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 ressource** (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 21st 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: ≥ 3 cm snow depth
  • Conversion of snow water equivalent (SWE) to snow depth with constant snow density: 312 kg m\(^{-3}\) (Sturm et al., 2010)
  • Indicators: **SWE**, snow-covered area, snow-covered period
Part I

Model Evaluation
## Reference snow datasets

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

*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) [%]

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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 21st Century, even for RCP2.6

- Scandinavia/Alps: **Almost complete loss** at low elevations for RCP8.5

- 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


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)