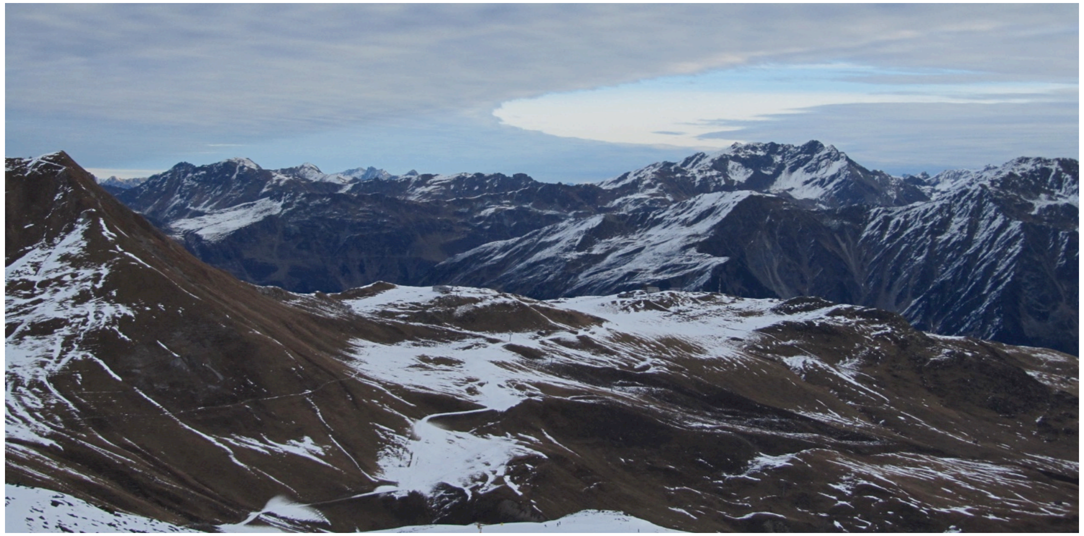
A snowfall downscaling scheme for mountainous terrain



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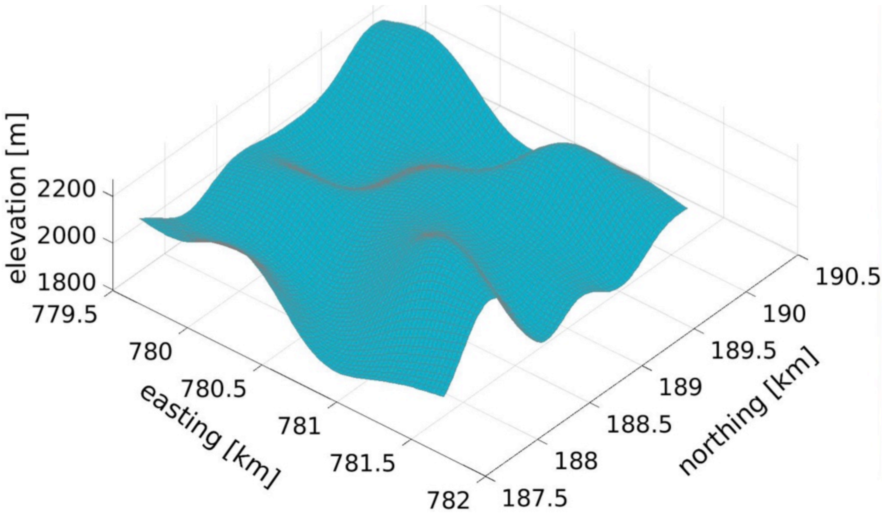
vEGU21: Gather Online 19-30 April 2021

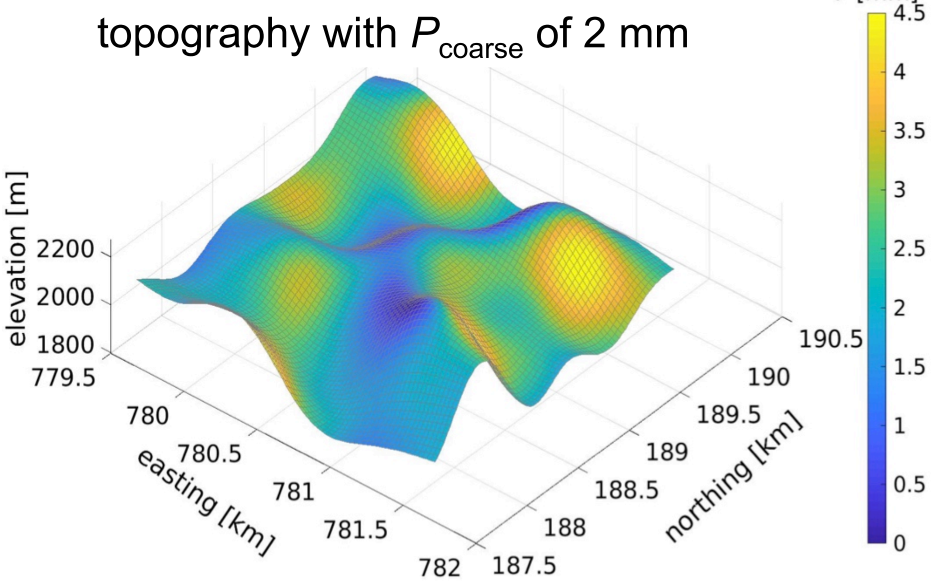
Motivation

To improve fine-scale snow cover modeling over mountainous terrain, an efficient downscaling scheme for coarse-scale snowfall is required.

Coarse-scale snowfall P_{coarse} of 2 mm on topography without downscaling scheme



Fine-scale modeled snowfall P on topography with P_{coarse} of 2 mm



Δx = 30 m

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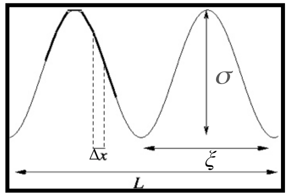
Goal: A snowfall downscaling scheme that takes into account wind-snowfall-topography interactions

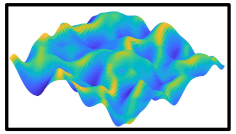
Recipe:
- Generate a large, diverse data pool of modelled fine-scale snowfall distributions in mountainous terrain
- Develop statistical parameterization

Ingredients:

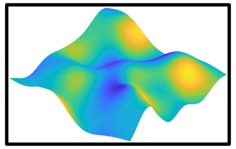
1) Large set of simulated topographies covering a broad range of topographic characteristics



2) Non-hydrostatic and compressible atmospheric model *ARPS (Advanced Regional Prediction System)* (Xue et al., 2001) to compute fine-scale wind fields



3) *Snow transport module of Alpine3D* to compute preferential deposition i.e. fine-scale snowfall distributions (Lehning et al., 2008)



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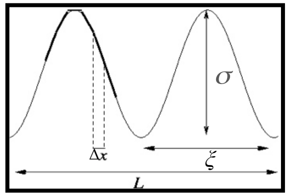

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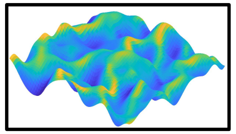

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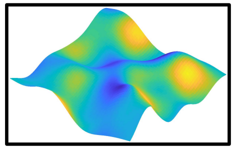
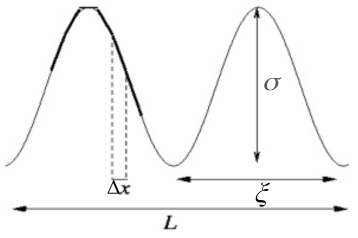


First ingredient: Simulated topographies that cover a broad range of topographic characteristics

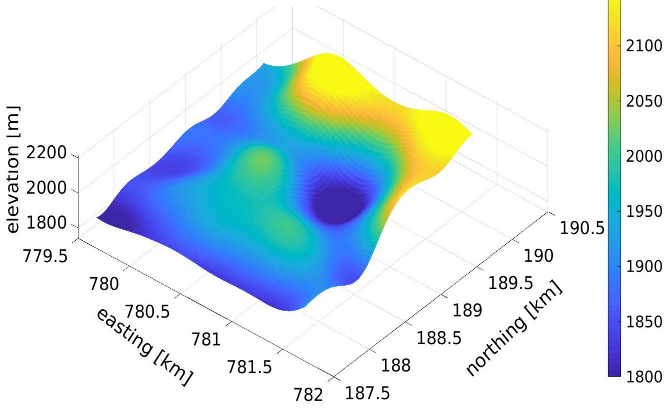
Topographies have domain size of L = 3 km, horizontal resolution of Δx = 30 m and cover:

- Different spatial mean slope angles ζ between 10° and 36°
- Terrain correlation length ξ between 200 m and 1000 m
- Standard deviation of elevation σ up to 365 m

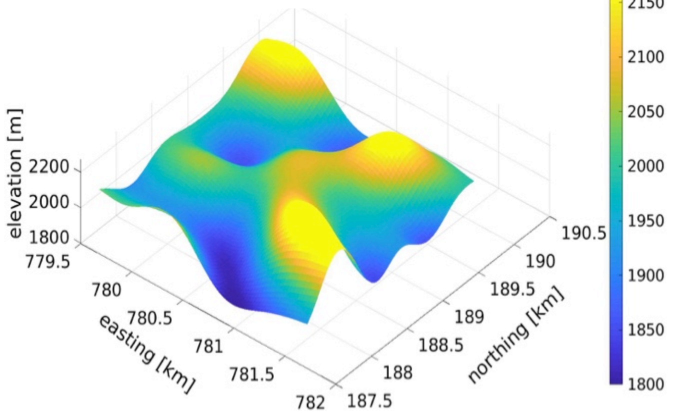


Three example topographies:

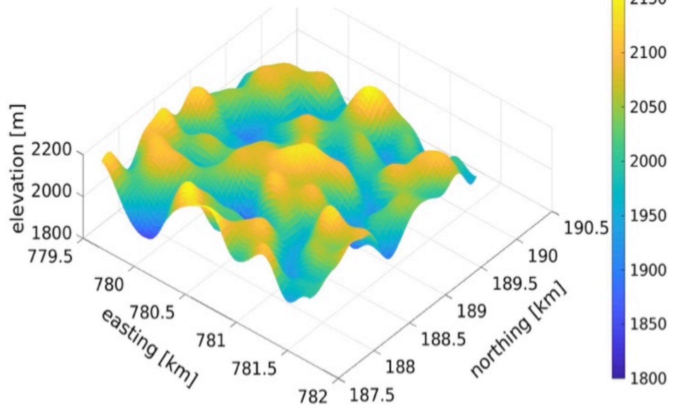
mean slope angle of 19°



mean slope angle of 25°



mean slope angle of 30°



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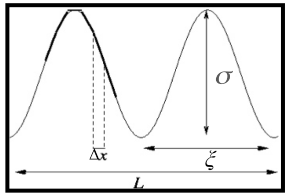

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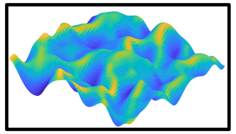

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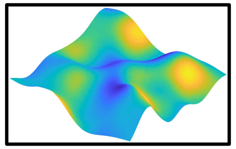
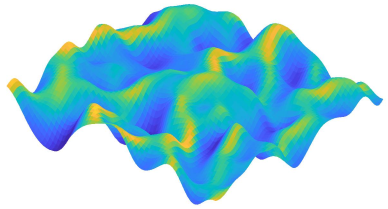


<u>Second ingredient:</u> Fine-scale *ARPS* wind fields for all topographies

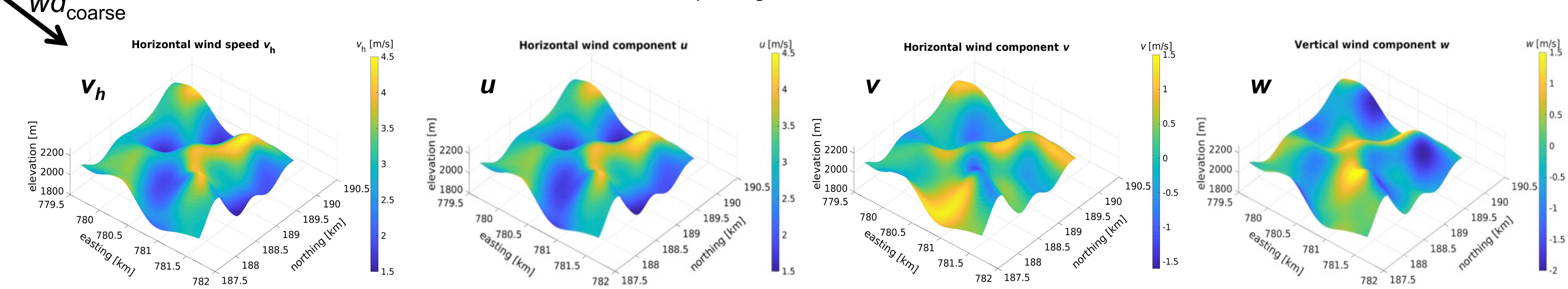
ARPS wind fields were derived for all topographies under controled conditions (Helbig et al., 2017):

- Coarse wind speed v_{coarse} of 3 and 5 m/s and fixed wind direction wd_{coarse} to West
- No thermally induced circulations and turbulent structures



Generated near-surface horizontal wind speed v_h and wind components, *u, v* and *w* for v_{coarse}= 3 m/s:

mean slope angle of 19°



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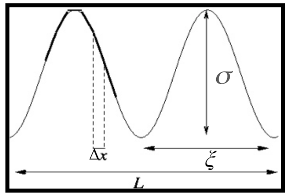

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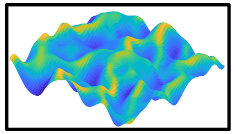

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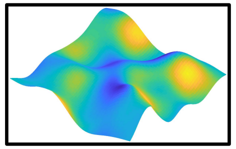

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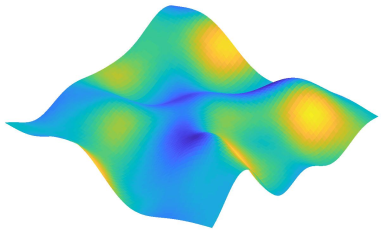
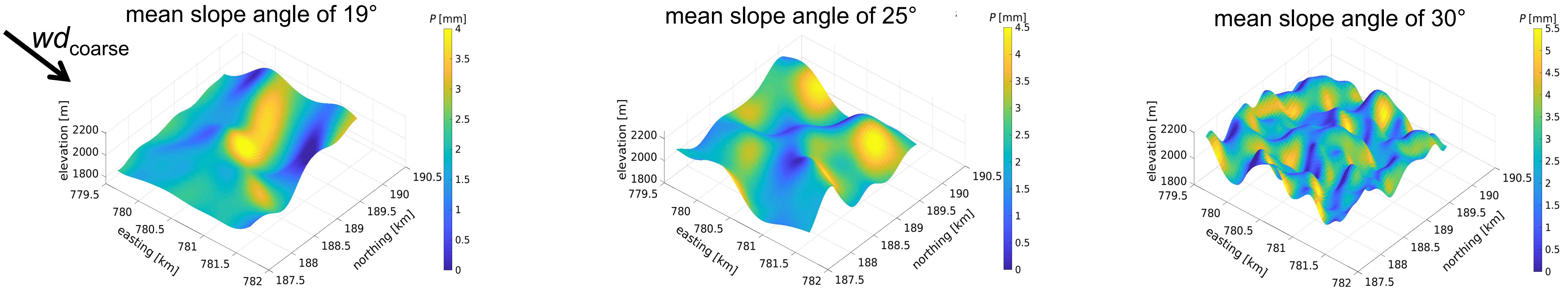
<u>Third ingredient:</u> Fine-scale snowfall distributions for all topographies

Fine-scale snowfall distributions using a snow transport model (Lehning et al., 2008) forced with *ARPS* wind fields for all topographies under controled conditions:



- Neglected erosion, saltation, drifting snow sublimation
- Coarse snowfall P_{coarse} is 2 mm, 5 mm and 8 mm; P_{coarse} and P are for one time step

Generated fine-scale snow deposition for P_{coarse} = 2 mm and v_{coarse}= 3 m/s:



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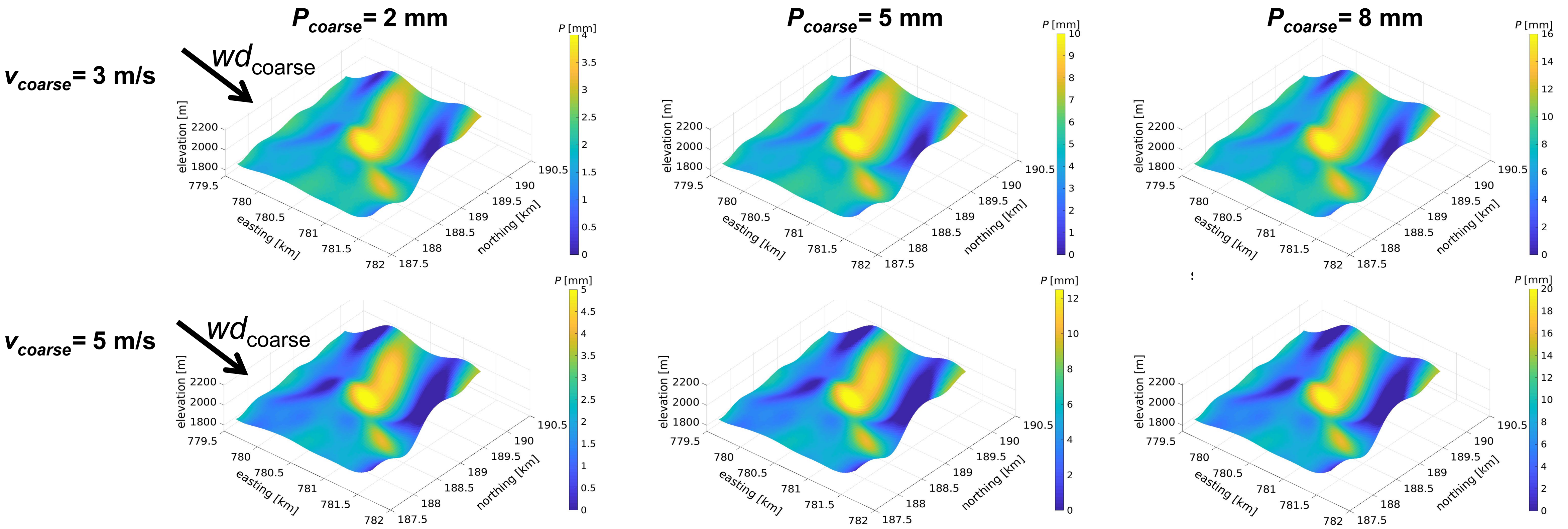
Results: Fine-scale modeled snowfall patterns

Fine-scale modeled snowfall patterns are similar, though enhanced with increasing coarse-scale snowfall P_{coarse} or coarse-scale wind speed v_{coarse}

Modeled fine-scale snow deposition patterns for one topography (different color scales):



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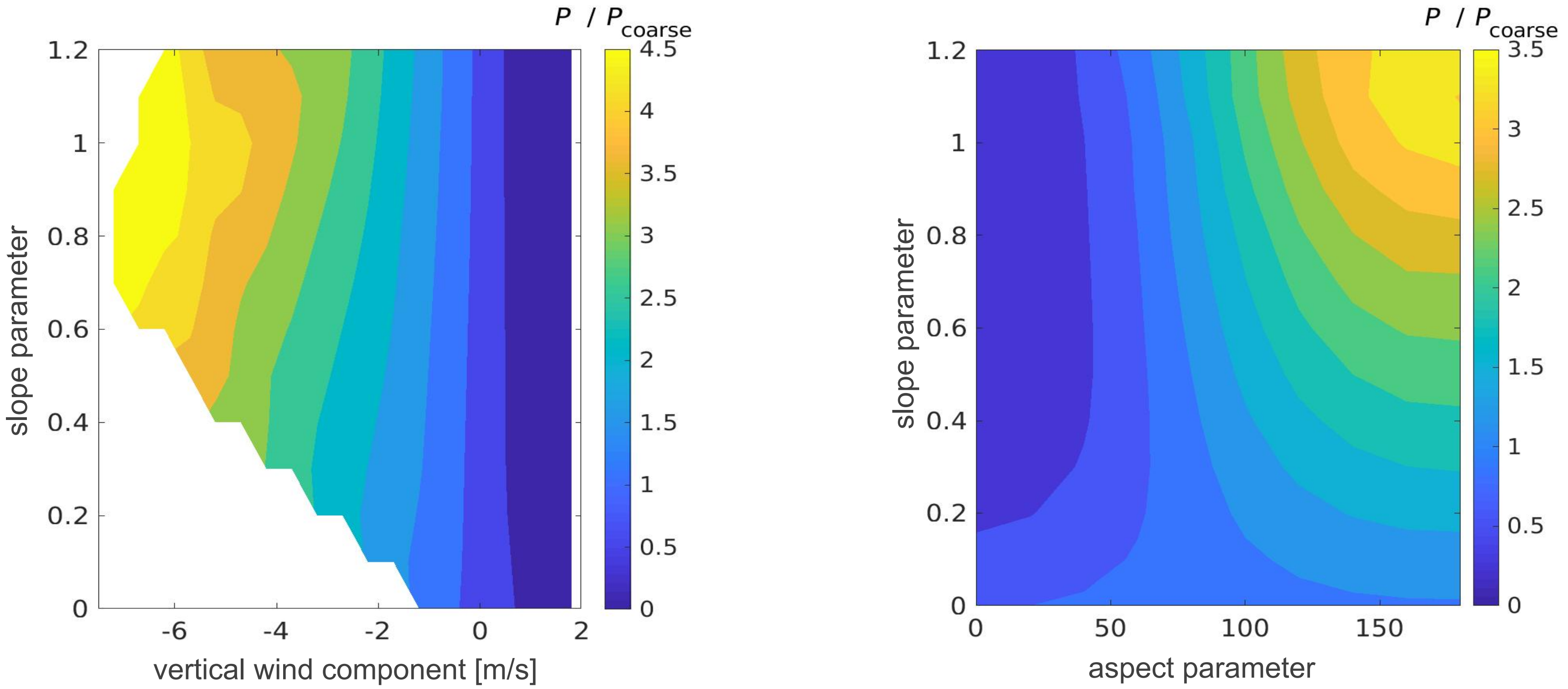
Results: Scaling factors for the snowfall downscaling scheme

Fine-scale modelled snowfall P correlates well with coarse snowfall P_{coarse} and
1) Fine-scale vertical wind component and a terrain slope parameter (called „**wind**“ scheme)
2) Fine-scale slope parameter and aspect relative to coarse wind direction wd_{coarse} (called „**aspect**“ scheme)



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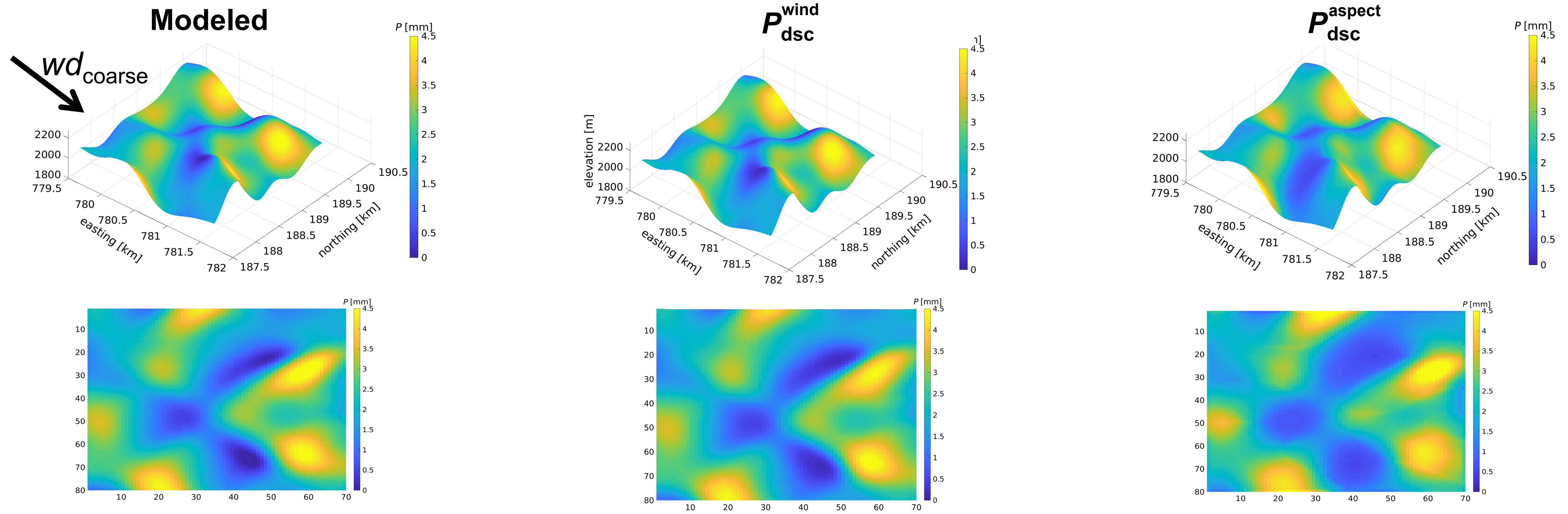
<u>Results:</u> Modeled and downscaled snowfall - Spatial patterns

Downscaled snowfall P_{dsc} describes spatial variability of modelled snowfall P well

- Spatial patterns similar for P_{dsc}^{wind} as well as for the simpler P_{dsc}^{aspect}
- Magnitudes are better described by P_{dsc}^{wind}

Modeled and downscaled snow deposition patterns for one topography with P_{coarse} = 2 mm:



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<u>Results:</u> Modeled and downscaled snowfall - Per aspect and slope

Downscaled and modeled snowfall patterns are similar across all aspects and for various P_{coarse}
- Larger snowfall on leeside increases and lower snowfall on windward side decreases with increasing slope
- Small differences with modeled P for the steepest slope angle bins

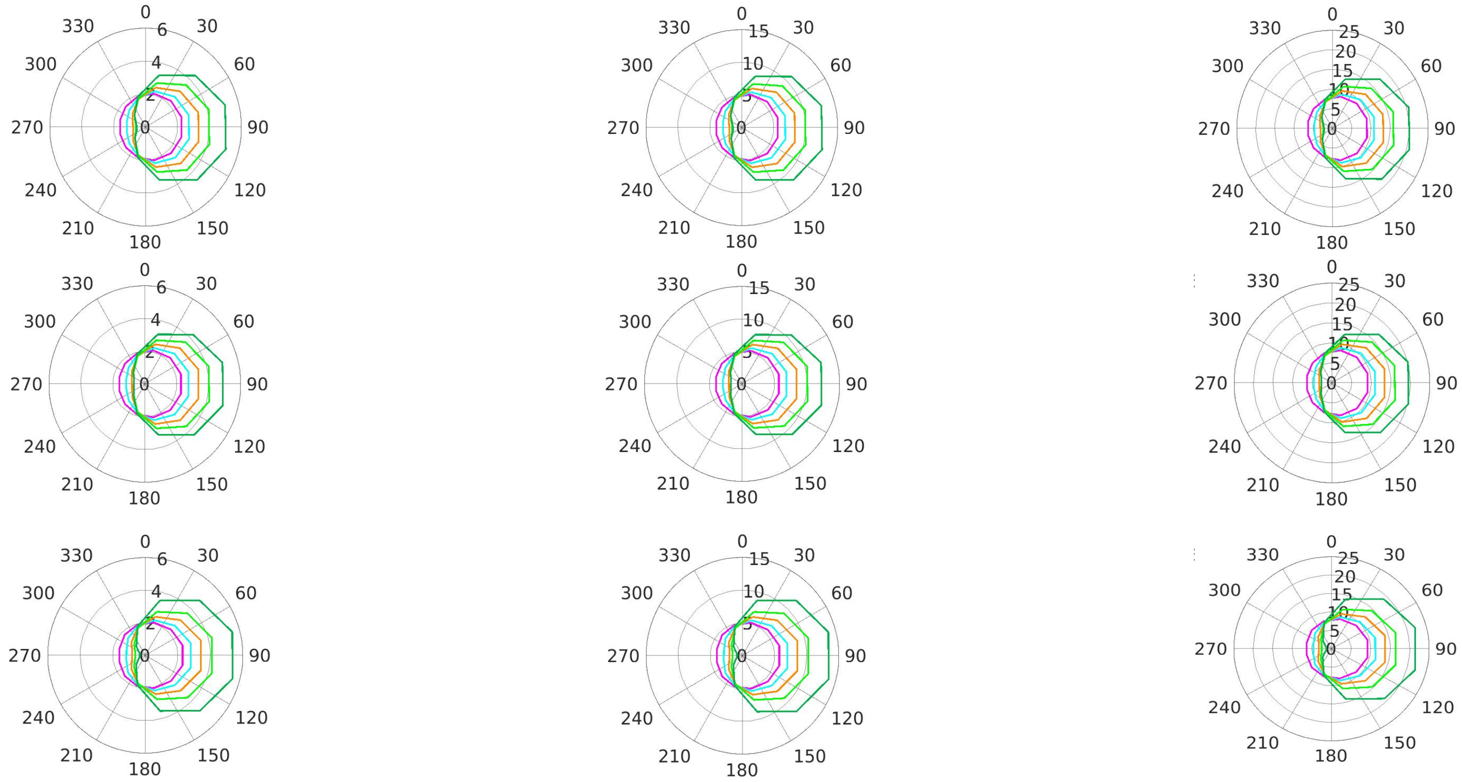
Binned per local slope angle ξ with $\Delta\xi$ =10° and local aspect Ψ with $\Delta\Psi$ = 30°:

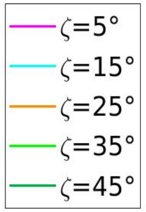
P_{coarse}= 2 mm | **P_{coarse}= 5 mm** | **P_{coarse}= 8 mm**

Modeled

P_{dsc}^{wind}

P_{dsc}^{aspect}





Wd_{coarse} = 270°

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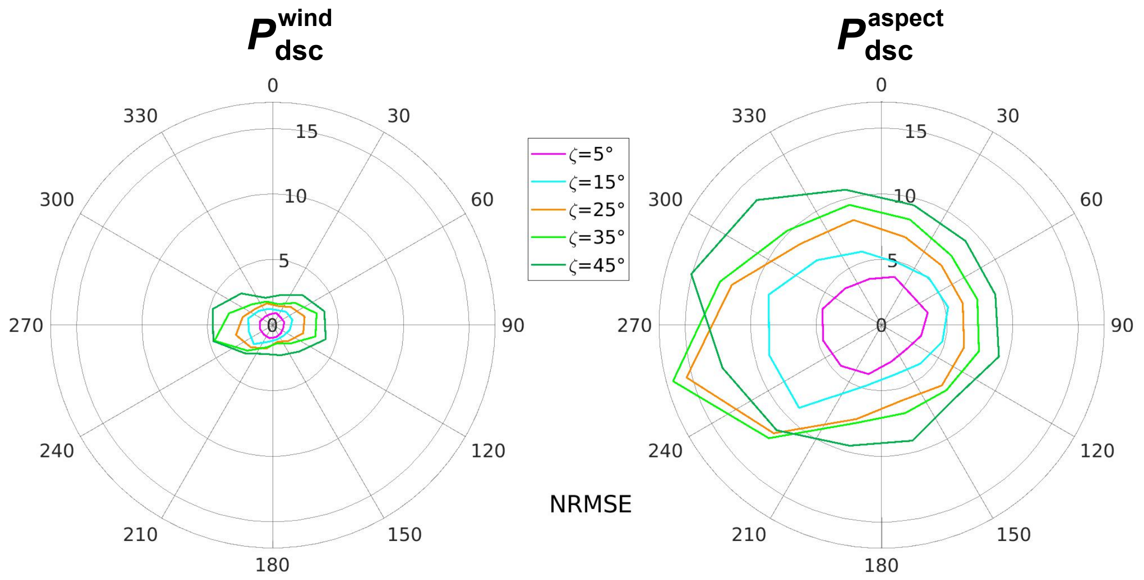
Results: Performances per aspect and slope

Overall low normalized root-mean-square error (NRMSE) for both downscaling schemes and P_{coarse}

- NRMSE increases with slope angles and is slightly larger on windward slopes
- Wind scheme has lower NRMSE than aspect scheme
- NRMSE similar for all P_{coarse} (not shown)

Binned per local slope angle ξ with $\Delta\xi$ =10° and local aspect Ψ with $\Delta\Psi$ = 30°:



P_{coarse}= 2 mm and for v_{coarse} = 3 m/s

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Conclusions

- Fine-scale modeled snowfall patterns (only preferential deposition) are similar for different coarse-scale snowfall and wind speed

- Large correlations between fine-scale modeled snowfall, vertical wind component as well as terrain aspect relative to coarse wind direction

- Two statistical downscaling schemes describe new snow patterns well for downscaled coarse snowfall of 2 mm, 5 mm and 8 mm :
    1) A wind scheme performs better than a simpler aspect scheme
    2) Performances decrease slightly on windward mountain sides and for steeper slopes (larger 40°)

Outlook

- For coarse wind speed of 5 m/s errors increase especially for steeper slopes (computed for one subset of all topographies only) →Further investigation currently underway to better account for different coarse wind speed

- Evaluation on real data

References

- Xue et al. (2001). The Advanced Regional Prediction System (ARPS) - A multi-scale, non-hydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications, *Meteorol. Atmos. Phys.*, 76, 143–165, https://doi.org/10.1007/s007030170027.
- Lehning et al. (2008). Inhomogeneous precipitation distribution and snow transport in steep terrain, *Water Resour. Res.*, 44, W07404, doi:10.1029/2007WR006545.
- Helbig et al. (2017). Parameterizing surface wind speed over complex topography, *J. Geophys. Res. Atmos.*, 122, 651– 667, doi:10.1002/2016JD025593.

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