Snow bias in EURO-CORDEX regional climate models and its dependence on topography mismatch and cold bias in the European Alps

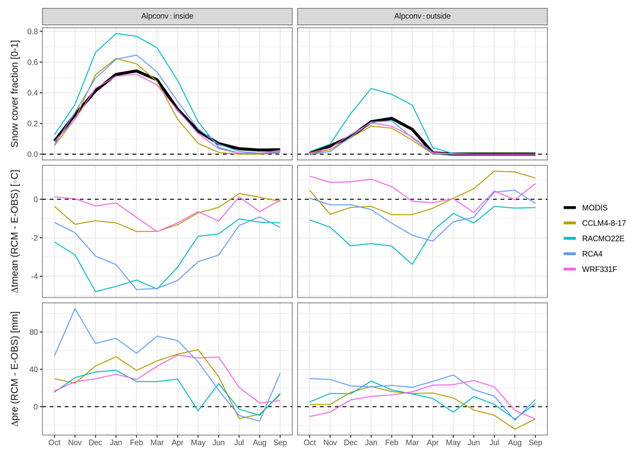
M. Matiu, A. Crespi, M. Petitta, C. Notarnicola, M. Zebisch
Eurac Research, Bolzano, Italy

INTRODUCTION

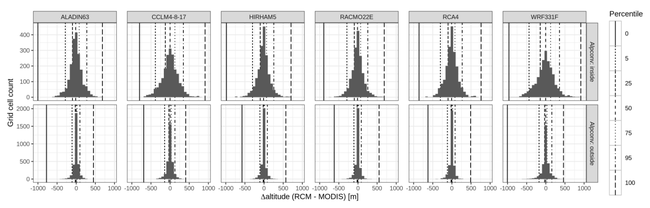
Regional climate models (RCMs) have
- cold bias in the Alps
- orography mismatch

Question:
How does this relate to snow in RCMs?

Aim:
Evaluate snow in the 0.11° (~12.5km) EURO-CORDEX RCMs using high-resolution observations

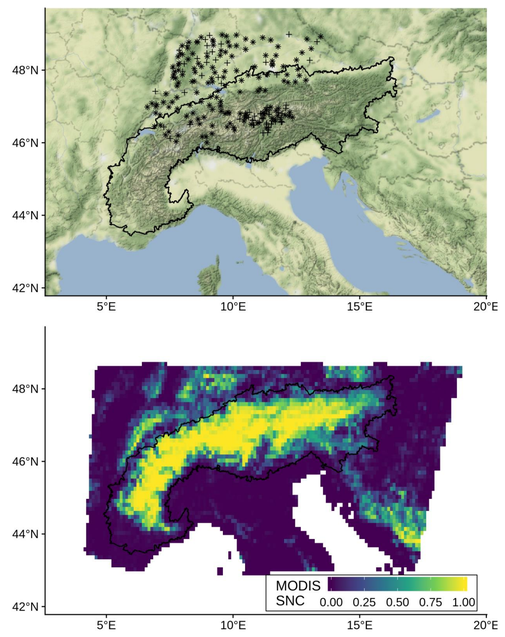


Comparison of reanalysis driven RCMs with observations (MODIS for snow cover, E-OBS for temperature and precipitation). Monthly averages are shown for inner (inside Alpconv) and outer (outside Alpconv) Alps for the period 2002-Oct to 2008-Sep for reanalysis driven RCMs (see Figure 1 for the Alpconv boundaries). Top panels show snow cover fraction over the year, middle panels show the difference between RCM and E-OBS mean temperature, and bottom panels show the difference between RCM and E-OBS precipitation.



Distribution of the differences between RCM and true (MODIS) altitude. Histograms of the altitude difference by RCM (columns) and alpine convention (Alpconv) boundaries (rows). Most high altitudes are present inside Alpconv. Vertical lines denote the different percentiles.

DATA / METHODS



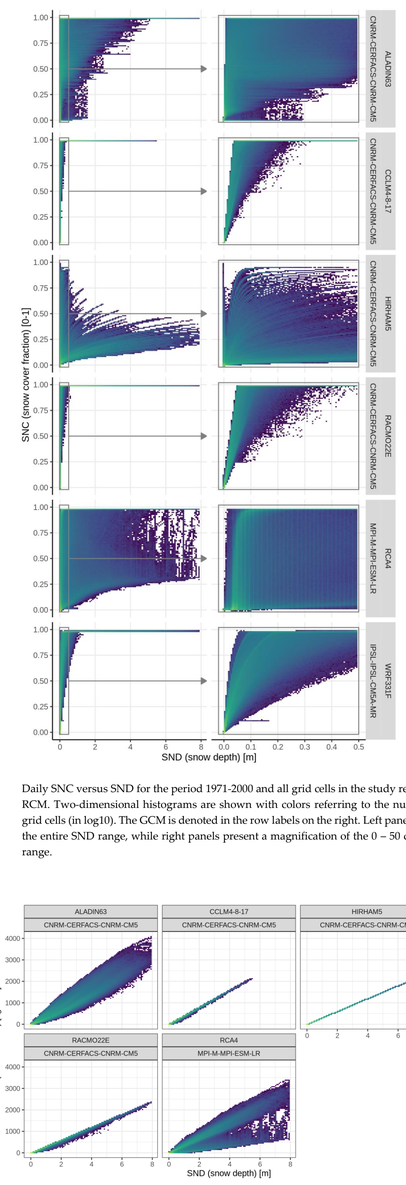
Map of study region (European Alps). **(top)** Terrain map with boundaries of the Alpine Convention (Alpconv), marking the core Alpine region. Points indicate the station locations (+: used for reanalysis driven RCMs, x: used for GCM driven RCMs; stars (+ and x overlaid): used for both). [Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under ODbL.] **(bottom)** Example map of MODIS snow cover fraction (SNC) for 2012, Jan 1, upscaled to RCM resolution (~0.11°).

4 sources of data:
- RCMs (snow cover, snow depth, temp, pre)
- MODIS (snow cover)
- E-OBS (temp, pre)
- Stations (snow depth, temp)

Overview of regional climate models (RCMs) and snow variables (SNC: snow cover fraction; SND: snow depth; SNW: snow amount) that were available in this study. Meaning of cell content: empty = variable not available from ESGF (Earth System Grid Federation) servers; X = variable available for both reanalysis and GCM driven runs; G = variable only available for GCM driven runs; (G) = variable only available for specific GCM driven runs.

Modelling institute	RCM	SNC	SND	SNW
CNRM	ALADIN53			X
CNRM	ALADIN63	G	G	G
CLMcom	CCLM4-8-17	X	X	X
DMI	HIRHAM5[1]	G	G	G
KNMI	RACMO22E	X	X	X
SMHI	RCA4	X	X	(G)
ICTP	RegCM4-6			X
MPI-CSC[2]	REMO2009			X
GERICS	REMO2015			X
IPSL-INERIS	WRF331F	X	X	
IPSL	WRF381P	X		X

RCM SNOW VARIABLES

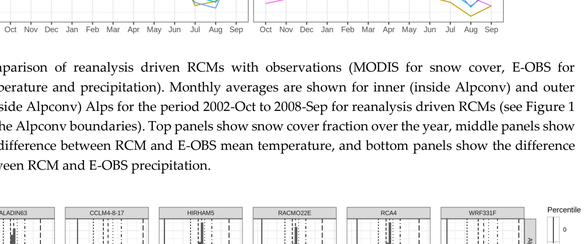


Daily SNC versus SND for the period 1971-2000 and all grid cells in the study region by RCM. Two-dimensional histograms are shown with colors referring to the number of grid cells (in log10). The GCM is denoted in the row labels on the right. Left panels show the entire SND range, while right panels present a magnification of the 0 – 50 cm SND range.

Daily SNW versus SND for the period 1971-2000 and all grid cells in the study region for individual RCMs. Two-dimensional histograms are shown with colors referring to the number of grid cells (in log10).

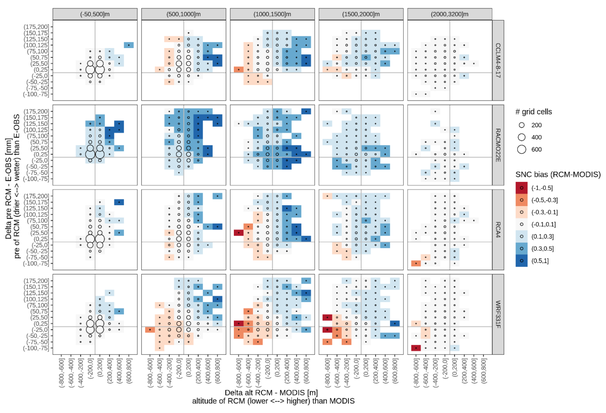
SNOW COVER RCM <-> MODIS/E-OBS

ΔSNC ~ ΔTEMP + ΔALT



January snow cover bias in relation to altitude difference and temperature difference. The average snow cover fraction (SNC, unitless) bias (RCM – MODIS) in January is shown for classes of altitude difference (RCM – MODIS, x-axis) and classes of temperature difference (RCM – E-OBS). Rows are the different RCMs, and columns MODIS altitude classes. Size of the bubbles indicate the number of grid cells in the respective bin. SNC bias values were averaged over all grid cells in the respective bin, and the underlying grid cell data is averages for reanalysis driven RCMs and MODIS for the common period 2002-Oct to 2008-Sep. Extreme values (delta temperature above 4 and below -8 degrees C, delta altitude above 800 or below -800m) were excluded from this plot for better visualization and because their number is insignificant.

ΔSNC ~ ΔPRE + ΔALT

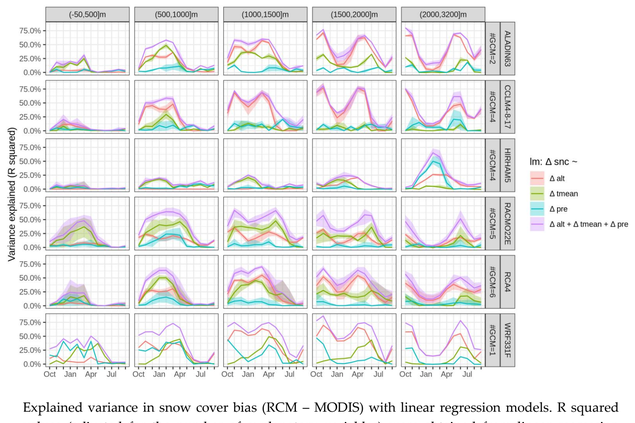


January snow cover bias in relation to altitude difference and precipitation difference. The average snow cover fraction (SNC, unitless) bias (RCM – MODIS) in January is shown for classes of altitude difference (RCM – MODIS, x-axis) and classes of precipitation difference (RCM – E-OBS). Rows are the different RCMs, and columns MODIS altitude classes. Size of the bubbles indicate the number of grid cells in the respective bin. SNC bias values were averaged over all grid cells in the respective bin, and the underlying grid cell data is averages for reanalysis driven RCMs and MODIS for the common period 2002-Oct to 2008-Sep. Extreme values (delta precipitation above 200 and below -100 mm, delta altitude above 800 or below -800m) were excluded from this plot for better visualization and because their number is insignificant.

ΔSNC ~ ΔTEMP + ΔPRE

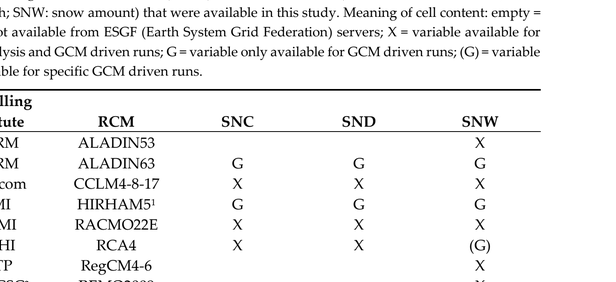
January snow cover bias in relation to temperature difference and precipitation difference. The average snow cover fraction (SNC, unitless) bias (RCM – MODIS) in January is shown for classes of temperature difference (RCM – E-OBS, x-axis) and classes of precipitation difference (RCM – E-OBS). Rows are the different RCMs, and columns MODIS altitude classes. Size of the bubbles indicate the number of grid cells in the respective bin. SNC bias values were averaged over all grid cells in the respective bin, and the underlying grid cell data is averages for reanalysis driven RCMs and MODIS for the common period 2002-Oct to 2008-Sep. Extreme values (delta temperature above 4 and below -8 degrees C, delta precipitation above 200 and below -100 mm) were excluded from this plot for better visualization and because their number is insignificant.

ΔSNC ~ ΔALT + ΔTEMP + ΔPRE

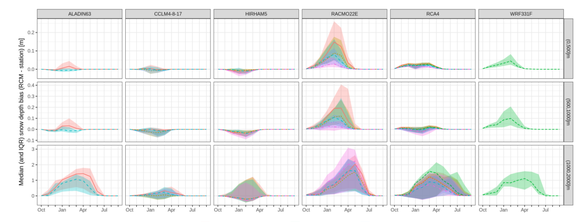


Explained variance in snow cover bias (RCM – MODIS) with linear regression models. R squared values (adjusted for the number of explanatory variables) were obtained from linear regression models of snow cover bias (RCM – MODIS) with different explanatory variables (covariates) (Δ alt: altitude difference (RCM - MODIS), Δ tmean: temperature difference (RCM – E-OBS), Δ pre: precipitation difference (RCM – E-OBS), Δ alt + Δ tmean + Δ pre: all three differences). Rows are the different RCMs, and columns MODIS altitude classes. RCMs are GCM driven; the number of different GCMs is given in row labels; the transparent band shows the minimum and maximum over all GCMs, while the solid line is the average.

SNOW DEPTH RCM <-> STATIONS



January snow depth bias (model – station observations) in reanalysis driven RCMs as function of altitude difference. The difference in snow depth is shown for the different RCMs (columns) and altitude classes of the stations (rows). Each point represents a station, and the difference in snow depth was calculated as the difference between the average monthly snow depth for all years that the station had in common with the RCM (during the period 1989-2008).



Average snow depth bias (RCM minus station) for stations that are within ±400m of altitude difference with RCM orography. Lines indicate the median snow depth difference between the different RCMs and stations, and the transparent band is the IQR (inter-quartile-range). RCMs are shown in columns, with the driving GCM indicated in colors; rows are elevation classes of the stations. The number of stations is not balanced between elevation classes, and is ~55 for (0,500], ~35 for (500, 1000], and ~9 for (1000, 2000].

CONCLUSION

1. Snow in RCMs OK
2. Biases Reanalysis < GCM
3. Snow bias ~ orography mismatch + temperature bias + precipitation bias
4. RCM biases: snow cover ≠ snow depth / snow water equivalent

MORE INFO

Matiu M, Petitta M, Notarnicola C, Zebisch M. 2020. Evaluating Snow in EURO-CORDEX Regional Climate Models with Observations for the European Alps: Biases and Their Relationship to Orography, Temperature, and Precipitation Mismatches. *Atmosphere*, 11(1): 46. https://doi.org/10.3390/atmos11010046.

OTHER RELATED LITERATURE

Lüthi S, Ban N, Kotlarski S, Steger CR, Jonas T, Schär C. 2019. Projections of Alpine Snow-Cover in a High-Resolution Climate Simulation. *Atmosphere*, 10(8): 463. https://doi.org/10.3390/atmos10080463.
Steger C, Kotlarski S, Jonas T, Schär C. 2013. Alpine snow cover in a changing climate: a regional climate model perspective. *Climate Dynamics*, 41(3–4): 735–754. https://doi.org/10.1007/s00382-012-1545-3.
Ronco PD, Michele CD, Montesarchio M, Mercogliano P. 2016. Comparing COSMO-CLM simulations and MODIS data of snow cover extent and distribution over Italian Alps. *Climate Dynamics*, 47(12): 3955–3977. https://doi.org/10.1007/s00382-016-3054-2.
Terzago S, Hardenberg J von, Palazzi E, Provenzale A. 2017. Snow water equivalent in the Alps as seen by gridded data sets, CMIP5 and CORDEX climate models. *The Cryosphere*, 11(4): 1625–1645. https://doi.org/10.5194/tc-11-1625-2017.

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