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Snow modeling

- Temperature-Index methods
  (Day-Degree Approach, e.g. in WaSiM)

- Energy balance (single-layer)
  (AMUNDSEN, SnowModel, Alpine3D, ...)

- Multi-layer model
  (SNTHERM, SNOWPACK, ...)

simple / estimation

complex / detailed physical description
• **AMUNDSEN (Alpine MUltiscale Numerical Distributed Simulation Engine)**

  - Radiation modelling
  - Energy and mass balance of the snow cover
  - Lateral snow transport
  - Snow-canopy interaction
  - Glacier dynamics
  - Skiing indicators
  - ...
Projects

- **SnowNPB** (Uni Graz/NPB): snow hydrology (Berchtesgaden)
- **MUSICALS** (Uni Graz/alpS): accumulation, runoff, hydropower (Gepatsch)
- **CC-Snow** (Uni Graz/ACRP): snow reliability, artificial snow (Tyrol/Styria)
- **AlpinRiskGP** (Uni Graz/StartClim): gravitational material flow (Pasterze)
- **Strahlgrid** (ZAMG/internal): daily global radiation (Austria)
- **Prosecco** (ZAMG/ÖAW): runoff generation (Goldbergkees)
- **u(glacier)** (ZAMG/ÖAW): glacier flow, runoff scenarios (Sonnblick)
- **Climpact** (ZAMG/Circle): degree-day glacier mass balance (Tienshan, lake Merzbacher)
- **Glacier MEMO** (Uni Graz/ZAMG/ÖGPF): refreezing, mass balance (Freya glacier, NE-Greenland)
- **FreyEx** (Uni Graz/ÖGPF): energy balance (Freya glacier, NE-Greenland)
- **Glacioburst** (ZAMG/FWF): lake outbursts (A.P. Olsen Icecap, NE-Greenland)
Project **WaterNPB**: Water Balance Modeling in the Berchtesgaden National Park

**SnowNPB** – Snow Cover and Runoff Dynamics  
**KarstNPB** – Subsurface and Groundwater Fluxes  
→ Gabriele Kraller, Uni Graz
Berchtesgaden National Park

- National Park: 210 km²  
  Catchment area: 433 km²

- Königssee: 603 m a.s.l.  
  Watzmann Mittelspitze: 2713 m a.s.l.  
  → large altitudinal gradient: 2110 m / ca. 3.5 km

- Mean annual precipitation:  
  from 1500 mm (valleys)  
  up to 2600 mm (elevated and peak regions)

- Biotopes:  
  44,1 %  Forests  
  21,0 %  Limestone grasslands  
  19,3 %  Rock and scree  
  12,4 %  Mountain pine  
  3,2 %  Lakes and glaciers
Snow in high mountain regions

- Large amounts of snow, long period of snow coverage
- Spatial and temporal variability of the snow cover
- Lateral snow transport (wind, snow slides, avalanches)
- Precipitation storage
- Runoff generation by melting snow
- Snow feeds glaciers and perennial firn fields (Blaueis, Watzmanngletscher, Eiskapelle, Schöllhorneis)

<table>
<thead>
<tr>
<th>Annual mean (2002 - 2007)</th>
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<tbody>
<tr>
<td>Precipitation (mm)</td>
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Distributed Hydrological Model

- WaSiM-ETH (Schulla and Jasper)
- Penman-Monteith
- Richards-Equation
- ...

Garmisch-Partenkirchen, 01.03.12

Michael Warscher, Institute for Meteorology and Climate Research (IMK-IFU)
Meteorological measurements

33 stations (19 automatic, 14 manual)
National Park administration, township Schoenau,
Bavarian avalanche service,
Central Institute for Meteorology and Geodynamics (ZAMG)

Gauges and subcatchments

433 km²
9 gauges and subcatchments
Input WaSiM-ETH

Land use

HABITALP (www.habitalp.org)
Standardised classification of
Color Infrared aerial photographs

Corine Land Cover CLC

Soil types

„Bodenübersichtskarte“ 1:25000
Bavarian Environmental Agency
Water balance

Annual mean (2002 - 2007)

- Precipitation (mm): 1611.4
- Rainfall (mm): 1111.5
- Snowfall (mm): 499.9
- Evapotranspiration (mm): 493.7
- Runoff (mm): 1013.3
- Air temperature (°C): 1.2
- Snow cover duration (days): 144

Nash-Sutcliffe

- Hintersee (Ramsauer Ache): 0.65
- Ramsau (Wimbach): -0.31
- Ilsank (Ramsauer Ache): 0.63
- Schwoeb (Koenigsseer Ache): 0.38
- Stanggass (Bischofswieser Ache): 0.12
- Klaeranlage (Berchtesgadener Ache): 0.91
- Almbachmuhle (Almbach): 0.44
- St. Leonhard (Berchtesgadener Ache): 0.82
Original approach:

WaSiM Day-Degree
(Temperature-Index method)

\[ M = c_0 \cdot (T - T_{0,m}) \cdot \frac{\Delta t}{24} \]
for \( T > T_{0,m} \), else \( M = 0 \)

- \( M \): melting rate in mm per time step
- \( c_0 \): temperature dependent melt factor [mm°C⁻¹·d⁻¹]
- \( T \): air temperature, casually using modification after equation
- \( T_{0,m} \): temperature for beginning with snow melt [°C]
- \( \Delta t \): time step [h]

Modeled days with snow coverage during winter 2005/2006
WaSiM-ETH Snow Module
Implementation of AMUNDSEN in WaSiM-ETH

What’s new?

- **Energy and mass balance** of the snow cover (radiation balance, turbulent fluxes, advective heat flux, soil heat flux)

- **Lateral snow redistribution**

\[ Q + H + E + A + B + M = 0 \]

- \( Q \) net radiation
- \( H \) sensible heat flux
- \( E \) latent heat flux
- \( A \) advective heat flux (precipitation)
- \( B \) soil heat flux
- \( M \) snowmelt or cooling/refreezing
Results – Energy balance

Temperature-Index vs. Energy-Balance at the station Kühroint

Snow water equivalent at the station Kühroint (1407 m a.s.l.)
Changes in modelled snow cover duration due to energy-balance method

Snowdays (energy-balance) MINUS Snowdays (Day-degree)
Locations of snow deposition by gravitational transport

**Snow and wind**

**Processes:**

1. Preferential deposition of snow precipitation (before it has reached the ground).
2. Wind-driven transport of previously fallen snow (erosion, saltation, and accumulation).
3. Effective sublimation of wind-blown snow into the atmosphere.

Depending on:
- Windspeed and direction,
- Snow cover,
- Shear stress,
- Snow surface properties,
- Snow density,
- Humidity,
- Temperature,
- Radiation, …

Plattner (2004)
Snow and wind

Methods

Bernhardt et al. (2009): *Using wind fields from a high-resolution* atmospheric *model* *for simulating snow dynamics in mountainous terrain*

Winstral and Marks (2002): *Simulating wind fields and snow redistribution using* terrain-based parameters *to model snow accumulation and melt over a semi-arid mountain catchment*
**Snow and wind**

**Coupled atmospheric / snow transport model**

![Map showing snow redistribution](image1.png)

**Parameterization (wind direction SW)**

![Map showing wind fields](image2.png)

**References**


Snow and wind

Coupled atmospheric / snow transport model

Parameterization (wind direction SW)

→ Similar spatial patterns


Landsat RGB ETM+
01.05.2005

NDSI (not showing negative values)
01.05.2005

Modelled mean snow cover duration
2002 – 2007
Remote Sensing

Landsat ETM+

NDSI (not showing negative values)
01.05.2005

Model (WaSiM-ETH + AMUNDSEN)

Modelled mean snow cover duration
2002 – 2007
Do we need that within hydrological LSMs?

Runoff, snowmelt and rainfall at gauge Hintersee (melting period spring 2006)
Ausblick

- Stabile Isotope im Wasser als Tracer
- Klimaimpaktanalyse (ECHAM5 → WRF → WaSiM-ETH + AMUNDSEN)
Klimaimpaktanalyse (ECHAM5 → WRF → WaSiM-ETH + AMUNDSEN)
2020-2050 vs. 1970-2000
Thanks!