Snow Cover Dynamics, Runoff Generation, and Water Balance in Complex, High Alpine Terrain: Physically-based, Distributed Modelling.

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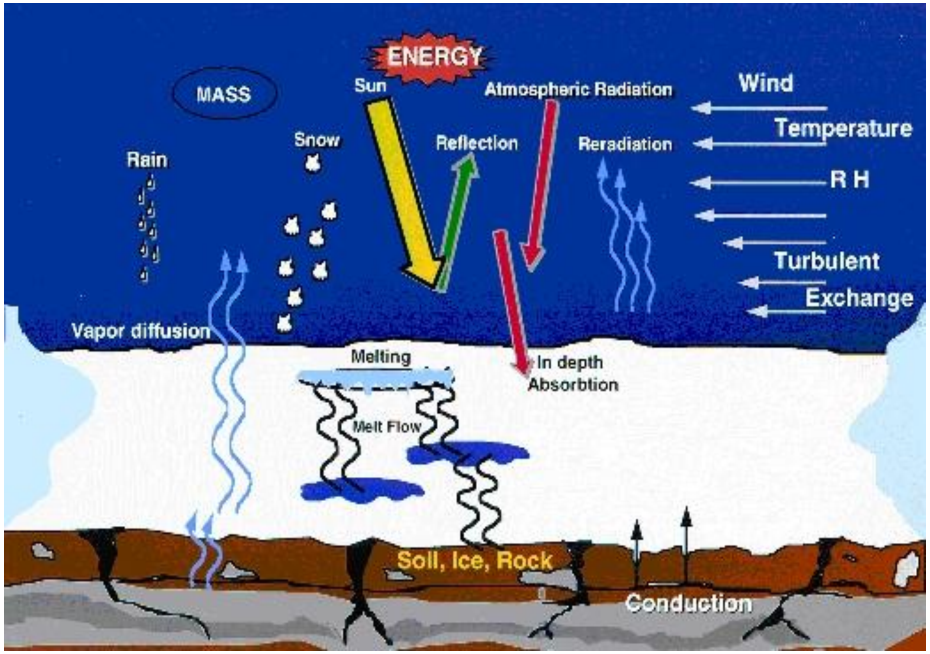
Snow modeling

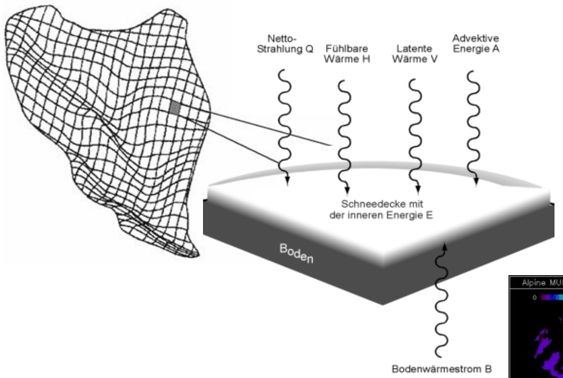
simple / estimation

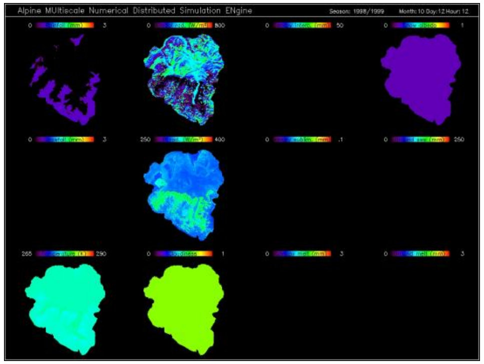
- Temperature-Index methods
  (Day-Degree Approach, e.g. in WaSiM)
- Energy balance (single-layer)
  (AMUNDSEN, SnowModel, Alpine3D, …)
- Multi-layer model
  (SNTHERM , SNOWPACK, …)

complex / detailed physical description



- **AMUNDSEN** (**A**lpine **MU**ltiscale **N**umerical **D**istributed **S**imulation **En**gine)
  - Radiation modelling
  - **Energy and mass balance** of the snow cover
  - **Lateral snow transport**
  - Snow-canopy interaction
  - Glacier dynamics
  - Skiing indicators
  - …





Strasser, U. (2008): Modelling of the mountain snow cover in the Berchtesgaden National Park, Berchtesgaden National Park research report, Nr. 55, Berchtesgaden.

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): refreecing, 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

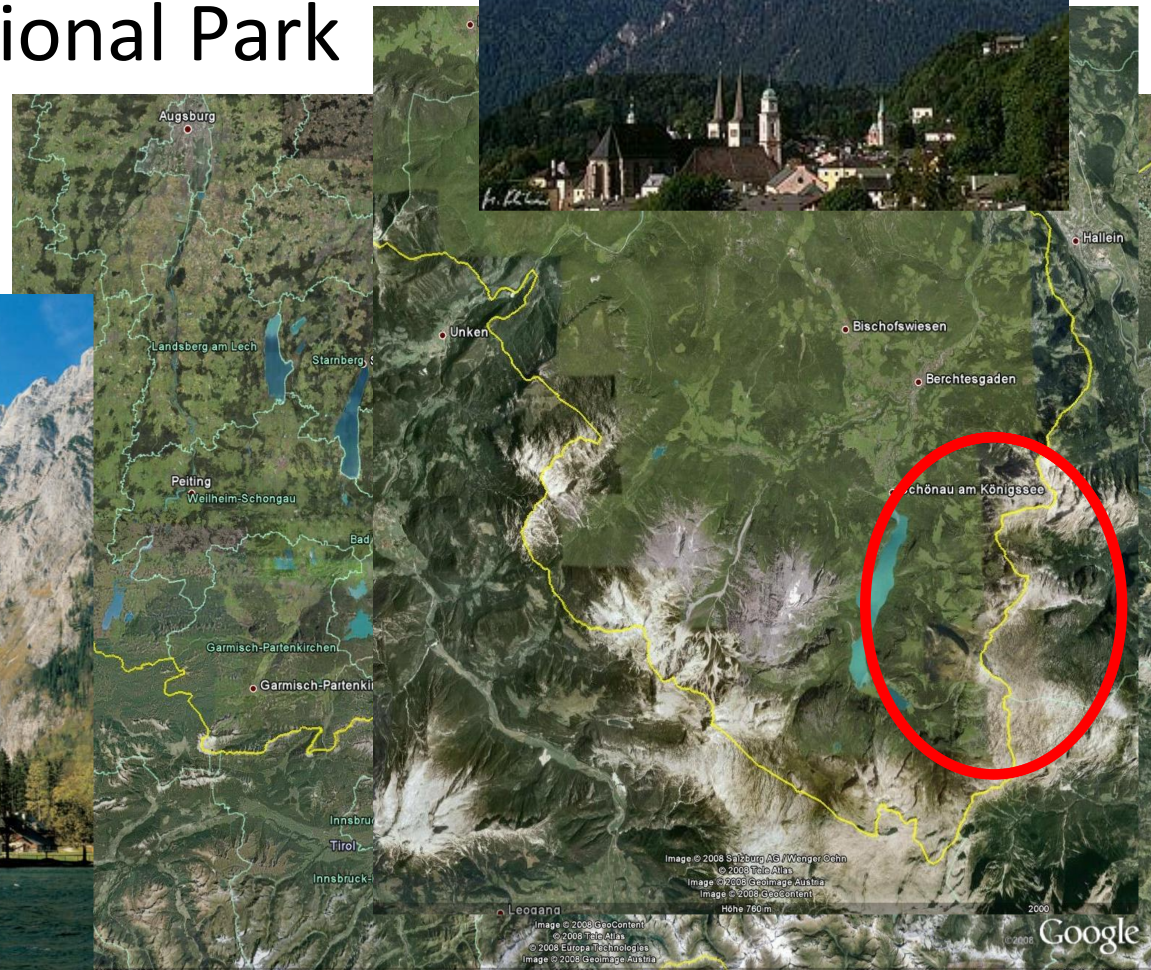
SnowNPB – Snow Cover and Runoff Dynamics

KarstNPB – Subsurface and Groundwater Fluxes

→ Gabriele Kraller, Uni Graz

Berchtesgaden National Park

- National Park: 210 km²
  Catchment area: 433 km²
- Königssee: 60…
  Watzmann Mi…
  → large altitu…
- Mean annual …
  from 1500 mr…
  up to 2600 mr…
- Biotopes:
  - 44,1 % Fore…
  - 21,0 % Lime…
  - 19,3 % Rock…
  - 12,4 % Mou…
  - 3,2 % Lake…

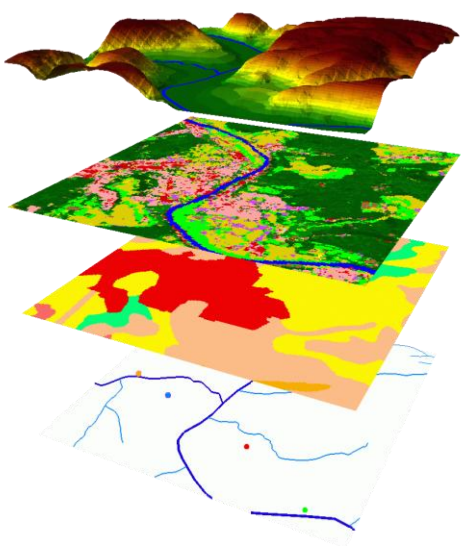


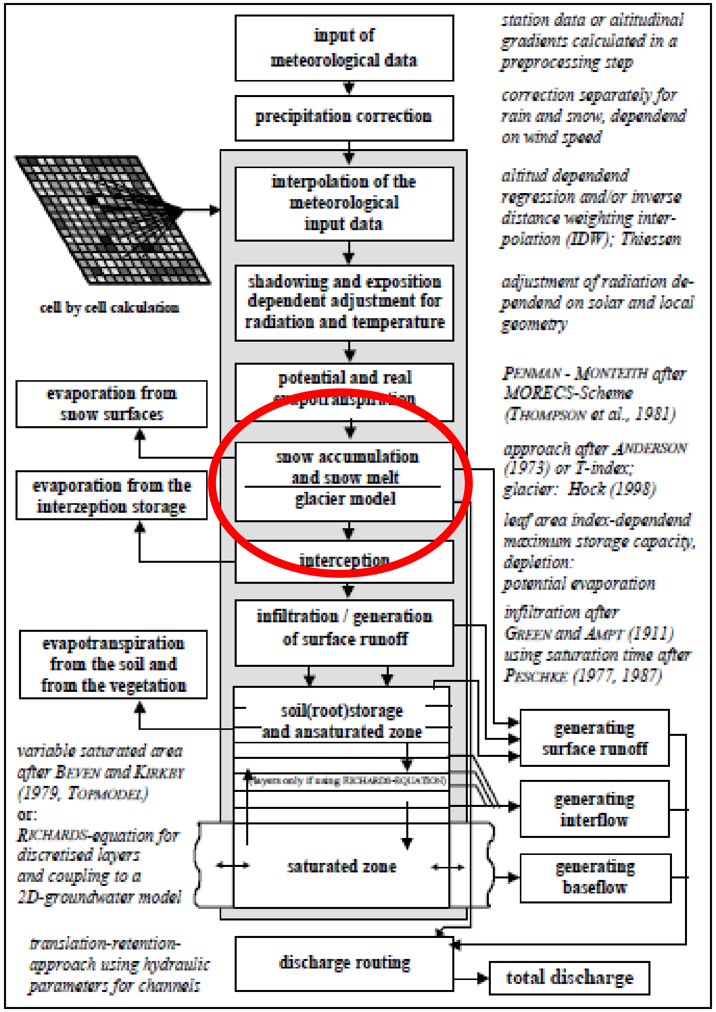
Snow in high mountain regions

- 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)

	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

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

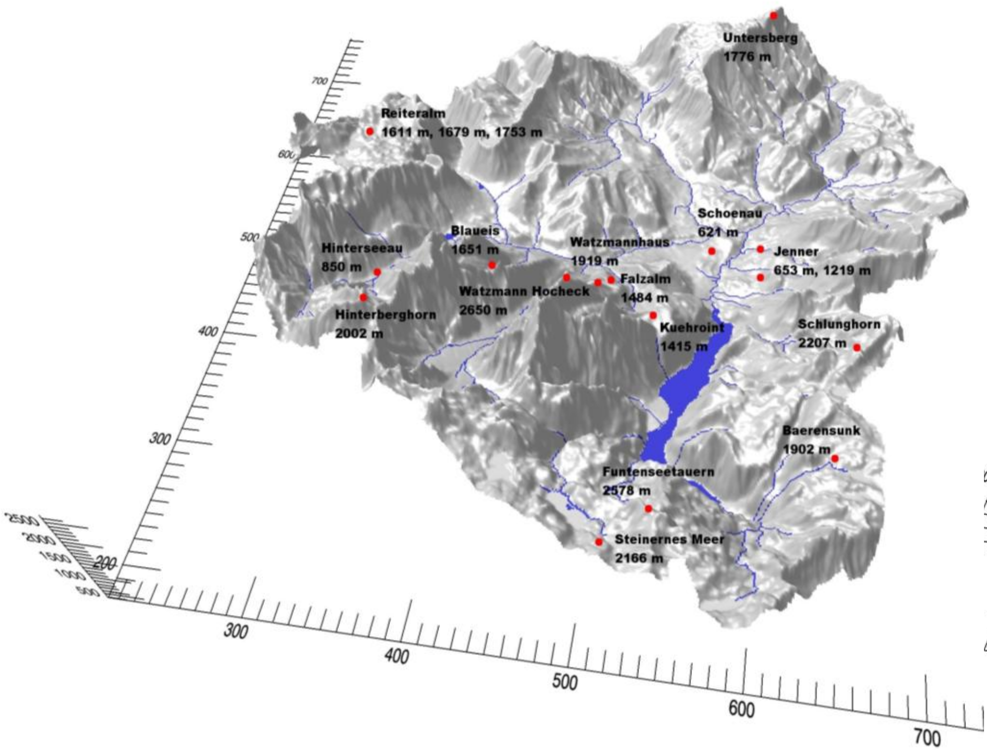




Input WaSiM-ETH

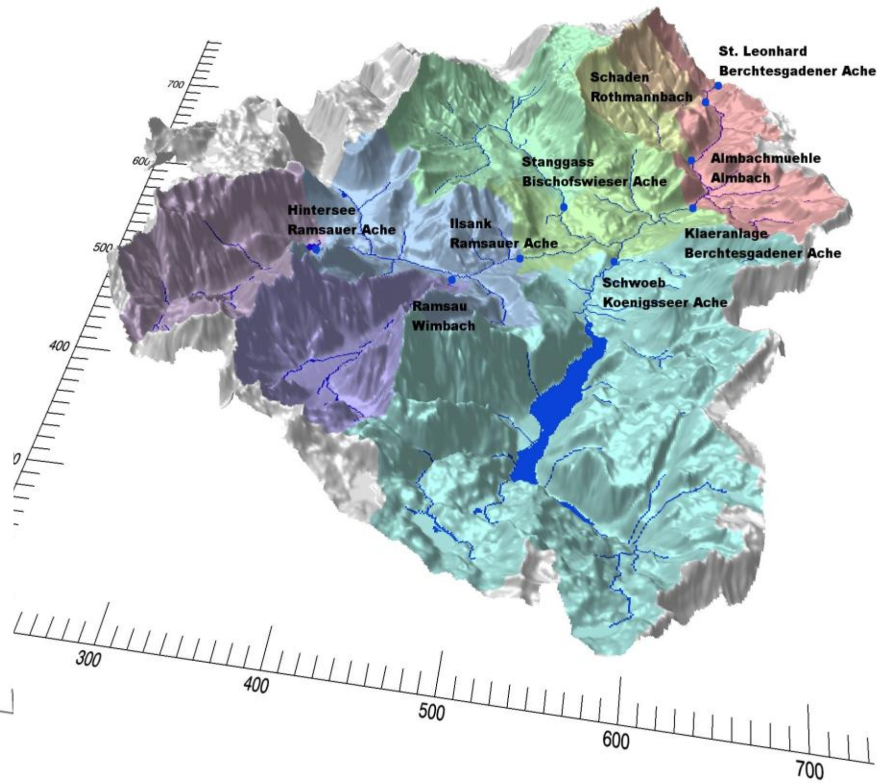
Karlsruhe Institute of Technology

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

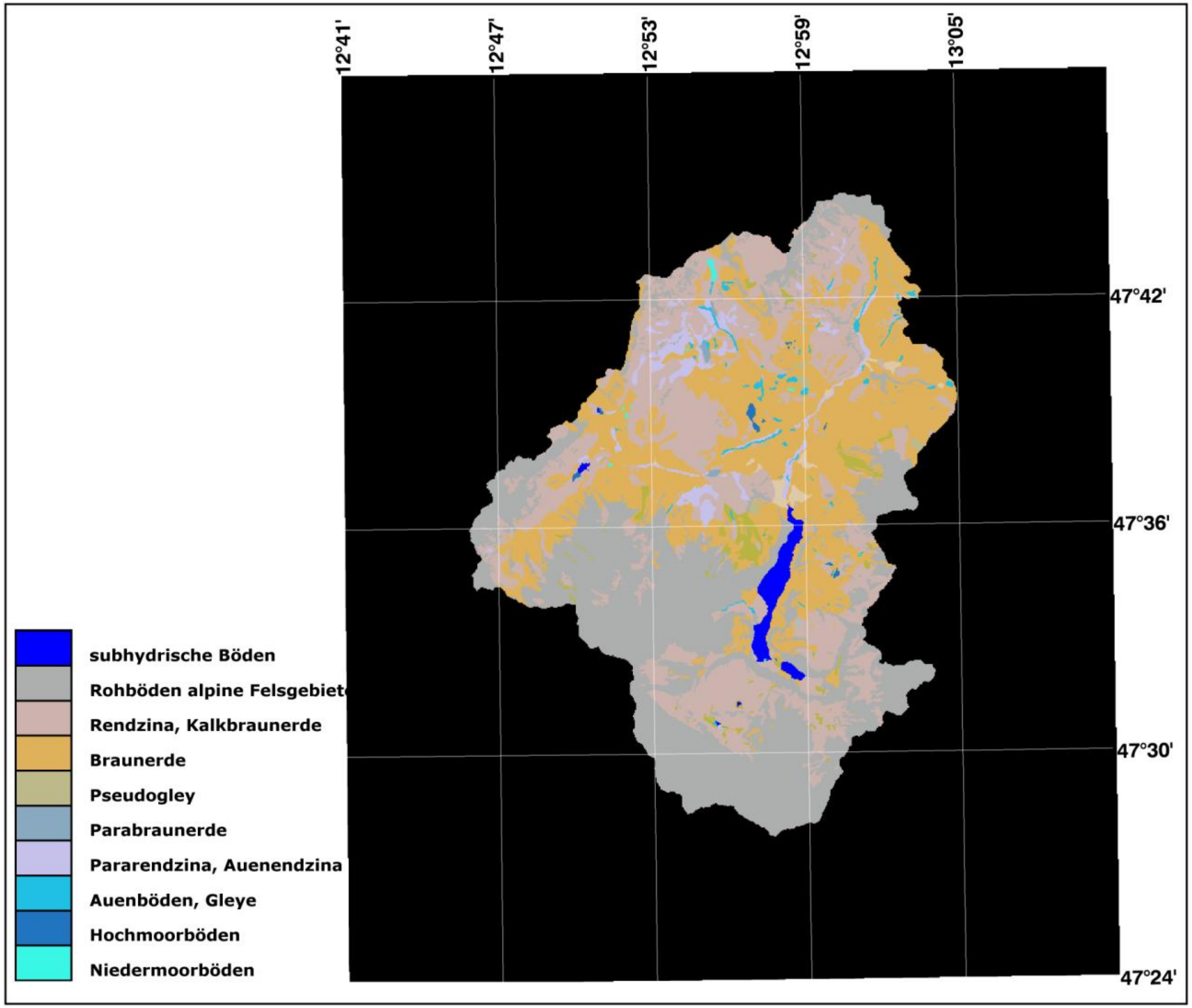
Land use

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

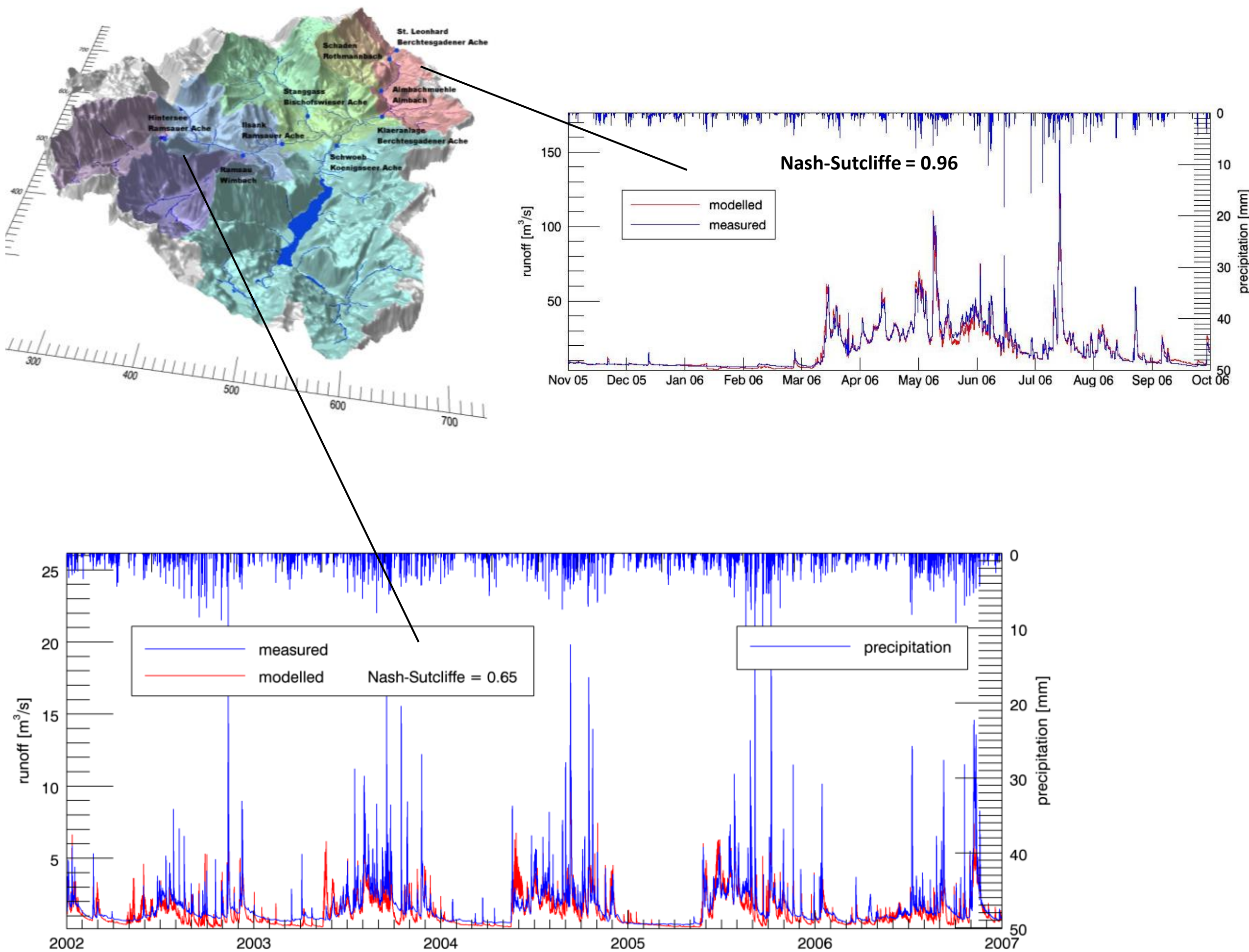
Corine Land Cover CLC

Soil types

„Bodenübersichtskarte“ 1:25000
Bavarian Environmental Agency



Water balance



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	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
Almbachmuehle (Almbach)	0.44
St. Leonhard (Berchtesgadener Ache)	0.82

WaSiM-ETH Snow Module

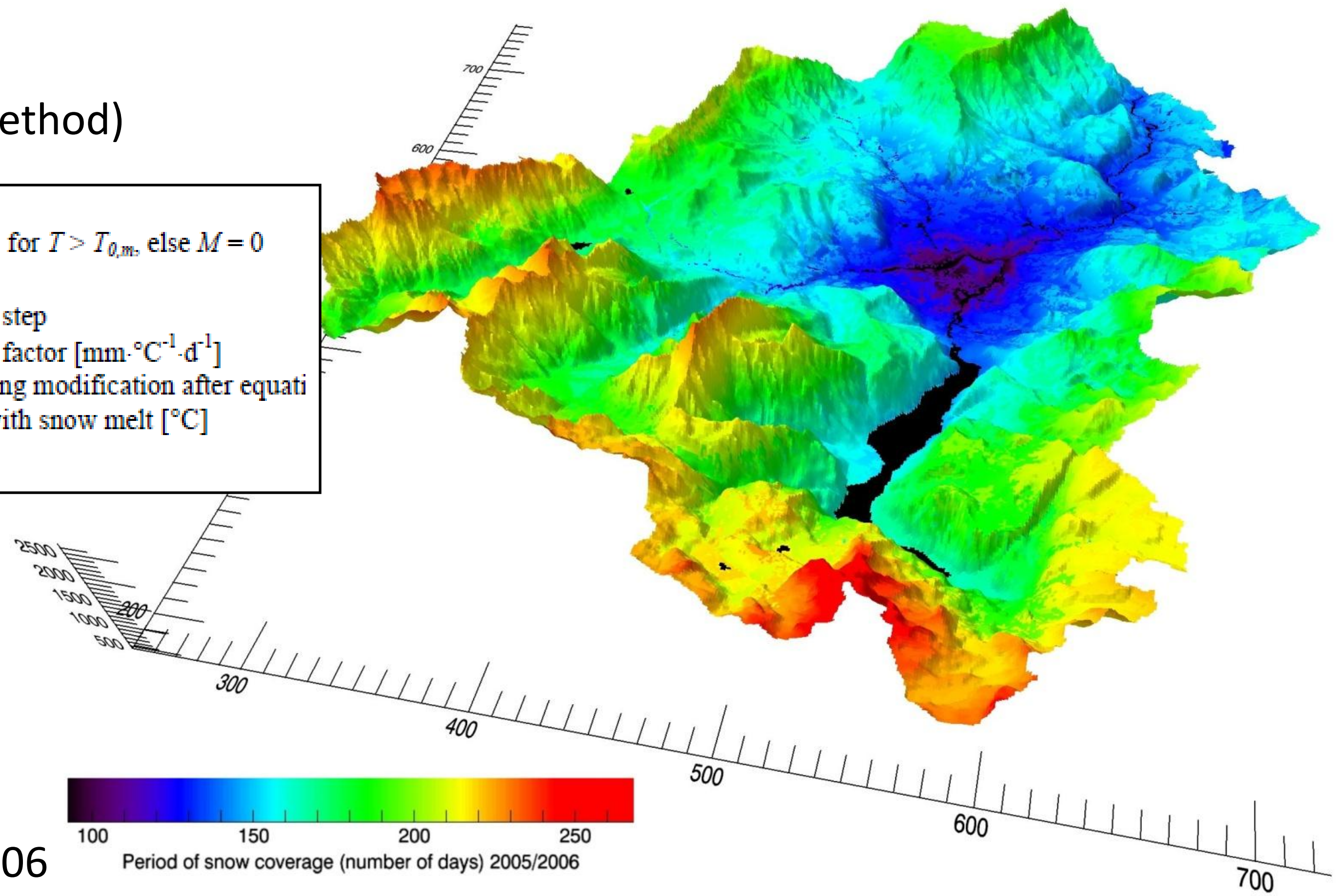
Original approach:

WaSiM Day-Degree

(Temperature-Index method)

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

with	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 equati
	$T_{0,m}$	temperature for beginning with snow melt [°C]
	Δt	time step [h]

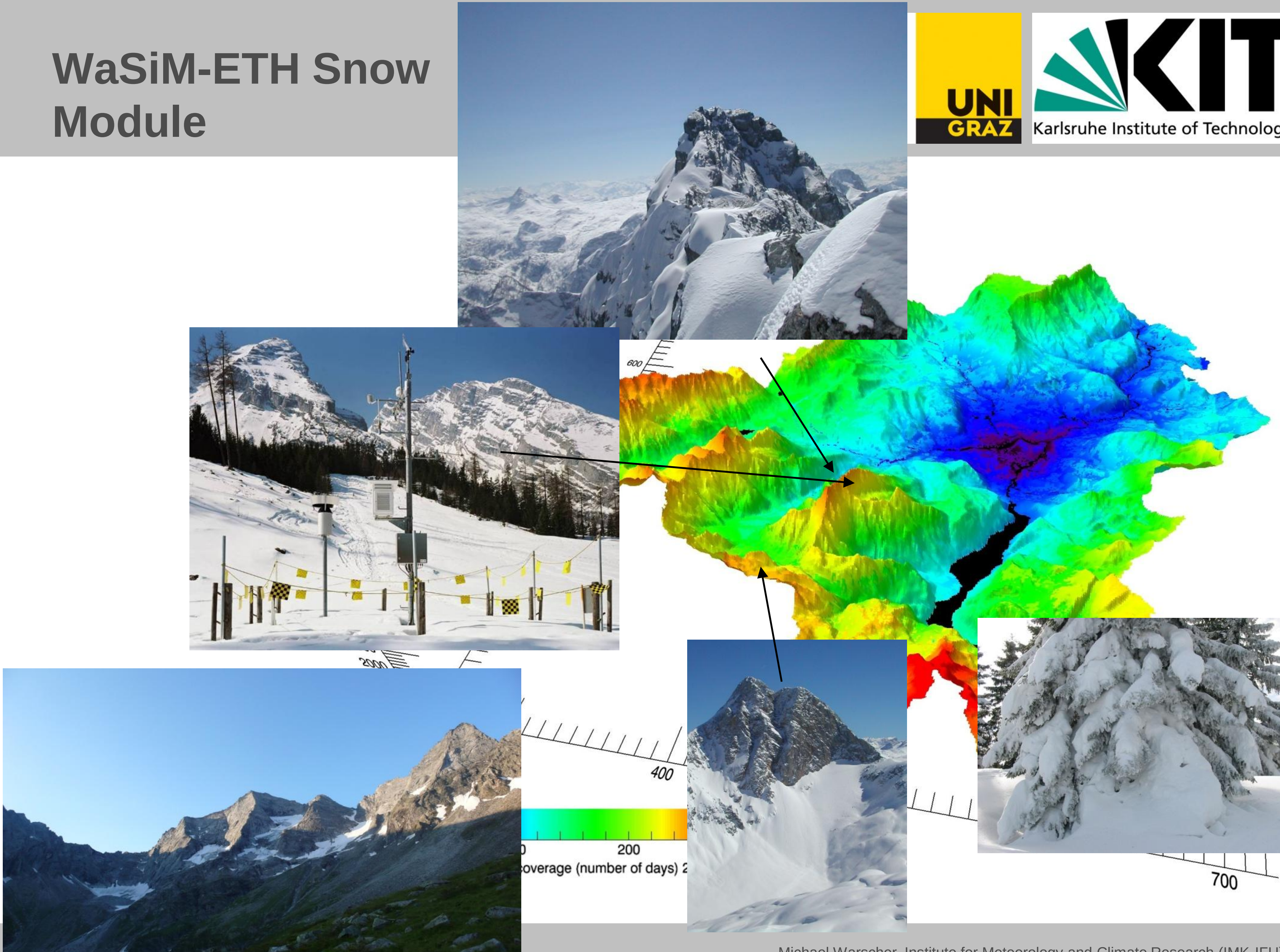


Modeled days with

snow coverage

during winter 2005/2006

WaSiM-ETH Snow Module



Implementation of AMUNDSEN in WaSiM-ETH

What‘s new?

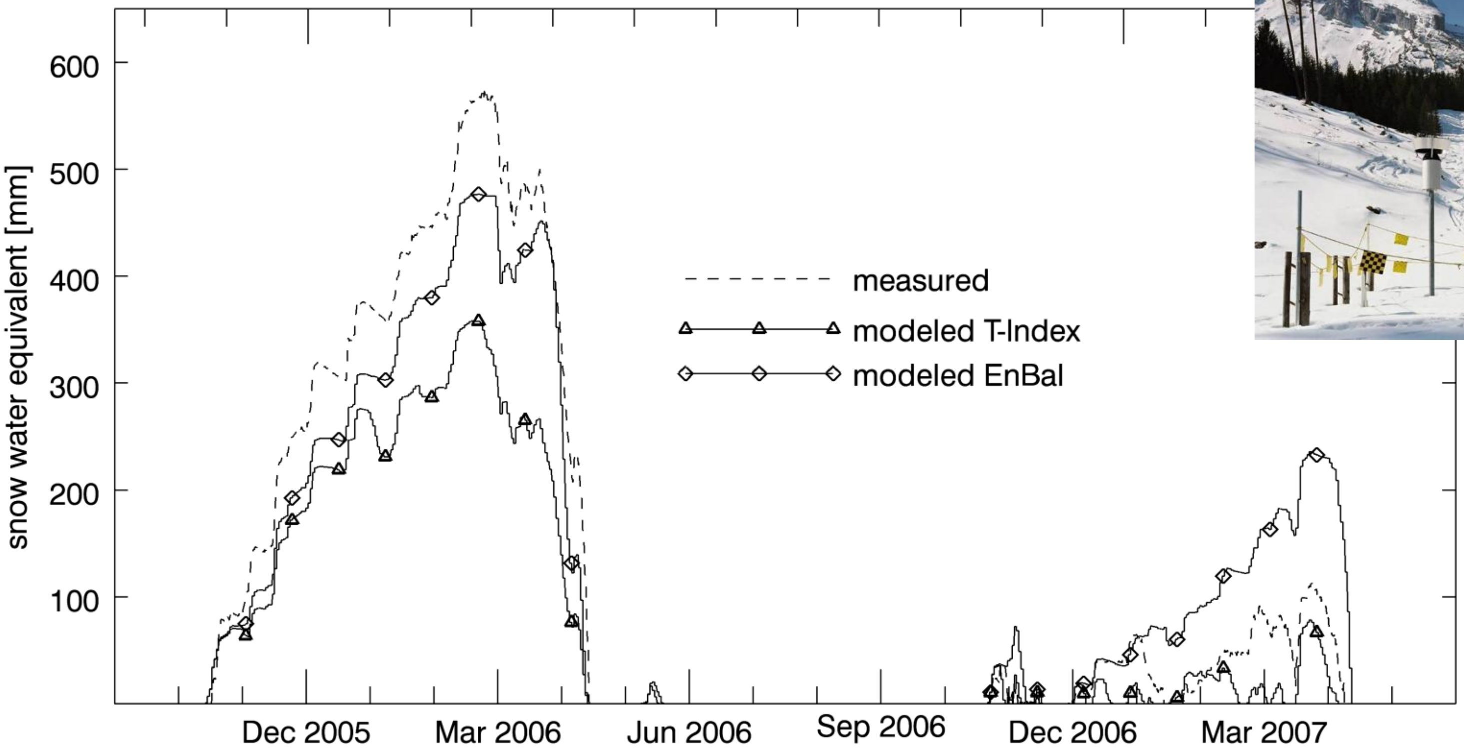
$$Q + H + E + A + B + M = 0$$

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

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

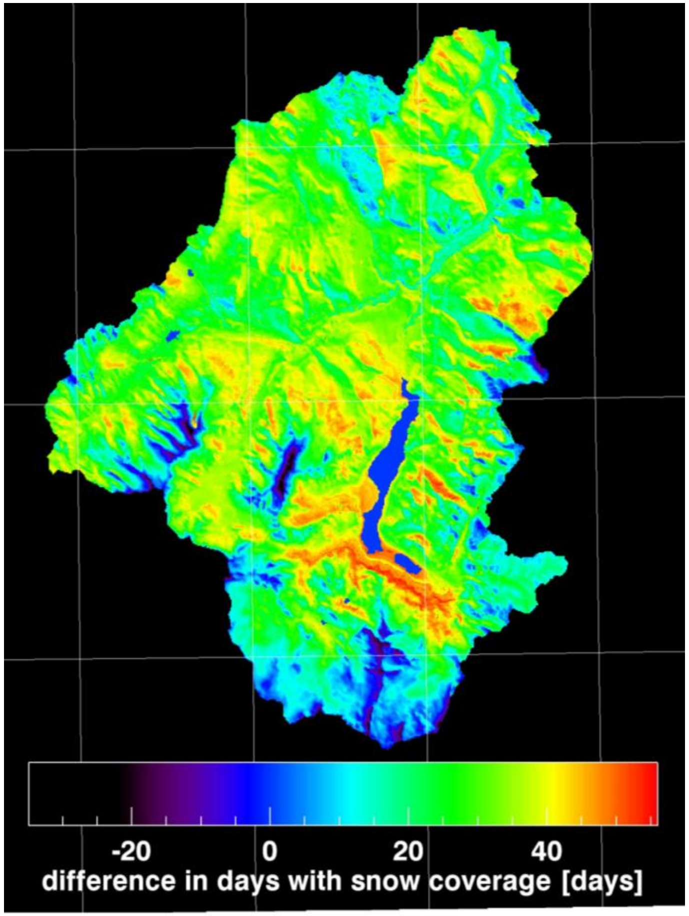


Snow water equivalent at the station Kühroint (1407 m a.s.l.)

Results – Energy balance

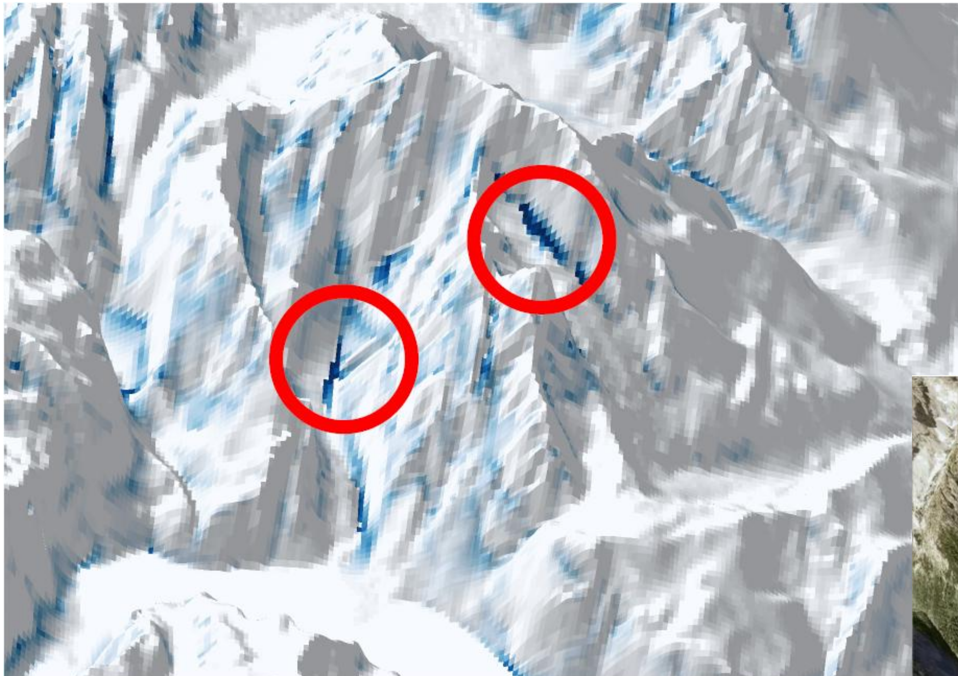
Changes in modelled snow cover duration due to

energy-balance method

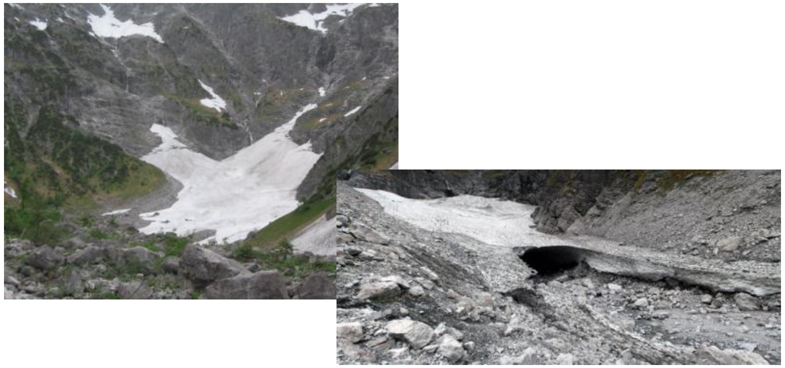


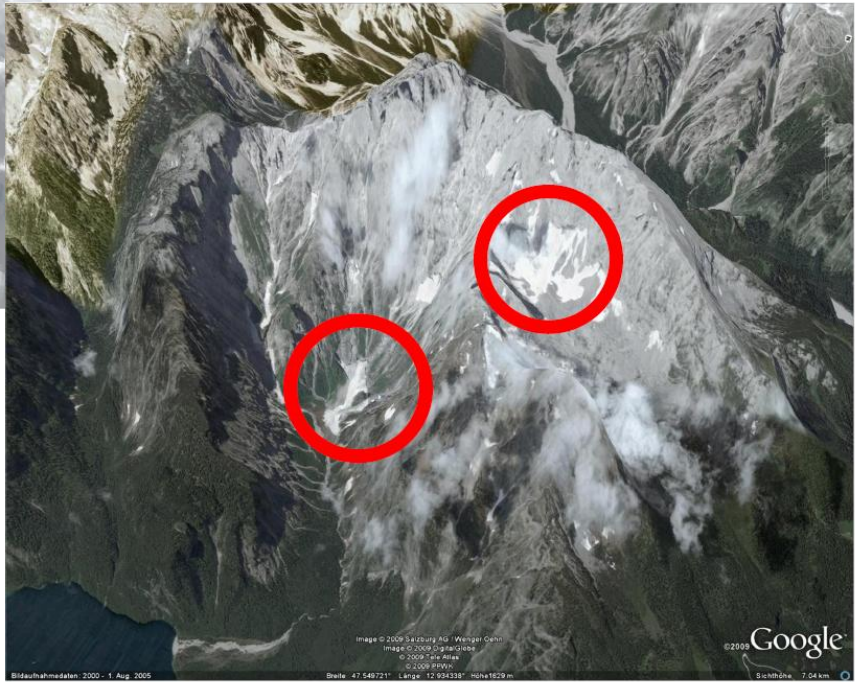
Snowdays (energy-balance) MINUS Snowdays (Day-degree)

Lateral snow transport



Locations of snow deposition by gravitational transport





Gruber, S.: A mass-conserving fast algorithm to parameterize gravitational transport and deposition using digital elevation models, Water Resour. Res., 43, W06412, doi:10.1029/2006WR004868, 2007.

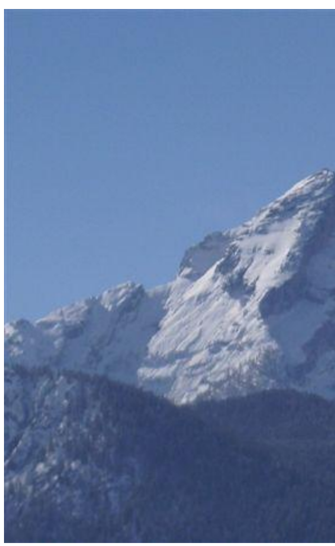
Snow and wind

Processes:

1. **Preferential de**

2. Wind-driven **tr**

3. Effective **subli**



Plattner (2004)

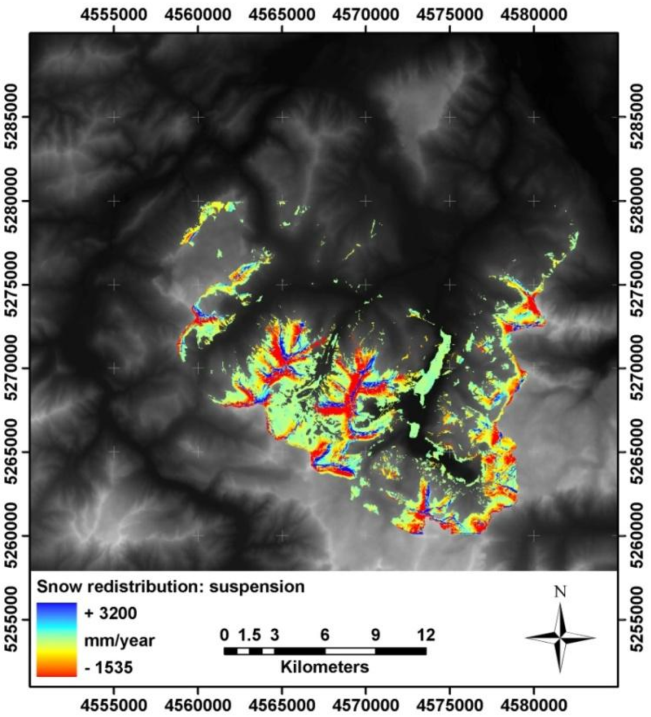
Methods

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

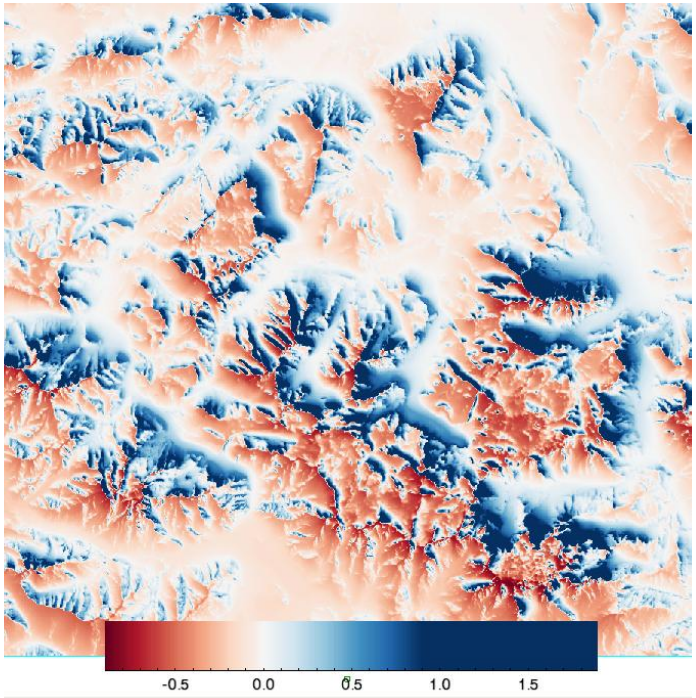
Winstral and Marks (2002): *Simulating wind fields and snow redistribution using* ***terrain-based parameters*** *to model snow accumulation and melt over a semi-arid mountain catchment*

Snow and wind

Coupled atmospheric / snow transport model



Parameterization (wind direction SW)



BERNHARDT, M., LISTON, G.E., STRASSER, U., ZÄNGL, G. AND SCHULZ, K. (2010): *High resolution modelling of snow transport in complex terrain using downscaled MM5 wind fields*, The Cryosphere, 4, 1-15.

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Snow and wind

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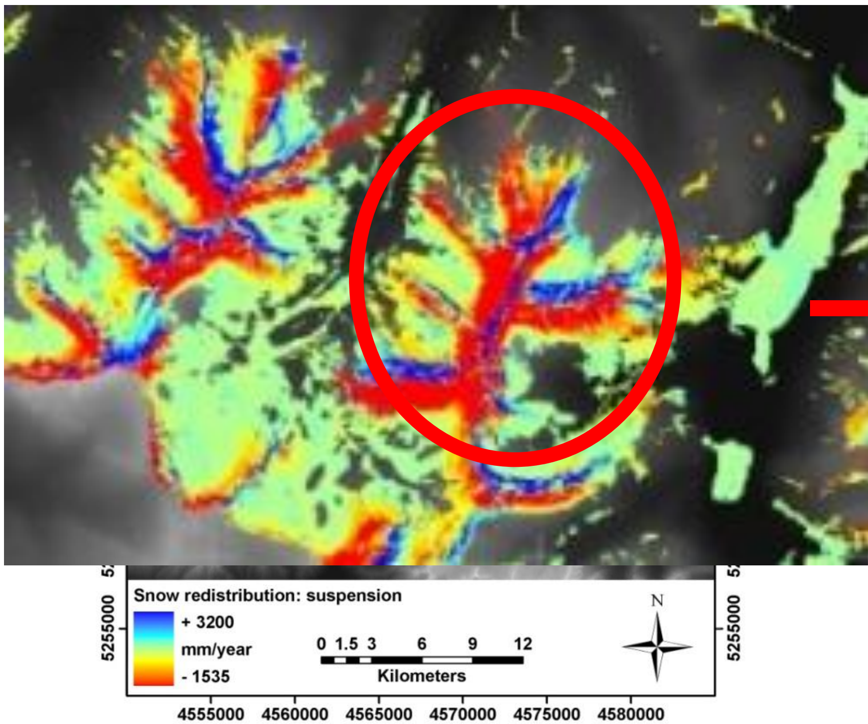

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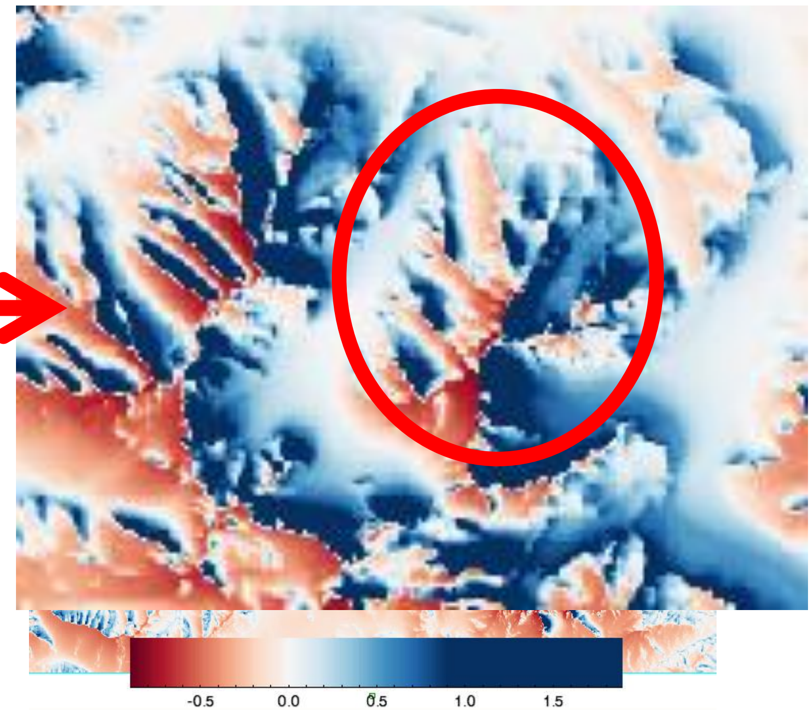

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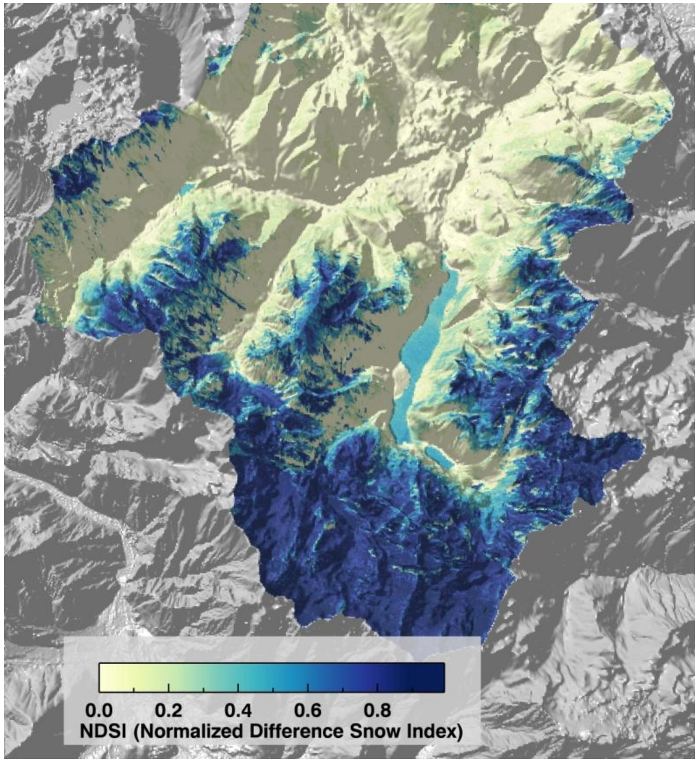
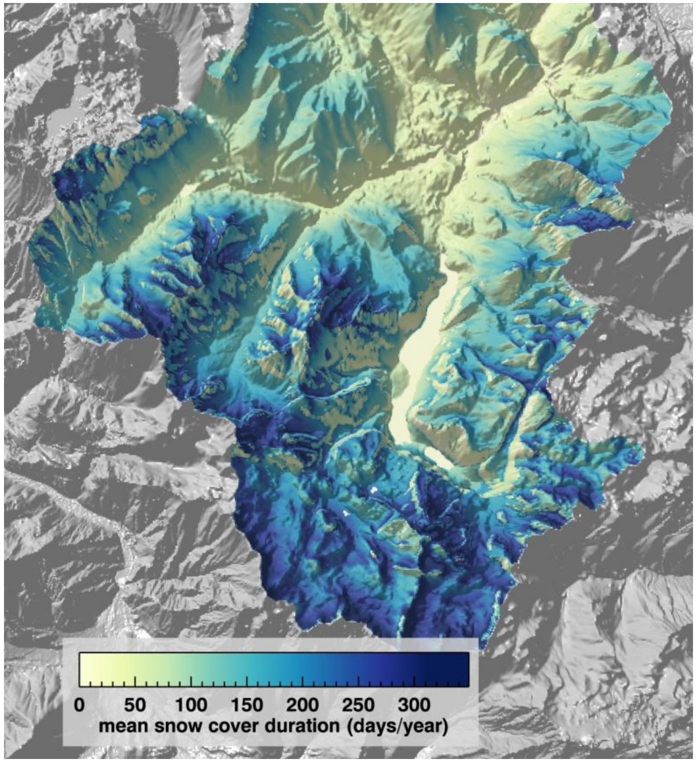
→ Similar spatial patterns

Landsat RGB ETM+
01.05.2005



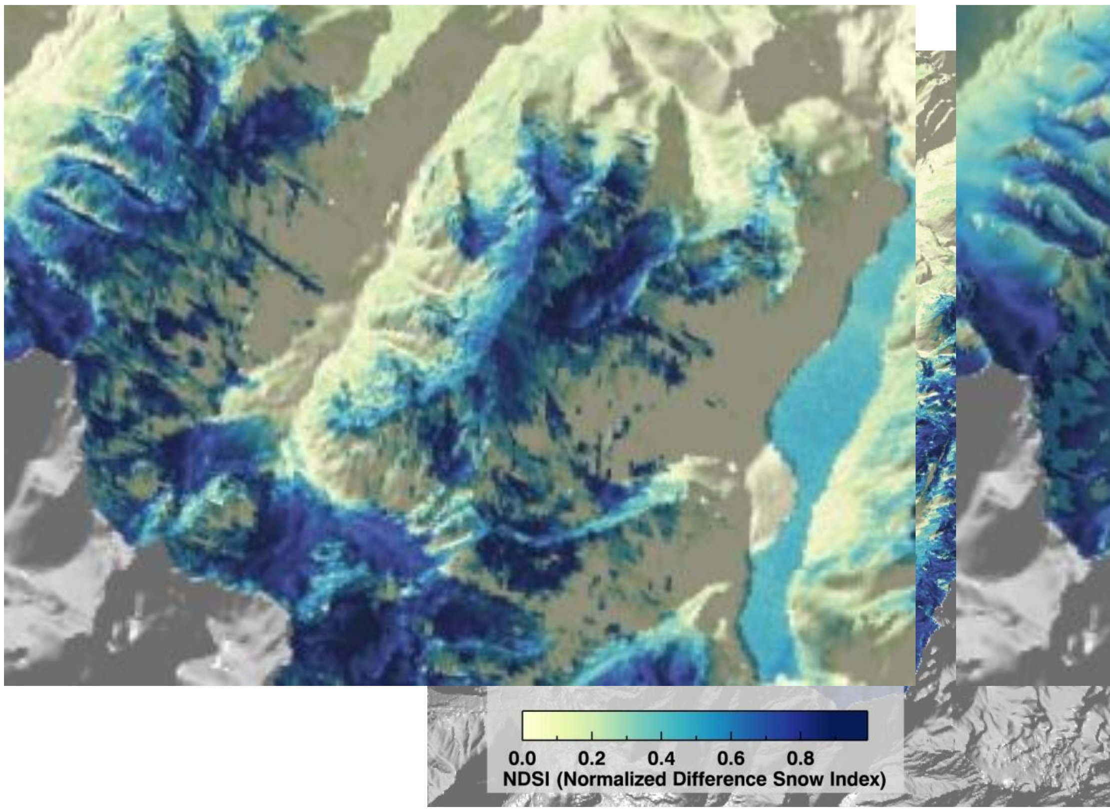
NDSI (not showing negative values)
01.05.2005



Modelled mean snow cover duration
2002 – 2007

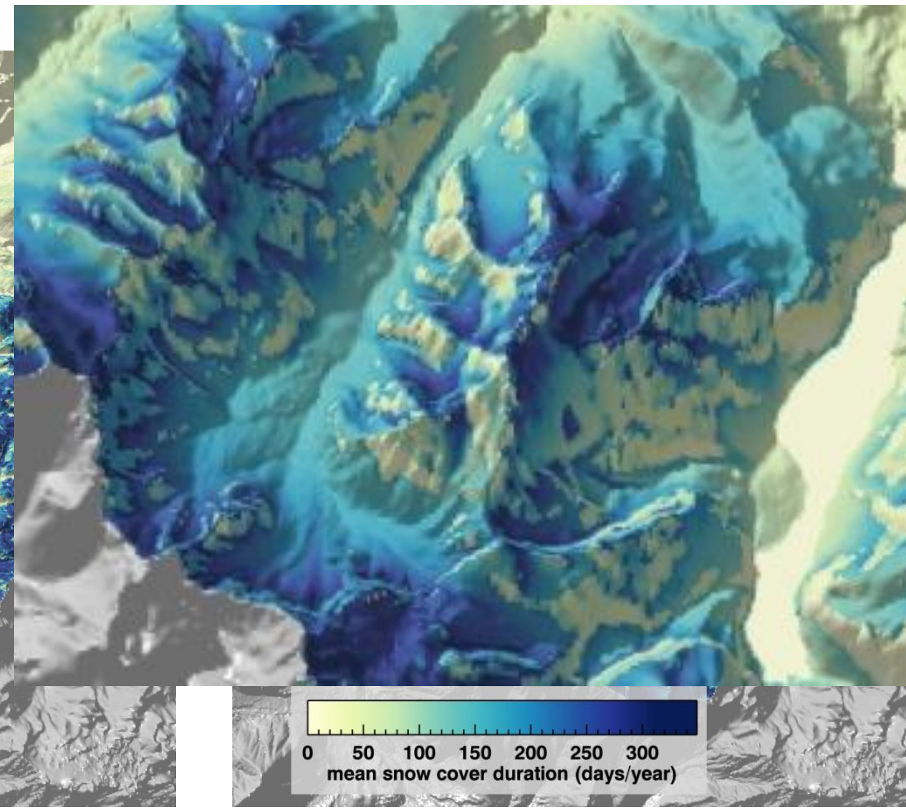
Remote Sensing

Landsat ETM+



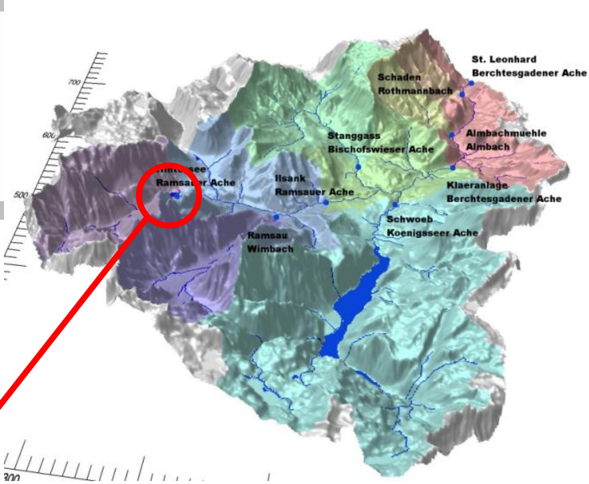
NDSI (not showing negative values)
01.05.2005

Model (WaSiM-ETH + AMUNDSEN)



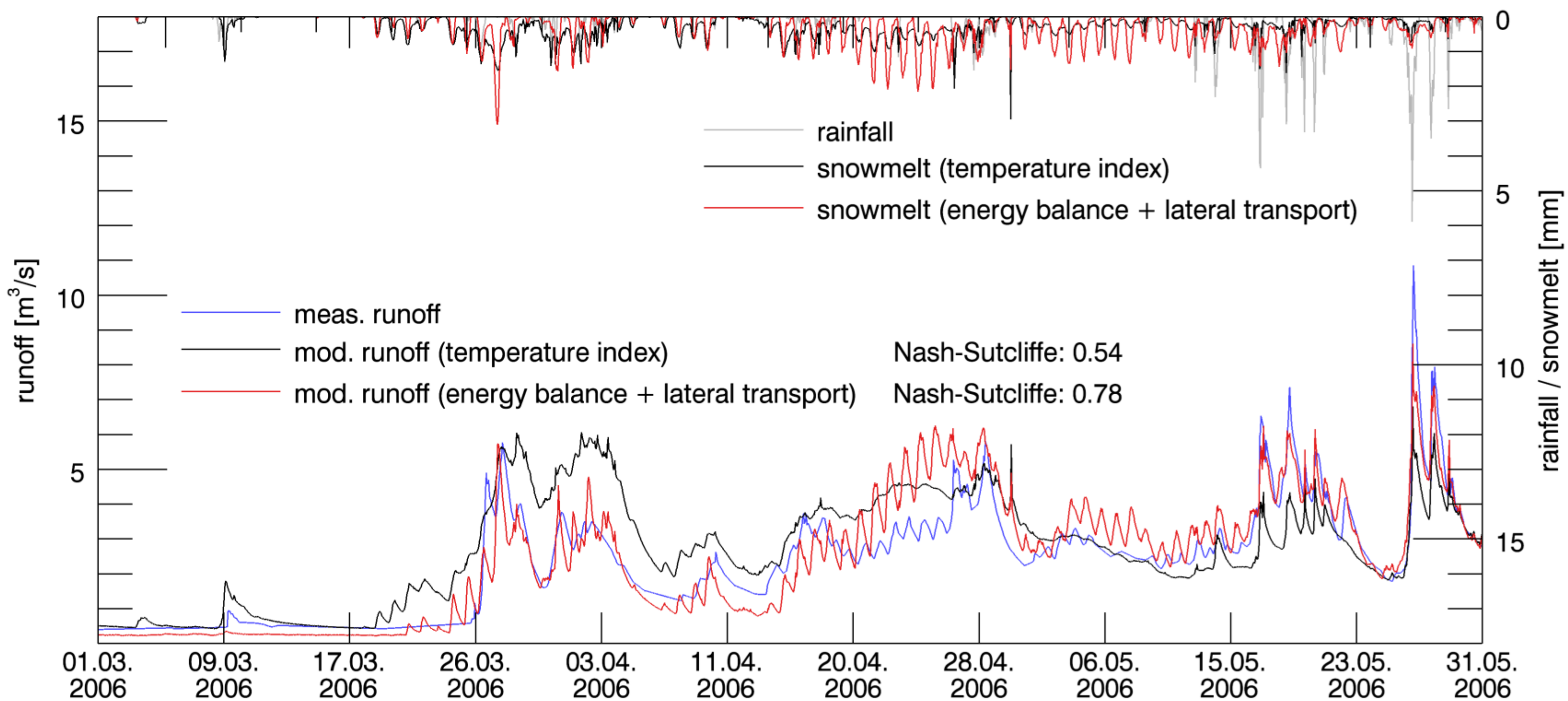
Modelled mean snow cover duration
2002 – 2007

Snowmelt and Runoff



Do we need that within hydrological LSMs?

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



Ausblick

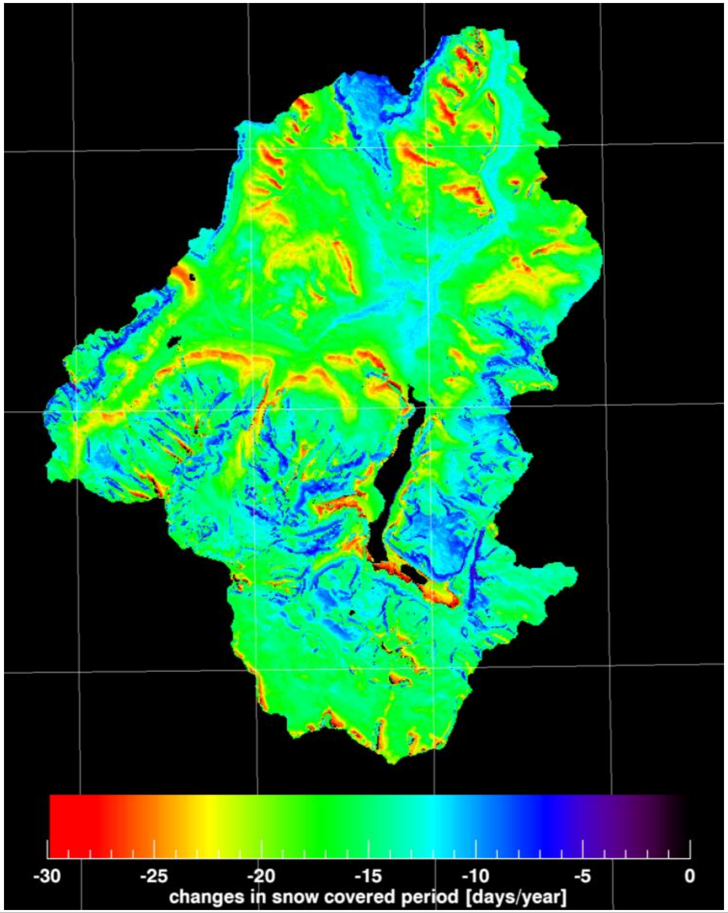
- **Stabile Isotope im Wasser als Tracer**

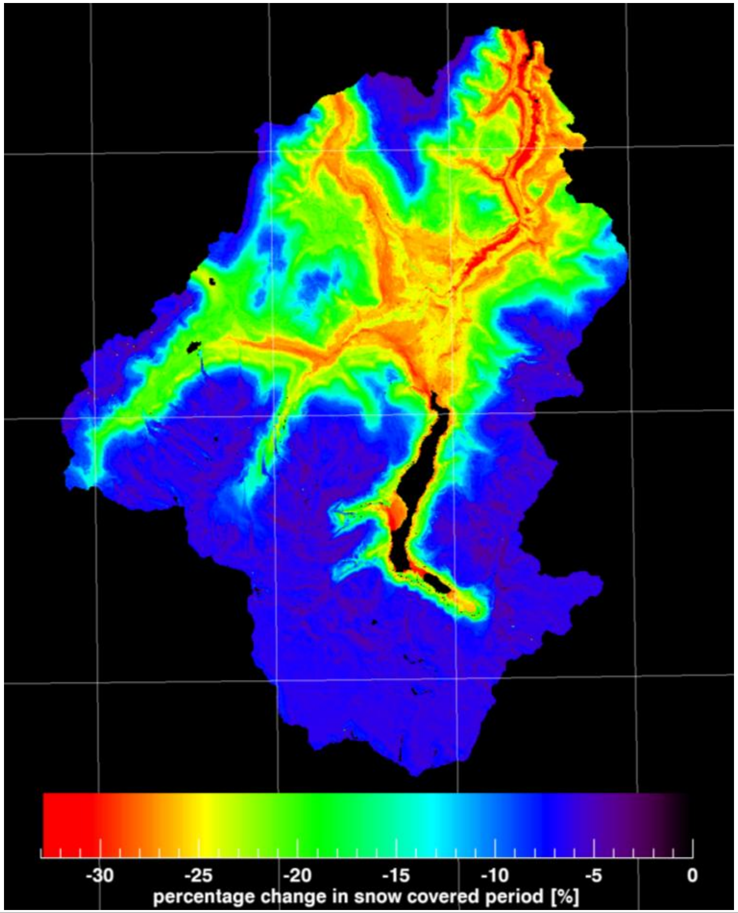
- **Klimaimpaktanalyse (ECHAM5 → WRF → WaSiM-ETH + AMUNDSEN)**

Ausblick

Klimaimpaktanalyse (ECHAM5 → WRF → WaSiM-ETH + AMUNDSEN)

2020-2050 vs. 1970-2000





Thanks!