

# **Can the latest generation of regional climate models reproduce European snow conditions and How do biases translate into uncertainties of snow cover projections?**

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# The evolution of snow is relevant...

- Important **natural water resource** (hydropower, water supply etc.)
  - Importance for **tourism and recreation** in many regions
  - **Natural hazards** (snow avalanches, spring meltwater, ...)
  - **Ecology, Agriculture, ...**
- **Feedback** to the atmosphere!
  - **Past decline of snow cover** on hemispheric scales



# Objectives and Data

## OBJECTIVES

- **Evaluate** state-of-the-art RCMs in terms of snow cover representation
- Derive **21<sup>st</sup> Century snow cover changes** on European scale

## DATA

- **EURO-CORDEX** RCM ensemble at 12 km resolution (EUR-11)
- **11** reanalysis-driven simulations
- **84** GCM-driven simulations  
(**18** x RCP2.6, **17** x RCP4.5, **49** x RCP8.5)



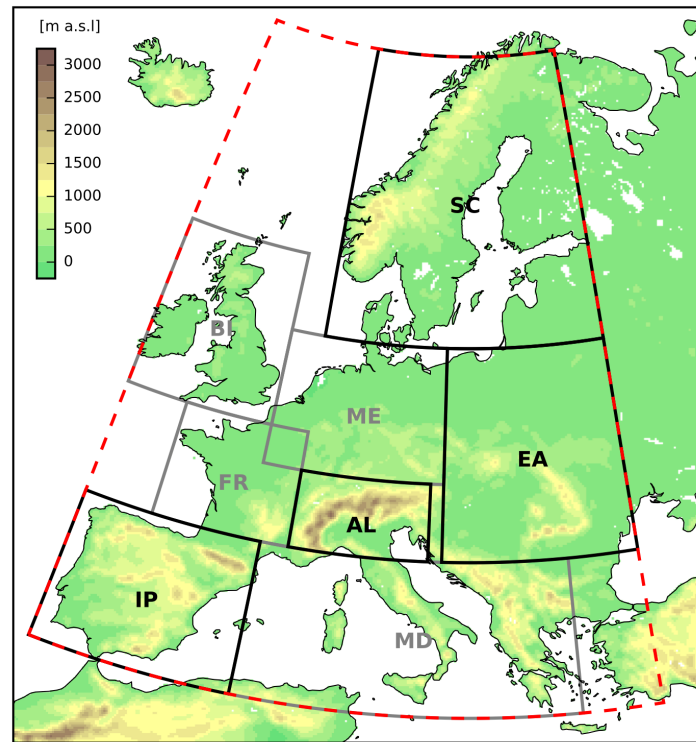
# Evaluation domain and methods

- **Regions**

- Analysis for PRUDENCE domains (Christensen and Christensen, 2007)
- Focus on regions with complex topography and/or high latitude: Alps (AL), Scandinavia (SC), Eastern Europe (EA), Iberian Peninsula (IP) and entire Europe (--)

- **Methods**

- Snow day definition:  $\geq 3$  cm snow depth
- Conversion of snow water equivalent (SWE) to snow depth with constant snow density:  $312 \text{ kg m}^{-3}$  (Sturm et al., 2010)
- Indicators: **SWE**, **snow-covered area**, **snow-covered period**



Part I

# Model Evaluation

# Reference snow datasets

Abbreviation	Name	Type	Spatial resolution	Temporal resolution*
ERA-Int	ERA-Interim	Reanalysis	~80 km	daily
ERA5	ERA5	Reanalysis	~30 km	daily
ERA5-Land	ERA5-Land	Land surface model	~9 km	daily
GLDAS	GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree V2.0	Land surface model	~30 km	daily
UERRA-H	UERRA-HARMONIE	Reanalysis	~11 km	daily
UERRA-MS	UERRA MESCAN-SURFEX	Land surface model	~5.5 km	daily
JASMES	JASMES Northern Hemisphere daily snow cover extent	Remote sensing	~5 km	daily
NSIDC-0046	Northern Hemisphere EASE-Grid 2.0 Weekly Snow Cover and Sea Ice Extent V4	Remote sensing	~25 km**	weekly
NSIDC-0271	Global Monthly EASE-Grid Snow Water Equivalent Climatology V1	Remote sensing	~25 km	monthly
GlobSnow	GlobSnow v3.0 NH SWE	Remote sensing	~25 km	daily

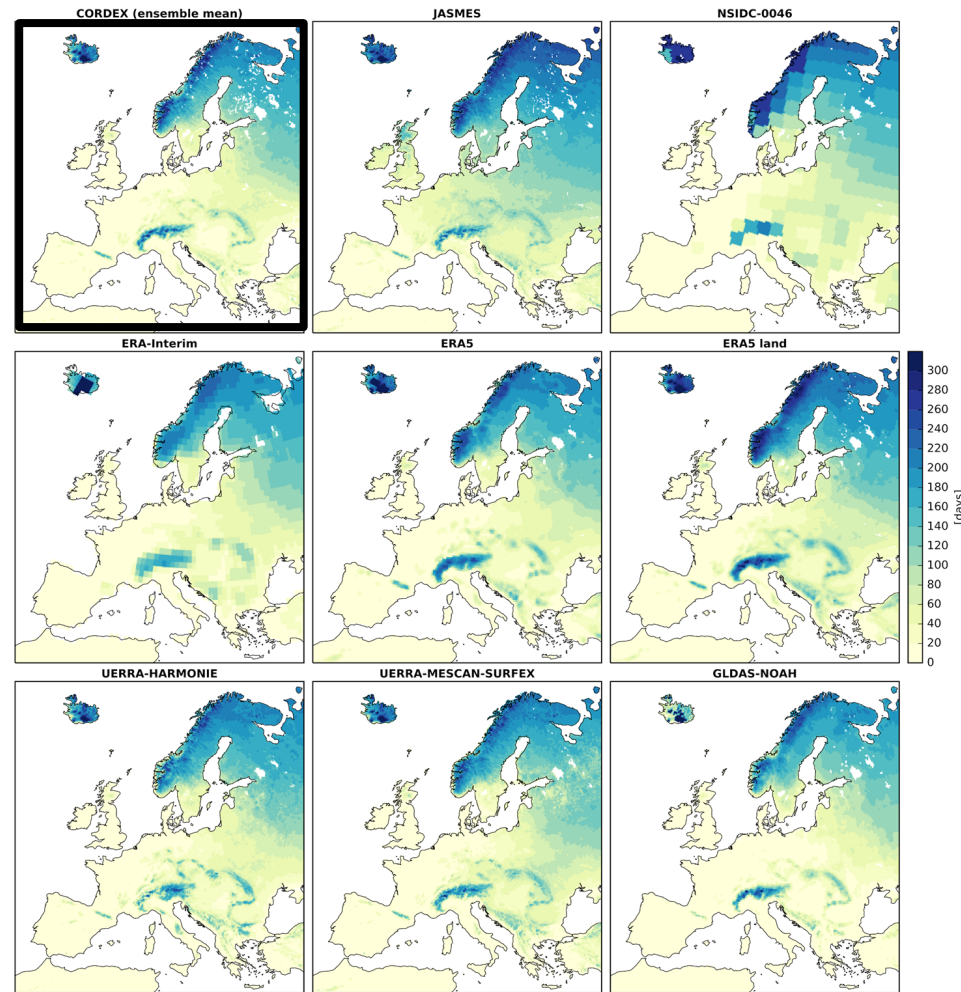
\*The temporal resolution refers to the one download.

\*\*The native spatial resolution of the land snow observations used for this product (NOAA/NCDC Climate Data Record of Northern Hemisphere Snow Cover Extent) is ~190 km.

# Snow cover duration

- **Yearly snow cover duration** [days per year] averaged over 1989 - 2008\* as represented by the CORDEX ensemble (ERA-Interim driven; black outline) and different observational and reanalysis datasets
- Generally **very good agreement** between CORDEX ensemble mean and reference data

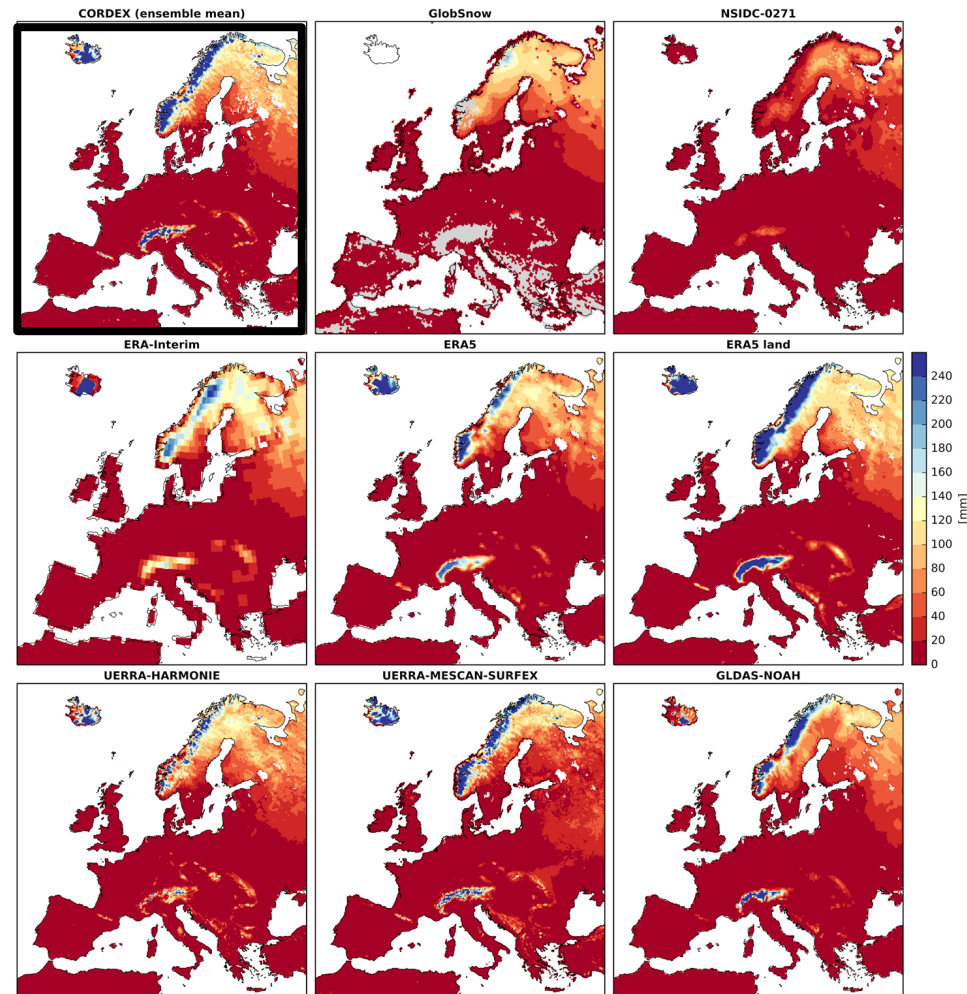
\*without the years 1994/1995 due to data gaps in the JASMES dataset





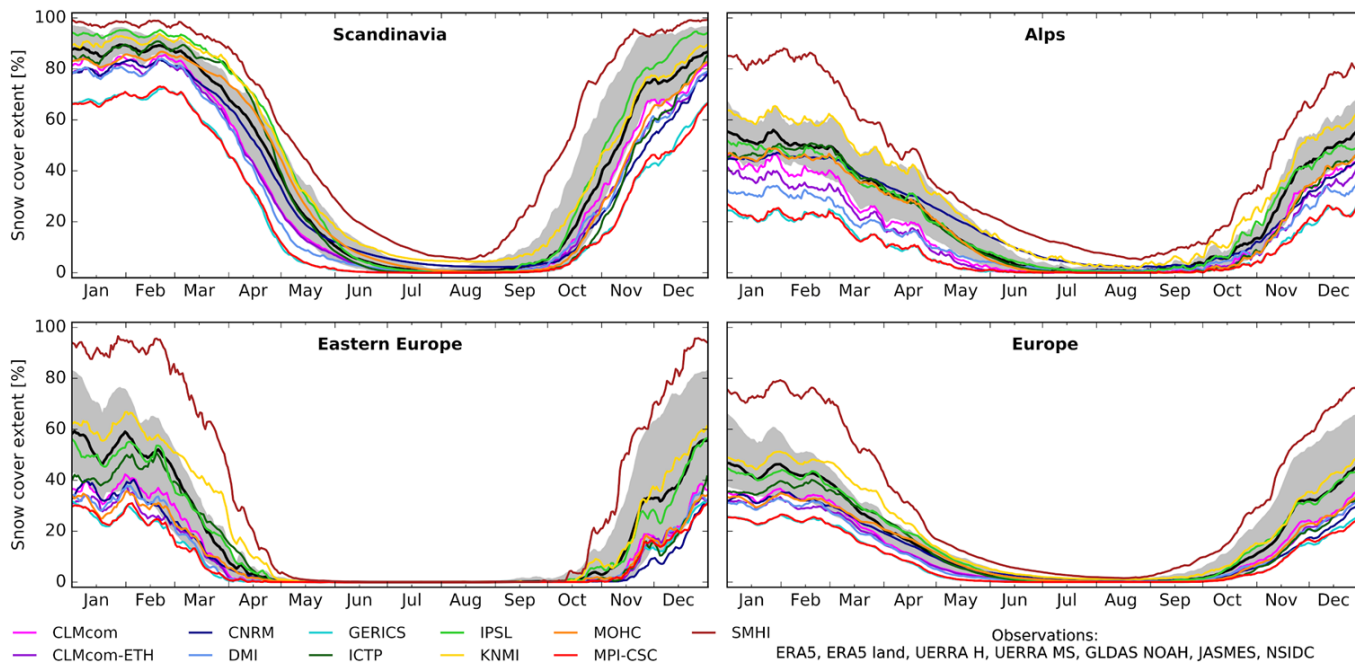
# Mean Winter SWE

- **Mean winter (NDJFMA) SWE [mm]** over 1989 - 2006 as represented by the CORDEX ensemble (ERA-Interim driven, black outline) and different observational and reanalysis datasets
- CORDEX ensemble mean reveals **higher SWE values in mountainous areas** than most reference datasets
- Satellite-derived SWE products generally indicate lower SWE values (particularly NSIDC-0271)





# Annual cycle of snow cover extent

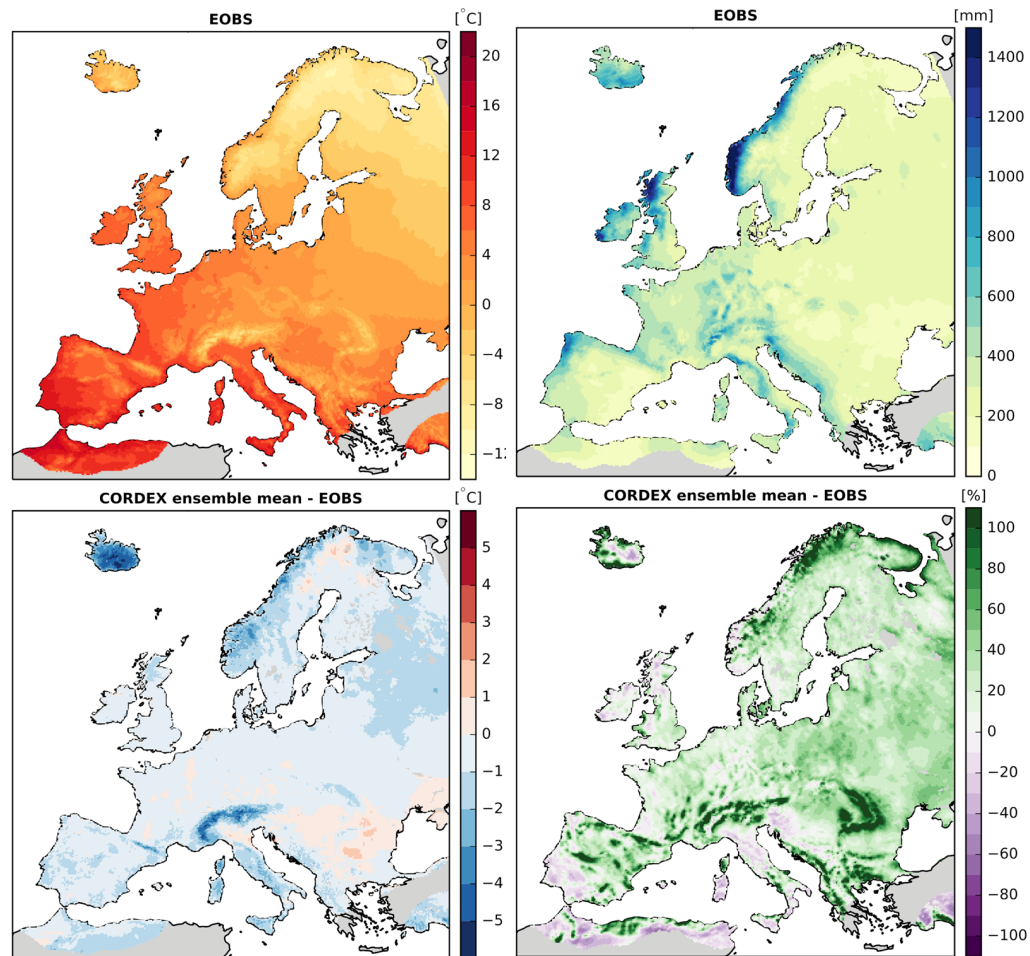


- Daily snow cover extent [% of total area] averaged over 1989 - 2008\*** as represented by the CORDEX ensemble mean (ERA-Interim driven) and different observational and reanalysis datasets (grey shading)
- \*without the years 1994/1995

# Biases in forcing

- Winter (NDJFMA) mean air temperature and precipitation for E-OBS and CORDEX ensemble mean (ERA-Interim driven; CORDEX - EOBS) averaged over 1989 - 2008\*
- RCMs indicate a general **cold** and **wet bias**; particularly in mountainous regions.

\*without the years 1994/1995 due to data gaps in the JASMES dataset



Part II

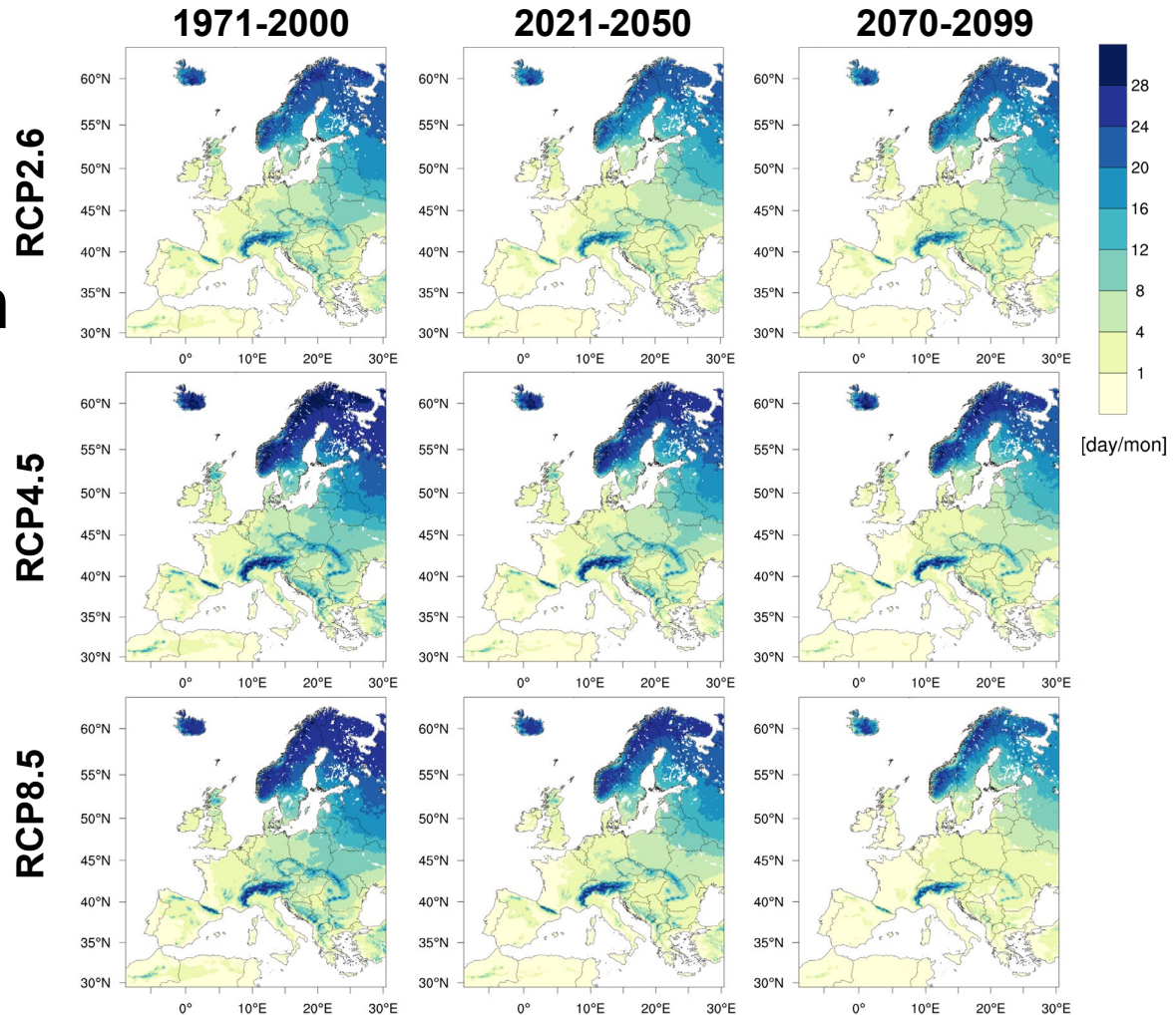
# Future Projections

*Note: preliminary results  
still under investigation!*

# Number of Snowdays (NDJFMA) Ensemble mean

- All three emission scenarios show a similar reduction till 2050
- RCP2.6 no further reduction after 2050
- RCP8.5 depicts the strongest reduction

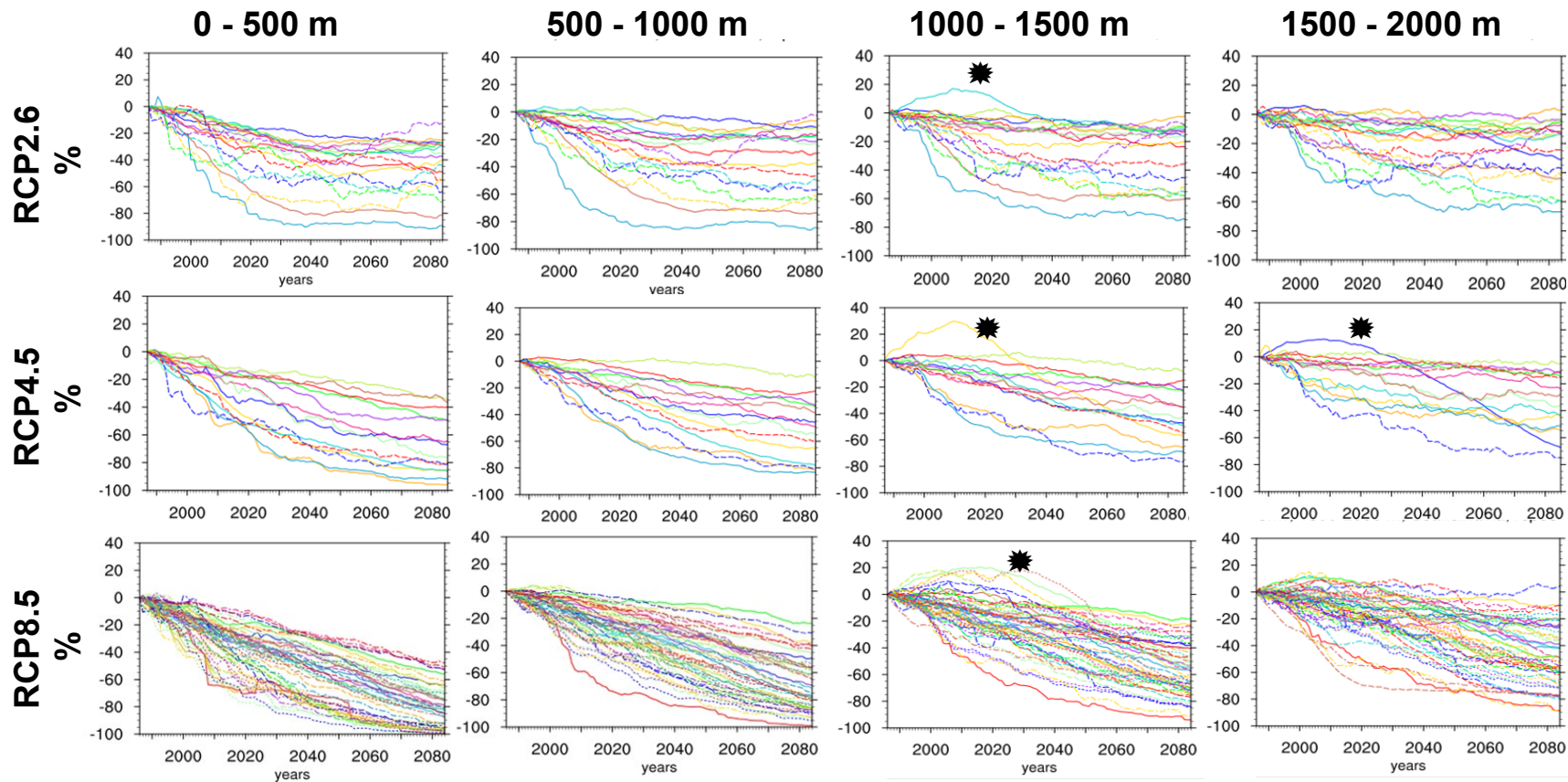
(Values in the historical time period vary due to different ensemble members and size )



# SWE change Scandinavia

- 30-year running mean change compared to (1971-2000) [%]

☀ needs revision



# Summary and conclusions

- RCM-simulated snow cover overall realistic, but **important high-elevation biases possible**
  - Possible reasons: **(a)** biased atmospheric forcing **(b)** missing/inappropriate treatment of perennial snow **(c)** neglect of important processes by simplified RCM snow cover schemes
  - Climate scenarios indicate **important reduction of European snow cover** by end of 21<sup>st</sup> Century, even for RCP2.6
  - Scandinavia/Alps: **Almost complete loss** at low elevations for RCP8.5
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- Strong control by **temperature changes** and, hence, by **driving GCM**
  - **Agreement** with earlier regional-scale studies using offline snow cover models



# THANK YOU

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# References

- Christensen and Christensen (2007): A summary of the PRUDENCE model projections of changes in European climate by the end of this century, Climatic Change, 81:7–30, doi: 10.1007/s10584-006-9210-7
- Sturm et al. (2010): Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes, Journal of Hydrometeorology, 11:1380-1394, doi: 10.1175/2010JHM1202.1

The present work is planned to be submitted to the journal «Atmosphere» (Special Issue «Cryosphere in and around Regional Climate Models», see [https://www.mdpi.com/journal/atmosphere/special\\_issues/cryosphere\\_climate\\_models](https://www.mdpi.com/journal/atmosphere/special_issues/cryosphere_climate_models))