Topographic effects on longwave and shortwave surface radiation in a kilometre-scale regional climate model

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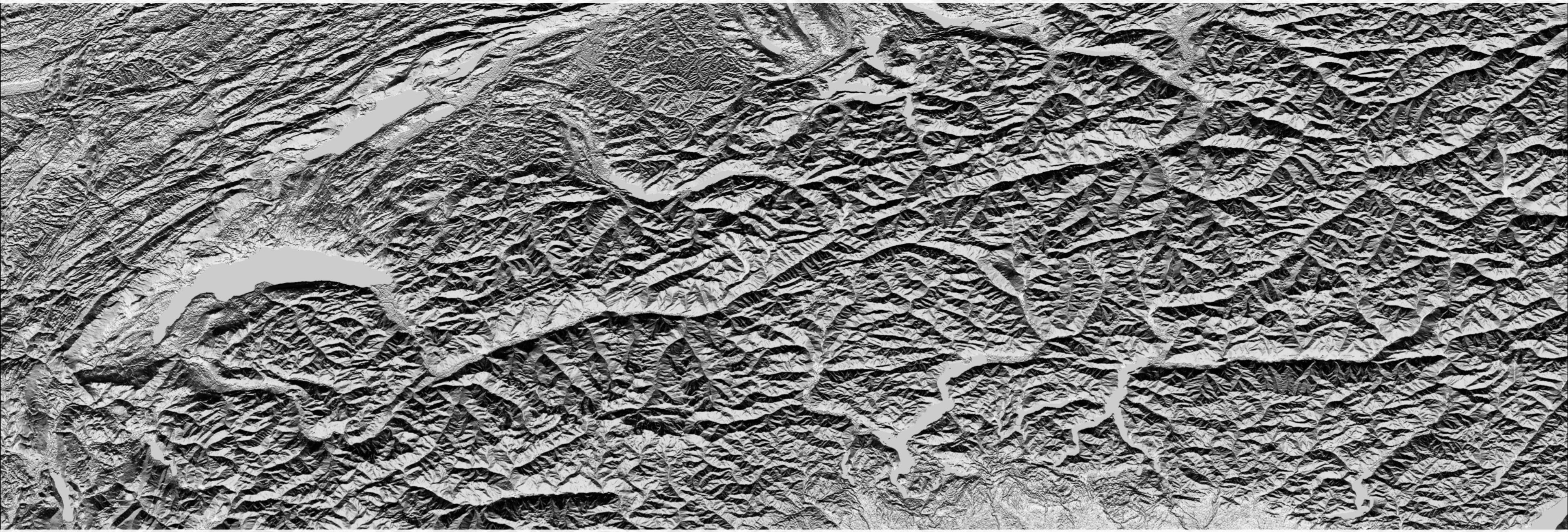

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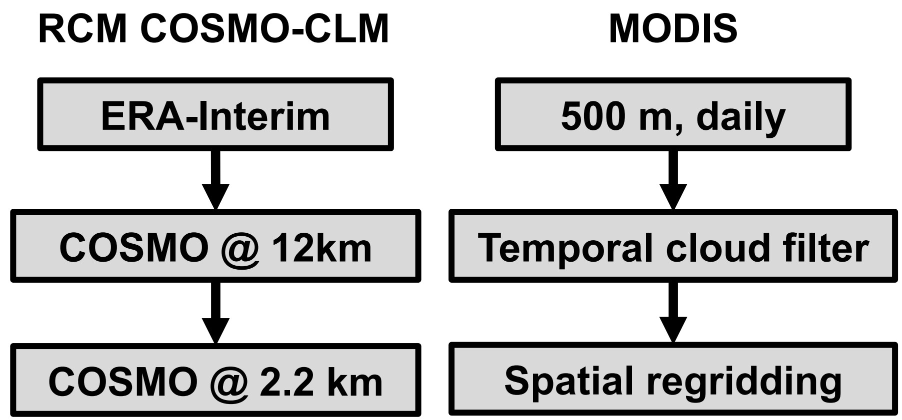
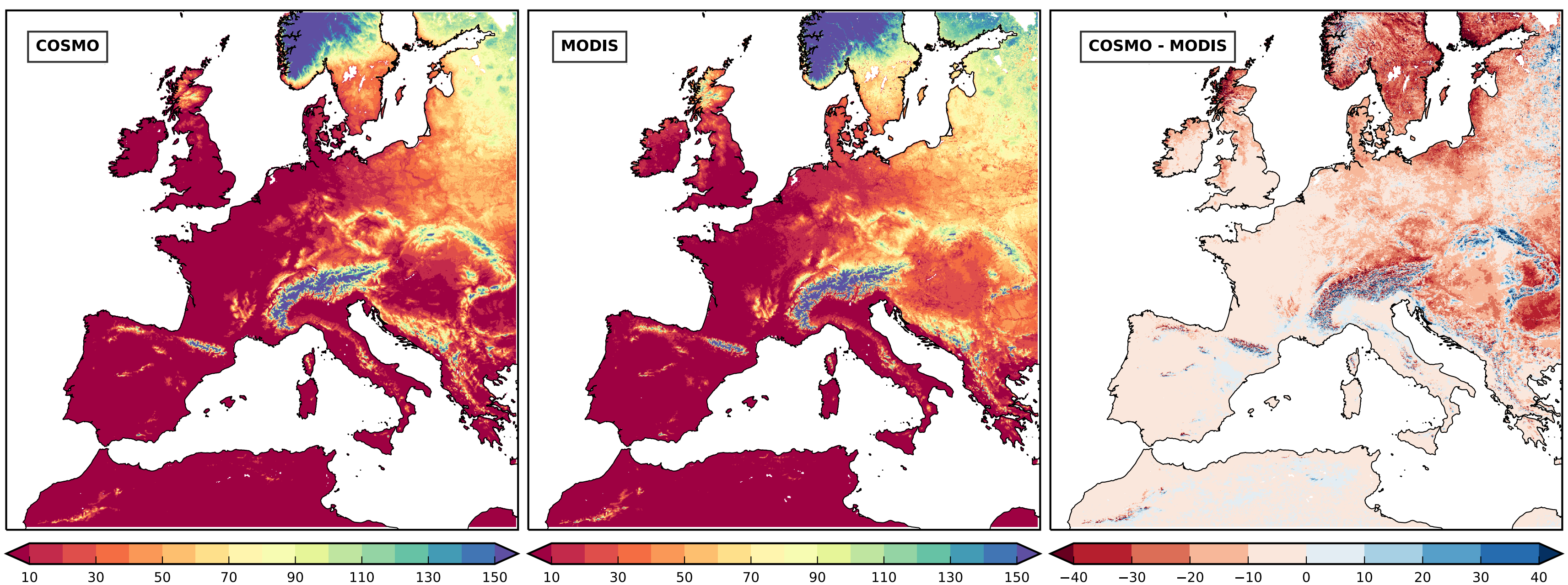
Preface – Evaluation of simulated snow cover duration (SCD) (I)

- Comparison of decadal-long high-resolution (~2km) COSMO-CLM simulation with MODIS snow cover data (MOD10A1/MYD10A1)
- Negative biases in SCD are likely related to simple single-layer snow model (e.g. no refreezing / liquid water retention and snow-forest interactions)



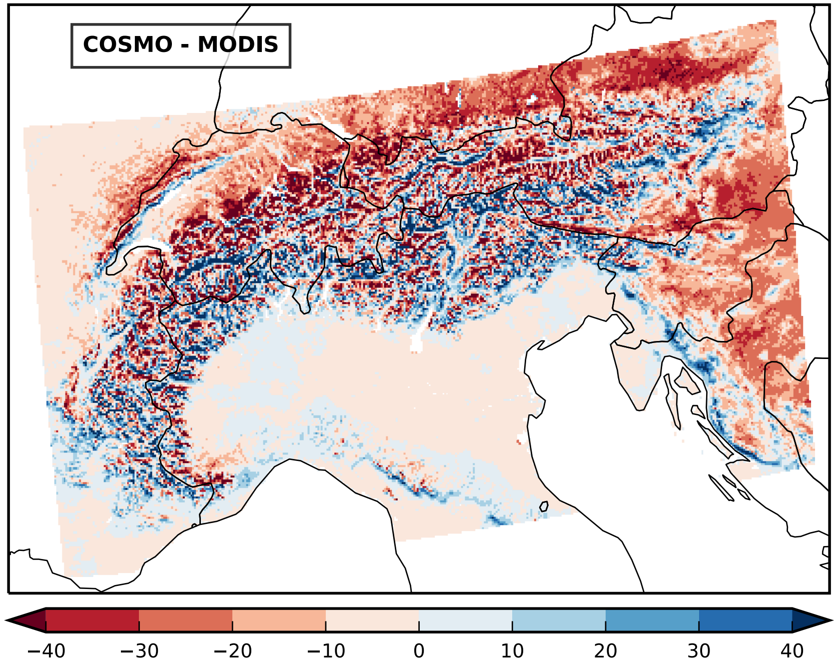
(2.2 km, mean 2001 – 2008, V4.19_GPU)

Europe - Snow covered days (Jan - Dec)



Preface – Evaluation of simulated snow cover duration (II)

- Zoom-in on Alps → biases in snow cover duration seem to be linked to topography
- Plotting SCD biases of individual grid cells as function of the grid cell's aspect reveals a clear dependency, which enhances with increasing slope of the grid cell → cause of this bias is likely related to incoming surface radiation, which controls snow ablation



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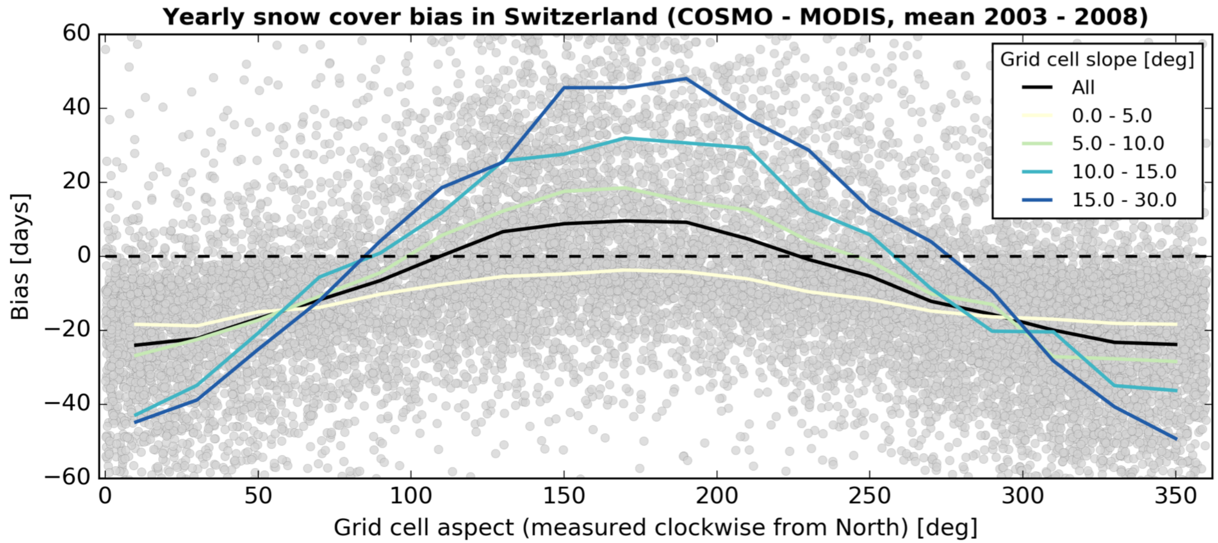


Introduction to topographic effects on surface radiation

Influence of topography on incoming surface radiation

- Shortwave (SW) radiation: Direct beam radiation is modified by shading and incident angle, diffuse radiation is altered by reduced sky view factor (SVF) (→ e.g. terrain reflectance)
- Longwave (LW) radiation: SVF determines radiation fraction from sky and surrounding terrain
- Example of effect: slope exposition determines incoming SW radiation and effects snow cover duration (see images)

Tschierv, Val Müstair, Switzerland, 30th March 2019

Representation of effects in regional models

- Two-stream approximation for radiation (vertical) → no lateral interaction with topography
- Only a few RCM consider topographic effects on radiation → e.g. Met Office Unified Model (Manners et al., 2012) and WRF (Arthur et al., 2018)

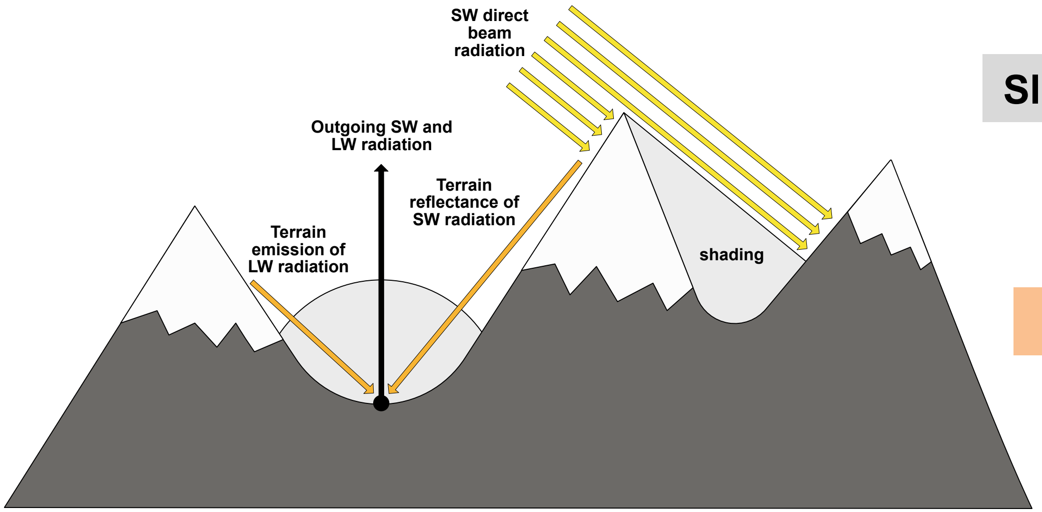
Motivation to consider effects

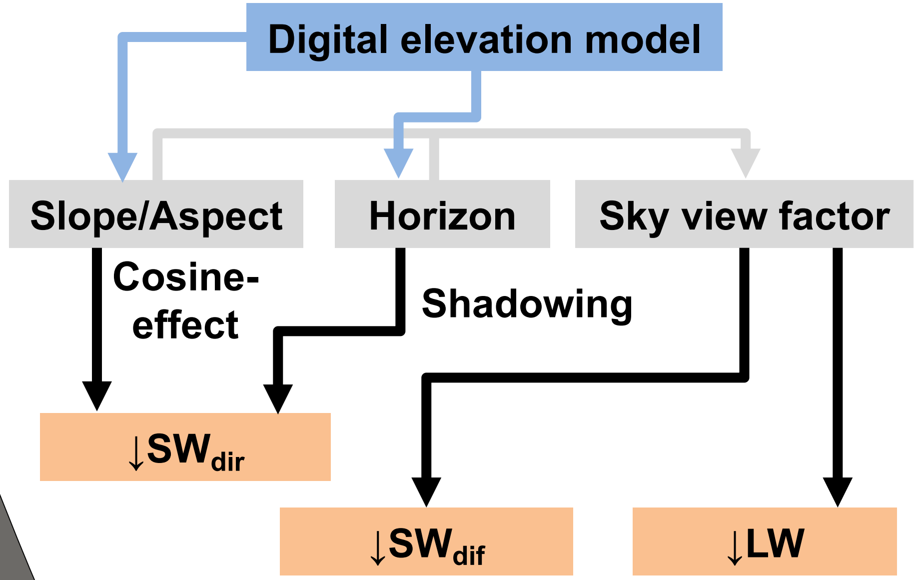
- Feedbacks to atmosphere (e.g. via snow albedo)
- Improve representation of near-surface variables for downstream applications and models

Overview of radiation correction scheme

Correction of radiation fluxes (based on Müller and Scherer (2005))

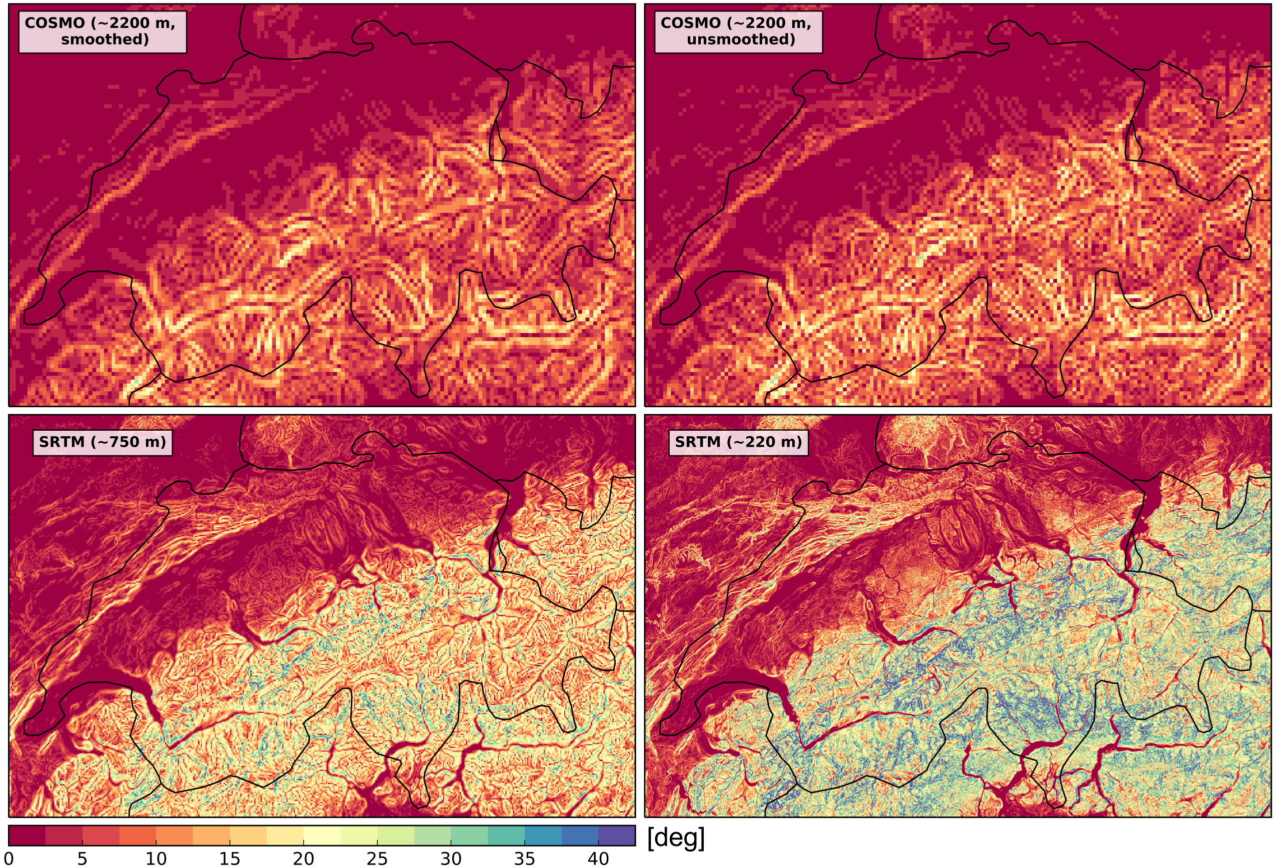
- Direct beam SW radiation: adjusted with slope angle (cosine-effect) and by considering shading
  → horizontal redistribution of energy influx (but no gain/loss on larger spatial scale)
- Diffuse SW radiation: scaling of incoming diffuse sky radiation with SVF; terrain reflectance is approximated with local outgoing SW flux (scaled by (1.0 – SVF))
- LW radiation: scaling of incoming sky radiation with SVF; emission from surrounding terrain is approximated with local outgoing LW flux (scaled by (1.0 – SVF))





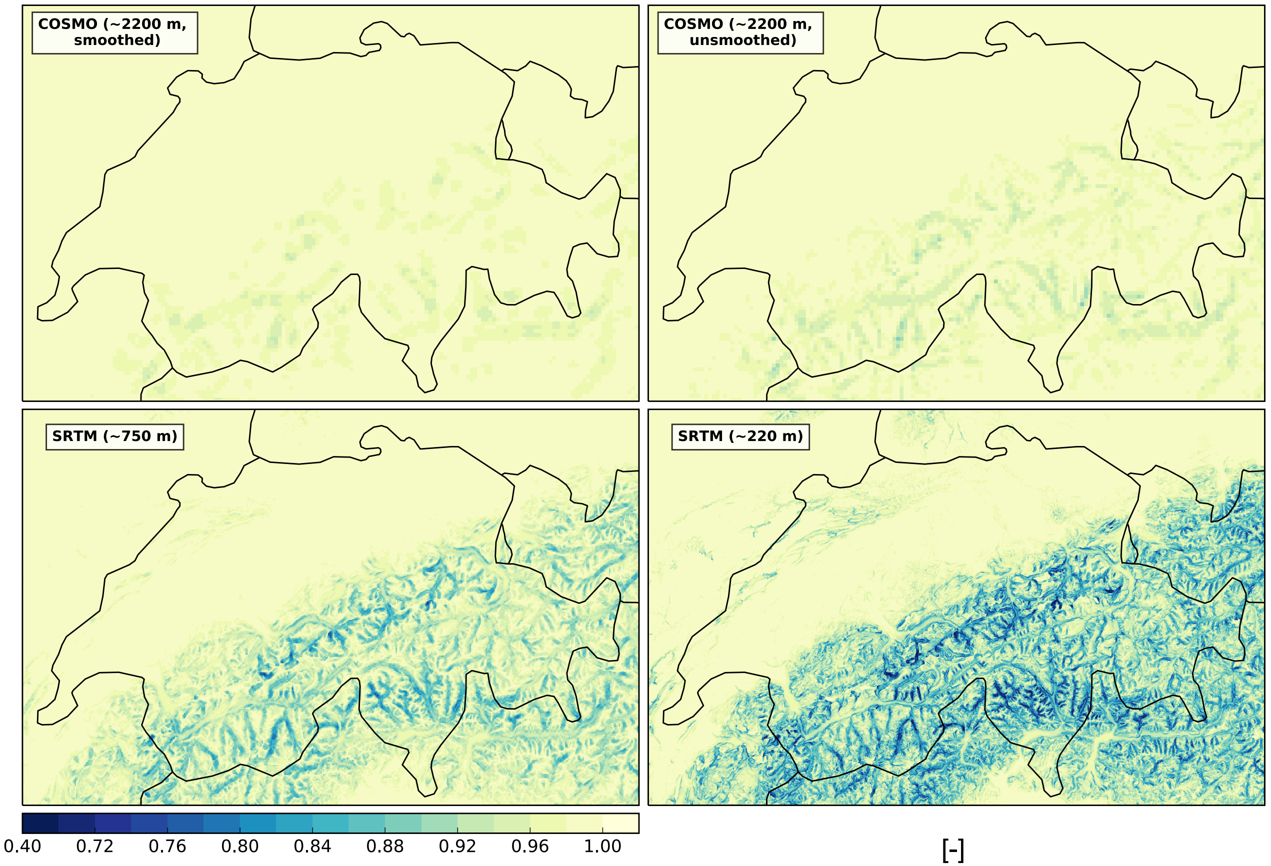
Current implementation in COSMO (Buzzi, 2008)

Slope angle (COSMO-CLM @ 2.2 km and sub-grid resolution)



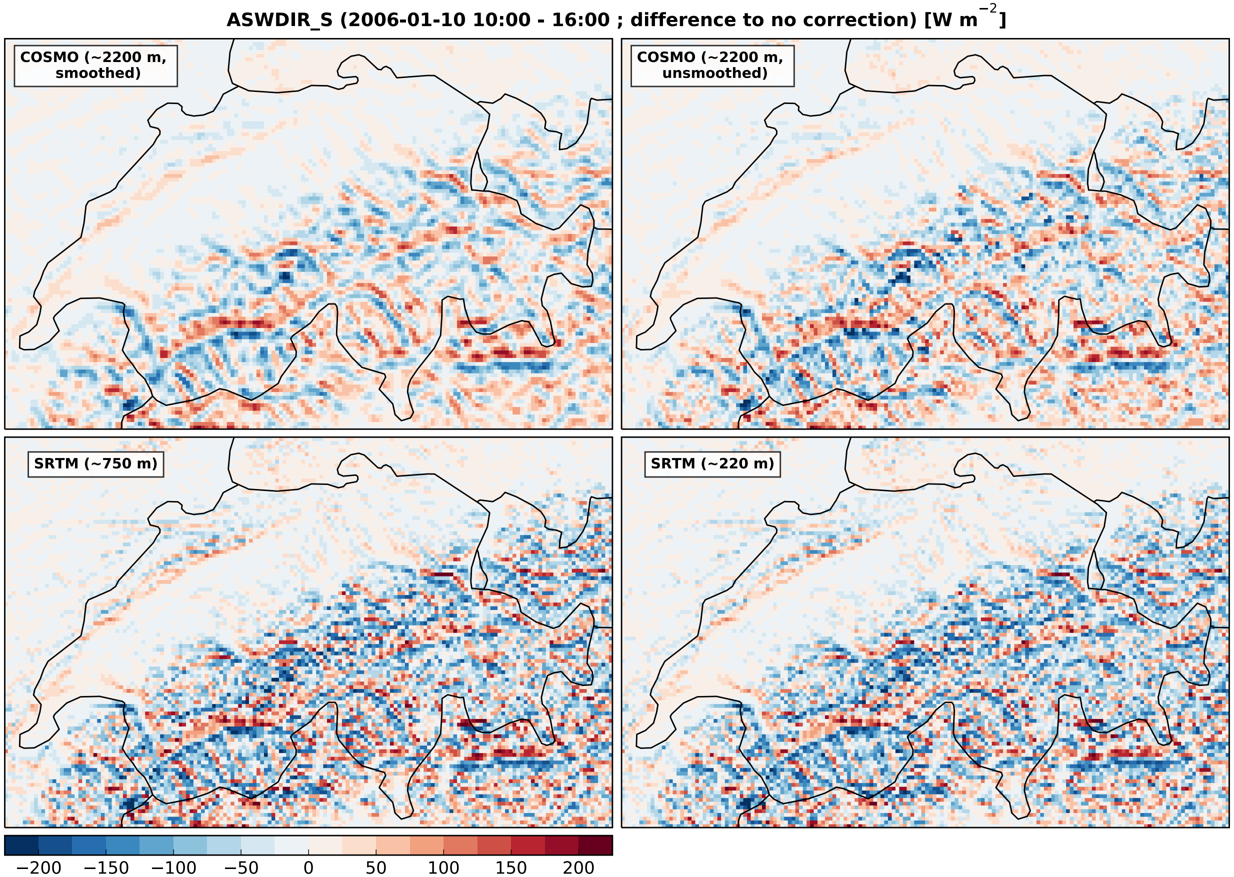
- In the current COSMO implementation, topographic parameters like slope angles are computed from the smoothed model topography (here at a resolution of ~2.2 km)
- However, topographic parameters can also be computed on a sub-grid resolution and subsequently be aggregated on the model grid

Sky view factor (COSMO-CLM @ 2.2 km and sub-grid resolution)



- The figure above shows that SVFs computed from model topography (~2.2 km) only marginally deviate from 1.0 (flat horizontal terrain). Incoming diffuse SW and LW radiation are thus only negligibly altered by the radiation correction scheme. Computing the SVF from a higher-resolution DEM yields distinctively lower values, even if the values are aggregated on the model resolution (not shown).

Radiation correction (COSMO-CLM @ 2.2 km and sub-grid resolution)

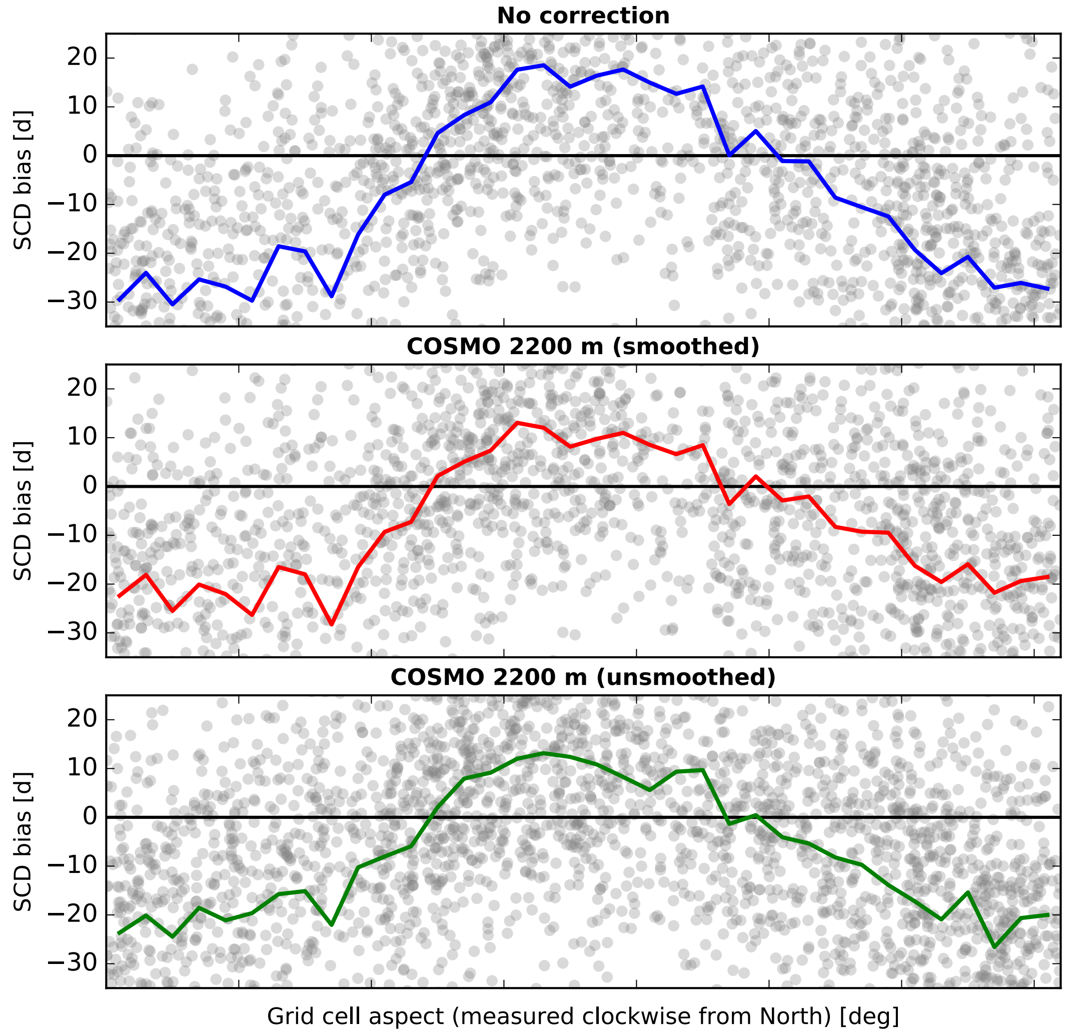


(COSMO-CLM 5.X_POMPA_crCLIM)

- The figure above shows the effect of the radiation correction scheme for direct beam SW radiation for a specific day (averaged over 10:00 – 16:00) and for different DEM resolutions. Apparently, the magnitude and patterns of these correction terms are rather insensitive to the chosen DEM resolution range.

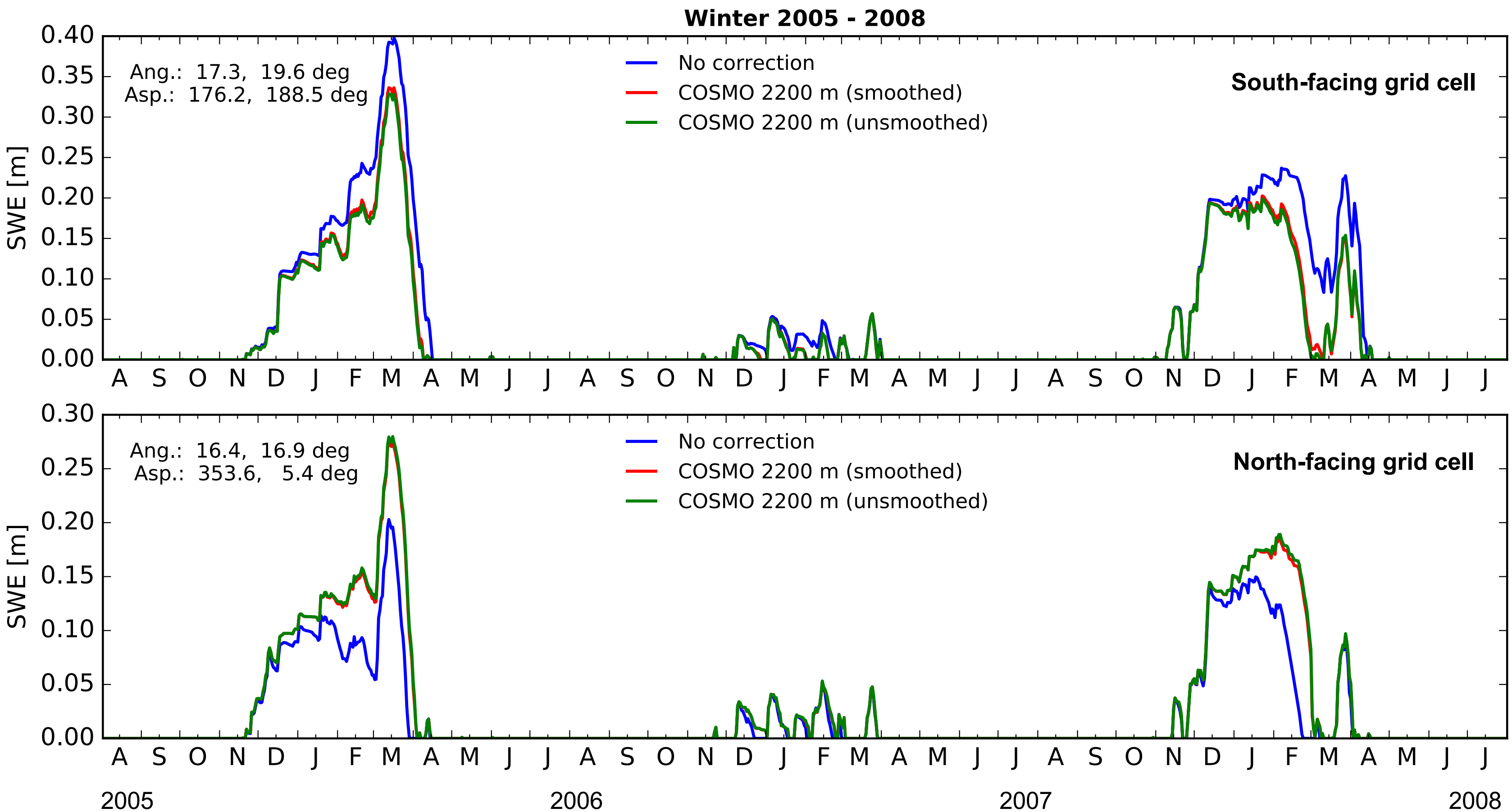
Preliminary results from TERRA-ML offline experiments (I)

- Offline experiments with the land surface model of COSMO-CLM (TERRA-ML) were conducted at a horizontal resolution of ~2 km and for 3 winters (2005 – 2008)
- The radiation correction scheme reduces biases in snow cover duration (SCD) but the bias decrease is less than expected
- Issue related to this deviating expectation: newer COSMO-CLM version (5.X_POMPA_crCLIM) simulates generally shorter snow cover durations → cause of this change currently unclear (ongoing work)



(Atmospheric forcing from COSMO-CLM 5.X_POMPA_crCLIM)

Preliminary results from TERRA-ML offline experiments (II)



- The figure above shows snow water equivalent (SWE) evolution for two grid cells in Switzerland. Topographic characteristics (slope angle/aspect) of the cells are given in the upper left corner of the panels. The upper panel shows a south-facing grid cell, for which SWE is considerably reduced with applied radiation correction. The opposite effect is visible for a north-facing grid cell (lower panel).

Conclusions

- Snow cover duration (SCD) of high-resolution COSMO-CLM simulation (~2km) is well represented (with respect to MODIS snow cover data) on an European scale
- Biases in SCD are distinctively linked to topography and likely caused by an inaccurate representation of surface radiation in areas with complex topography
- Applying a radiation correction scheme on the model grid scale reduces the bias. This reduction seems to be dependent on the COSMO-CLM version and is likely linked to differing surface energy fluxes during the snow ablation phase (*ongoing work*)

Munt Buffalora, Switzerland, March 2019

References

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- Buzzi (2008): Challenges in operational numerical weather prediction at high resolution in complex terrain (PhD thesis)
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- Müller and Scherer (2005): A Grid- and Subgrid-Scale Radiation Parameterization of Topographic Effects for Mesoscale Weather Forecast Models, Mon. Wea. Rev., 133, 1431–1442, doi: 10.1175/MWR2927.1