LMDZ for regional climate study : “cold bias” in High Mountain Asia (HMA)

Mickaël Lalande

PhD Student 2019-2022
Supervisors : Gerhard Krinner et Martin Ménégoz
Institut des Géosciences de l’Environnement (IGE, Grenoble, France)

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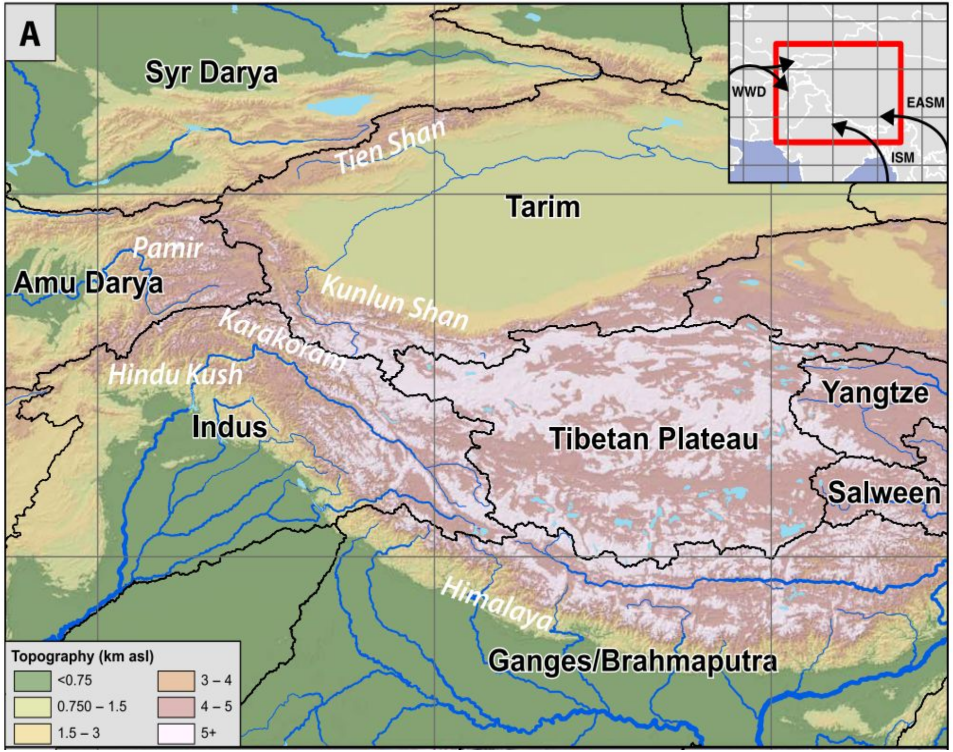
High Mountain Asia (HMA): Introduction

- The Tibetan Plateau (TP) region is the world's highest plateau (average elevation 4000m). It exerts a considerable influence on regional and global climate. (Orsolini et al., 2019)
- The region provides ecosystem services (e.g., water, food, energy) that directly sustain the livelihoods of 240 million people in the mountain and hills of the HKH*. (Sharma et al., 2019)
- Nearly 1.9 billion people living in the 10 river basins also benefit directly and indirectly from its resources, while more than 3 billion people enjoy the food produced in its river basins. (Sharma et al., 2019)

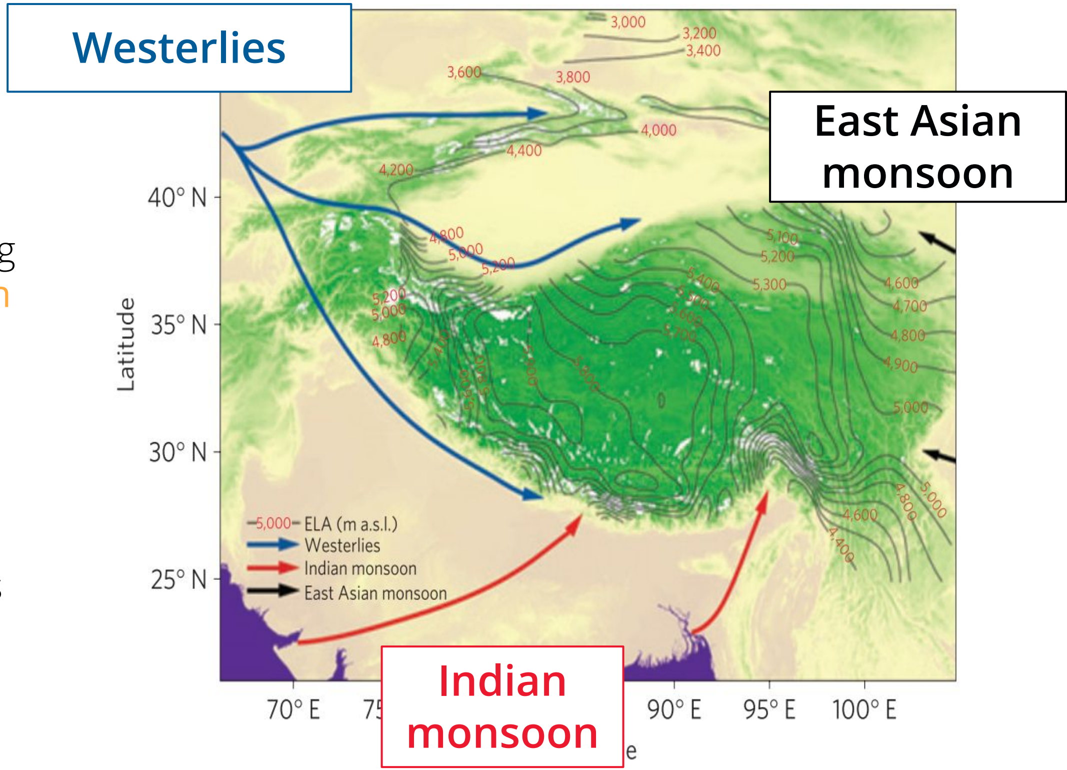


Smith and Bookhagen (2018), Fig. 1A

*Hindu Kush Himalaya

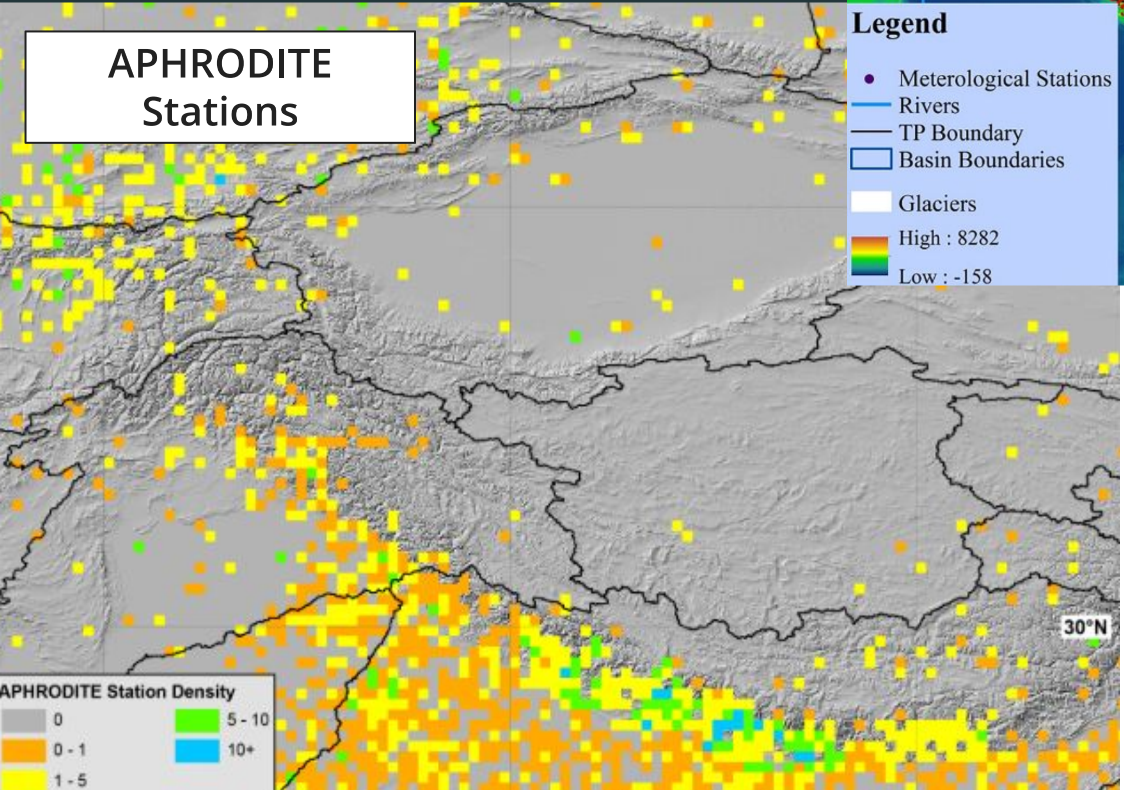
High Mountain Asia (HMA): two climatic regimes

- Two distinct climatic regimes:
  - the winter westerly disturbances (from December to March) contributing to more than 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)

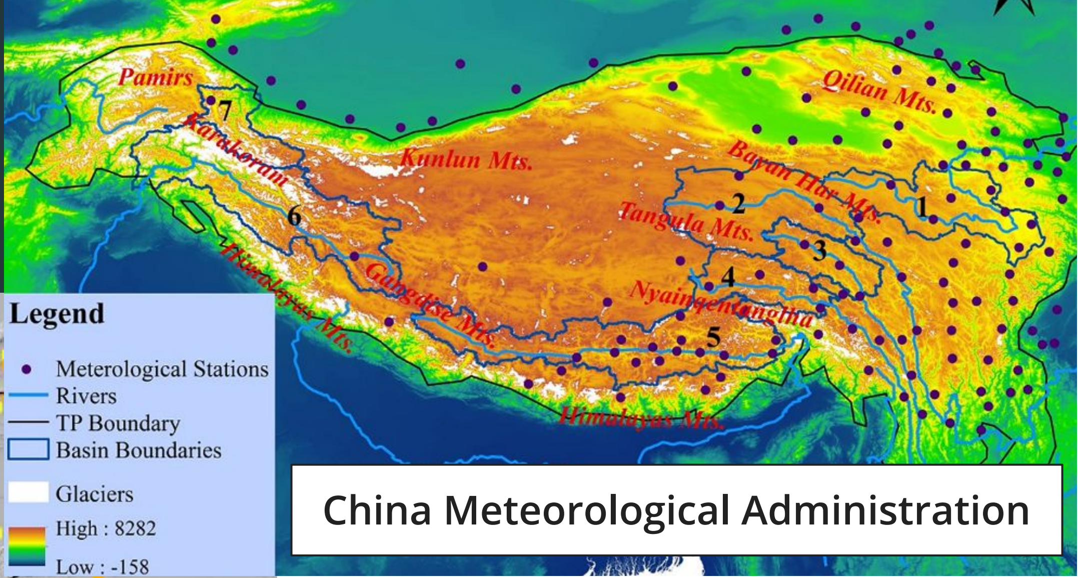


Yao et al. (2012), Fig. 1

High Mountain Asia (HMA): station observations



Smith and Bookhagen (2018), Fig. S1



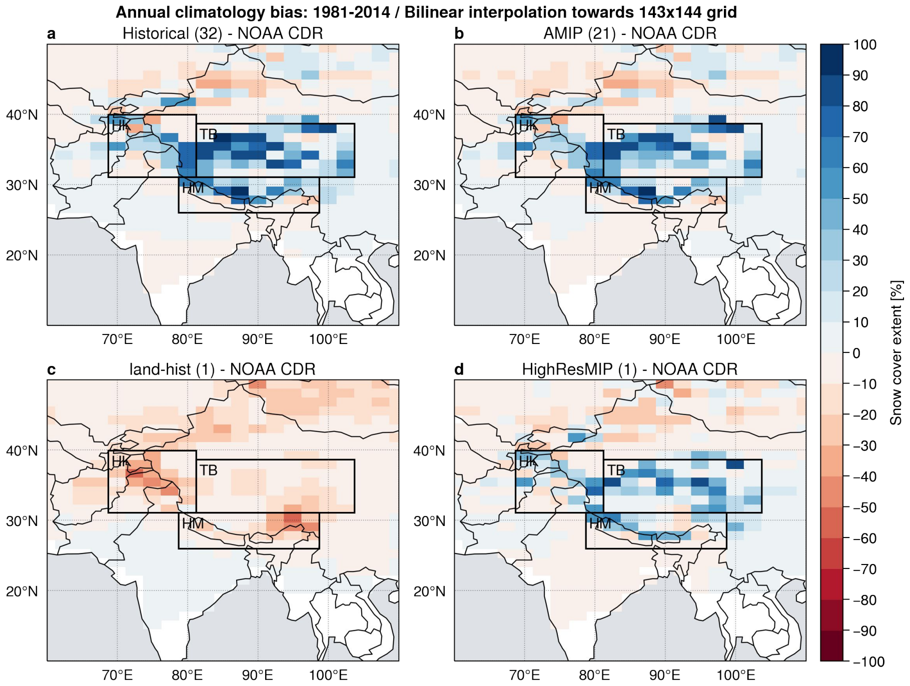
Li et al. (2018), Fig. 1

- 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)

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

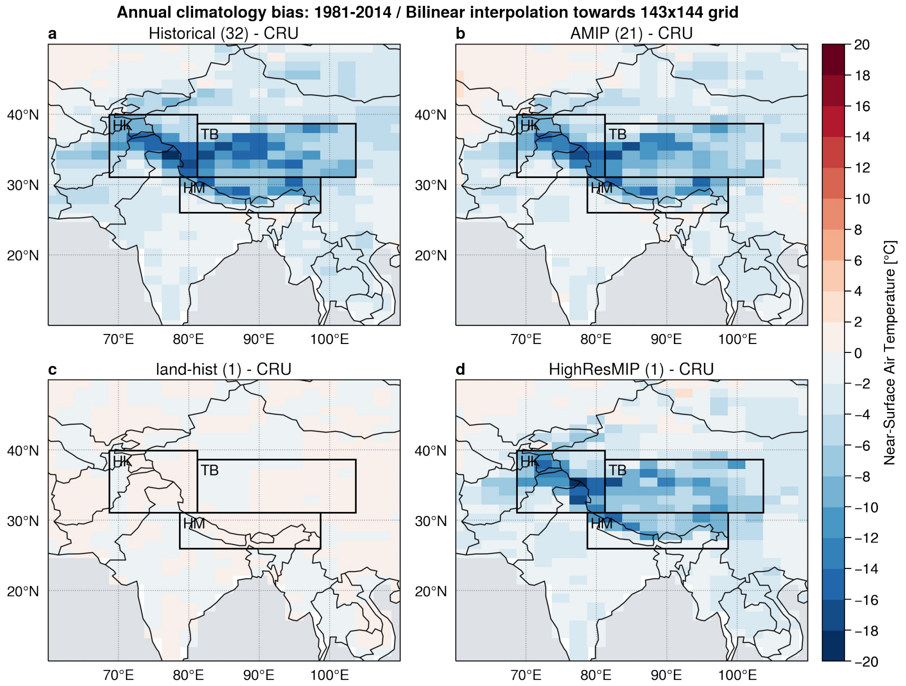
Snow cover bias

(versus satellite observations)



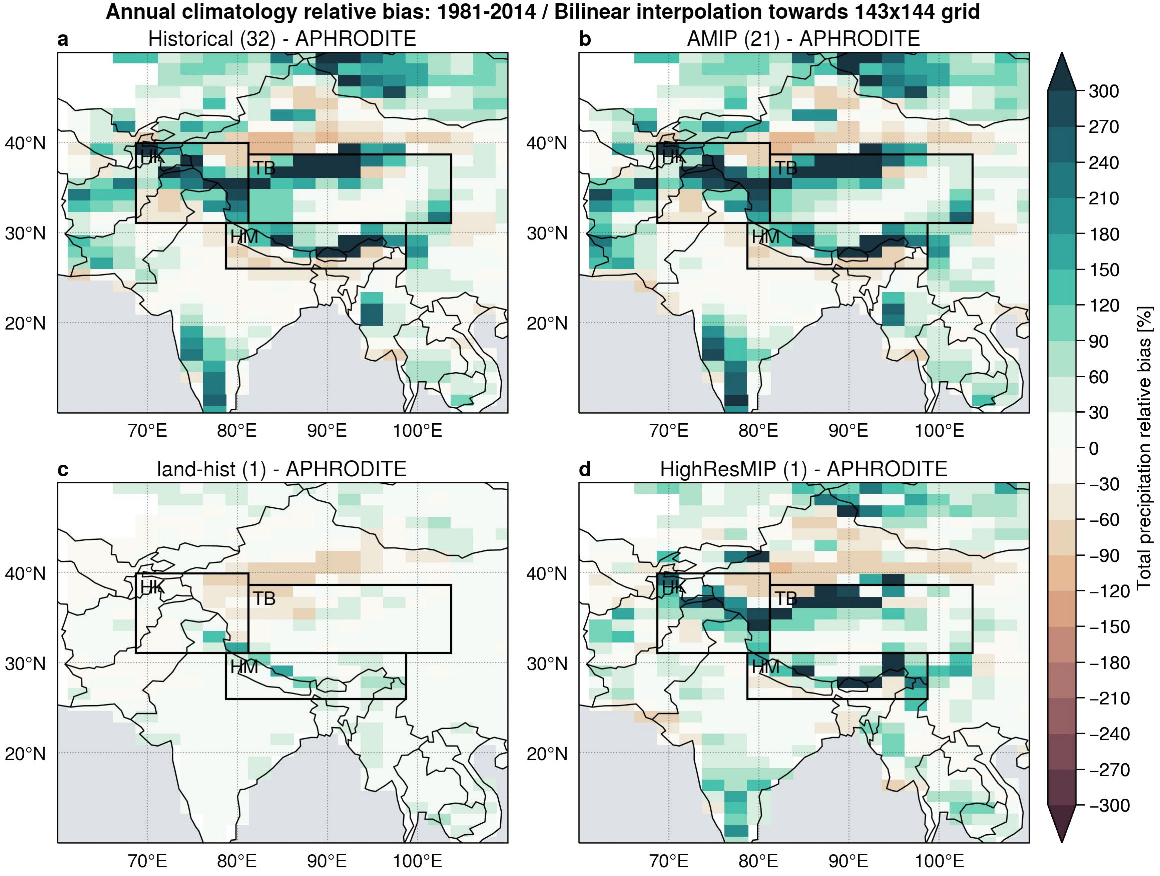
Temperature bias

(versus stations observations)



- Large cold bias and excess of snow cover mainly located on the Tibetan Plateau (see more)
- land-hist slightly underestimate the snow cover → the bias seems coupled with the atmosphere
- This bias is documented from 1998 (Mao and Robock, 1998 — First AMIP experiments) and still present in last CMIP5 experiments (Su et al., 2013; Xu et al., 2017; Chen et al., 2017; Salunke et al., 2019) so not restricted to IPSL-CM model (see more)

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



Total precipitation **relative** bias

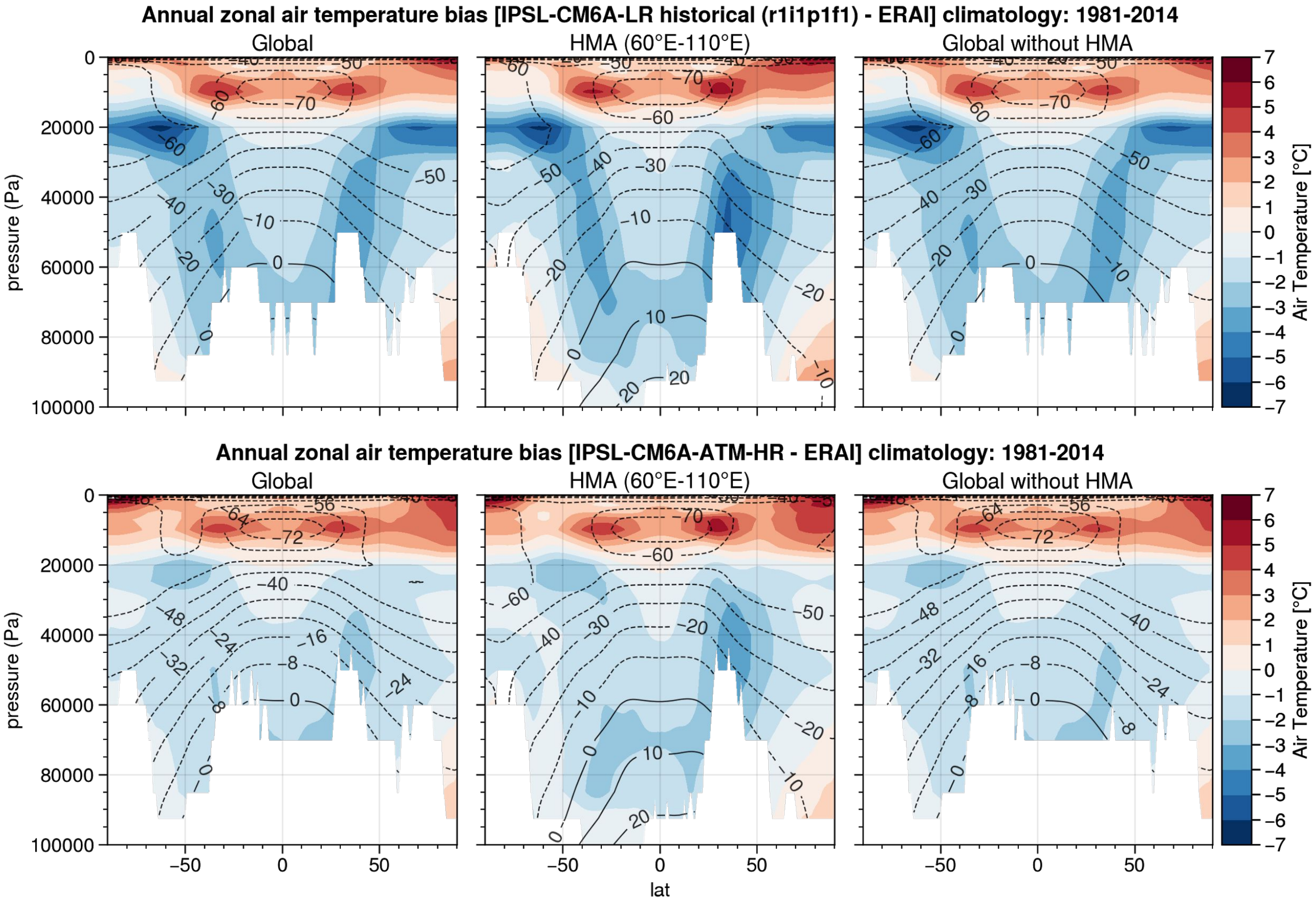
(versus stations observations)

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)

Air Temperature zonal means bias global versus HMA

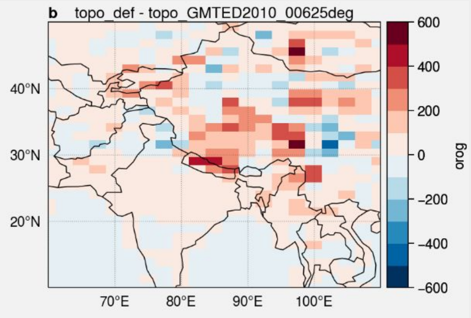


- Cold bias in troposphere and hot bias in stratosphere
- Cold bias of air temperature not restricted to HMA!
- HMA seems to amplify this bias
- The bias is reduced in HighResMIP

Same to zonal means from Boucher et al., Fig. 3 (submitted)

Different options

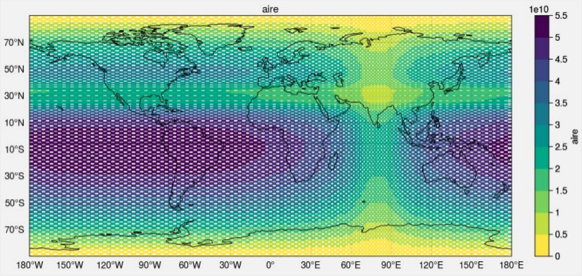
Problem with elevation?



Original file of elevation has more than 500 m differences locally! (but doesn't look much correlated with the bias...)

→ 2 experiments with original and new topographic file in process

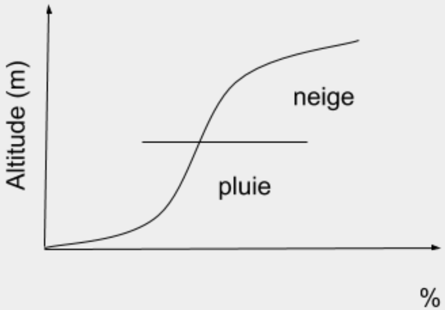
Problem with troposphere/resolution?



Amplification of temperature biases in the troposphere and/or feed back from the surface?

→ zoomed and nudged experiment?

Problem with subgrid parameterization?



Wrong phase distribution over complex terrain?
(but the bias are not much related to the std of elevation... + land-hist ok...)

→ 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

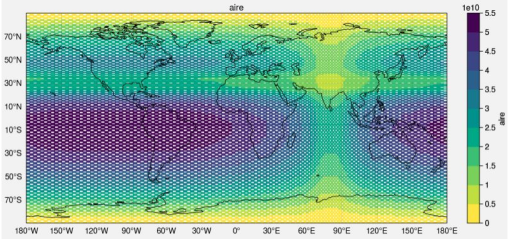
Getting ready for a test zoom x2 simulation over HMA on Jean Zay

Version: LMDZOR_v6.1.11

1. Create initial files with CREATE_amip (limit.nc, start.nc and startphy.nc)*

⚠️ in COMP/lmdz.card: LMDZ_Physics=NPv6.1 does not fit with the usual version of the Physics of LMDZOR_v6.1.11 (NPv6.1.3) so be aware to modify the right file for setting the zoom or change the right version: PARAM/gcm.def_144x142_NPv6.1

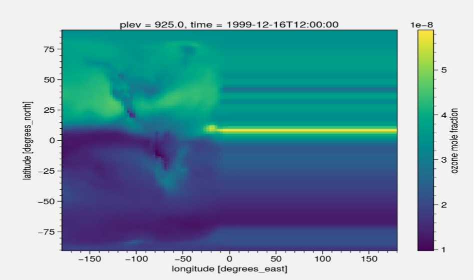
clon = 80. / clat = 30. (HMA)
grossismx/y = 2.0 (zoom x2 for test) / dzoomx/y=0.1
day_step = 672 ➝ 1344 (day_step = day_step(regular grid) * max grossismx/y)
iphysiq = 7 ➝ 14 (iphysiq * 86400 / day_step = 900 s ➝ model time step of 15 min)
tetagdiv, tetagrot, tetatemp?



See: https://lmdz.lmd.jussieu.fr/LMDZPedia/howto-run-at-different-horizontal-resolutions

⚠️ read_climoz=1 with this version:

Boundary/..._climoz_LMDZ.nc



https://github.com/mickaellalande/PhD/blob/master/Jean-Zay/ELI-144x142x79-zoomx2-himalaya-test.ipynb

*/gpfswork/rech/goe/ufz23bm/LMDZOR_v6/modipsl/config/LMDZOR_v6/ELI-144x142x79-zoomx2-himalaya-test

Getting ready for a test zoom x2 simulation over HMA on Jean Zay

2. I tried a simulation without forcing files to check if it works (ozone, tropospheric and stratospheric aerosols)

- COMP/lmdz.card point to the new limit.nc, start.nc and startphy.nc created before
- copy the last gcm.def in the right gcm.def_144x142_NPv6.1.3 (PARAM)
- remove ozone (in COMP/lmdz.card):
  - read_climoz=0
- remove tropospheric aerosols (in COMP/lmdz.card):
  - flag_aersols=0
  - ok_ade=n
  - ok_aie=n
  - ok_cdnc=n
- remove stratospheric aerosols (in PARAM/config.def):
  - flag_aerosol_strat=0

Not easy to find informations about these options... more comments in the code would be nice!

More info that I found:

- https://lmdz.lmd.jussieu.fr/utilisateurs/formation/2013/2013_12_slides/Configurations_input_forcing.pdf
- https://lmdz.lmd.jussieu.fr/utilisateurs/formation/2019/input_forcing-pdf

Still bug!

⚠️ deactivate the river routing that does not work with zoom grid! RIVER_ROUTING=n (in PARAM/orchidee.def_CWRR)

It works! 😃

Getting ready for a test zoom x2 simulation over HMA on Jean Zay

3. Interpolate forcing files on the zoomed grid (ozone, tropospheric and stratospheric aerosols)

- Tropospheric aerosols: /gpfswork/rech/psl/commun/IGCM/ATM/AEROSOLS/CMIP6/v1/144x142/L79
- Ozone: /gpfswork/rech/psl/commun/IGCM/ATM/OZONE/UReading/historical.v20160711.v2
- Stratospheric aerosols: /gpfswork/rech/psl/commun/IGCM/ATM/STRATAERO/CMIP6/v3/144x142/L79

Example of interpolation with CDO (remapbil or remapcon?):
/gpfswork/rech/psl/commun/IGCM/ATM/AEROSOLS/CMIP6/v1/256x256/L79/README

But not easy!

I helped myself from files that I got a bit from everywhere/one that I stored here if it can help you:
https://github.com/mickaellalande/PhD/tree/master/Tools (a bit messy)

For stratospheric aerosols it is even more complicated! We should use volc.sh (see README in http://forge.ipsl.jussieu.fr/igcmg/svn/TOOLS/CMIP6_FORCING/AER_STRAT/), needs at least 1 year simulation with zoom... I gave up on this so far... and used the routine from the link above.

Is there a documentation of this somewhere and/or a better way to do?

References

Smith, T., & Bookhagen, B. (2018). Changes in seasonal snow water equivalent distribution in High Mountain Asia (1987 to 2009). *Science Advances*, *4*(1), e1701550. https://doi.org/10.1126/sciadv.1701550

Orsolini, Y., Wegmann, M., Dutra, E., Liu, B., Balsamo, G., Yang, K., … Arduini, G. (2019). Evaluation of snow depth and snow cover over the Tibetan Plateau in global reanalyses using in situ and satellite remote sensing observations. The Cryosphere, 13(8), 2221–2239. https://doi.org/10.5194/tc-13-2221-2019

Sharma, E., Molden, D., Rahman, A., Khatiwada, Y. R., Zhang, L., Singh, S. P., … Wester, P. (2019). Introduction to the Hindu Kush Himalaya Assessment. In The Hindu Kush Himalaya Assessment (pp. 1–16). https://doi.org/10.1007/978-3-319-92288-1_1

Yao, T., Thompson, L., Yang, W., Yu, W., Gao, Y., Guo, X., … Joswiak, D. (2012). Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings. Nature Climate Change, 2(9), 663–667. https://doi.org/10.1038/nclimate1580

Bookhagen, B., & Burbank, D. W. (2010). Toward a complete Himalayan hydrological budget: Spatiotemporal distribution of snowmelt and rainfall and their impact on river discharge. Journal of Geophysical Research: Earth Surface, 115(3), 1–25. https://doi.org/10.1029/2009JF001426

Li, C., Su, F., Yang, D., Tong, K., Meng, F., & Kan, B. (2018). Spatiotemporal variation of snow cover over the Tibetan Plateau based on MODIS snow product, 2001-2014. International Journal of Climatology, 38(2), 708–728. https://doi.org/10.1002/joc.5204

Mao, J., & Robock, A. (1998). Surface Air Temperature Simulations by AMIP General Circulation Models: Volcanic and ENSO Signals and Systematic Errors. Journal of Climate, 11(7), 1538–1552. https://doi.org/10.1175/1520-0442(1998)011<1538:SATSBA>2.0.CO;2

References

Lee, D. K., & Suh, M. S. (2000). Ten-year east Asian summer monsoon simulation using a regional climate model (RegCM2). Journal of Geophysical Research Atmospheres, 105(D24), 29565–29577. https://doi.org/10.1029/2000JD900438

Gu, H., Wang, G., Yu, Z., & Mei, R. (2012). Assessing future climate changes and extreme indicators in east and south Asia using the RegCM4 regional climate model. Climatic Change, 114(2), 301–317. https://doi.org/10.1007/s10584-012-0411-y

Wang, X., Yang, M., Wan, G., Chen, X., & Pang, G. (2013). Qinghai-Xizang (Tibetan) Plateau climate simulation using the regional climate model RegCM3. Climate Research, 57(3), 173–186. https://doi.org/10.3354/cr01167

Su, F., Duan, X., Chen, D., Hao, Z., & Cuo, L. (2013). Evaluation of the Global Climate Models in the CMIP5 over the Tibetan Plateau. Journal of Climate, 26(10), 3187–3208. https://doi.org/10.1175/JCLI-D-12-00321.1

Boos, W. R., & Hurley, J. V. (2013). Thermodynamic bias in the multimodel mean boreal summer monsoon. Journal of Climate, 26(7), 2279–2287. https://doi.org/10.1175/JCLI-D-12-00493.1

Xu, J., Gao, Y., Chen, D., Xiao, L., & Ou, T. (2017). Evaluation of global climate models for downscaling applications centred over the Tibetan Plateau. International Journal of Climatology, 37(2), 657–671. https://doi.org/10.1002/joc.4731

Chen, X., Liu, Y., & Wu, G. (2017). Understanding the surface temperature cold bias in CMIP5 AGCMs over the Tibetan Plateau. Advances in Atmospheric Sciences, 34(12), 1447–1460. https://doi.org/10.1007/s00376-017-6326-9

Salunke, P., Jain, S., & Mishra, S. K. (2019). Performance of the CMIP5 models in the simulation of the Himalaya-Tibetan Plateau monsoon. Theoretical and Applied Climatology, 137(1–2), 909–928. https://doi.org/10.1007/s00704-018-2644-9

References

Palazzi, E., von Hardenberg, J., & Provenzale, A. (2013). Precipitation in the Hindu-Kush Karakoram Himalaya: Observations and future scenarios. Journal of Geophysical Research: Atmospheres, 118(1), 85–100. https://doi.org/10.1029/2012JD018697

Immerzeel, W. W., Wanders, N., Lutz, A. F., Shea, J. M., & Bierkens, M. F. P. (2015). Reconciling high-altitude precipitation in the upper Indus basin with glacier mass balances and runoff. Hydrology and Earth System Sciences, 19(11), 4673–4687. https://doi.org/10.5194/hess-19-4673-2015

Boucher, O., Albright, A. L., Aumont, O., Balkanski, Y., Bastrikov, V., Bekki, S., ... Kageyama, M. (submitted). Presentation and evaluation of the IPSL-CM6A-LR climate model. Retrieved from https://www.lmd.jussieu.fr/~hourdin/PUBLIS/IPSL_CM6A_LR.pdf

WALLAND, D. J., & SIMMONDS, I. (1996). SUB-GRID-SCALE TOPOGRAPHY AND THE SIMULATION OF NORTHERN HEMISPHERE SNOW COVER. International Journal of Climatology, 16(9), 961–982. http://doi.wiley.com/10.1002/%28SICI%291097-0088%28199609%2916%3A9%3C961%3A%3AAID-JOC72%3E3.0.CO%3B2-R

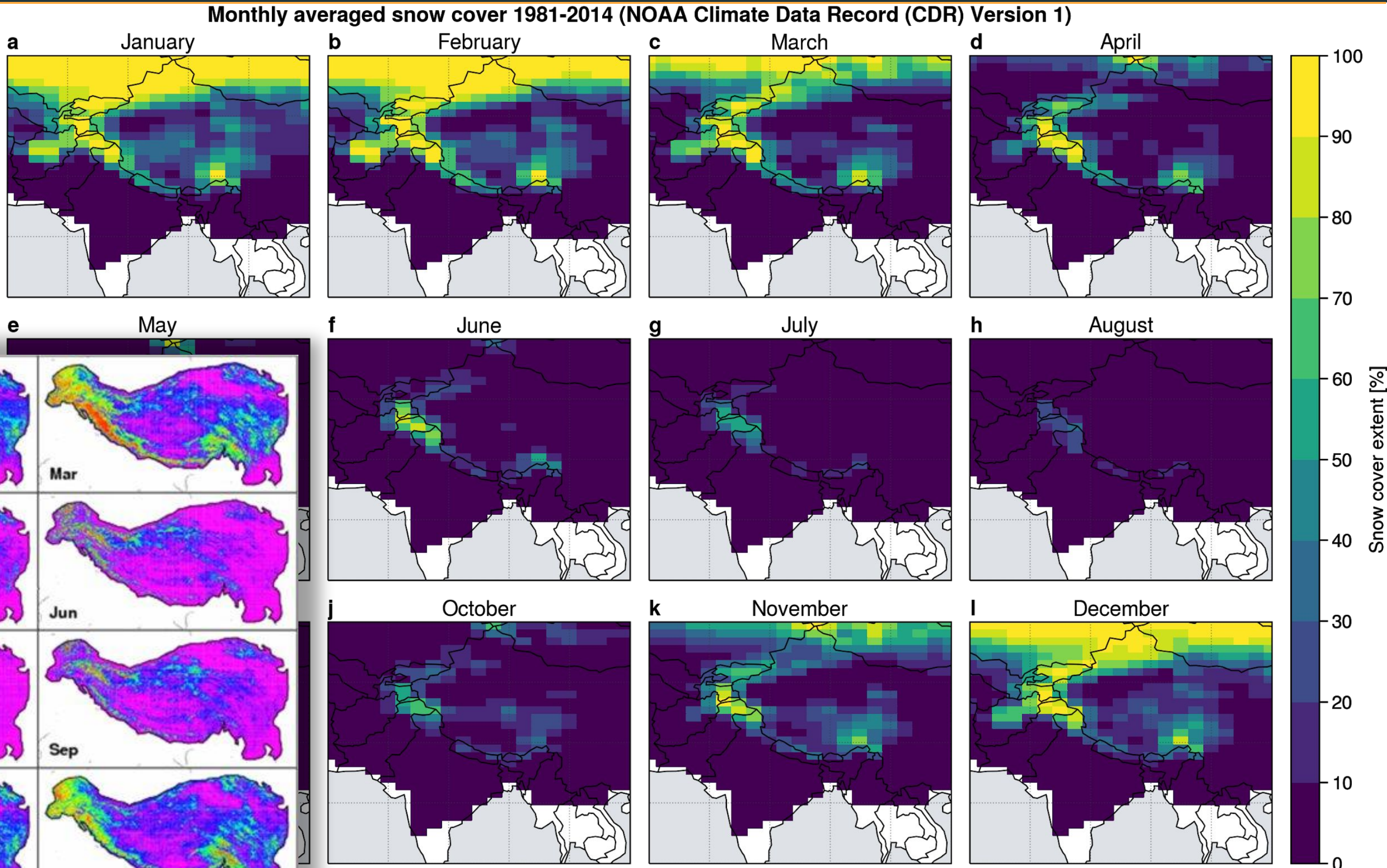
Younas, W., Hay, R. W., MacDonald, M. K., Islam, S. U., & Déry, S. J. (2017). A strategy to represent impacts of subgrid-scale topography on snow evolution in the Canadian Land Surface Scheme. Annals of Glaciology, 58(75pt1), 1–10. https://doi.org/10.1017/aog.2017.29

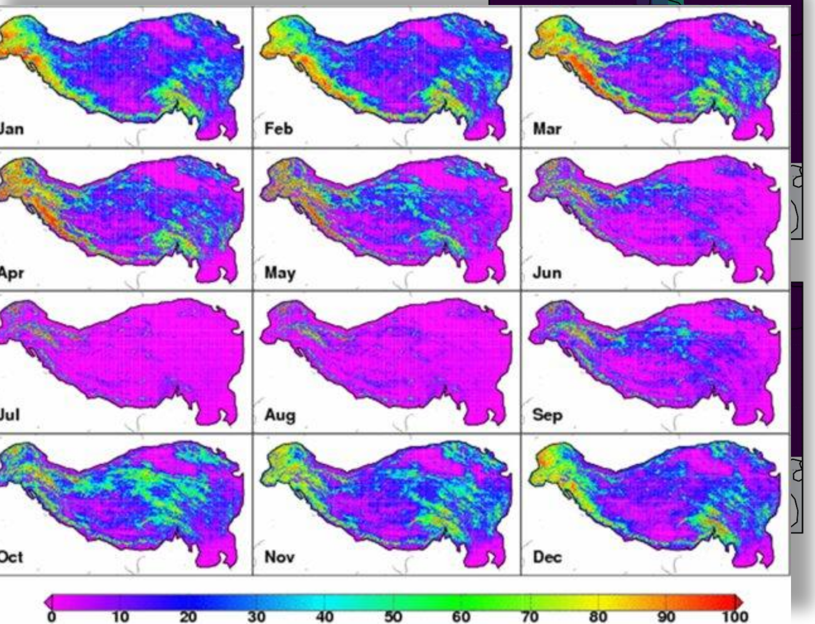
Monthly snow cover climatologies (from satellite observations)

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

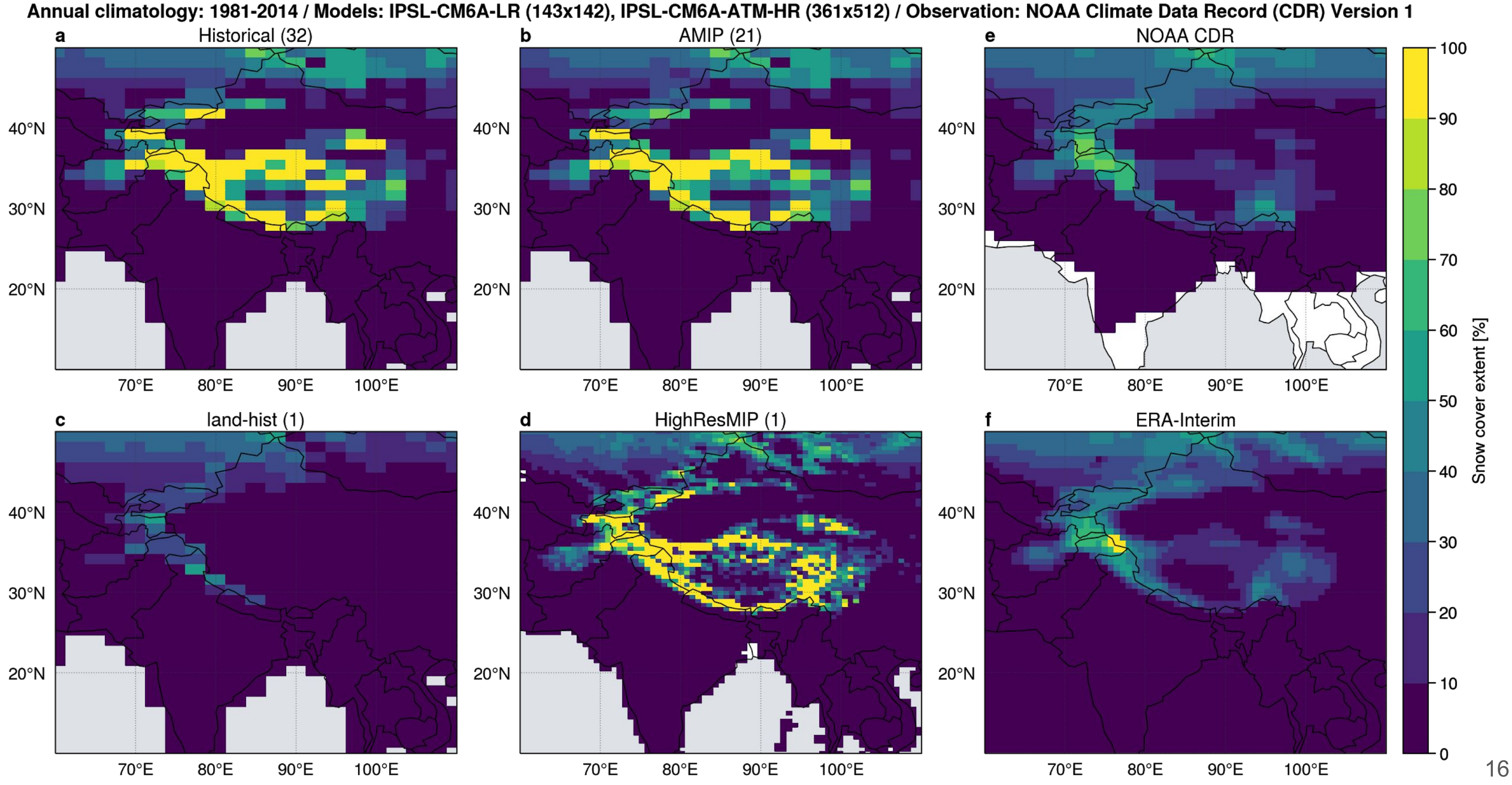
MODIS/Terra Snow Cover 8-Day L3 Global 0.05Deg CMG, Version 6 (2001-2014)

Li et al. (2018), Fig. 2



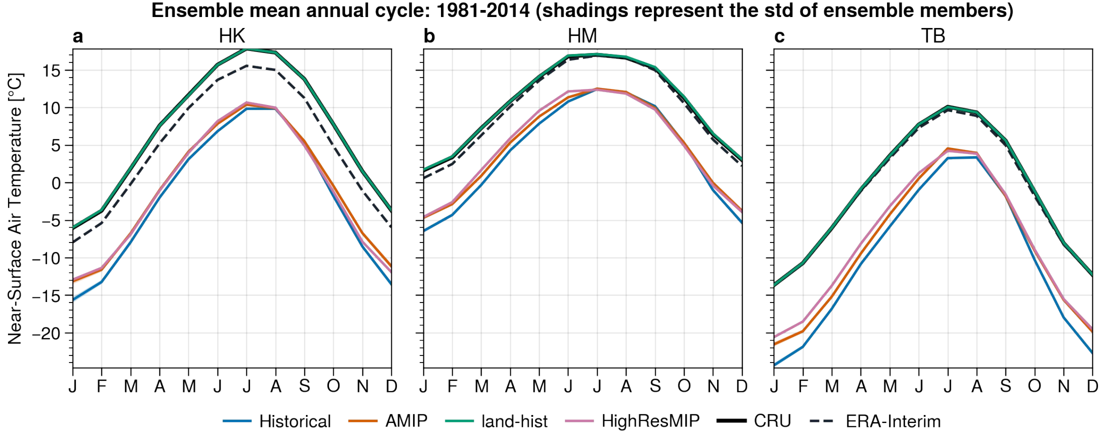


Snow cover climatology (1981-20014)

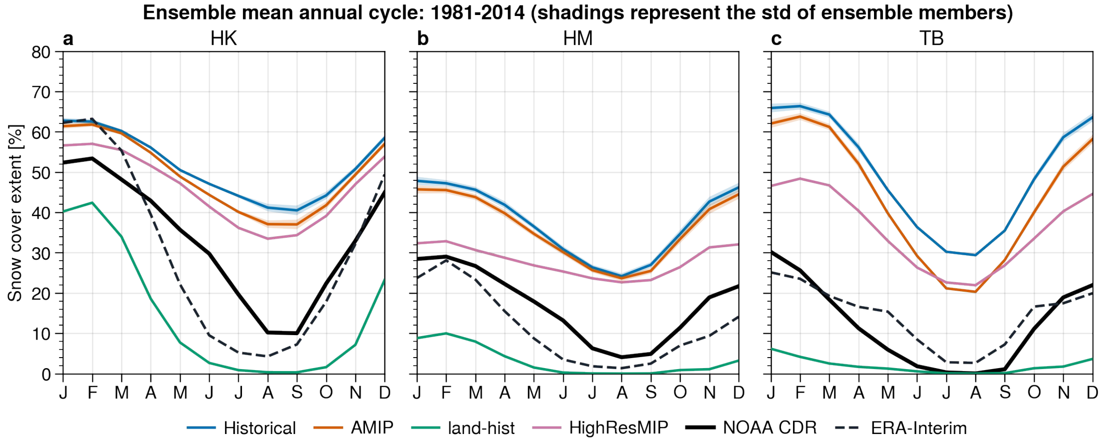


Temperature and Snow cover: annual cycles

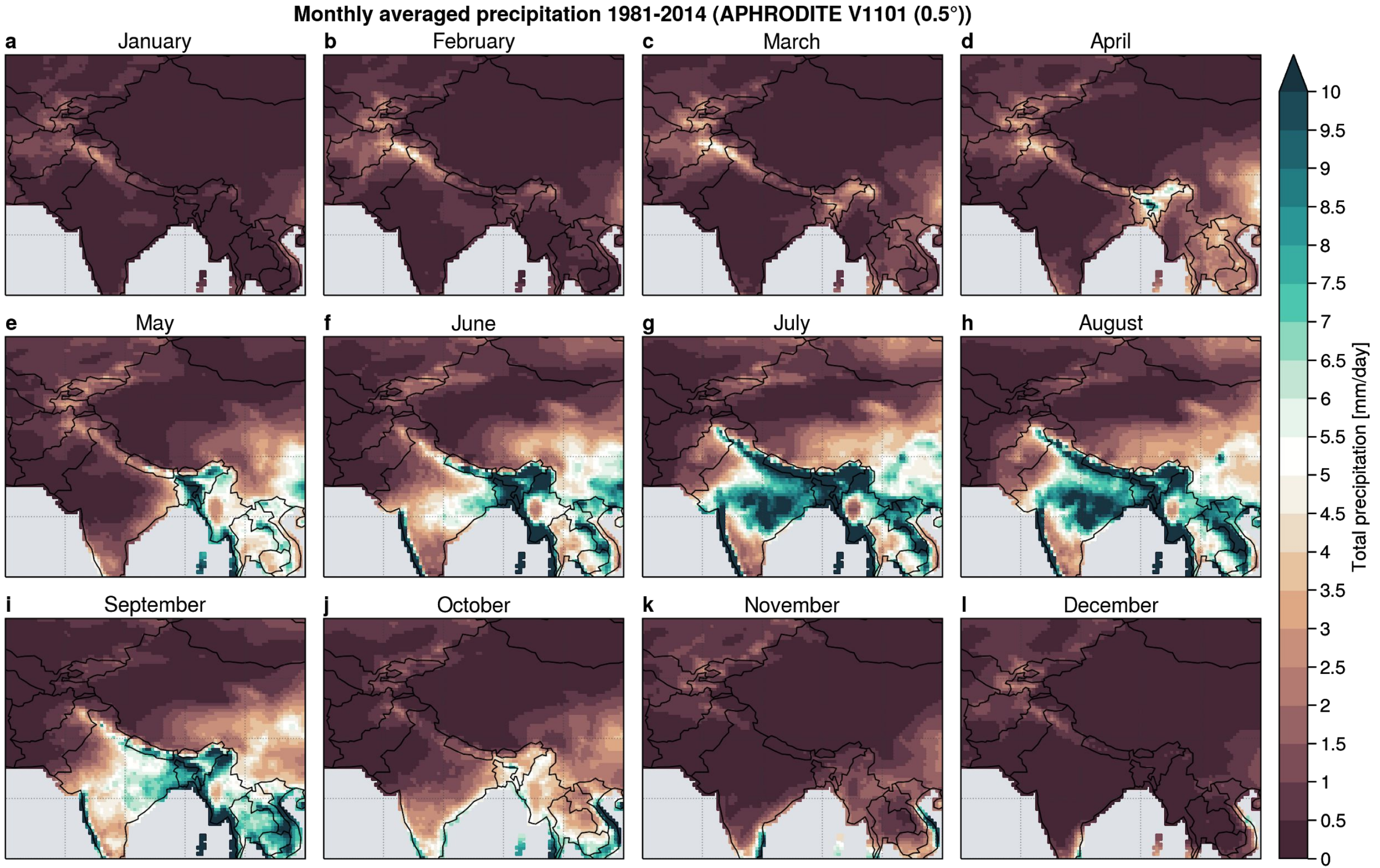
Temperature



Snow cover

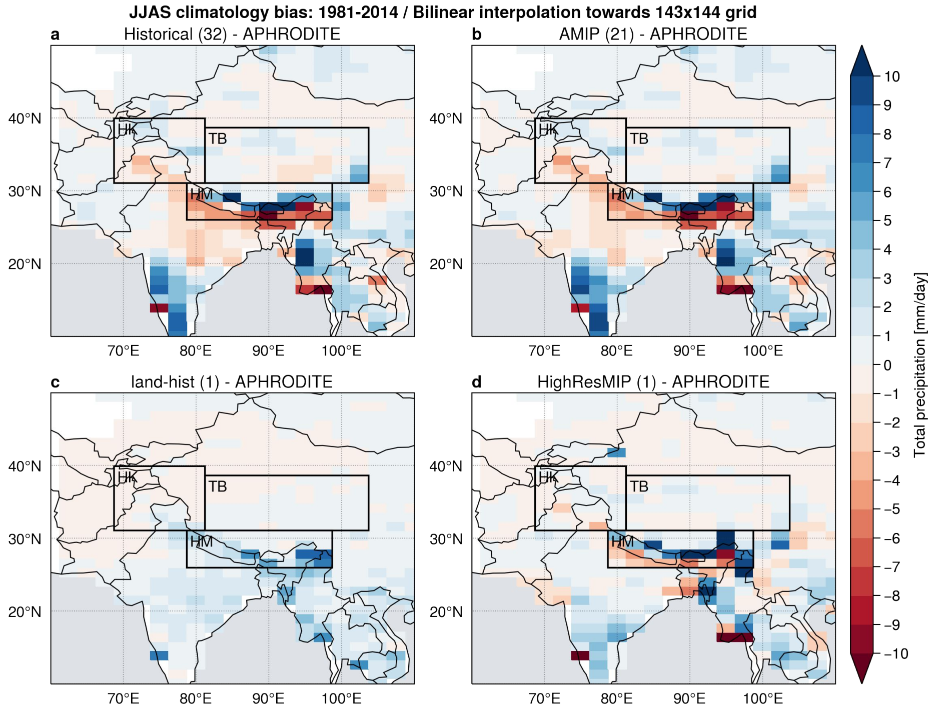


Precipitation climatologies (APHRODITE)

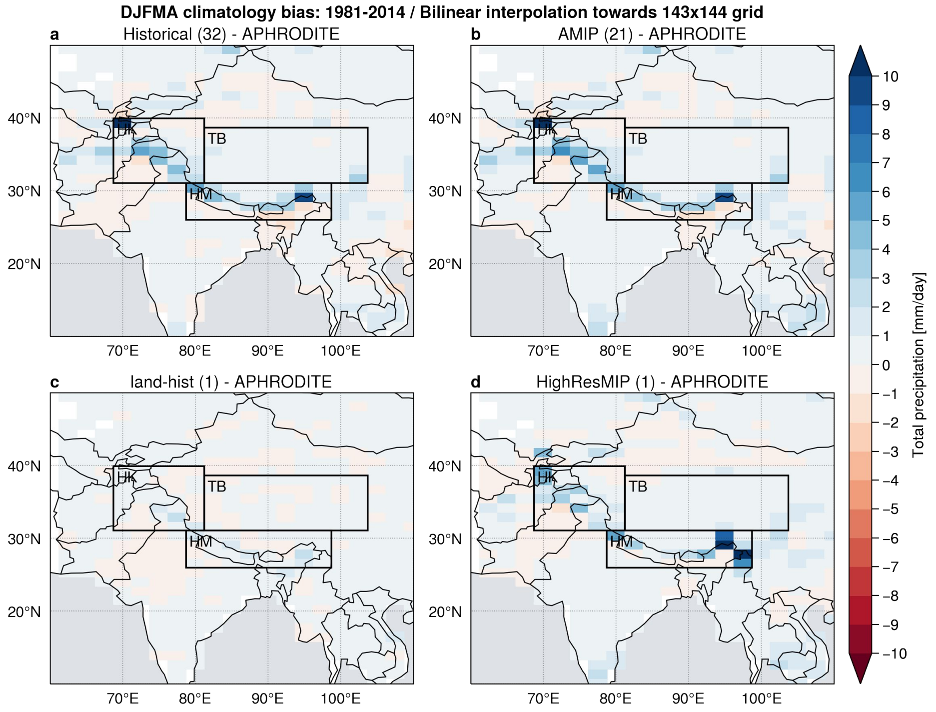


Precipitation climatologies bias

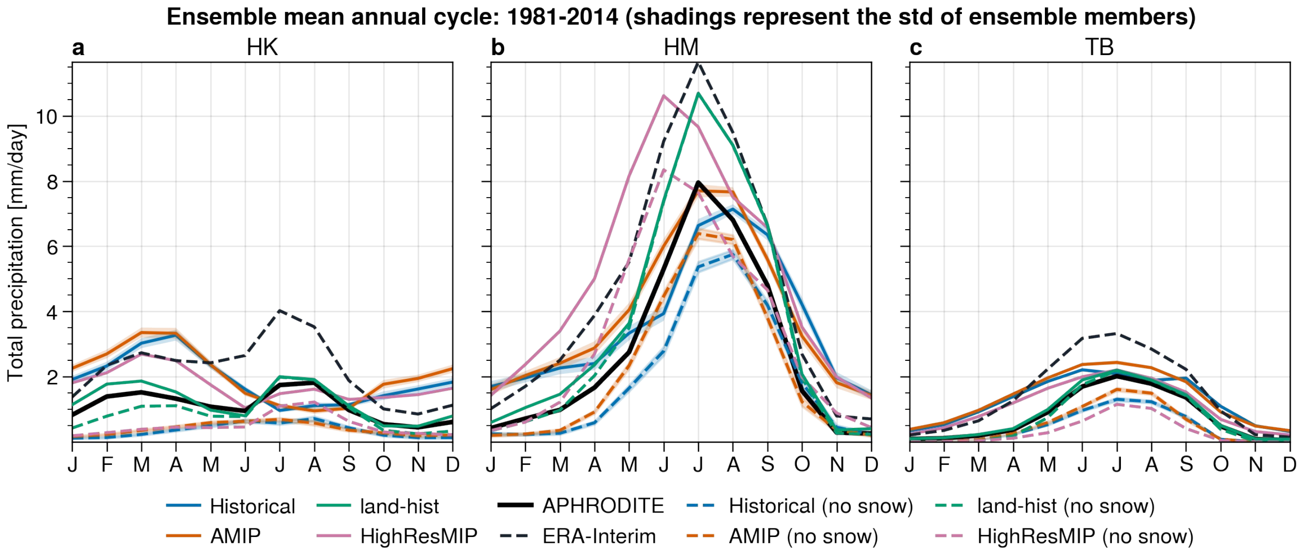
Summer (JJAS)



Winter (DJFMA)



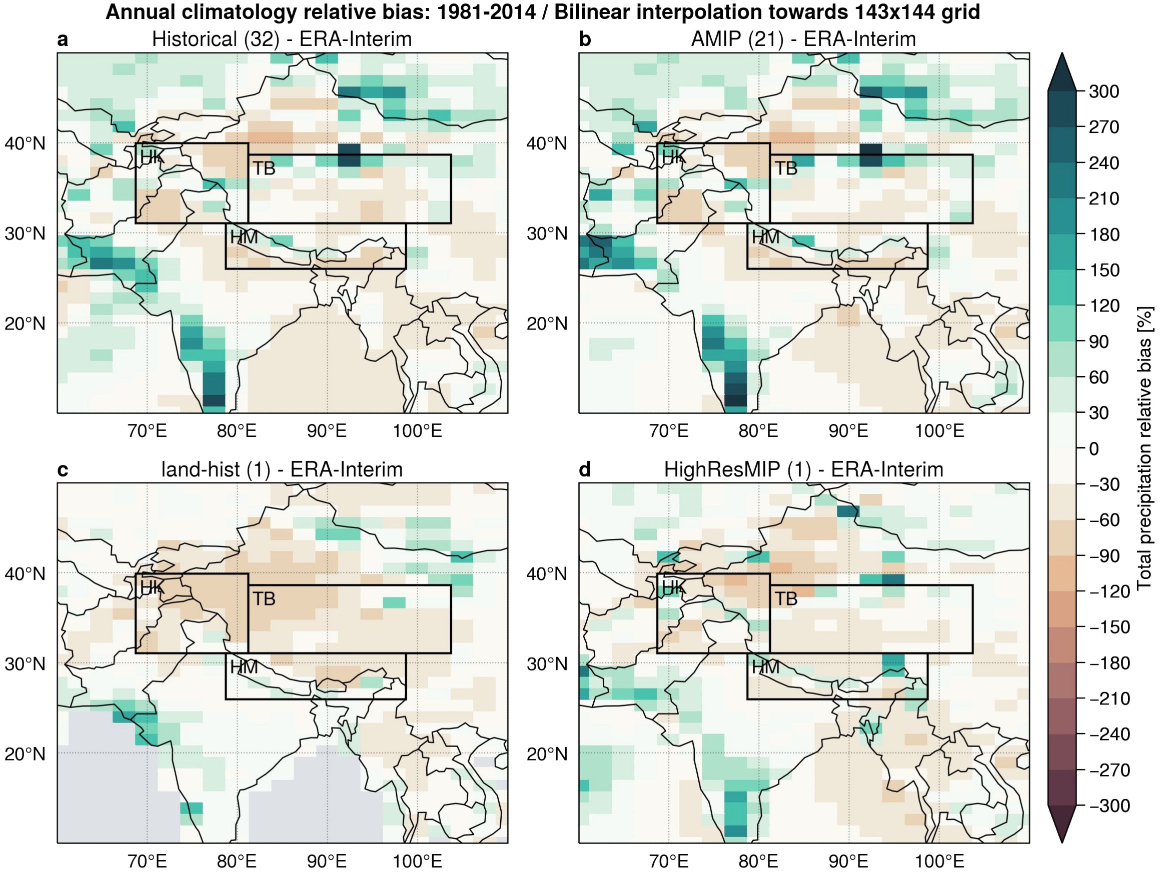
Precipitation: annual cycles



*"**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 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

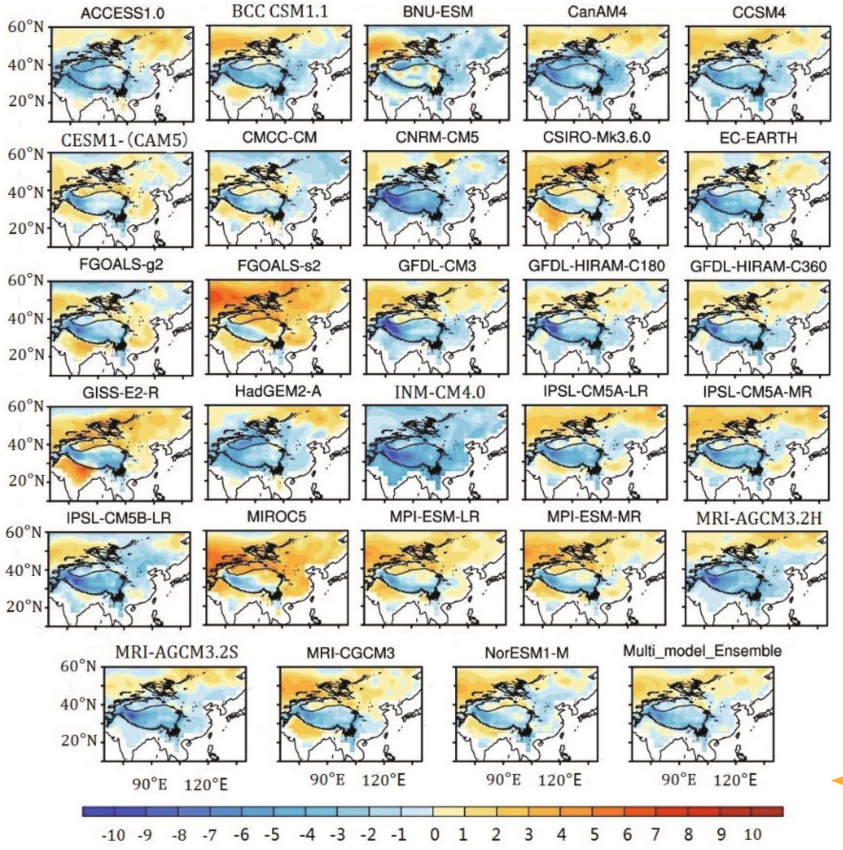
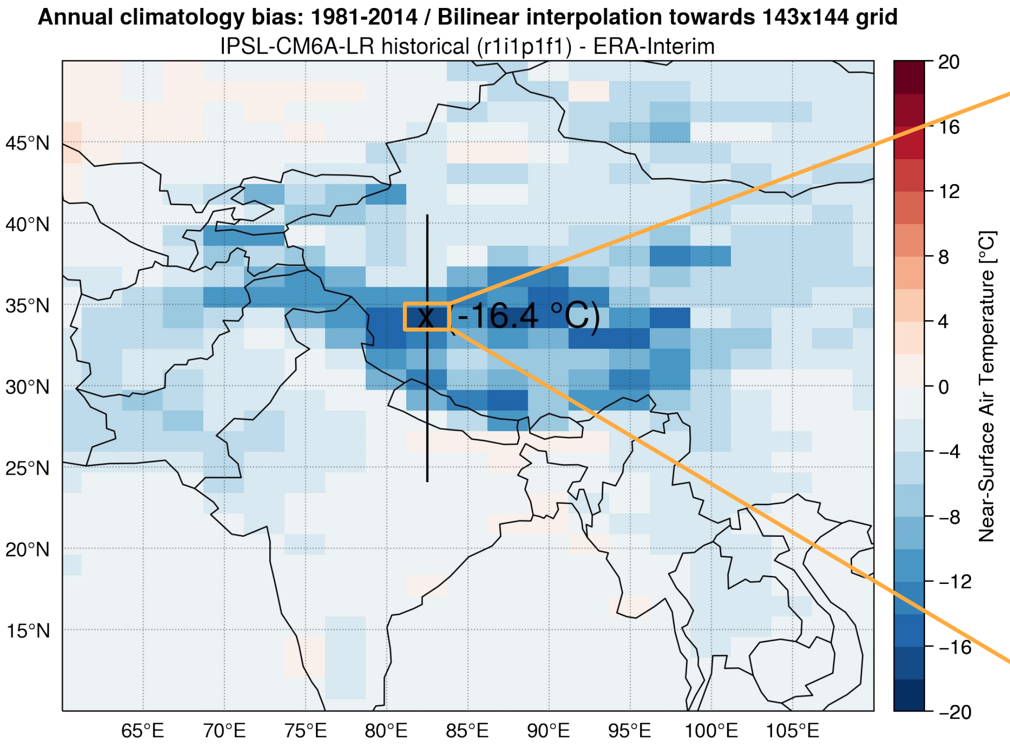


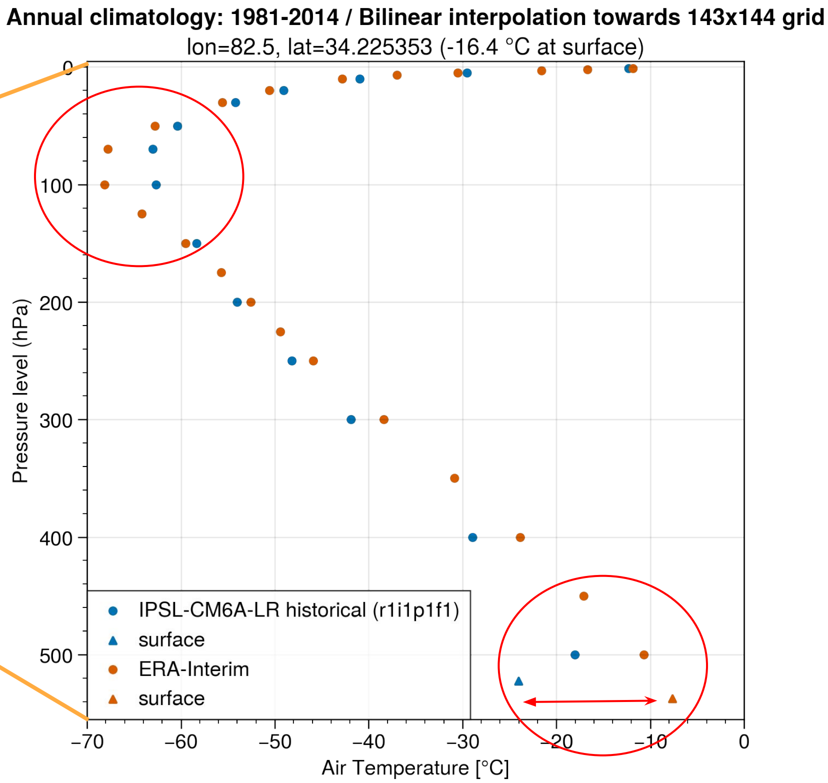
Fig. 2. Annual mean T_{as} (°C) differences between various models and CRU data averaged during 1979–2005. All air temperature values in the models have been corrected to real elevation at a resolution of 2.5°×2.5°.

- 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.

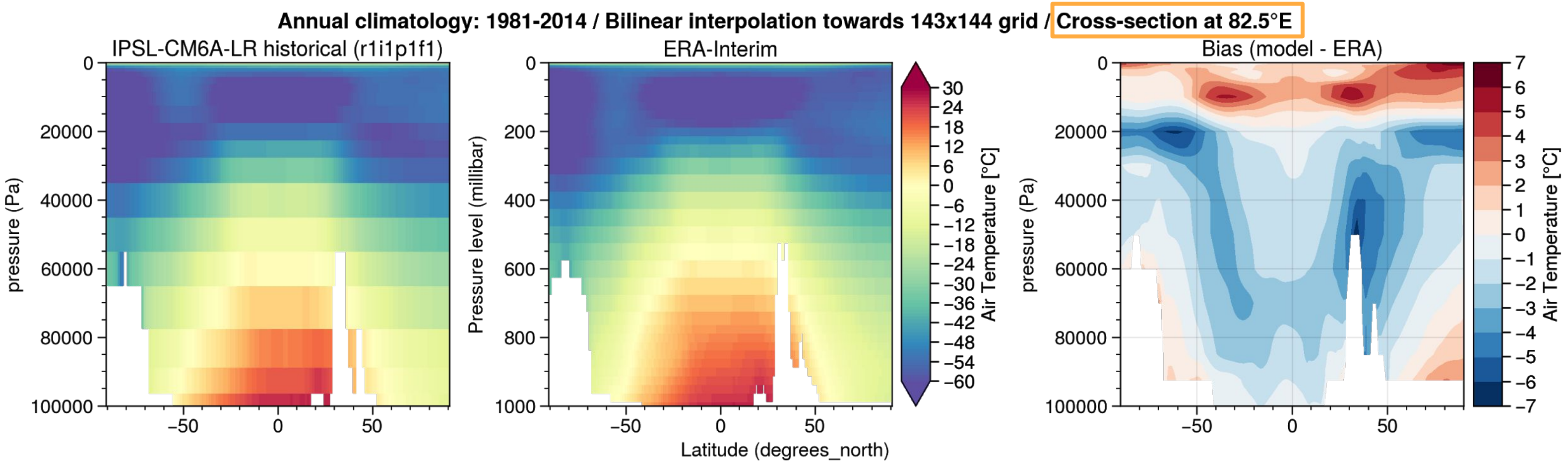
Back

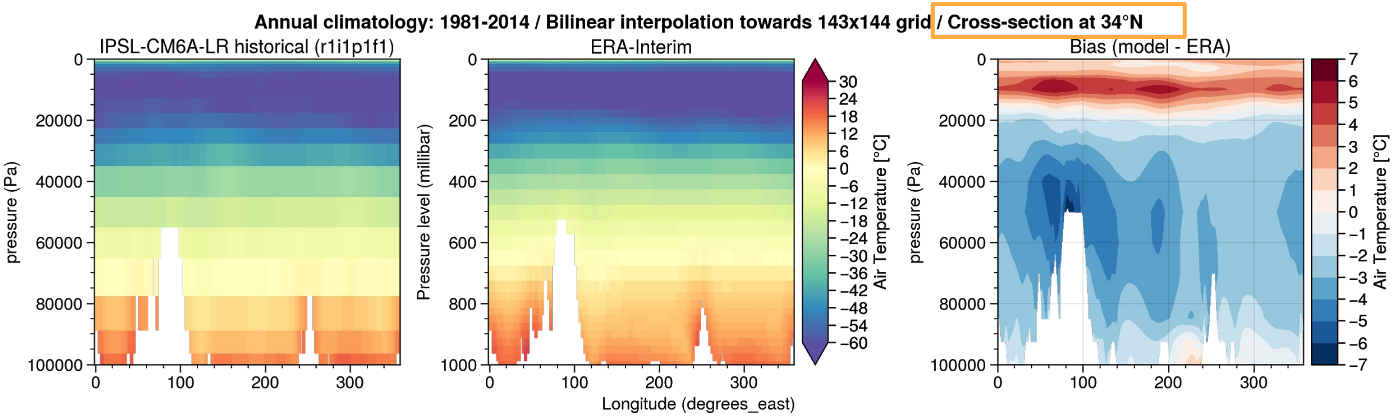
Air Temperature of historical (r1i1p1f1)





Air Temperature cross sections of historical (r1i1p1f1)

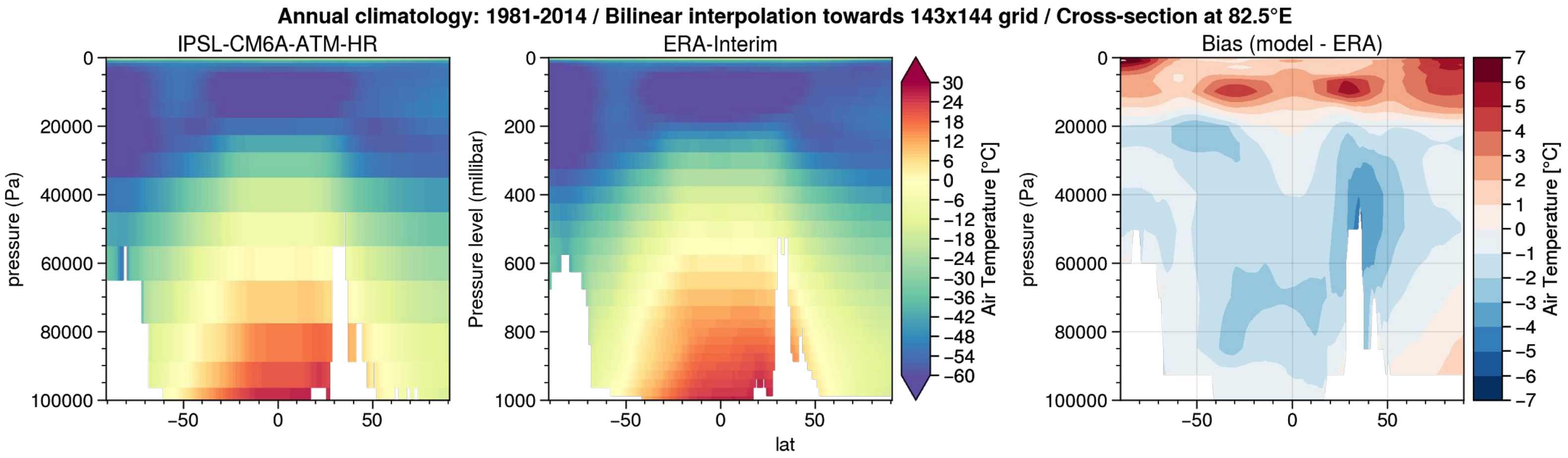


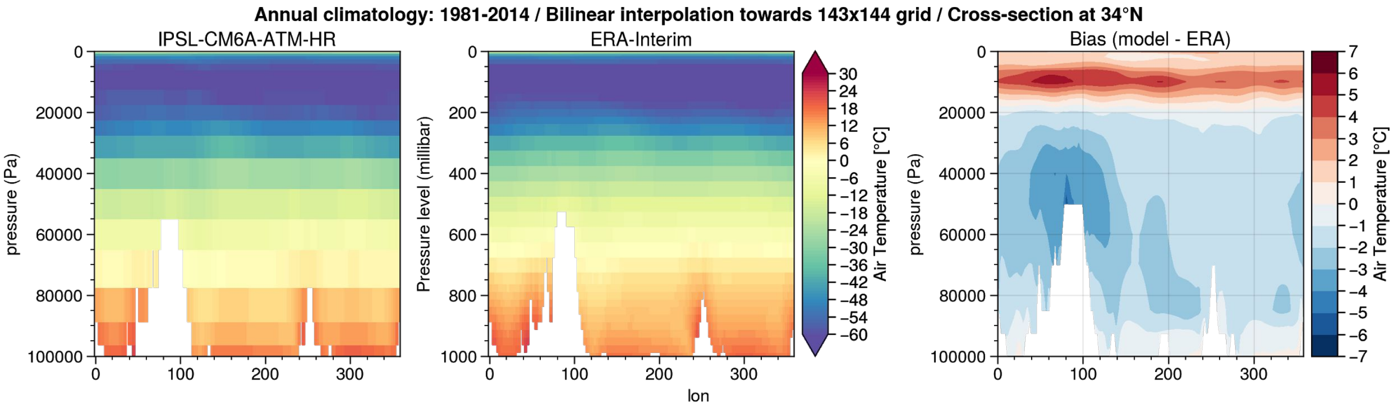


Similar to zonal means from Boucher et al., Fig. 3 (submitted)

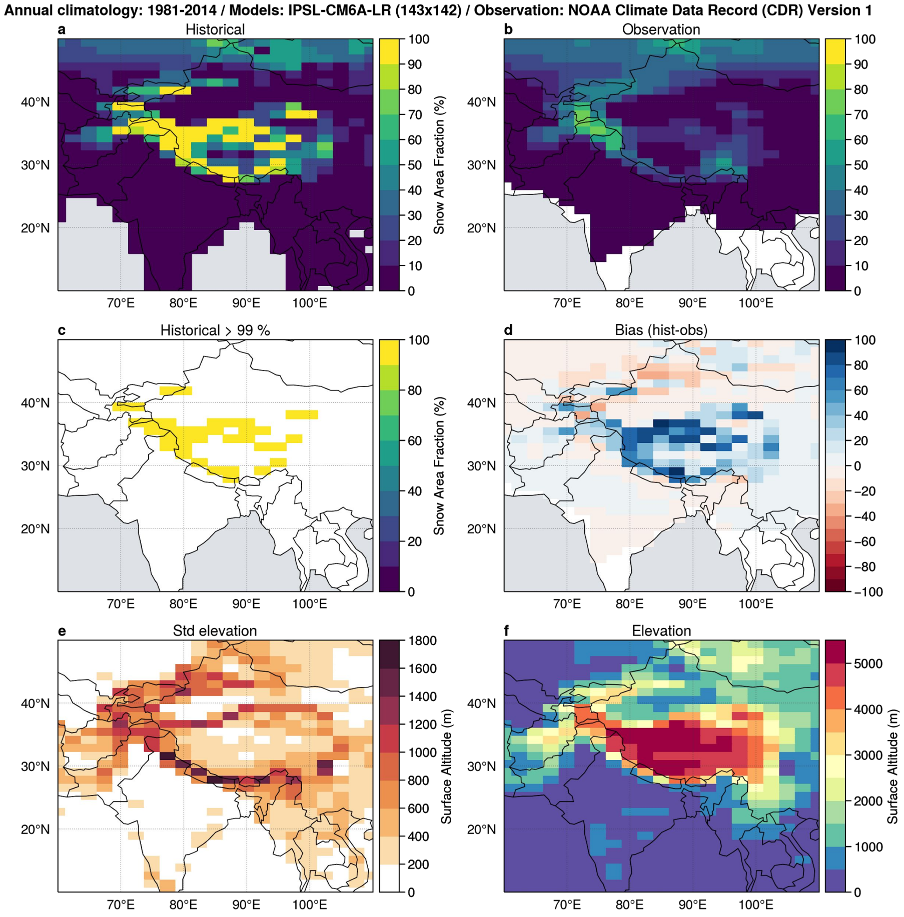
→ so not restricted to HMA!

Air Temperature cross sections of HighResMIP





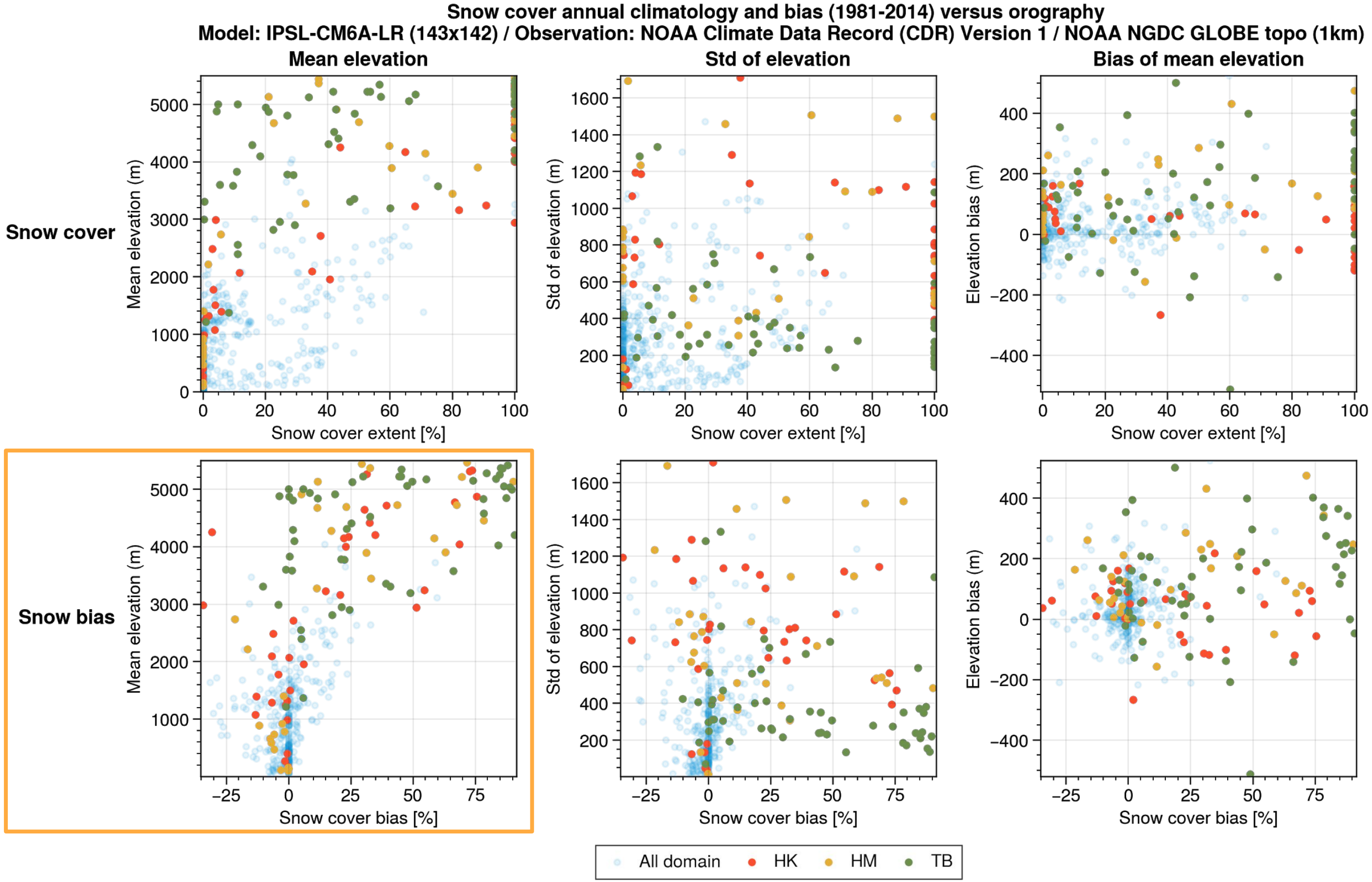
Link with orography?



- Some cells stays at 100% of snow cover all the time!
- Seems related with elevation
- No obvious link with the standard deviation of elevation...

[Back](#)

Link with orography?



Link with orography?