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EGU General Assembly, CR6.2, 24 April 2023

Simulating snow drift in WRF

First results and future plans of a novel module

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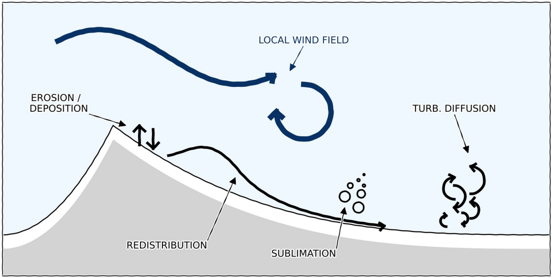

Get the abstract:

EGU23-12384

Get the model:

Code available at : https://github.com/manuelsaigger/WRFsnowdrift

Schmid, C., 2021: Implementierung eines Schneedriftmoduls in das Weather Research and Forecasting (WRF) Modell und eine erste Evaluierung, Doctoral thesis, Friedrich-Alexander-Universität Erlangen-Nürnberg.

M³OCCA IDP

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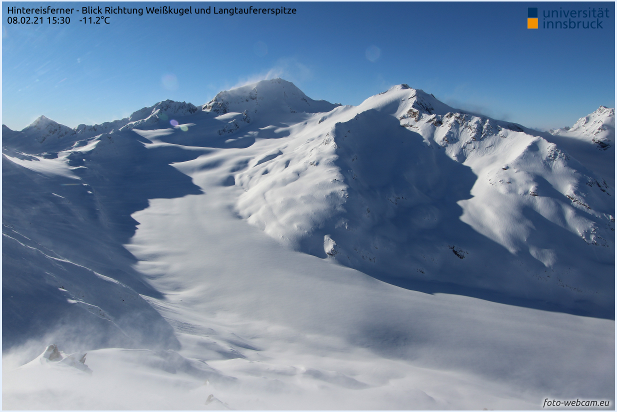
WHY STUDY SNOW DRIFT?

- Redistribution of snow → influence on glacier mass balance
- Interaction of drifting snow with ambient flow field.



Model Components

ATMOSPHERE

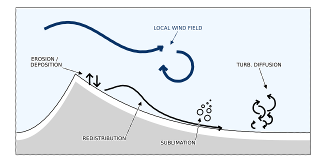
SNOW

EROSION

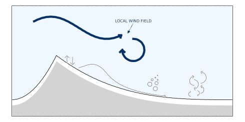
DEPOSITION

SUBLIMATION

ADVECTION + TURB. DIFFUSION



Atmospheric Model



- Snow drift module included as a physical parameterization into the Weather Research and Forecasting Model (WRF, Skamarock et al. 2019).
- Tested for WRF versions 4.1 to 4.3, idealized and real-case applications, meso-scale and LES simulations.

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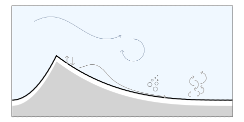
Snow Module



- Use snow model of land-surface model Noah-MP (Niu et al. 2011).
- Three-layer snow
- Solves energy and mass balance of snow (processes: precipitation, heat conduction, melting, liquid-water storage and transport, refreezing of meltwater, compaction, interception)
- Interaction with drifting snow as a function of snow density.

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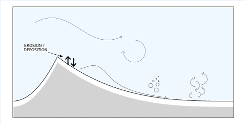
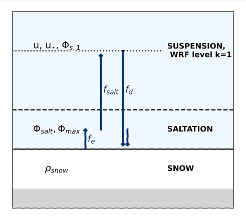
Erosion Module



- Divide drifting snow into saltation layer and suspension
- Erosion depending on excess shear stress $\rightarrow$ flux into saltation layer f_e where $u_\star > u_{th}$ (Gallée et al. 2001; Sauter et al. 2013)
- Threshold friction velocity u_{th} following Walter et al. (2004) as function of snow density
- Bulk transfer approach for flux to suspension f_{salt} (into lowest mass level of WRF) following Gallée et al. (2001) and Sauter et al. (2013)
- Exact equations here



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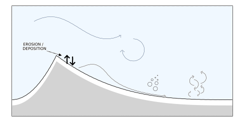
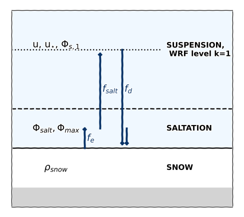
Deposition Module



- Particle fall speed similar to Vionnet et al. (2014)
  → spherical particles, balance between gravity and drag force
- Particle size depending on height and friction velocity (Pomeroy 1988; Gordon et al. 2010)
- Deposition where $u_\star < u_{th}$ similar to Sauter et al. (2013)
- Optional: define constant fall speed or particle size at the surface
- Exact equations here



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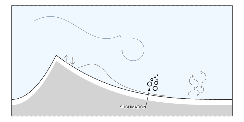
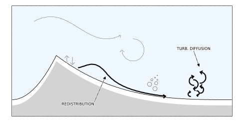
Sublimation Module



- Sublimation following Thorpe and Mason (1966)
  → solve energy and mass balance for single particle, transfer to ensemble of particles (similar to, e.g., Sauter et al. 2013; Vionnet et al. 2014)
- Feedback to temperature and moisture fields: energy required for sublimation is taken from surrounding air (→ cooling), water vapor is given to specific humidity
- optional: switch off sublimation, switch off sublimation feedback

Advection and Turbulent Diffusion



- Snow particles treated as passive tracers (subsidence treated in deposition module)
  → use WRF-internal modules for advection and diffusion.
- possible to use all available schemes and options for advection and turbulent diffusion in WRF

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Equations of Erosion and Deposition

$$f_e = e_{salt}\rho_{air}\left(\left(u_\star + (u_{th} - u_\star)\left(\frac{\Phi^2_{salt}}{\Phi^2_{max}}\right)\right)^2 - u^2_{th}\right)$$

$$u_{th} = 0.0195 + (0.021\sqrt{\rho_{snow}})$$

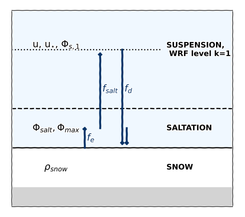
$$\Phi_{max} = \frac{\rho_{air}}{3.29u_\star}\left(1 - \frac{u^2_{th}}{u^2_\star}\right)$$

$$f_{salt} = uC_d(\Phi_{salt} - \Phi_{s,1})$$

$$v_p = \frac{-A}{r} + \sqrt{\left(\frac{A}{r}\right)^2 + Br}; A = \frac{6.203\nu_{air}}{2}; B = \frac{5.516\rho_{ice}g}{4\rho_{air}}$$

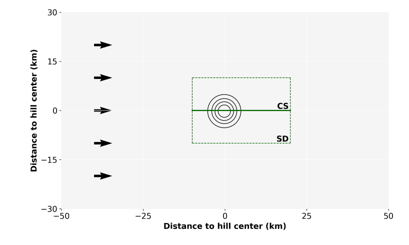
$$r(z) = r_0 z^{-0.258}; r_0 = 0.5\left(\frac{7.8\cdot 10^{-6}u_\star}{0.036} + 3.1\cdot 10^{-5}\right)$$

$$f_d = v_{p,1}\Phi_{s,1}\cdot \max\left(\frac{u^2_{th} - u^2_\star}{u^2_{th}}, 0\right)$$



Setup Test Simulations

- WRF ARW version 4.1.2
- Domain with one bell-shaped hill in the center (h = 500 m)
- $\Delta x = \Delta y = 200$ m
- Lowest mass level at 5 m agl, model top at 10000 m, $\Delta z = 10$ m close to surface.
- Initialize with constant profiles of $u = 7.5$ m s^{-1} (log profile in lowest 100 m), and $N = 0.015$ s^{-1} $\rightarrow$ non-dimensional mountain height $\epsilon = 1$
- $rh = 80$ % close to the ground, decreasing with height
- 1 m of snow with $\rho_{snow} = 100$ kg m^{-3} over entire domain
- total model runtime 6 h, use 3 to 6 h for evaluation (steady-state after spin-up)



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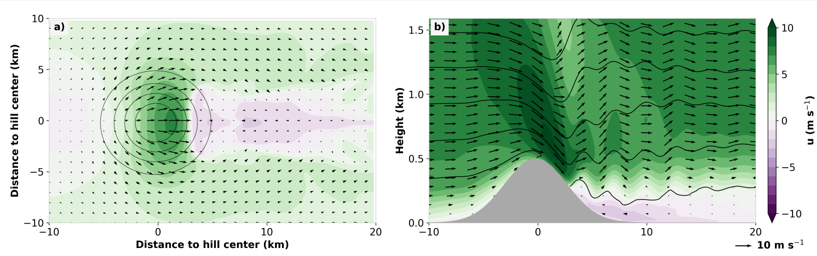
Test Simulations: Wind Fields

- mean fields of wind and potential temperature (b, contour interval 1 K)



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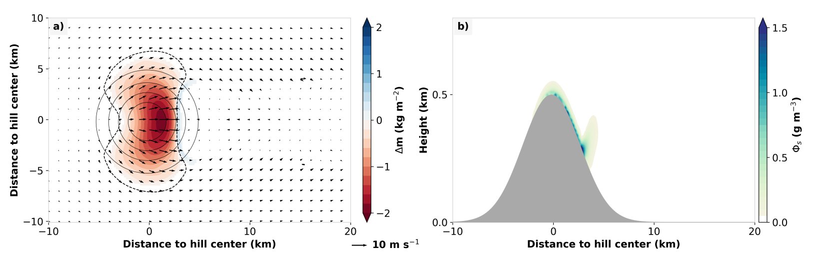
Test Simulations: Drifting Snow Fields

- Accumulated erosion and deposition (a), mean snow particle concentration (b)
- Erosion in regions of highest wind speed, where $u_\star > u_{th}$ (dashed contour).
- Snow particles stay in shallow layer, deposition in region of flow separation.



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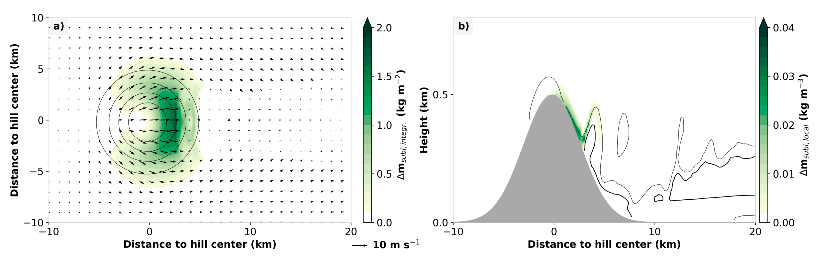
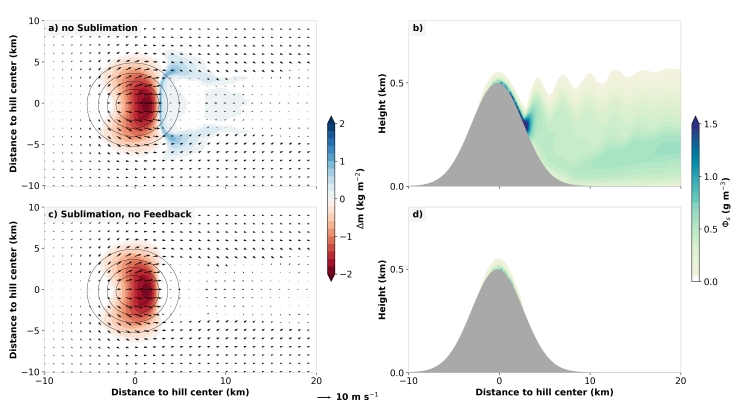
Test Simulations: Drifting Snow Sublimation

- Accumulated sublimation (a: vertically integrated, b: local), mean relative humidty (b, thin/thick contours 95/99%)
- Sublimation removes large parts of eroded snow
- Damping due to increased air moisture



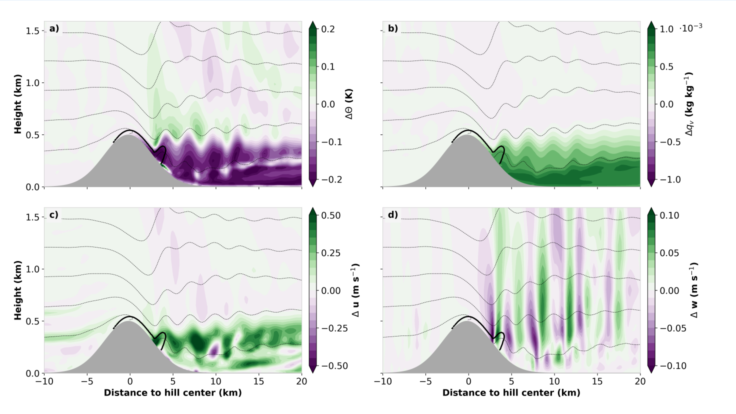
Test Simulations: Influence of Sublimation

- no sublimation: stronger deposition + lee-ward transport; no sublimation feedback: no damping of sublimation due to moisture increase → less deposition



Test Simulations: Non-local Effect of Sublimation

- Difference in mean fields for control simulation and with switched off sublimation
- local cooling and moistening due to sublimation, but also non-local effect downstream and influence on gravity wave field



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Future Plans

How does drifting snow influence glacier mass balance?

- Case studies with Large-Eddy-Simulations and terrestrial laser scanning on Hintereisferner (Austria)
  $\rightarrow$ see Voordendag and Goger (PICO3a.3, EGU23-5236)
- (Multi-) seasonal perspective $\rightarrow$ incorporate machine-learning techniques

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