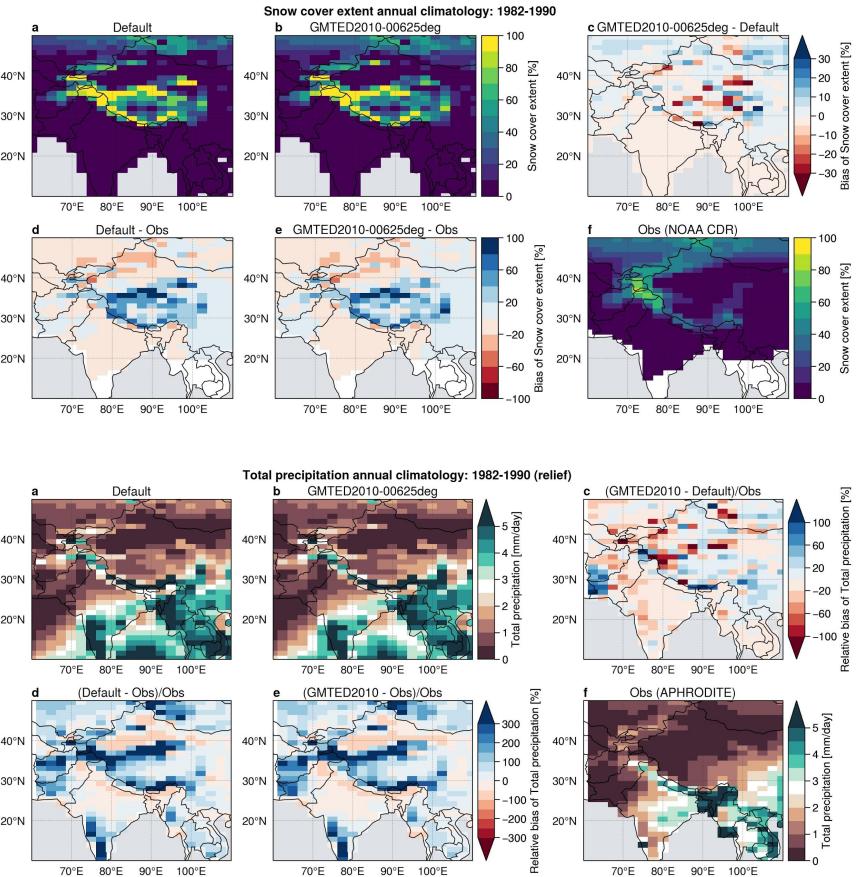


Original file of elevation has more than **500 m differences** locally!

Already targeted in 2018 : <https://lmdz.lmd.jussieu.fr/utilisateurs/reunion-utilisateurs/2018/lmdz2018-sepulchre.pdf>

→ 2 climatological experiments of 10 years with original and new topography (GMTED2010)

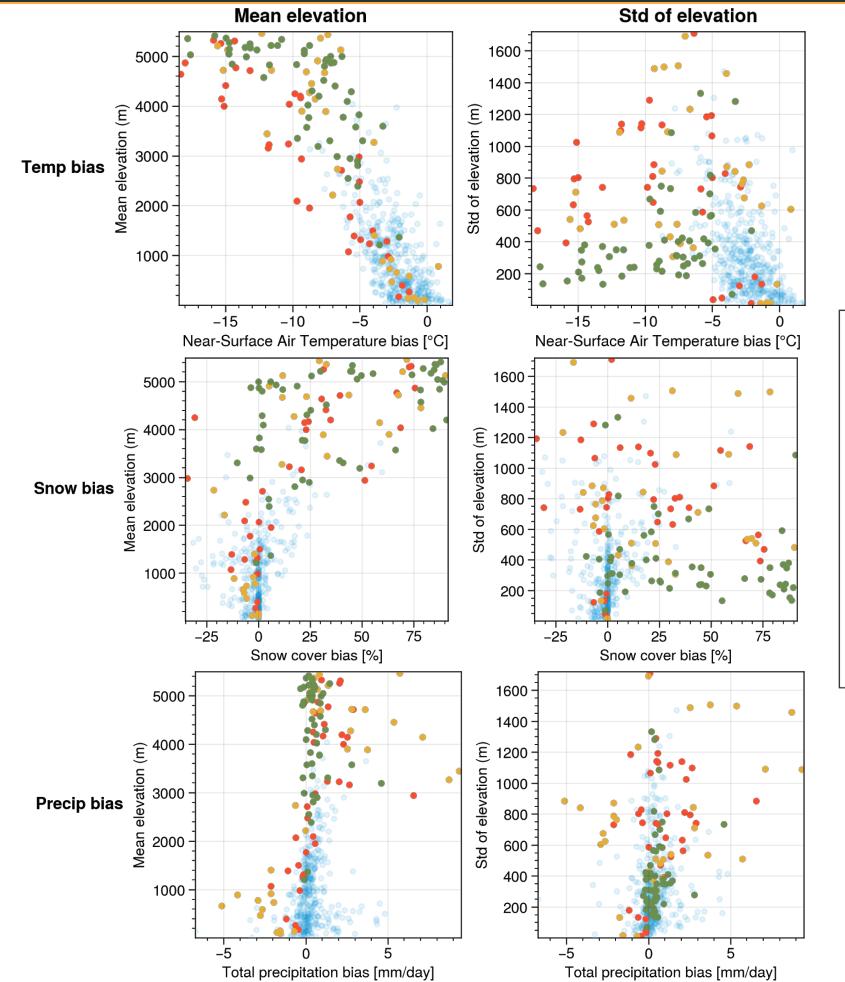
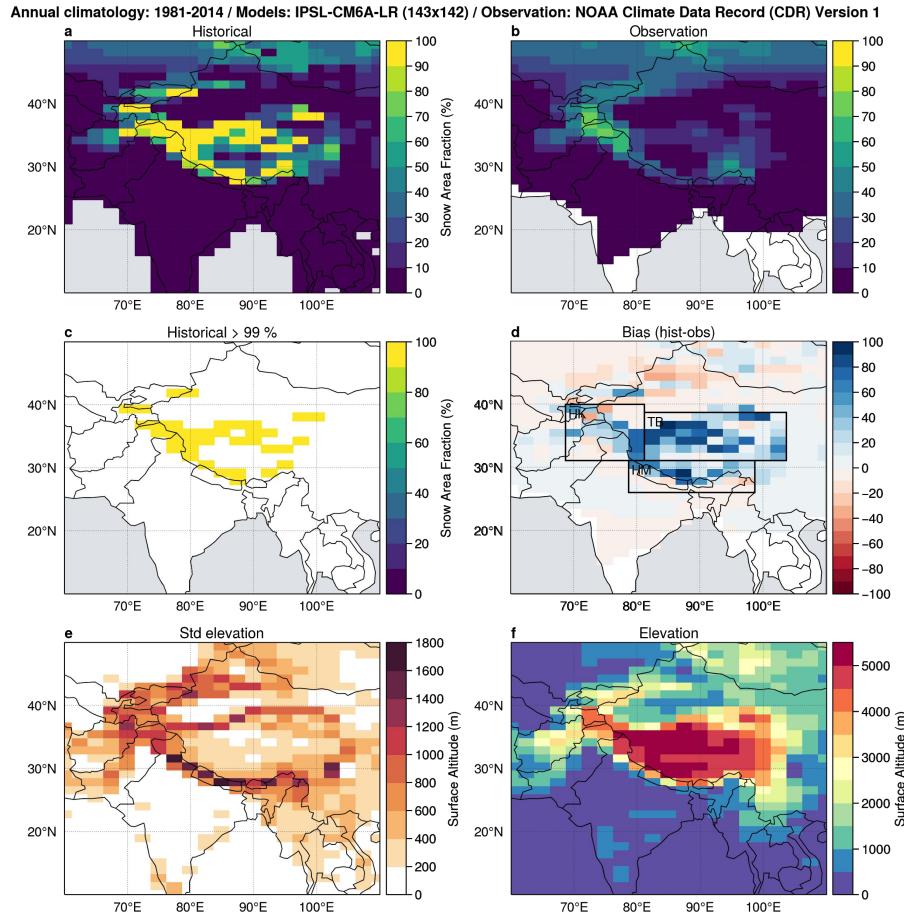
Problem with elevation?



- Some improvements around the area of high elevation differences

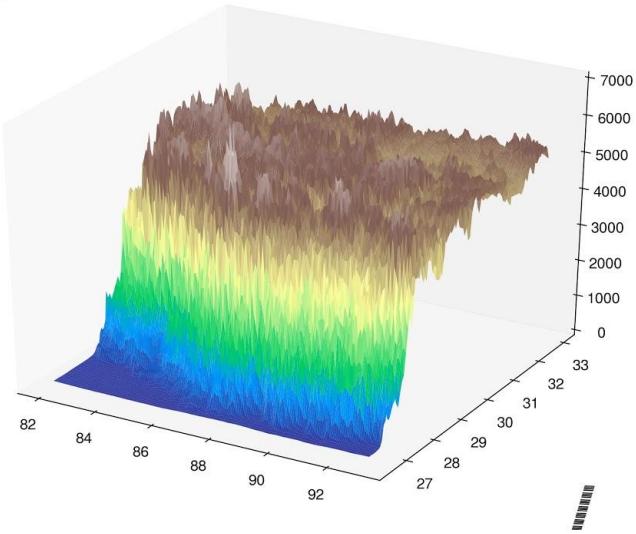
● Bias still present!

Link with orography?



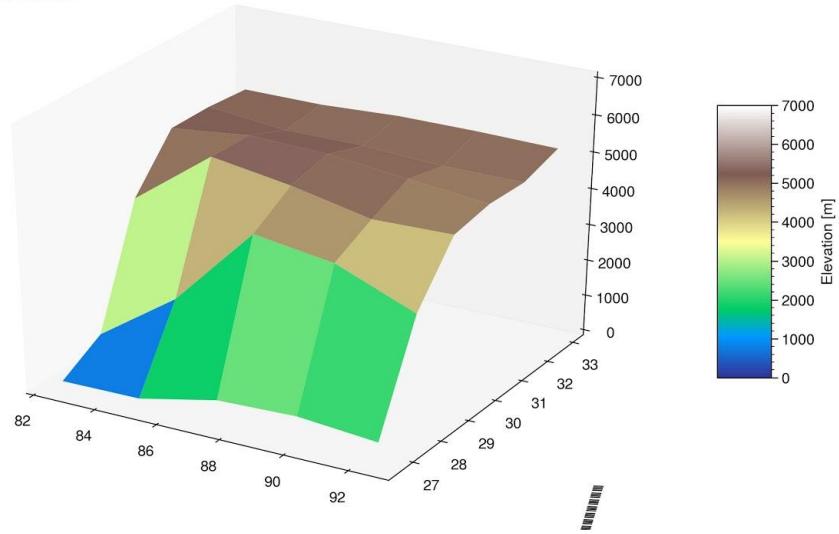
Comparaison de la topographie

GMTED



GMTED2010 à 0.0625°
(~6km) de résolution

IPSL_CM6A_LR

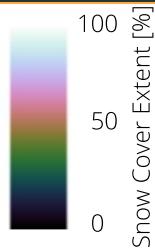


IPSL-CM6-LR
(~150x250km)



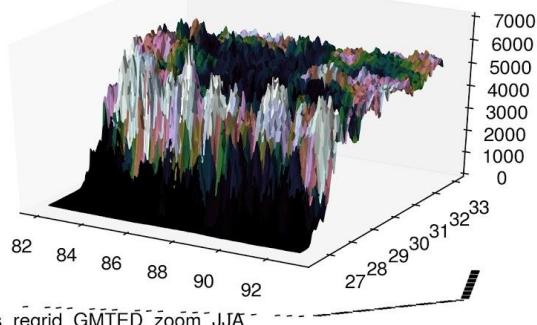
Couverture de neige

1999-2012 climatologies / Observations : [MEaSURES*](#) (25 km de résolution)
Nearest neighbor regrid towards [GMTED2010](#) grid (6km)

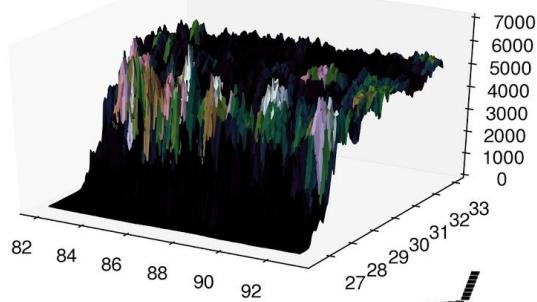


MEaSURES

obs_regrid_GMTED_zoom_DJF

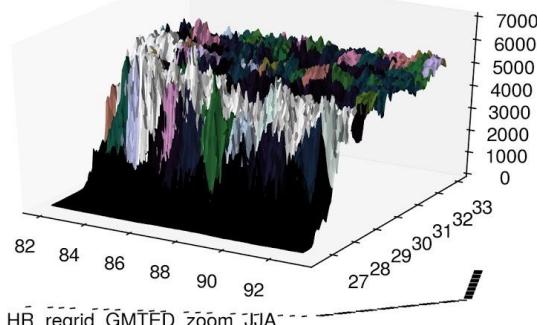


obs_regrid_GMTED_zoom_JJA

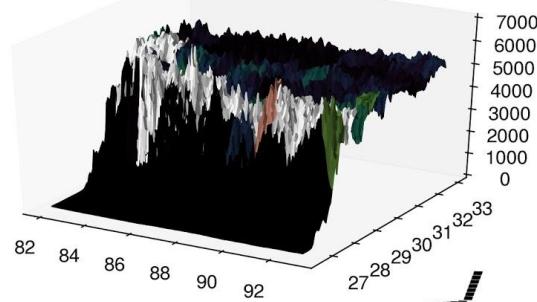


IPSL-CM6A-ATM-HR

da_HR_regrid_GMTED_zoom_DJF

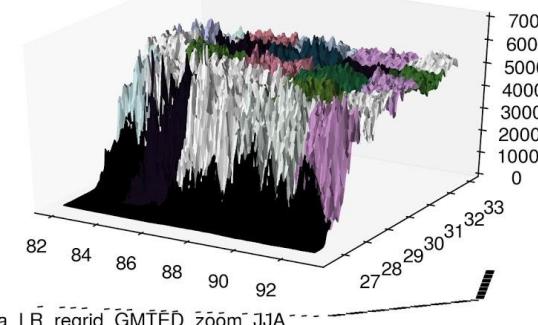


da_HR_regrid_GMTED_zoom_JJA

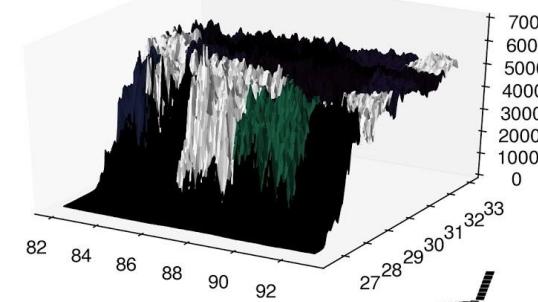


IPSL-CM6A-LR

da_LR_regrid_GMTED_zoom_DJF



da_LR_regrid_GMTED_zoom_JJA



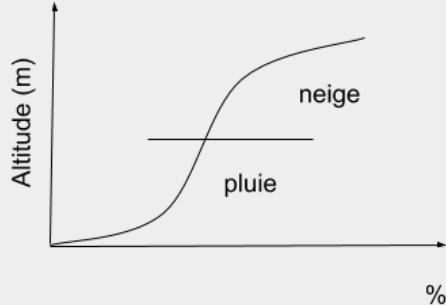
Hiver

Été

*Notebook comparaison [MEaSURES](#) / [NOAA CDR](#) : [Snow cover-MEaSURES.ipynb](#) + IPSL-CMA6-LR HighResMIP vs CMIP: [snc_bias_HighResMIP_comparison_LR.ipynb](#)

Paramétrisation sous-maille de la topographie

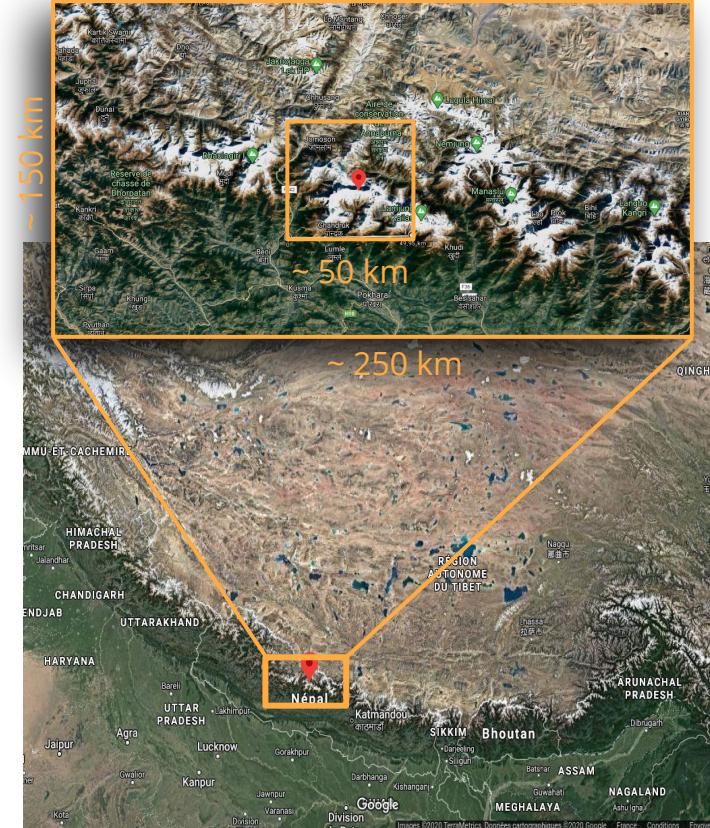
Problem with subgrid parameterization?



Wrong phase distribution / surface energy budget over complex terrain?

→ Walland and Simmons, [1996](#): SUB-GRID-SCALE TOPOGRAPHY AND THE SIMULATION OF NORTHERN HEMISPHERE SNOW COVER

→ Younas et al., [2017](#): A strategy to represent impacts of subgrid-scale topography on snow evolution in the Canadian Land Surface Scheme



Walland and Simmons, 1996: Melbourne University GCM

Not computationally efficient to explicitly represent the height distribution on a fine scale

→ use a measure of **variability of height** within each grid-square together with some **statistical distribution** theory to approximate the distribution

Normal distribution? include the **skewness** and **kurtosis** of the distribution

Approximation of the percentage of heights that fall below a certain level (Abramowitz and Stegun, [1965](#))

$$P(x) = P_{\text{nor}}(x) - \left[\frac{\gamma_3}{6} Z^{(2)}(x) \right] + \left[\frac{\gamma_4}{24} Z^{(3)}(x) + \frac{\gamma_3^2}{72} Z^{(6)}(x) \right] + \dots$$

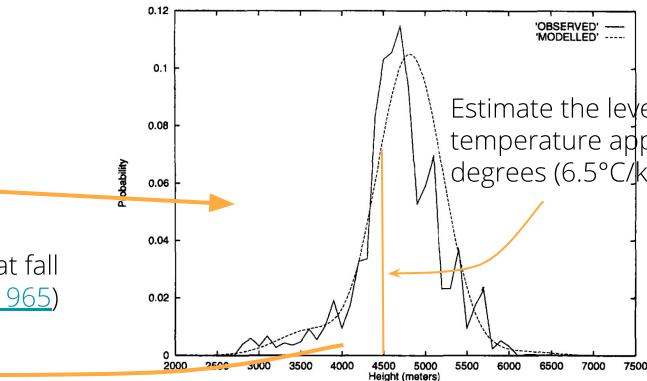


Figure 1. Observed and modelled distributions of height within a ($5.6^\circ \times 3.3^\circ$)grid-box over the Himalayan plateau (95.6°E , 34.7°N)

Walland and Simmons ([1996](#))

$$T_{a_{\ln}} = \frac{T_{a_{\text{mean}}} - fr_{sn} \times T_{a_{sn}}}{1.0 - fr_{sn}}$$

$$q_{sn} = \frac{q_{sat_{sn}}}{q_{sat_{\text{mean}}}} \times q_{\text{mean}}$$

$$\frac{\partial w_g}{\partial t} = P_r - E + \text{melt}$$

$$c_p d_{sn} \frac{\partial T_s}{\partial t} = Q_s + Q_l + Q_h + Q_e + Q_m \equiv Q_{\text{tot}}$$



New mean weighted average temperature is computed!

$$T_{a_{sn}} = T_{a_{\text{mean}}} - \Delta T$$

$$q_{\ln} = \frac{q_{\text{mean}} - fr_{sn} \times q_{sn}}{1.0 - fr_{sn}}$$

$$\frac{\partial d_{sn}}{\partial t} = P_{sn} - E - \text{melt}$$

$$c_p d_{sn} \frac{\partial T_s}{\partial t} = Q_s + Q_l + Q_h + Q_e + Q_m \equiv Q_{\text{tot}}$$

Younas et al., 2017: Canadian Land Surface Scheme (CLASS)

- elevation bands at **100 m intervals** to capture air temperature lapse rates ($6.4^{\circ}\text{C}/\text{km}$)
- five **slope angles on four aspects** to resolve solar radiation impacts on the evolution of snow depth and SWE

Then results for snow depth and SWE **averaged either over all ten elevation bands**

- **elevation has more influence** than slope and aspect angles when comparing **spatial averages**.
- representing snowpacks using only mean (model grid cell) topographic characteristics masks the **non-linear effects** elevation, slope and aspect introduce in their evolution through time

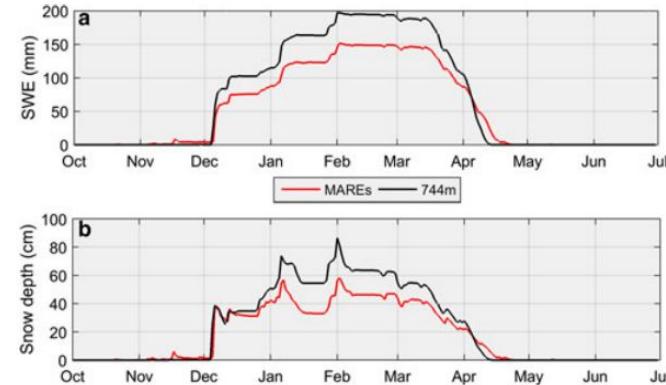


Fig. 4. Elevational dependence of average daily (a) SWE and (b) snow depth, comparing simulated CLASS results for the mean elevation (744 m) with the mean of all remaining elevations (MAREs), from 1 July 2008 to 30 June 2009.

Younas et al. (2017)

→ **26%** peak SWE differences
(**elevation dominates** the control of peak SWE values)

Éléments de code

Albedo

- <https://orchidas.lsce.ipsl.fr/dev/albedo/>

Code Orchidée

- http://forge.ipsl.jussieu.fr/orchidee/browser/branches/ORCHIDEE_2_2/ORCHIDEE/src_sechiba/explicitsnow.f90
- http://forge.ipsl.jussieu.fr/orchidee/browser/branches/ORCHIDEE_2_2/ORCHIDEE/src_sechiba/condveg.f90
- http://forge.ipsl.jussieu.fr/orchidee/browser/branches/ORCHIDEE_2_2/ORCHIDEE/src_sechiba/enerbil.f90

*"An independent hydrological budget is calculated for each soil tile, to prevent forests from exhausting all soil moisture. In contrast, **only one energy budget (and snow budget) is calculated for the whole grid cell.**"*

Boucher et al. (2020)

Code LMDZ topography

- http://trac.lmd.jussieu.fr/LMDZ/browser/LMDZ6/trunk/libf/phylmd/grid_noro_m.F90

```
REAL, INTENT(OUT) :: zmea(:,:) !--- MEAN OROGRAPHY (imar+1,jmar)
REAL, INTENT(OUT) :: zstd(:,:) !--- STANDARD DEVIATION (imar+1,jmar)
REAL, INTENT(OUT) :: zsig(:,:) !--- SLOPE (imar+1,jmar)
REAL, INTENT(OUT) :: zgam(:,:) !--- ANISOTROPY (imar+1,jmar)
REAL, INTENT(OUT) :: zthe(:,:) !--- SMALL AXIS ORIENTATION (imar+1,jmar)
REAL, INTENT(OUT) :: zpic(:,:) !--- MAXIMUM ALTITUDE (imar+1,jmar)
REAL, INTENT(OUT) :: zval(:,:) !--- MINIMUM ALTITUDE (imar+1,jmar)
```

```
!==== FILTERS TO SMOOTH OUT FIELDS FOR INPUT INTO SSO SCHEME.
!---- FIRST FILTER, MOVING AVERAGE OVER 9 POINTS.
```

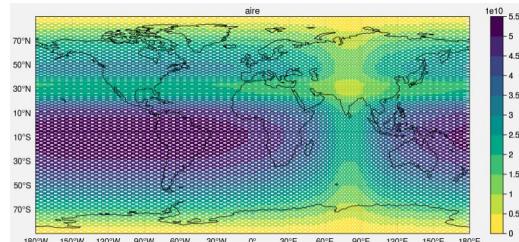
```
!----- ! GK211005 (CG) UNSMOOTHED TOPO
phi(:,:)=zmea(:,:)
CALL MVA9(zmea); CALL MVA9(zstd); CALL MVA9(zpic); CALL MVA9(zval)
CALL MVA9(zxtzx); CALL MVA9(zxtzy); CALL MVA9(zytzy)
```

Autres prospectives

Autres prospectives

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

- Introduction de la nouvelle **paramétrisation sous-maille** (en cas de succès) dans le modèle afin de faire des simulations plus précises et mieux représenter les changements de la cryosphère
 - 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)
 - Etudier les expériences **DAMIP** déjà à 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



Exemple de grille zoomée

Conclusions

Conclusions sur le déroulement de la thèse

Thèse

- Début de première année : formations, biblio, prise en main des outils
- Milieu de première année : Analyse des biais + essaie de **simulations**
→ **Biais plus important dans LMDZ CMIP6** (couplé) que CMIP5 sur les **HMA** (lien possible avec la troposphère, la topographie, les précipitations et d'autres variables non étudiées : albédo, couverture nuageuse, aérosols, couche limite, bilan énergétique de surface)
- Fin de première année : Analyse **multimodèle CMIP6 + paramétrisation de la couverture de neige** liée à la topographie sous-maille dans LMDZ + autres

Encadrement

- Encadrants, labo, Grenoble top → toujours aussi motivé pour la suite !

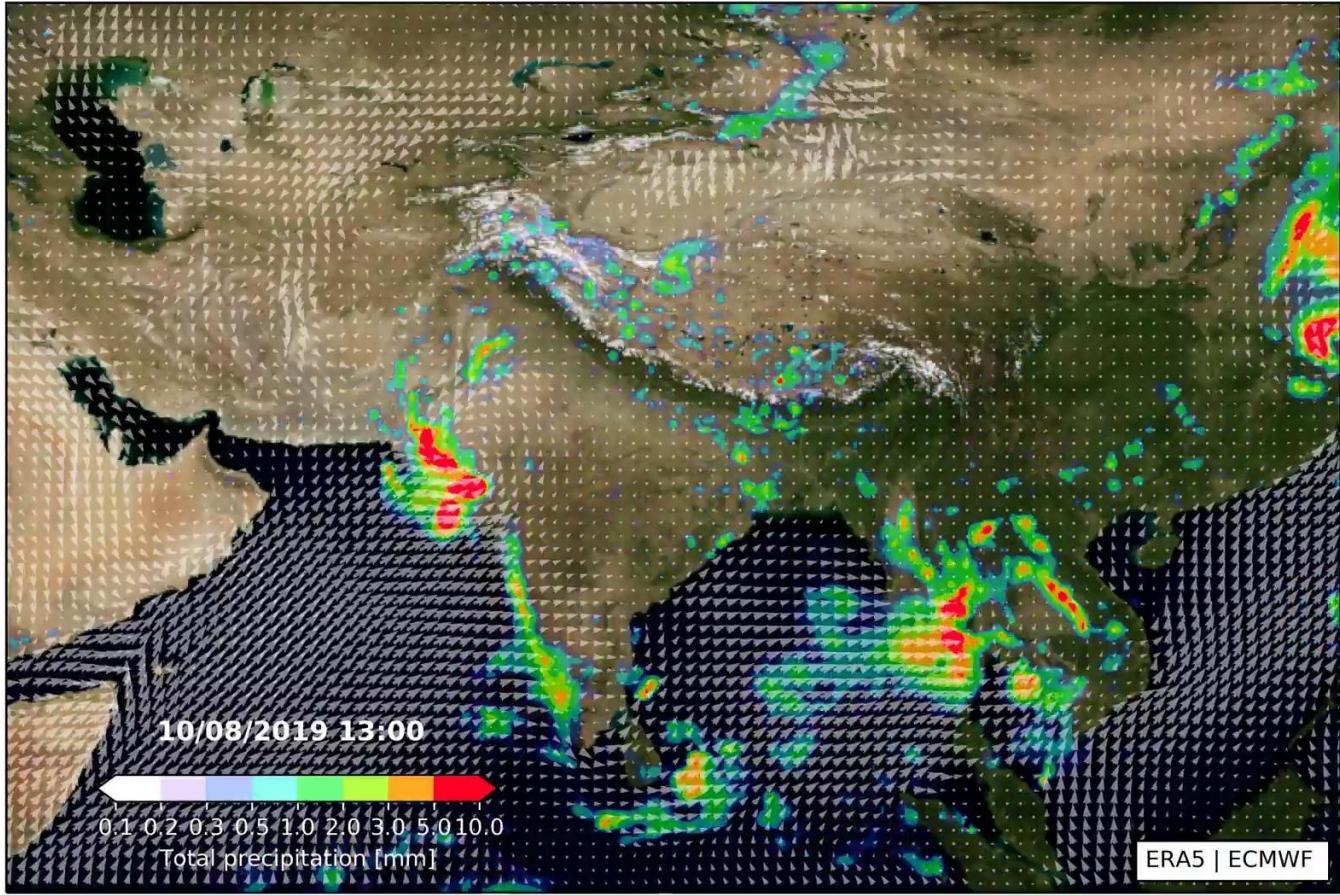
Perso

- Pas mal investi dans les outils émergents d'analyses (Python, Jupyter, [xarray](#), [dask](#), [intake](#), [proplot](#), [xESMF](#), etc.)
 - [MC-Toolkit](#) à l'IGE / Échange avec Guillaume Levasseur pour mettre en place sur CICLAD un catalogue [Intake](#) + Dask (parallélisation) + environnement [Pangeo](#)
 - Tout mon projet est sur [Github](#) (+ liens sur les figures) + présentations sur mon [site internet](#)

Bonus

- Projet de chaîne Youtube sur la vulgarisation autours du climat ([Sciences et Climat](#))
- Quelques [photos](#) de randonnées

Conclusions



Bibliographie

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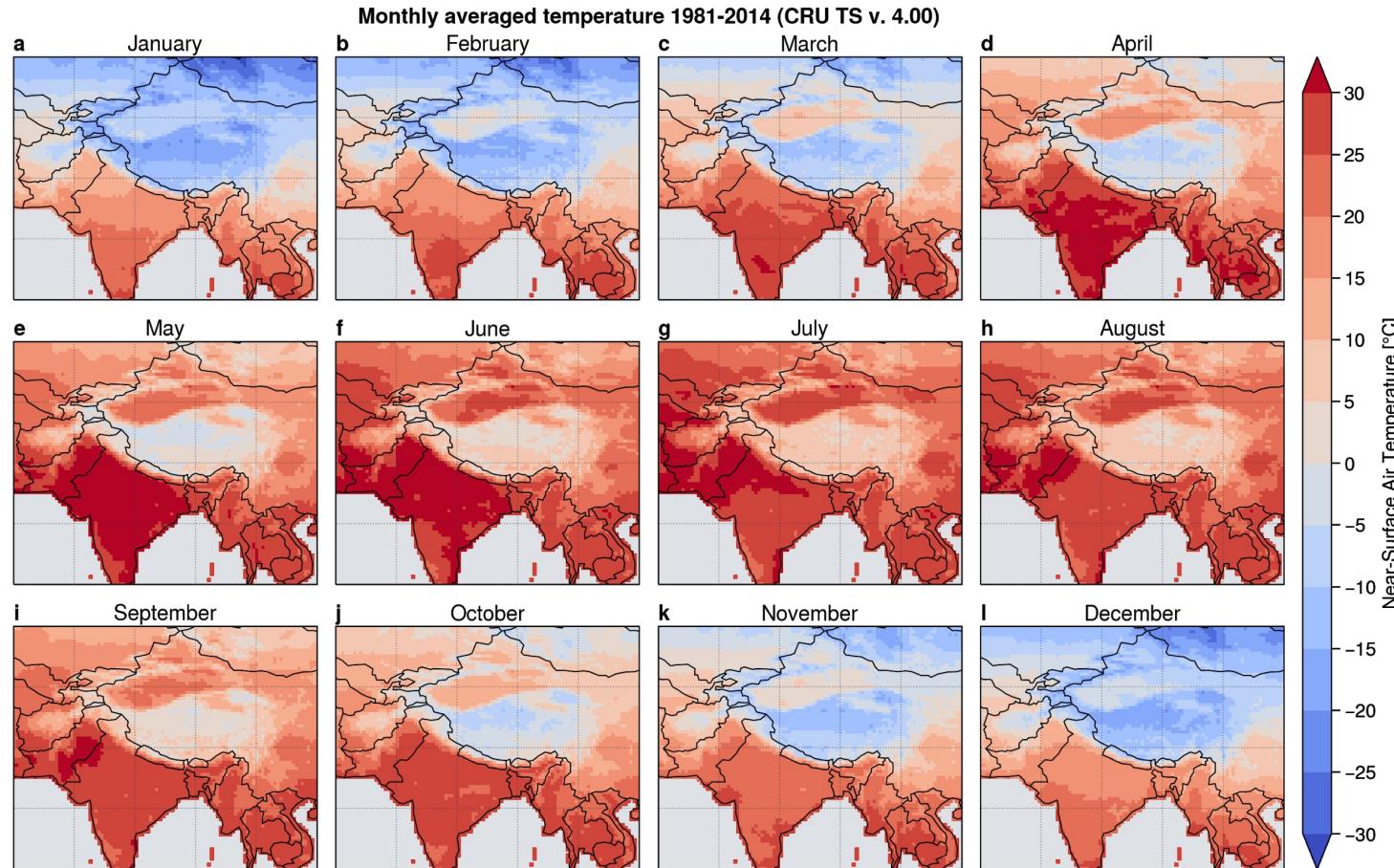
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Slides complémentaires

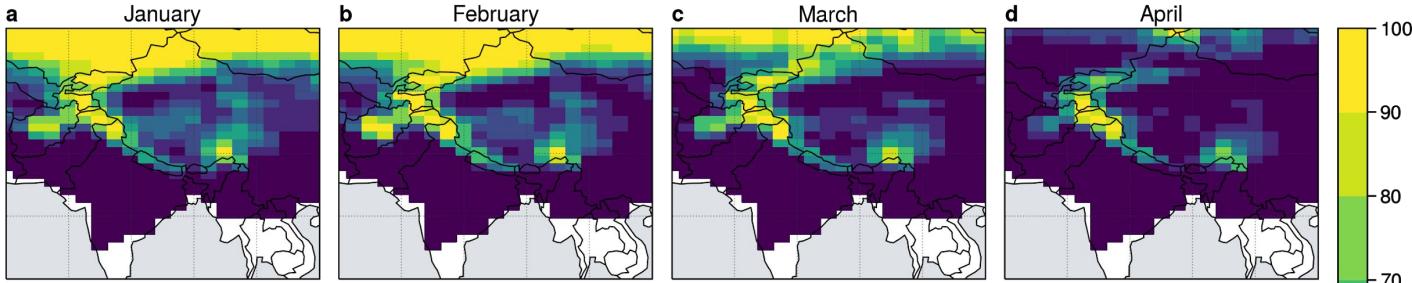
Near-Surface Air Temperature climatologies (CRU)



Monthly snow cover climatologies (from satellite observations)

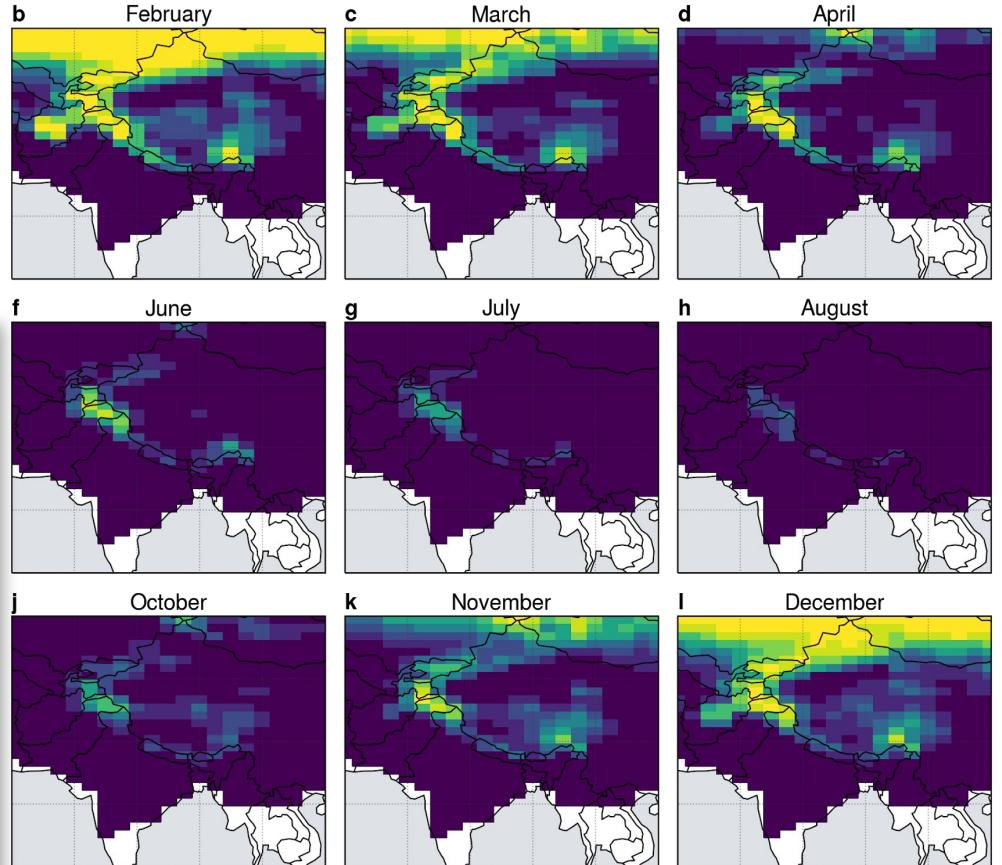
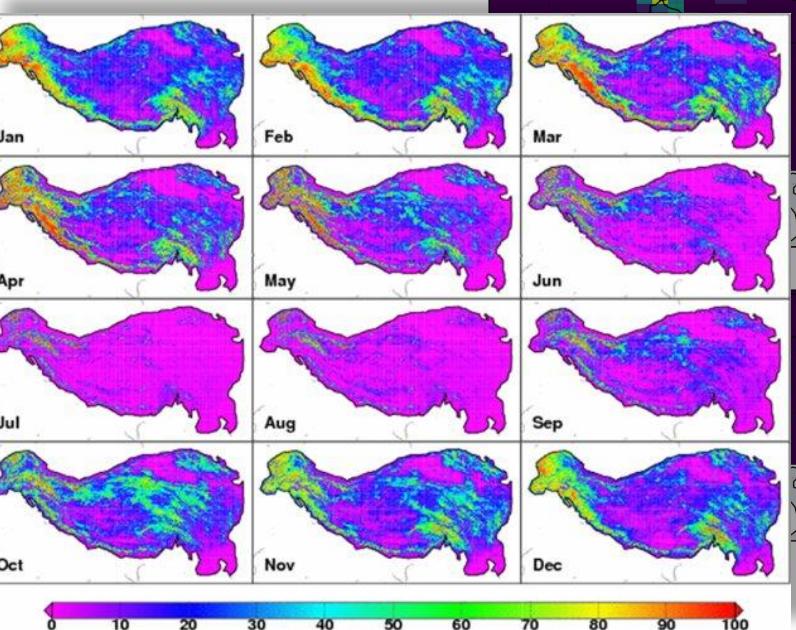
NOAA Climate Data Record (CDR) of Northern Hemisphere (NH) Snow Cover Extent (SCE), Version 1
(1981-2014)

Monthly averaged snow cover 1981-2014 (NOAA Climate Data Record (CDR) Version 1)



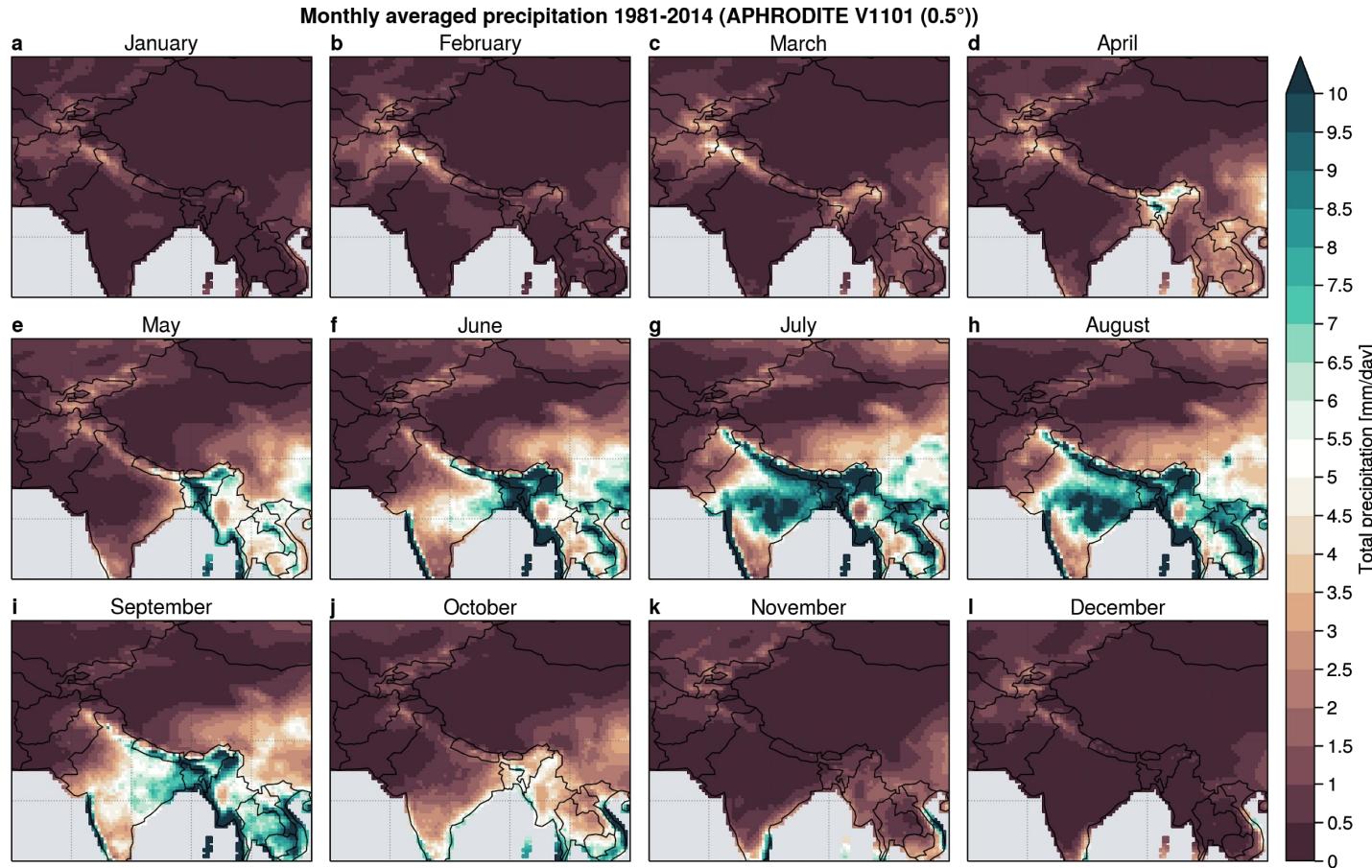
MODIS/Terra Snow Cover 8-Day L3 Global 0.05Deg CMG, Version 6
(2001-2014)

Li et al. (2018), Fig. 2

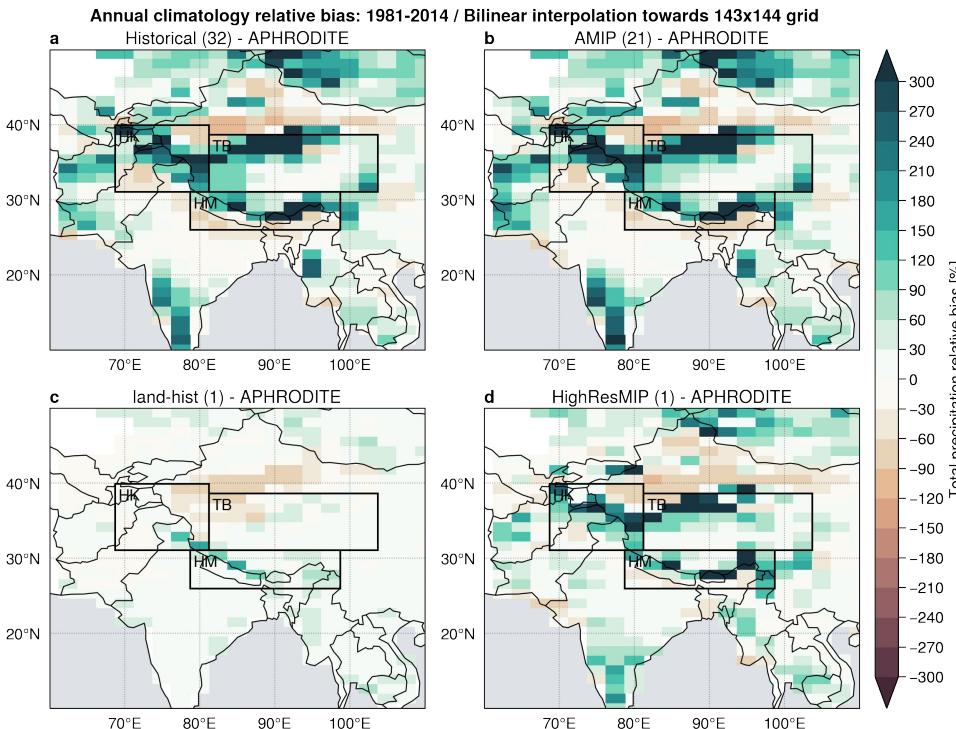


0 10 20 30 40 50 60 70 80 90 100
43

Precipitation climatologies (APHRODITE)



Total precipitation **relative** bias (versus stations observations)

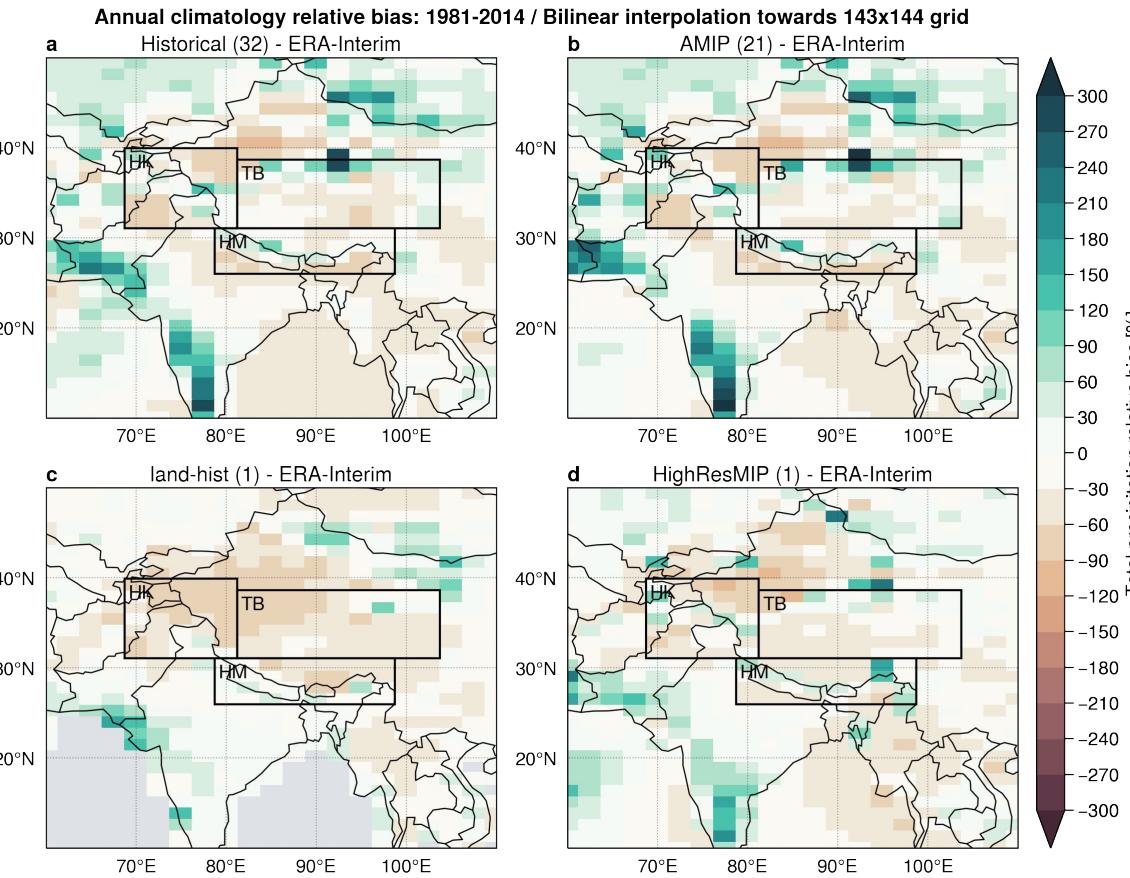


BUT... ([see ERAI](#))

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



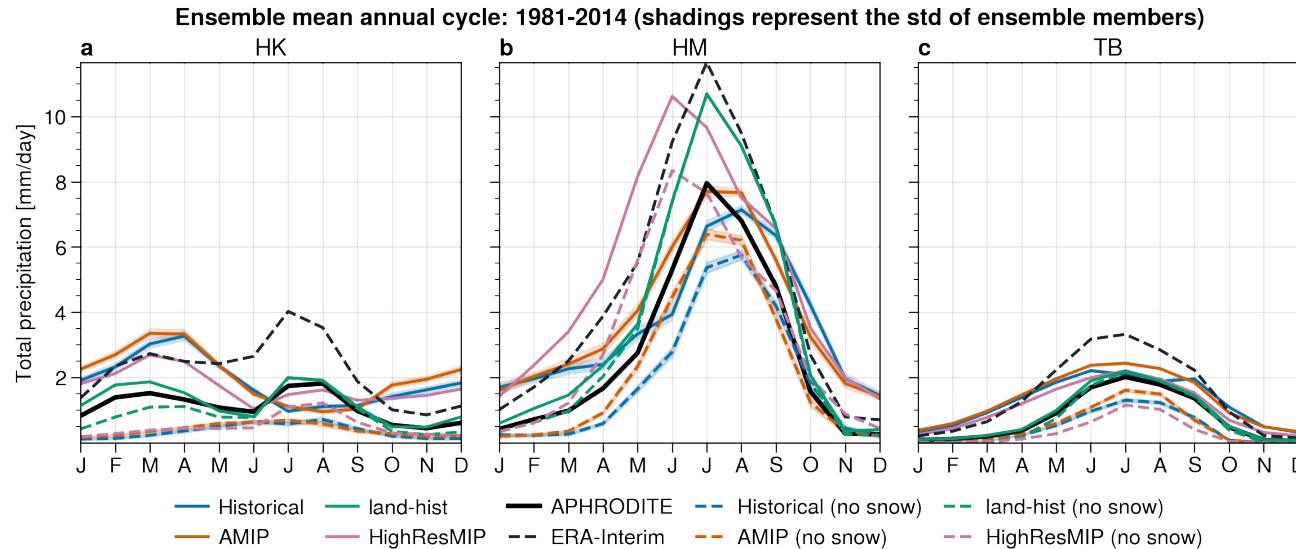
Total precipitation **relative bias**
(versus reanalysis)

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](#)

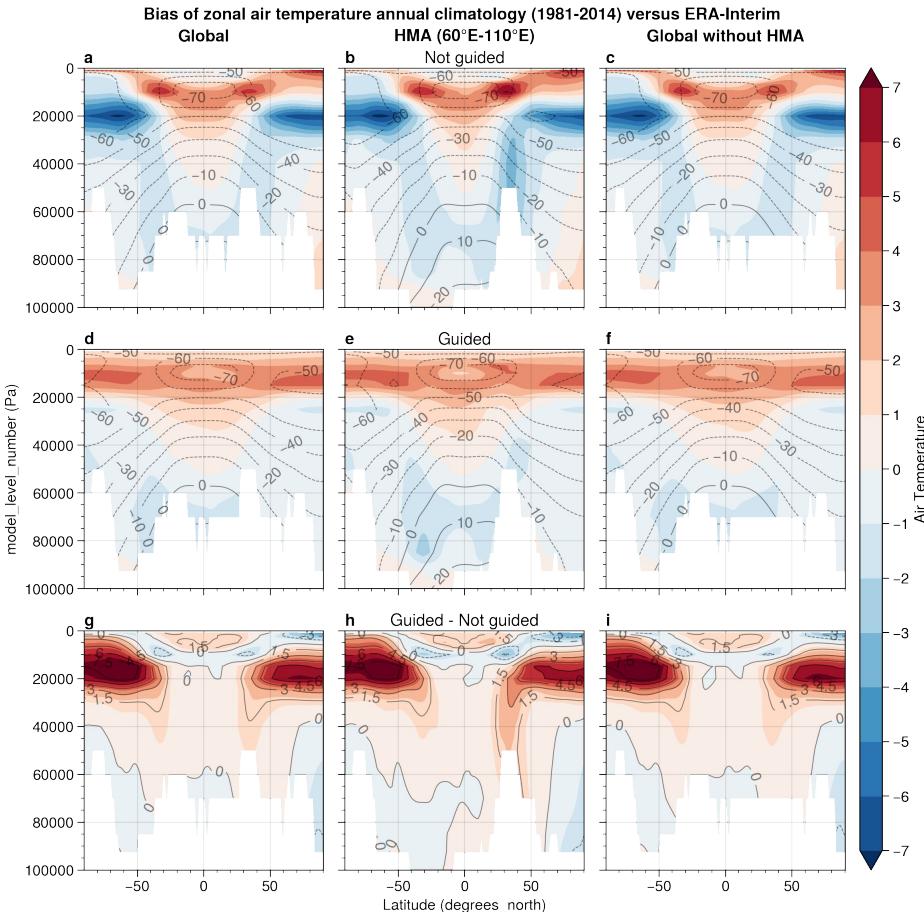
Precipitation: annual cycles



“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)

Nudged versus not nudged



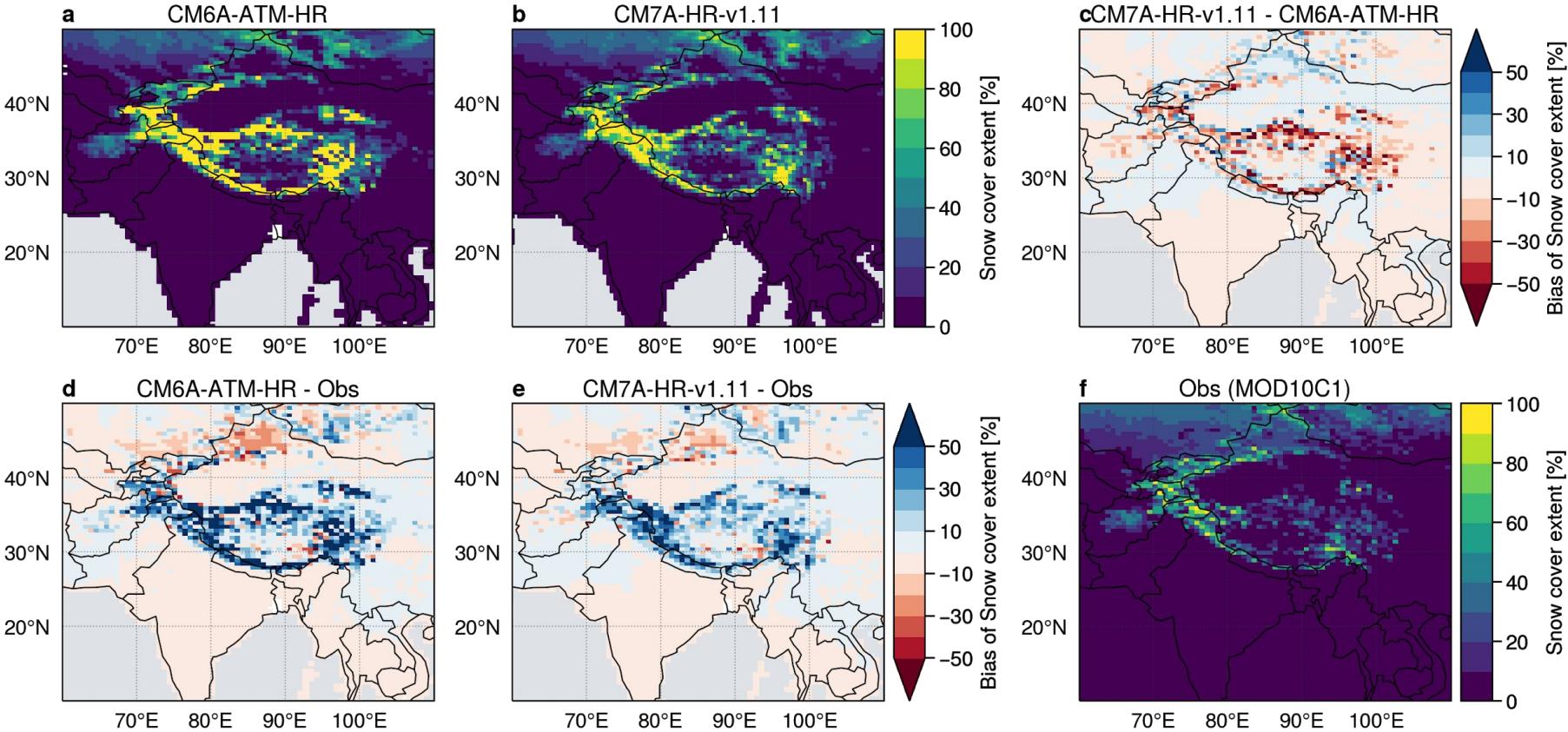
More:

<https://docs.google.com/document/d/1SpVhVviaGEyB9KObkgC4U2hC-qraRfaE-ojLayZcDGPU/edit?usp=sharing>

[Back](#)

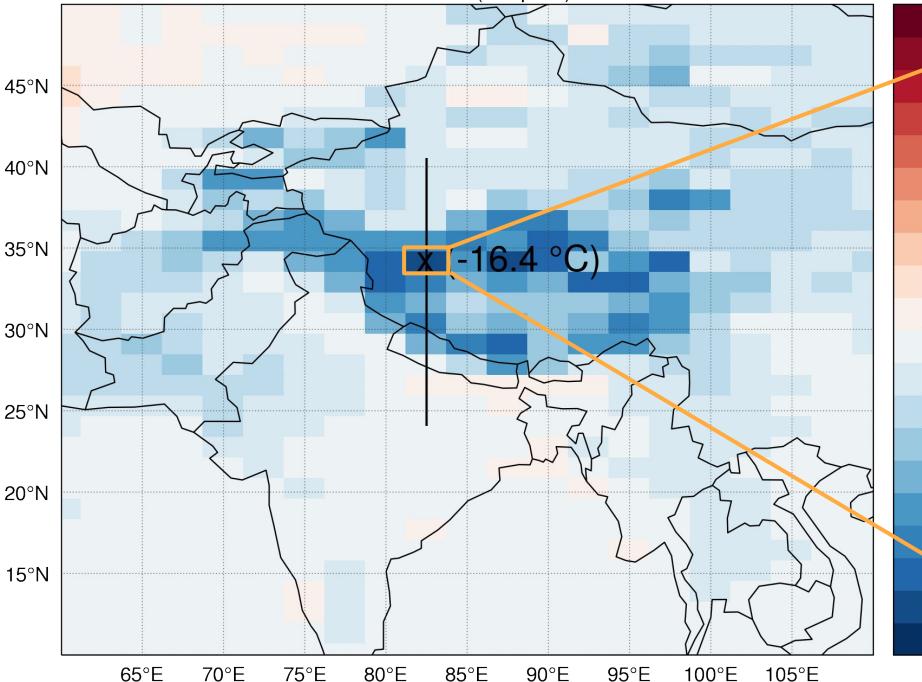
Dynamico versus HighResMIP: snow cover*

Snow cover extent annual climatology: 2001-2014

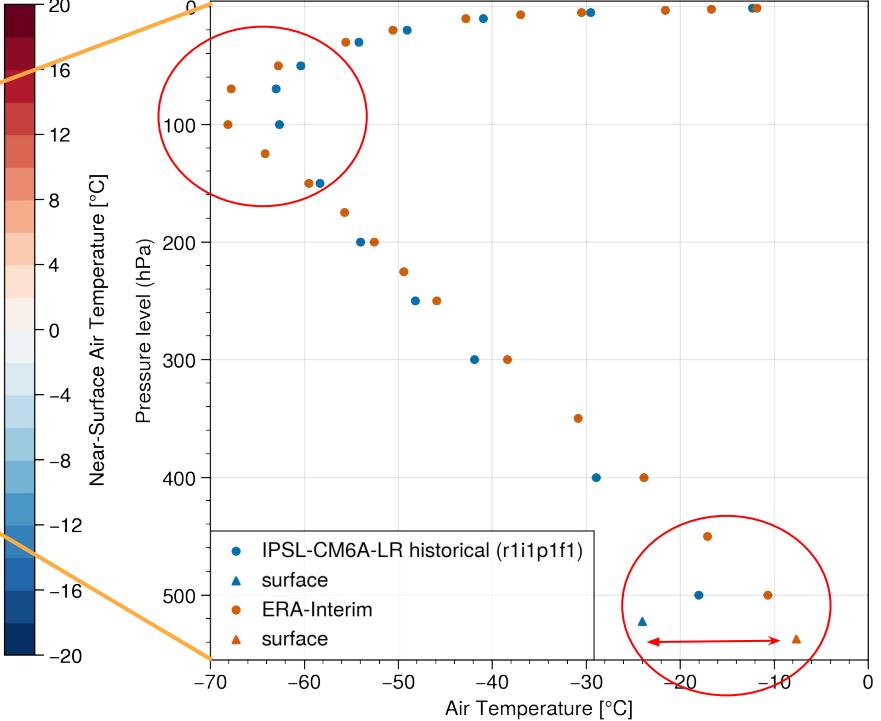


Air Temperature of historical (r1i1p1f1)

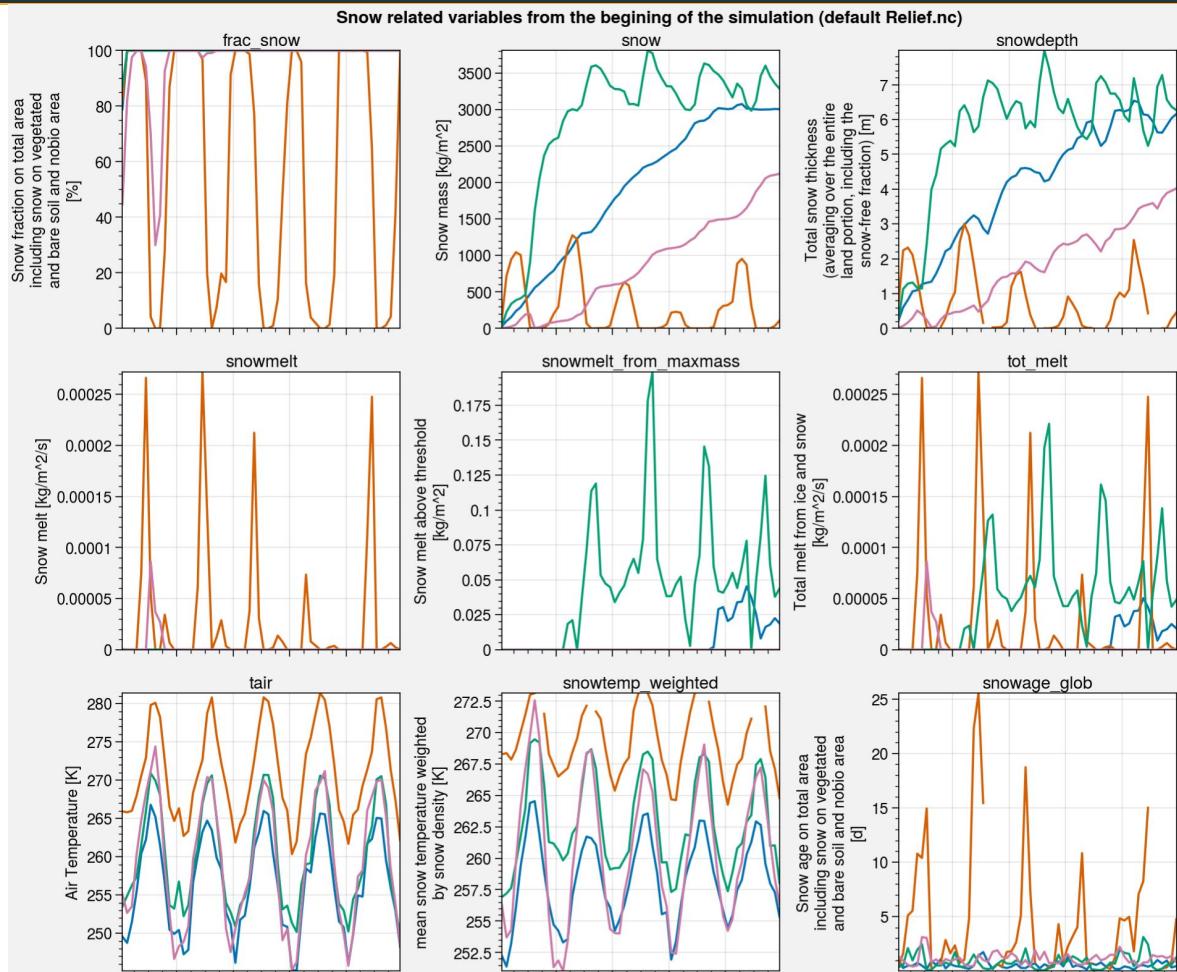
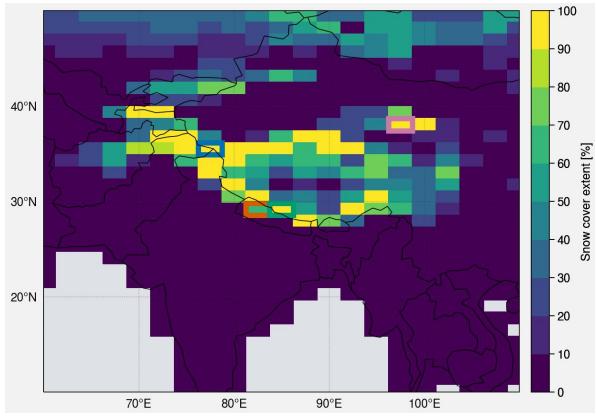
Annual climatology bias: 1981-2014 / Bilinear interpolation towards 143x144 grid
IPSL-CM6A-LR historical (r1i1p1f1) - ERA-Interim



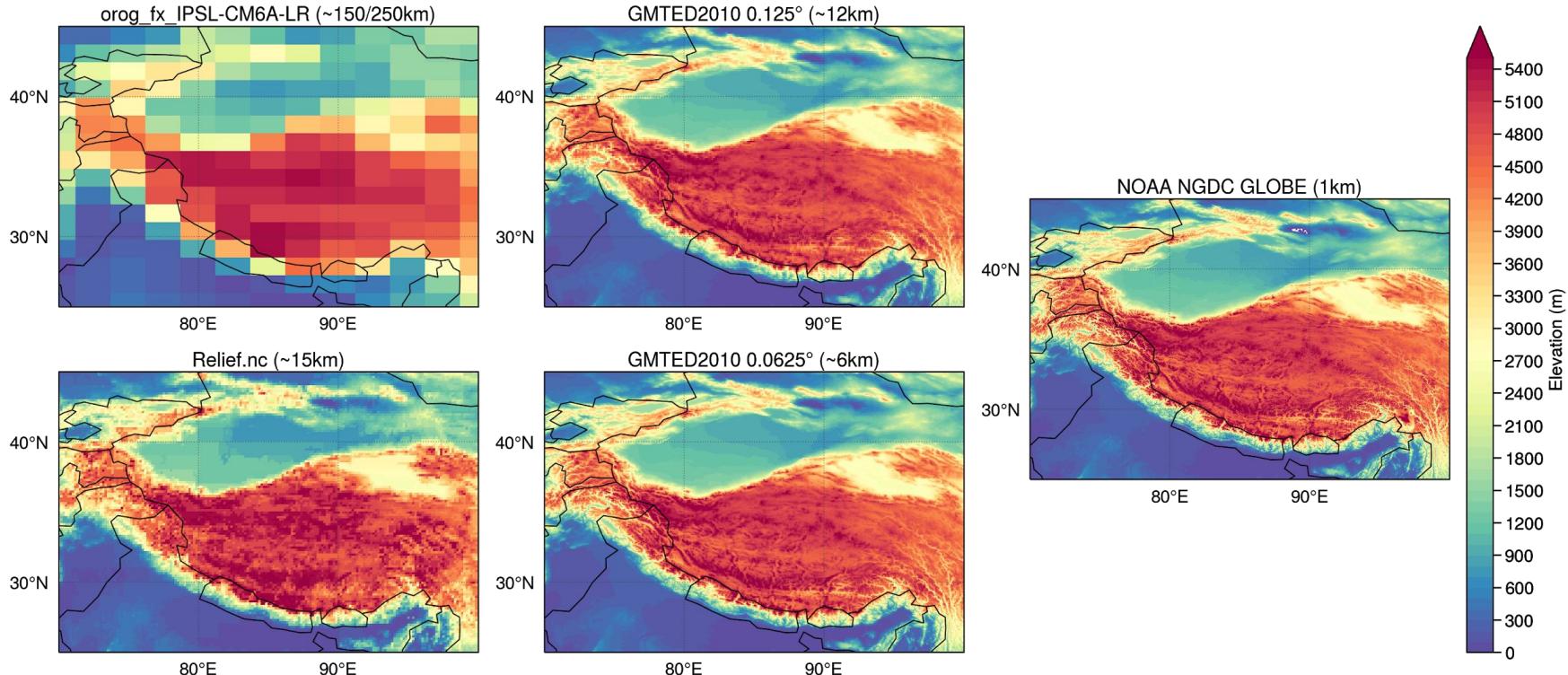
Annual climatology: 1981-2014 / Bilinear interpolation towards 143x144 grid
lon=82.5, lat=34.225353 (-16.4 °C at surface)



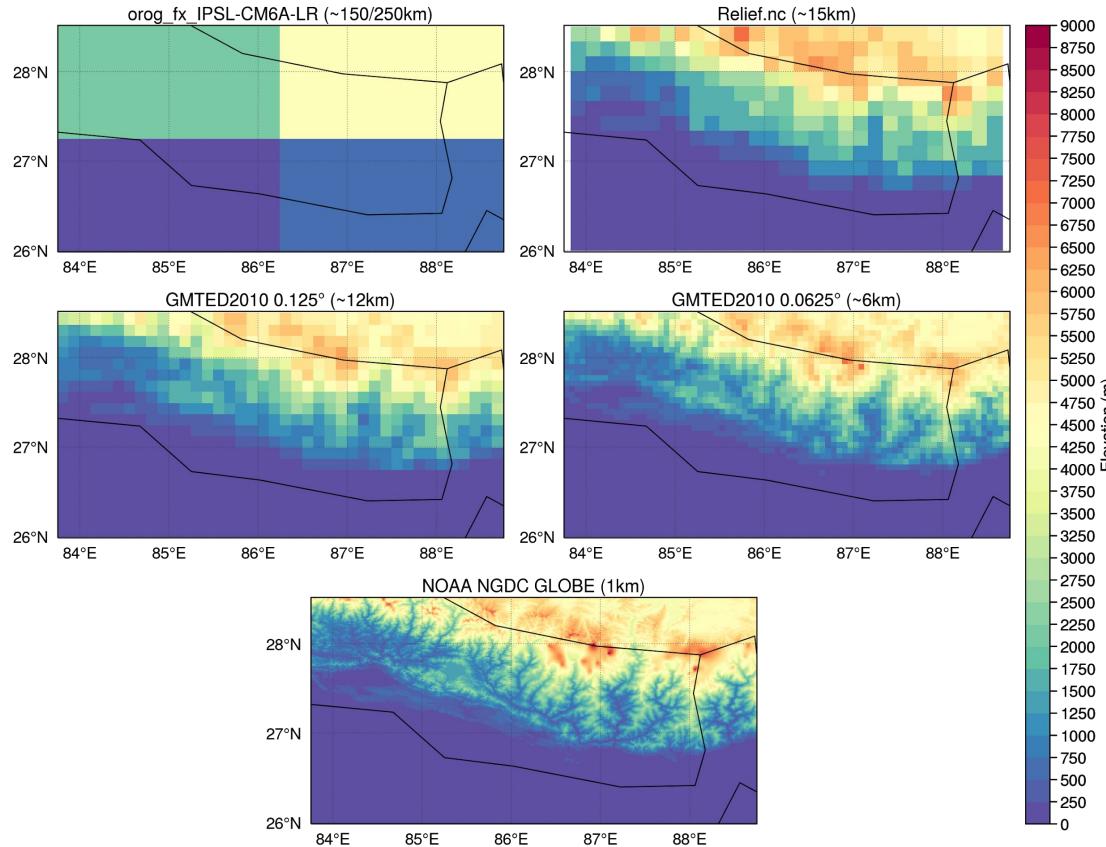
Snow evolution



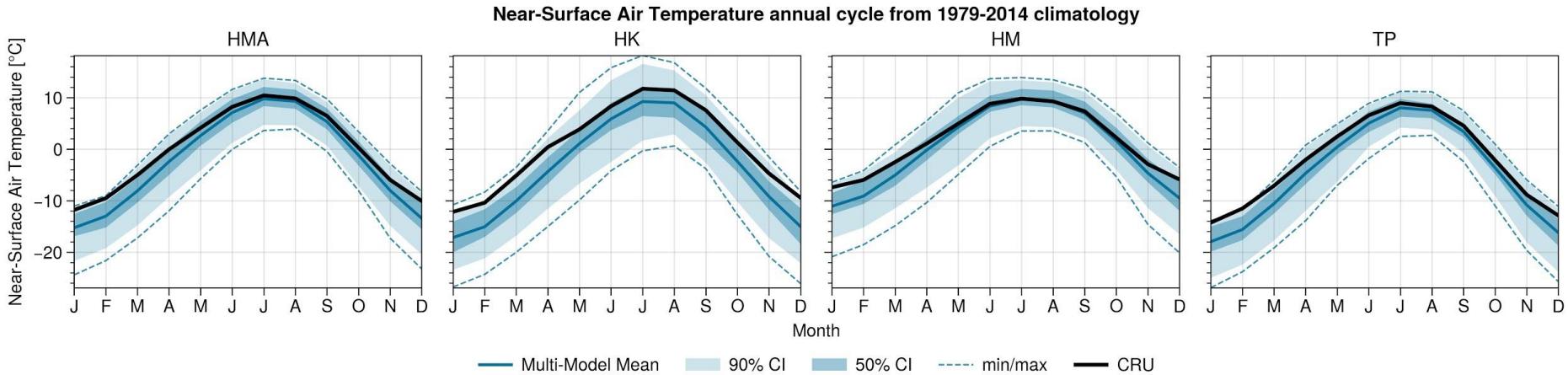
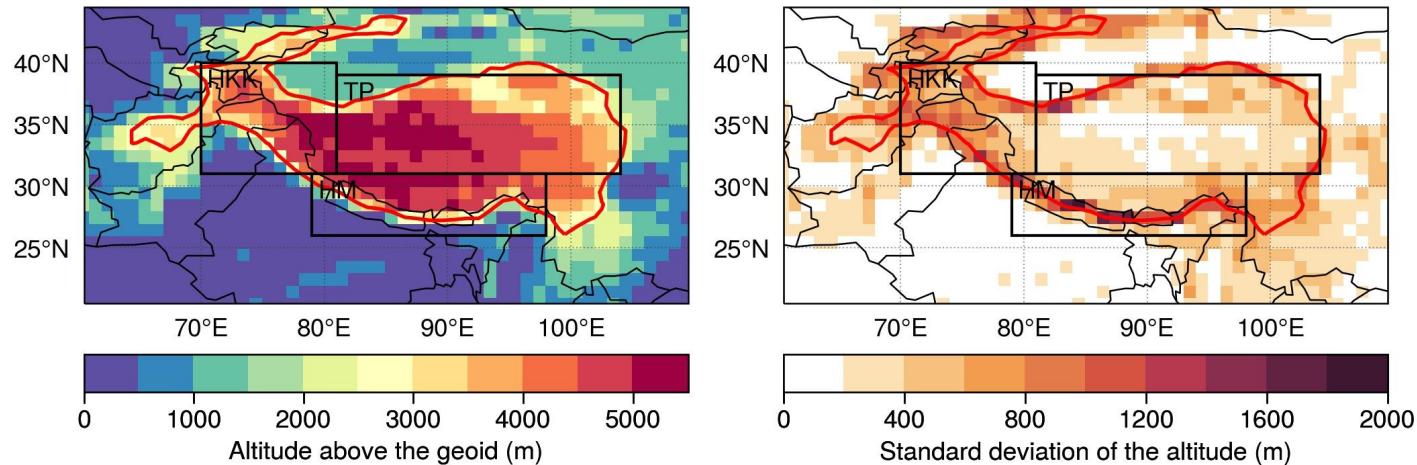
Paramétrisation sous-maille de la topographie



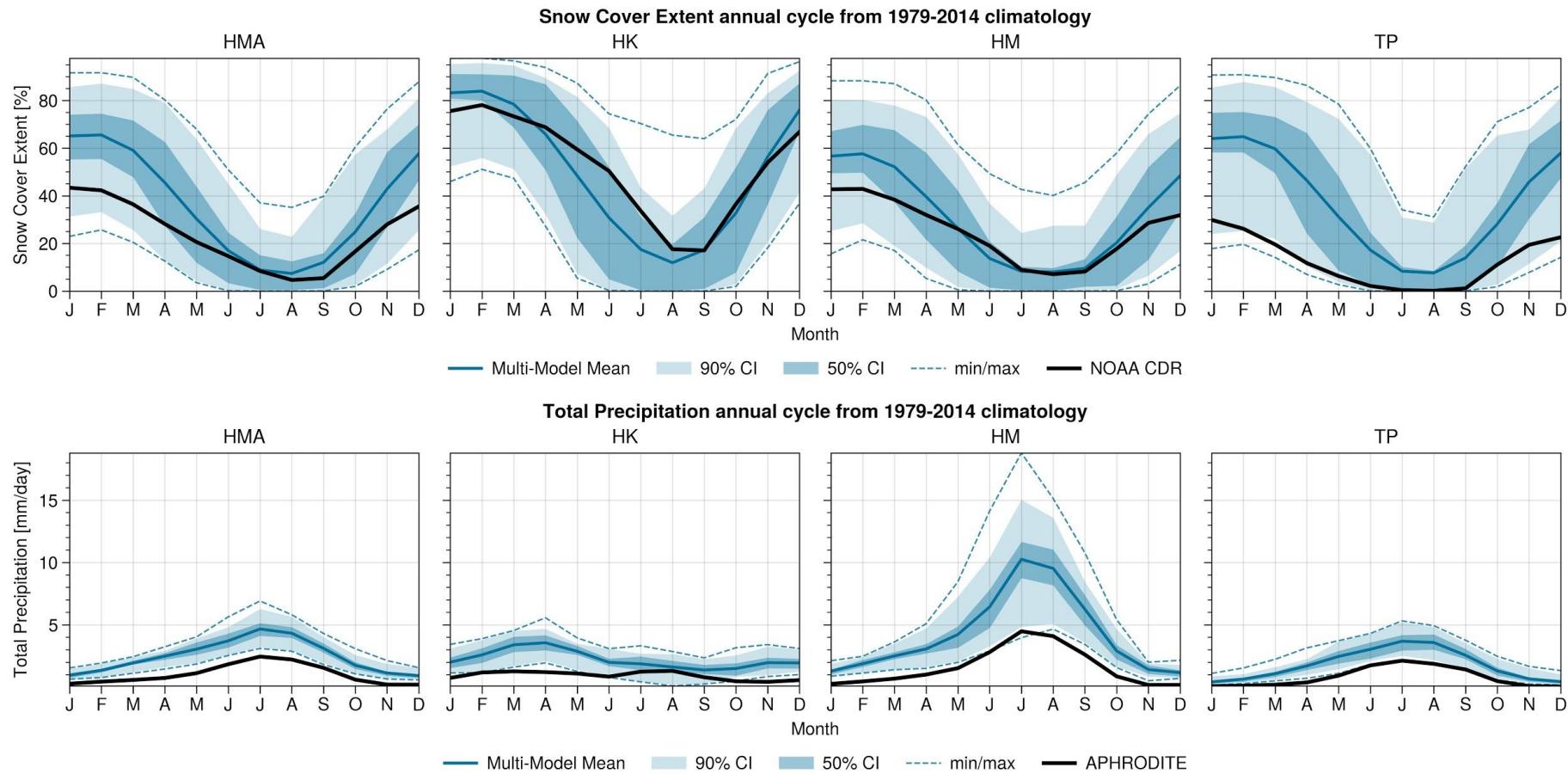
Paramétrisation sous-maille de la topographie



CMIP6 other models: Annual cycles

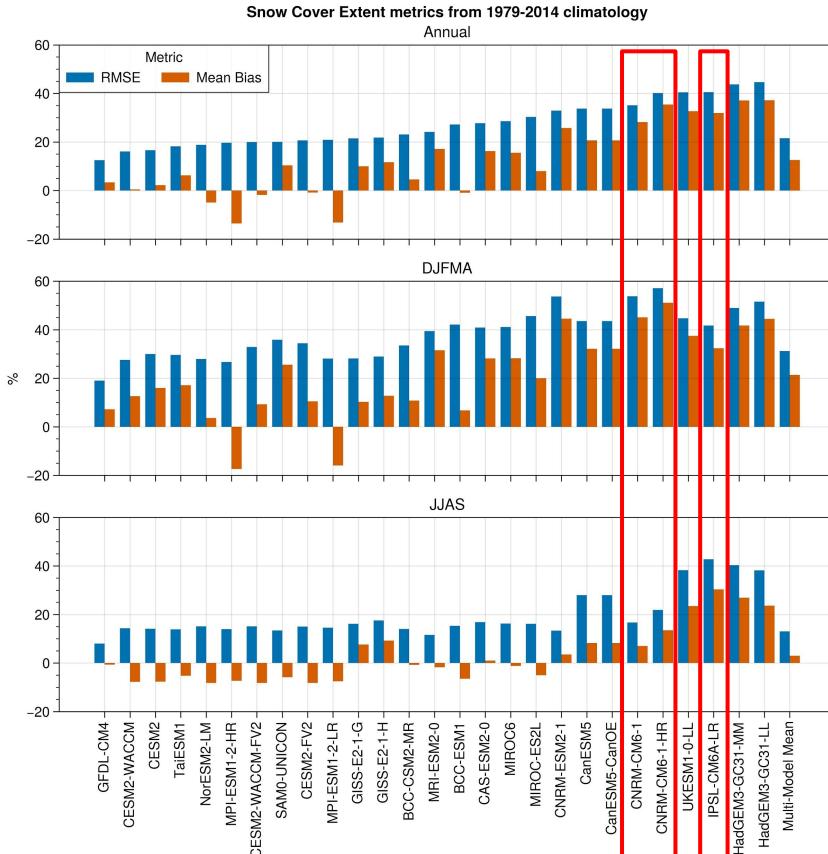


CMIP6 other models: Annual cycles

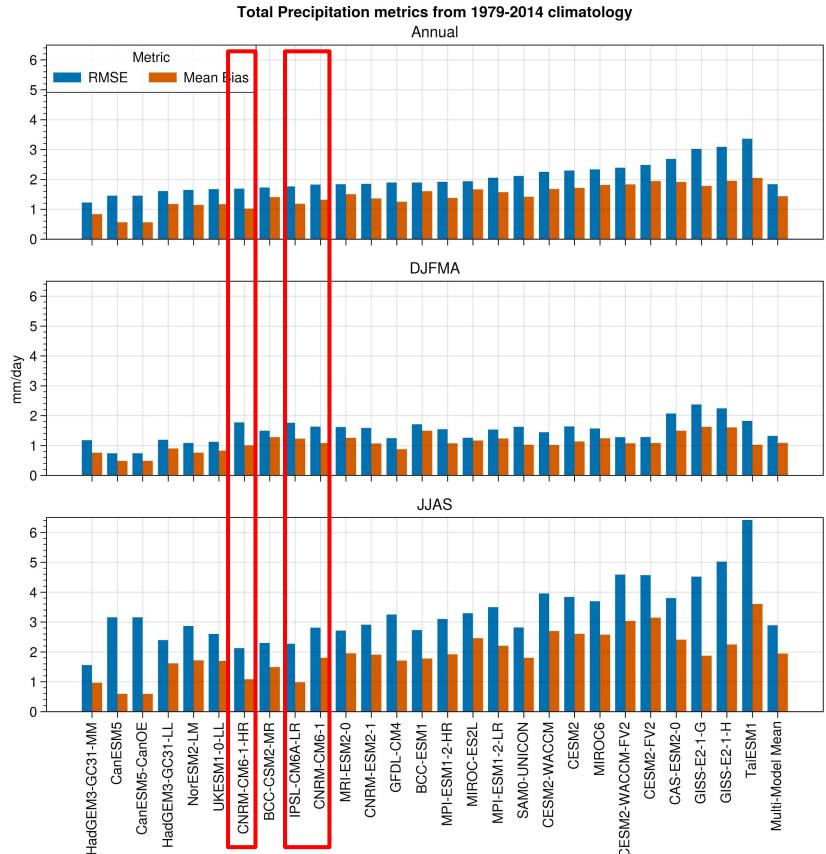


CMIP6 other models: Near-Surface Air Temperature metrics

Sorted by annual RMSE



Sorted by resolution



Atmospheric component of the IPSL integrated climate

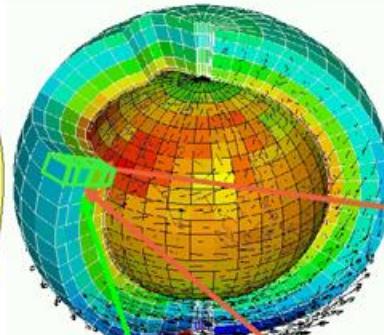
model LMDZ4

LMDZ 3D dynamical core

Finite difference formulation
conserving enstrophy and angular momentum

Single-column model

ID monitor for
academic or test cases



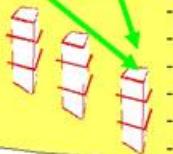
Atmospheric tracers

Transport by winds
Finite volume
methods

* Turbulent mixing
* Convective transport

LMDZ parametrized physics

Earth
Mars
Titan
Parametrized



- radiation (Fouquart/Morcrette)
- boundary layer (LDM + options)
- convection (Emanuel and Tiedtke)
- clouds (statistical scheme)
- orography (Lott)
- ...

INCA

* Chemistry
* Aerosol microphysics

Oceanic GCM

ORCA LIM

Sea ice

* Soil thermodyn.
* vegetation
* hydrology
* carbon cycle

Glaciers
ORCHIDEE