Modelling the water balance in the Berchtesgaden Alps (Bavaria, Germany)

Snow cover dynamics, groundwater and karst system in complex high alpine terrain

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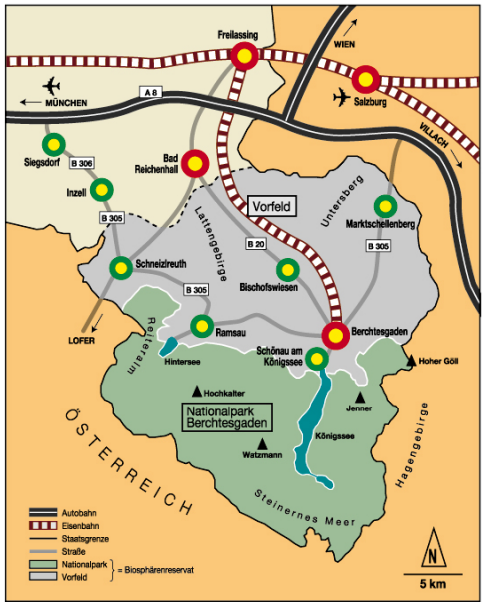
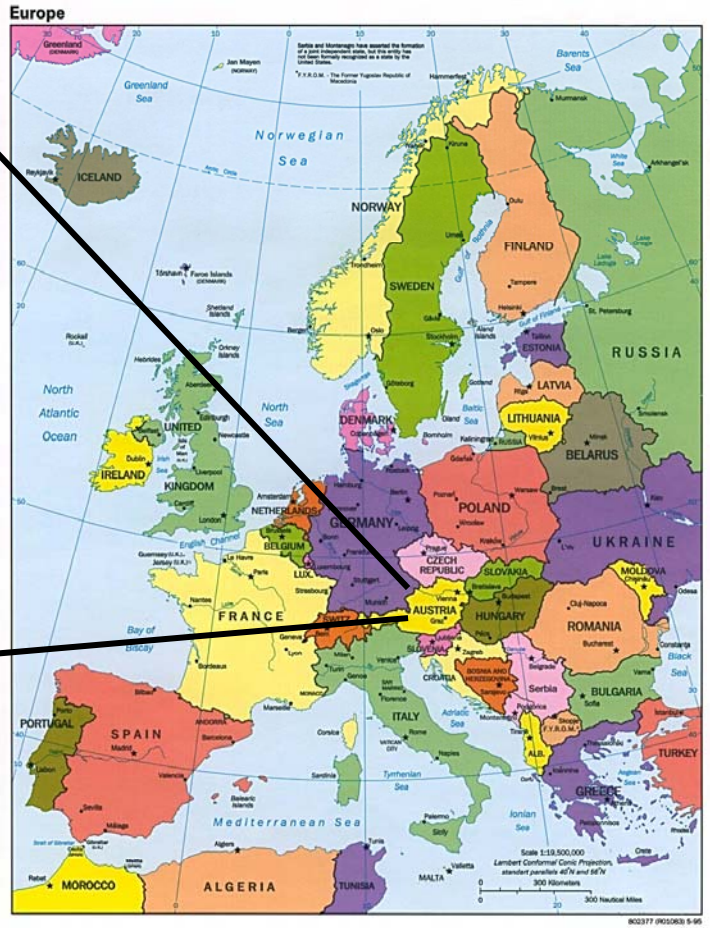
Berchtesgaden National Park





- Berchtesgaden National Park, Germany (IUCN Category II)
- Part of UNESCO Biosphere Reserve

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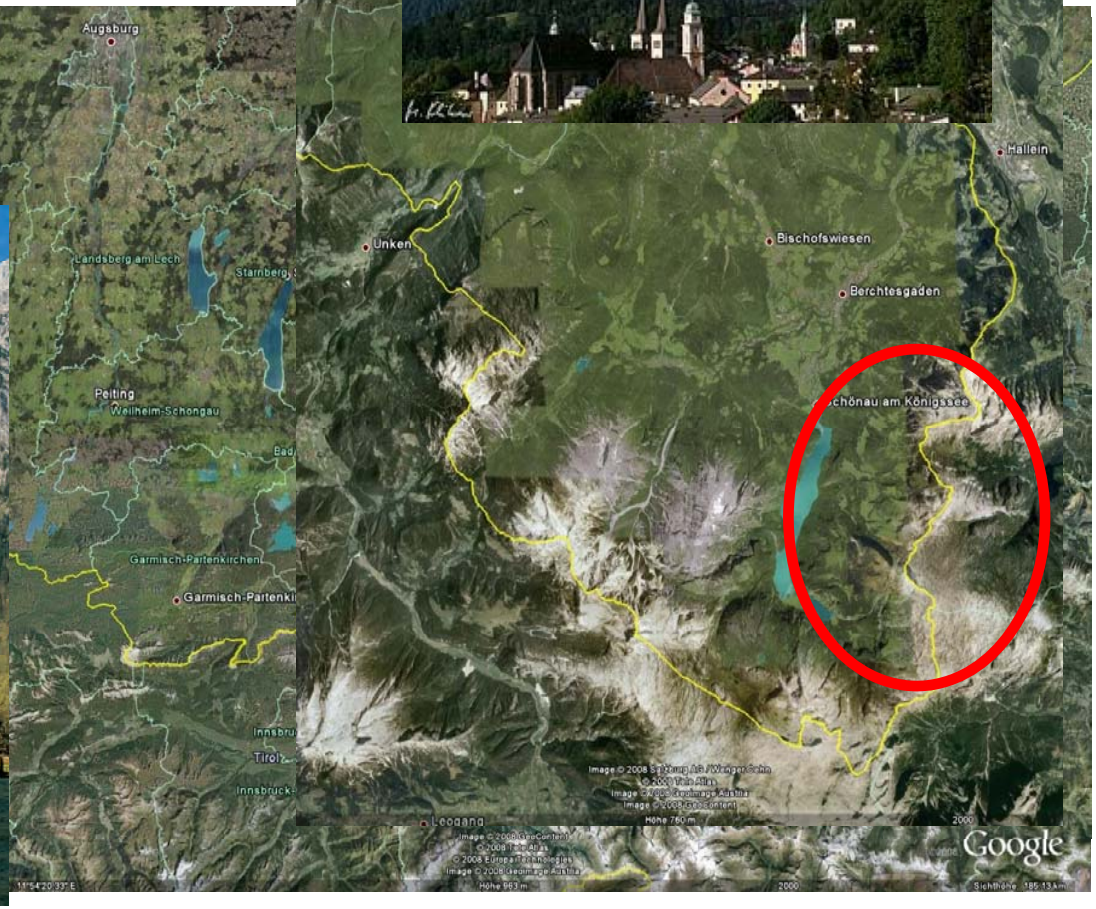
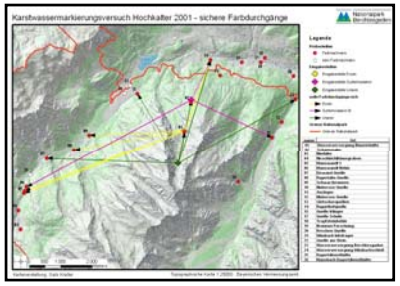
Berchtesgaden National Park

- National Park: 210 km²
  Catchment area: 433 km²
- Königssee: 60[illegible]
  Watzmann M[illegible]
  → large altitu[illegible]
- Mean annual [illegible]
  from 1500 m[illegible]
  up to 2600 m[illegible]
- Biotopes:
  - 44,1 % Fore[illegible]
  - 21,0 % Lim[illegible]
  - 19,3 % Roc[illegible]
  - 12,4 % Mo[illegible]
  - 3,2 % Lake[illegible]





Groundwater and karst system

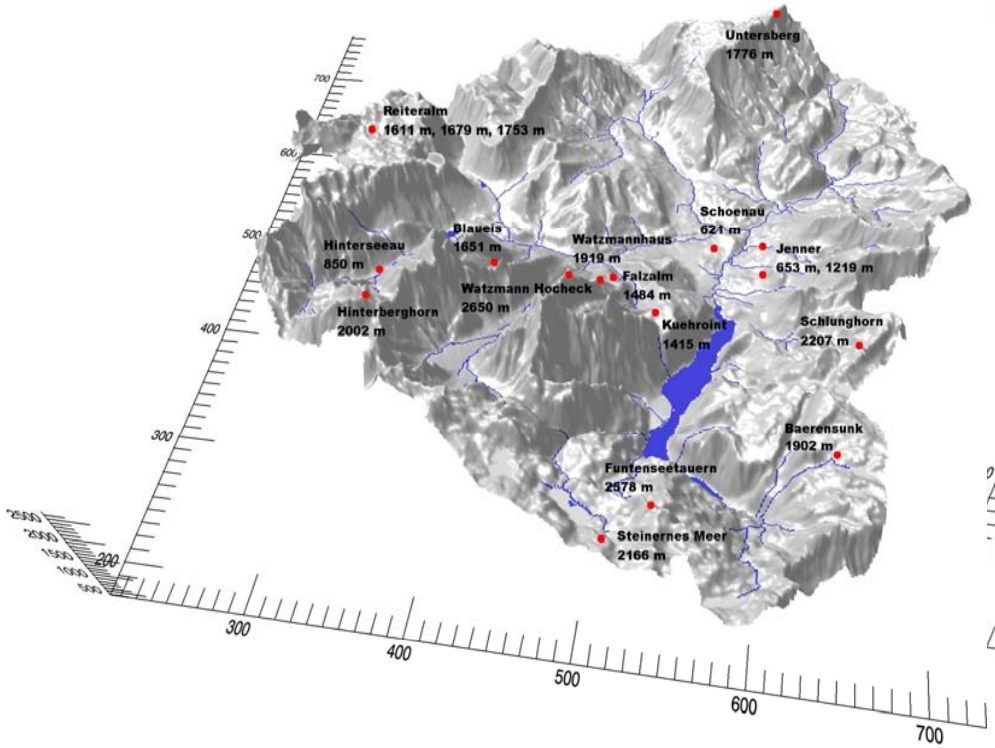
- Complex hydrogeological situation
- Subsurface pathways
- Storage system
- Groundwater redistribution

Snow cover dynamics

- 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 during winter, runoff generation by melting snow
- Snow „feeds“ glaciers and perennial firn fields

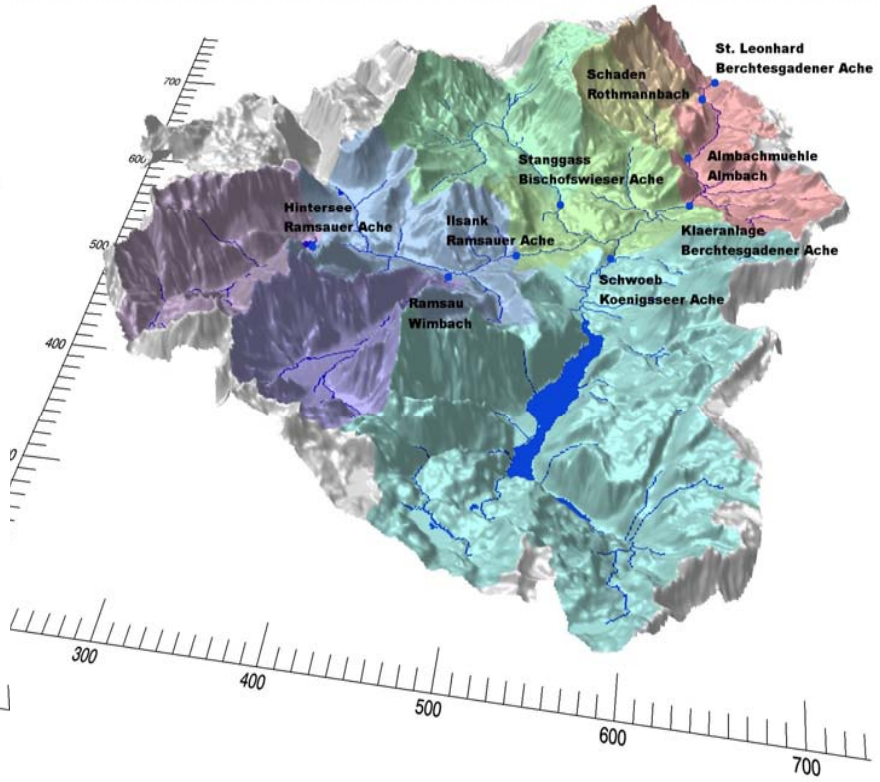
Input WaSiM-ETH

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

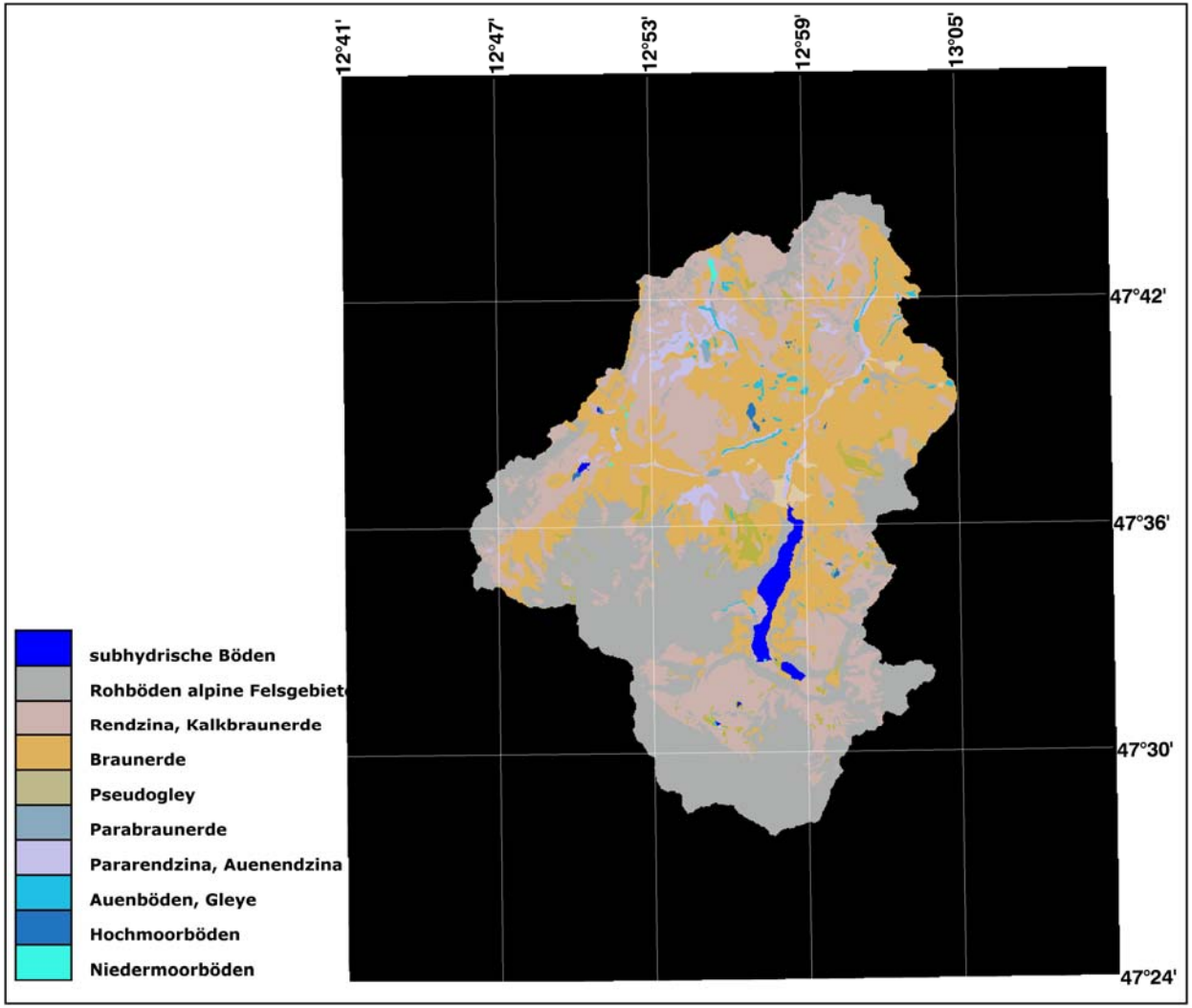
Land use

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

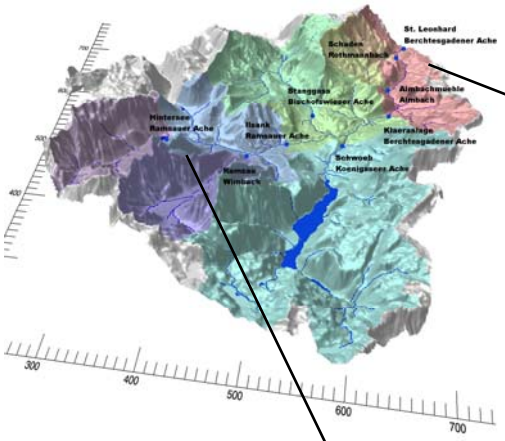
Corine Land Cover CLC

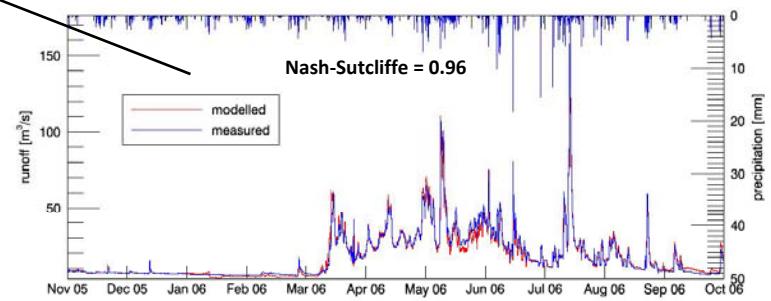
Soil types

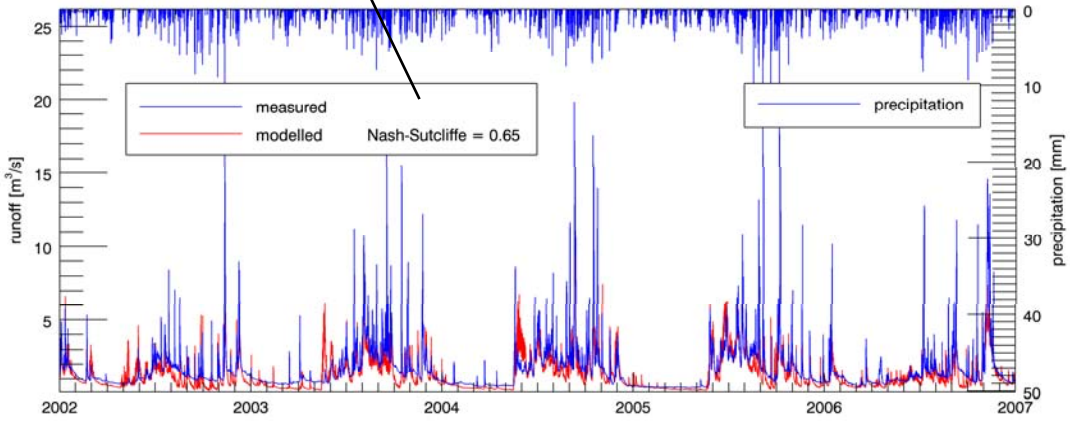
„Bodenübersichtskarte“ 1:25000
Bavarian Environmental Agency



First results water balance



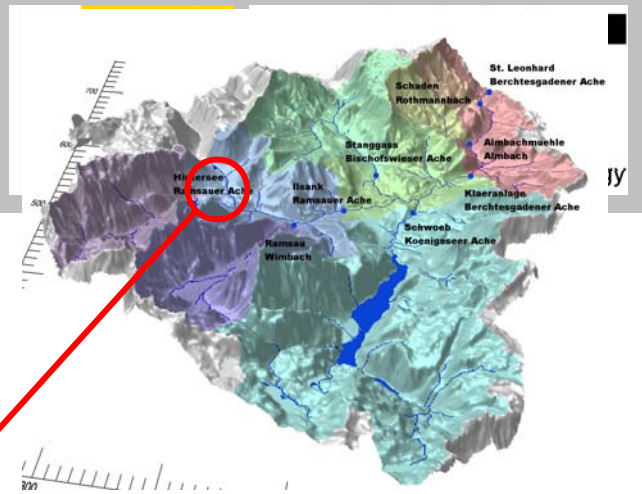




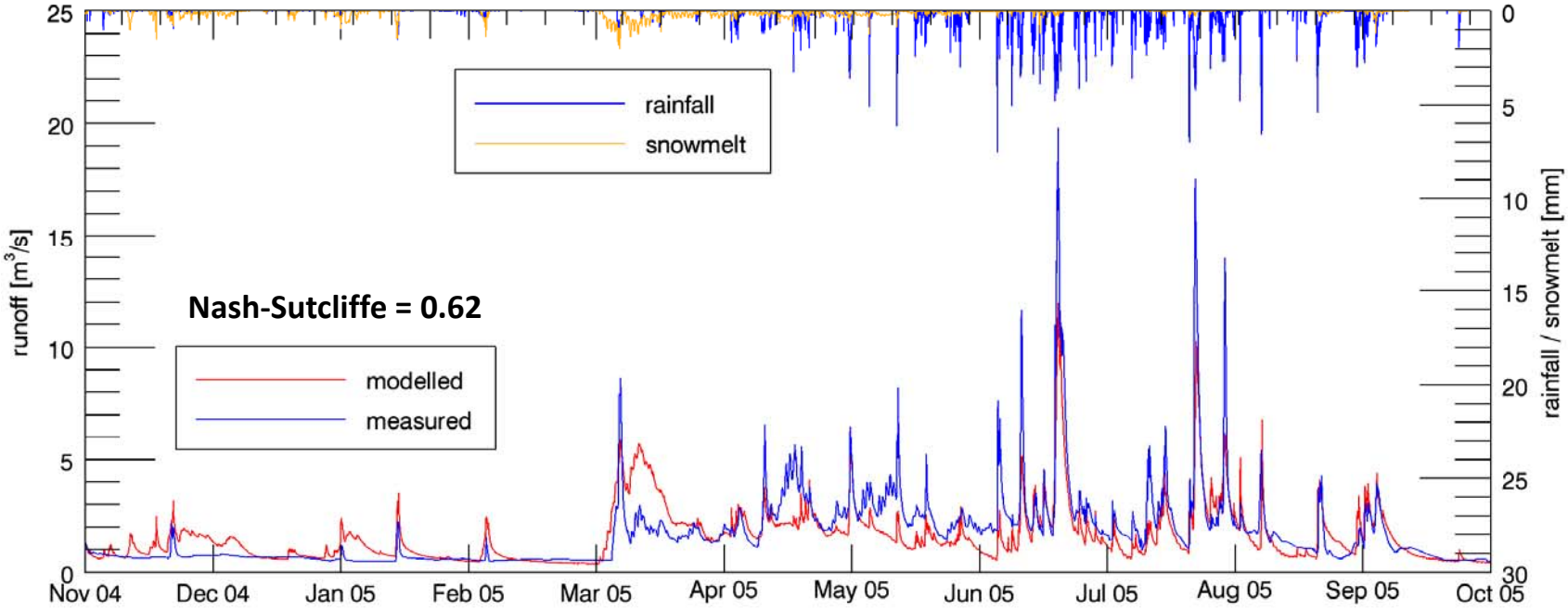
	annual mean (2002 - 2007)
Precipitation (mm)	1611.4
Rainfall (mm)	1111.5
Snowfall (mm)	499.9
Evapotranspiration (mm)	493.7
Runoff (mm)	1013.3
Air temperature (°C)	1.2
Snow cover duration (days)	144

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

Discharge modelling

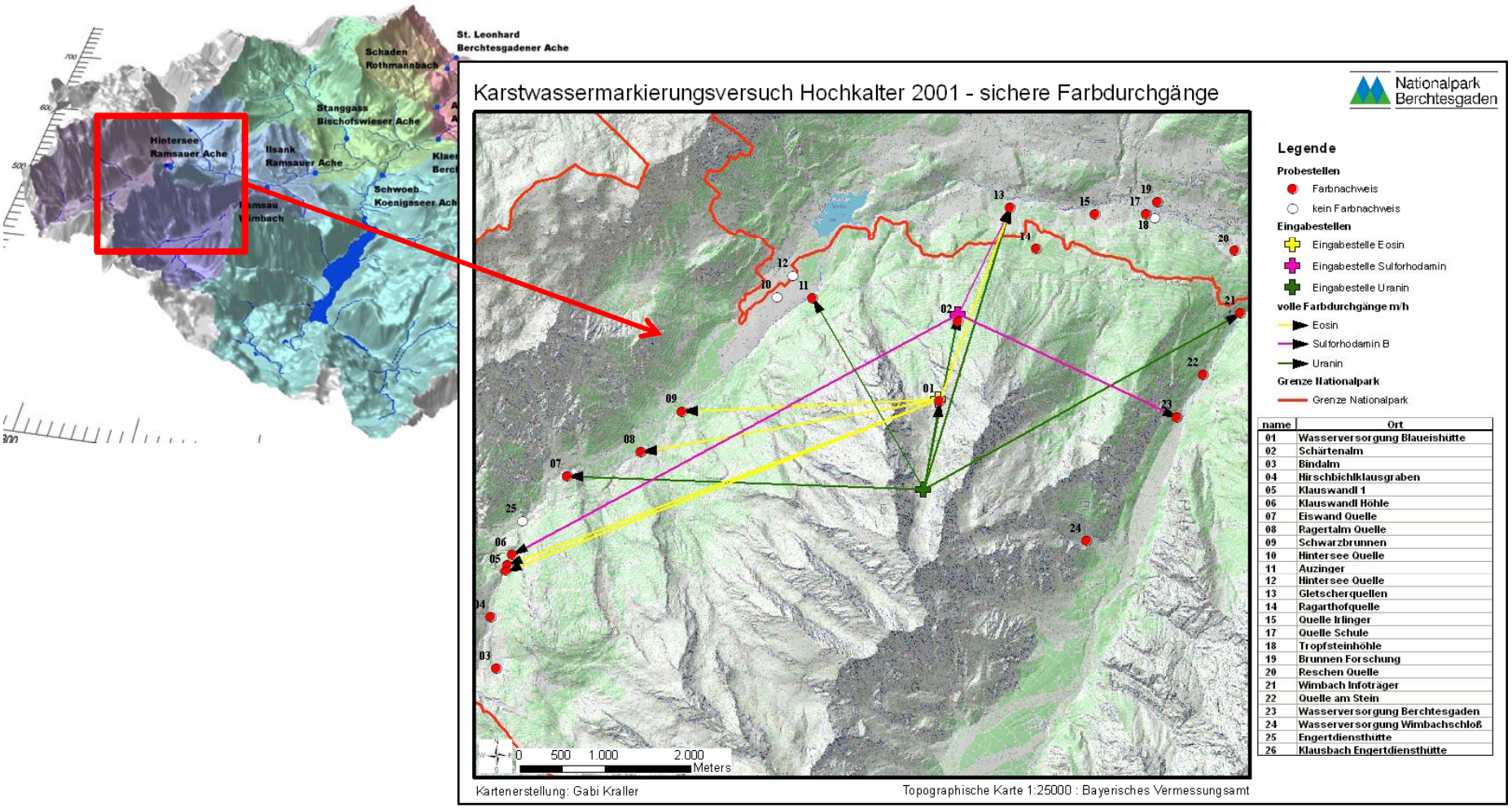


Modelled and measured total runoff at gauge Hintersee 2004/2005 (Headwater catchment)



Measured and modelled runoff at gauge "Hintersee" Nov. 2004 - Oct. 2005 in m³/s

Regional Hydrology



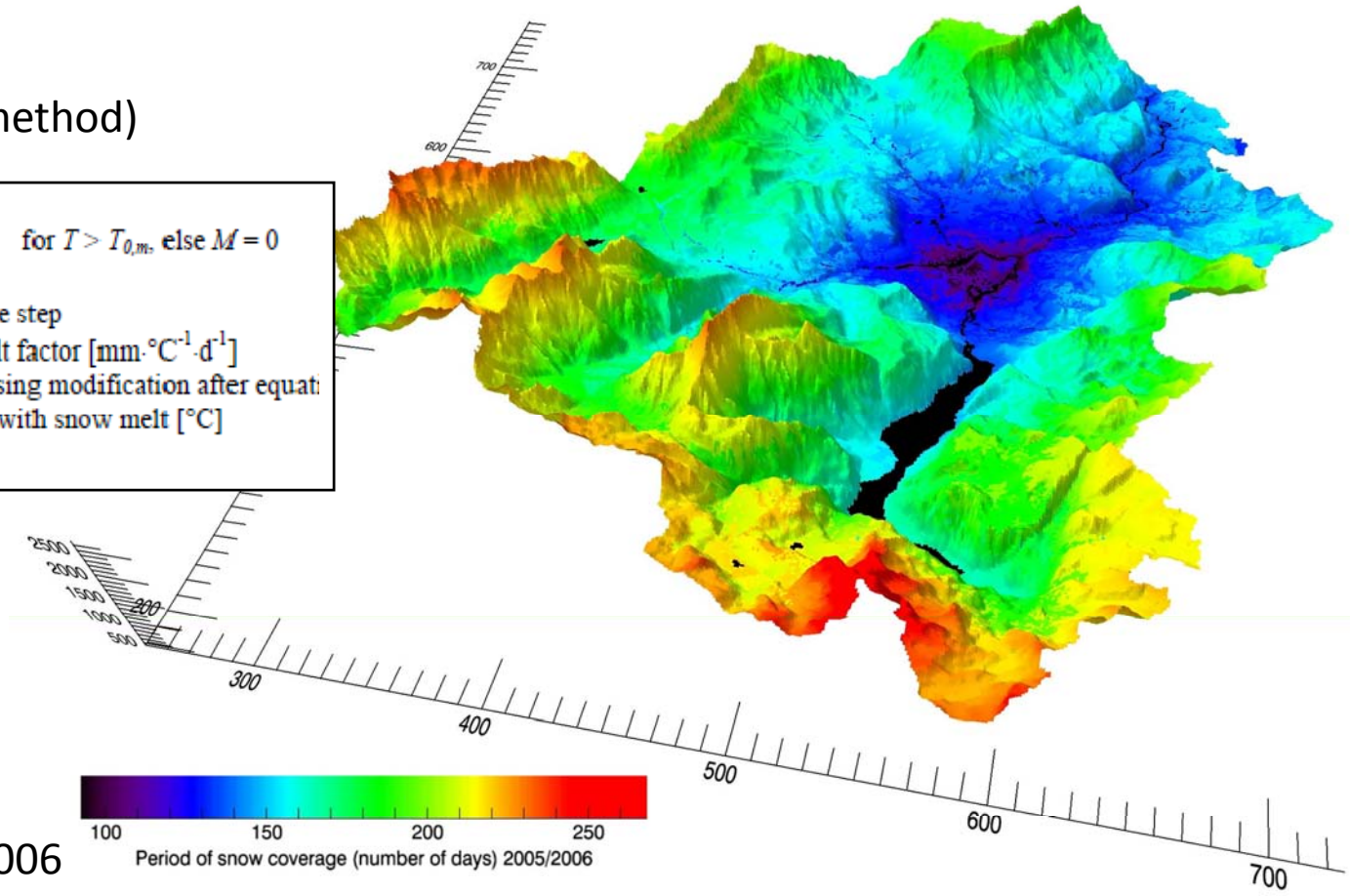
name	Ort
01	Wasserversorgung Blaueishütte
02	Schärtenalm
03	Bindalm
04	Hirschbichlklausgraben
05	Klauswandl 1
06	Klauswandl Höhle
07	Eiswand Quelle
08	Ragertalm Quelle
09	Schwarzbrunnen
10	Hintersee Quelle
11	Auzinger
12	Hintersee Quelle
13	Gletscherquellen
14	Ragarthofquelle
15	Quelle Irlinger
17	Quelle Schule
18	Tropfsteinhöhle
19	Brunnen Forschung
20	Reschen Quelle
21	Wimbach Infoträger
22	Quelle am Stein
23	Wasserversorgung Berchtesgaden
24	Wasserversorgung Wimbachschloß
25	Engertdiensthütte
26	Klausbach Engertdiensthütte

Original approach:

WaSiM Day-Degree
(Temperature-Index method)

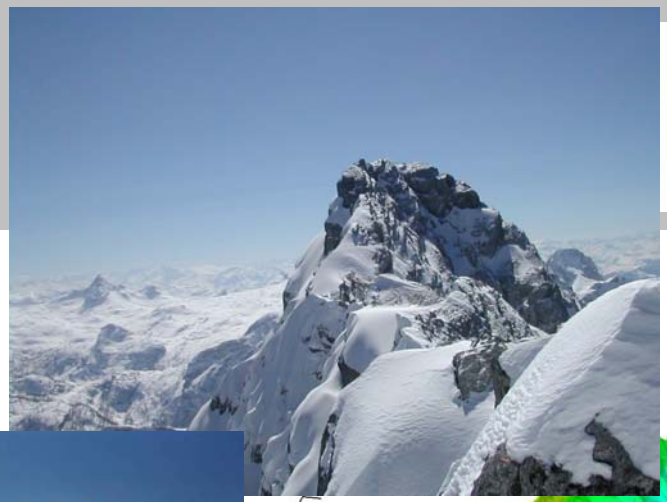
$$M = c_0 \cdot (T - T_{0,m}) \cdot \frac{\Delta t}{24} \qquad \text{for } T > T_{0,m}, \text{ else } M = 0$$

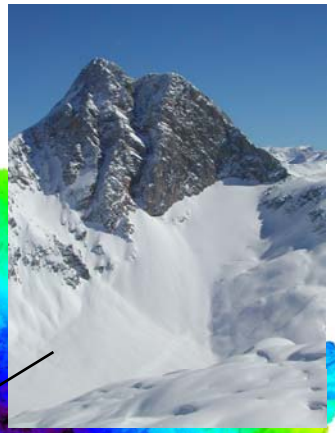
with
- M melting rate in mm per time step
- c_0 temperature dependent melt factor [mm·°C^{-1}·d^{-1}]
- T air temperature, casually using modification after equat
- $T_{0,m}$ temperature for beginning with snow melt [°C]
- Δt time step [h]

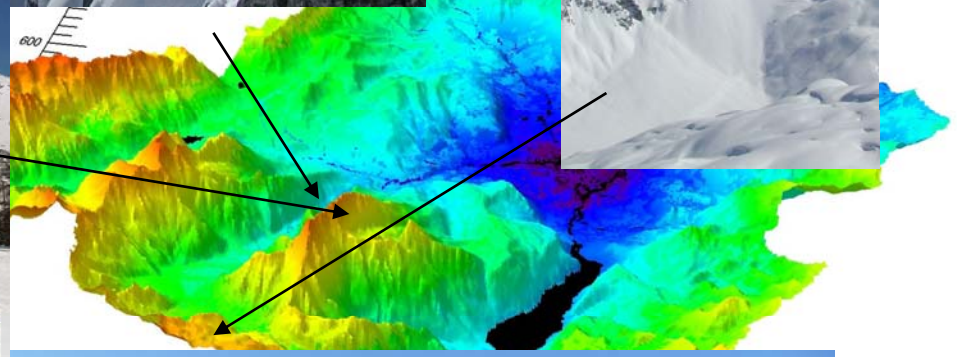


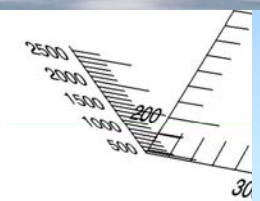
Modelled days with
snow coverage
during winter 2005/2006

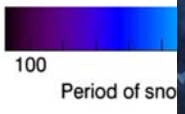
WaSiM snow module

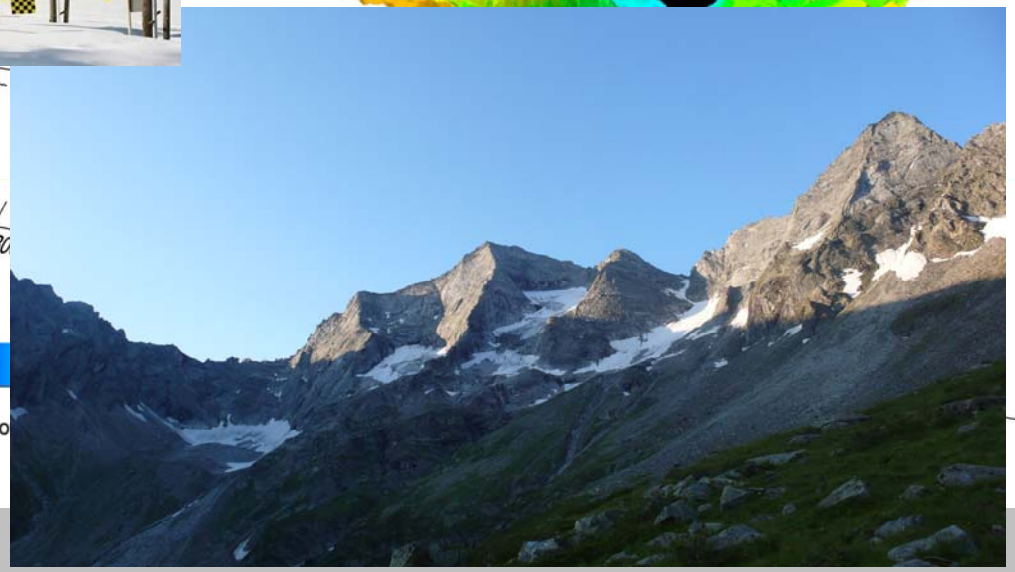


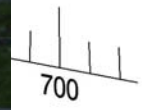




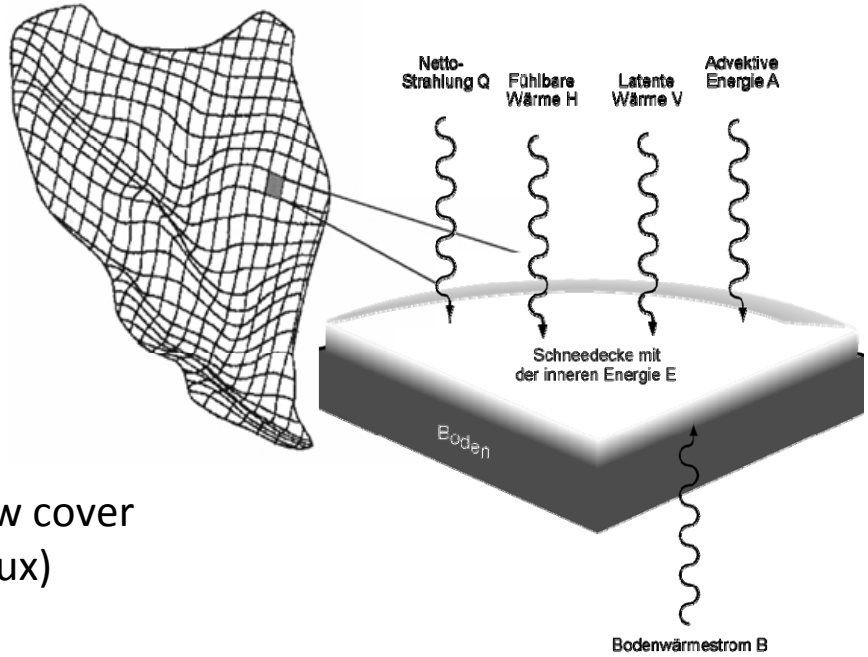








AMUNDSEN (Strasser 2008)
(**A**lpine **MU**ltiscale **N**umerical **D**istributed **S**imulation **EN**gine)

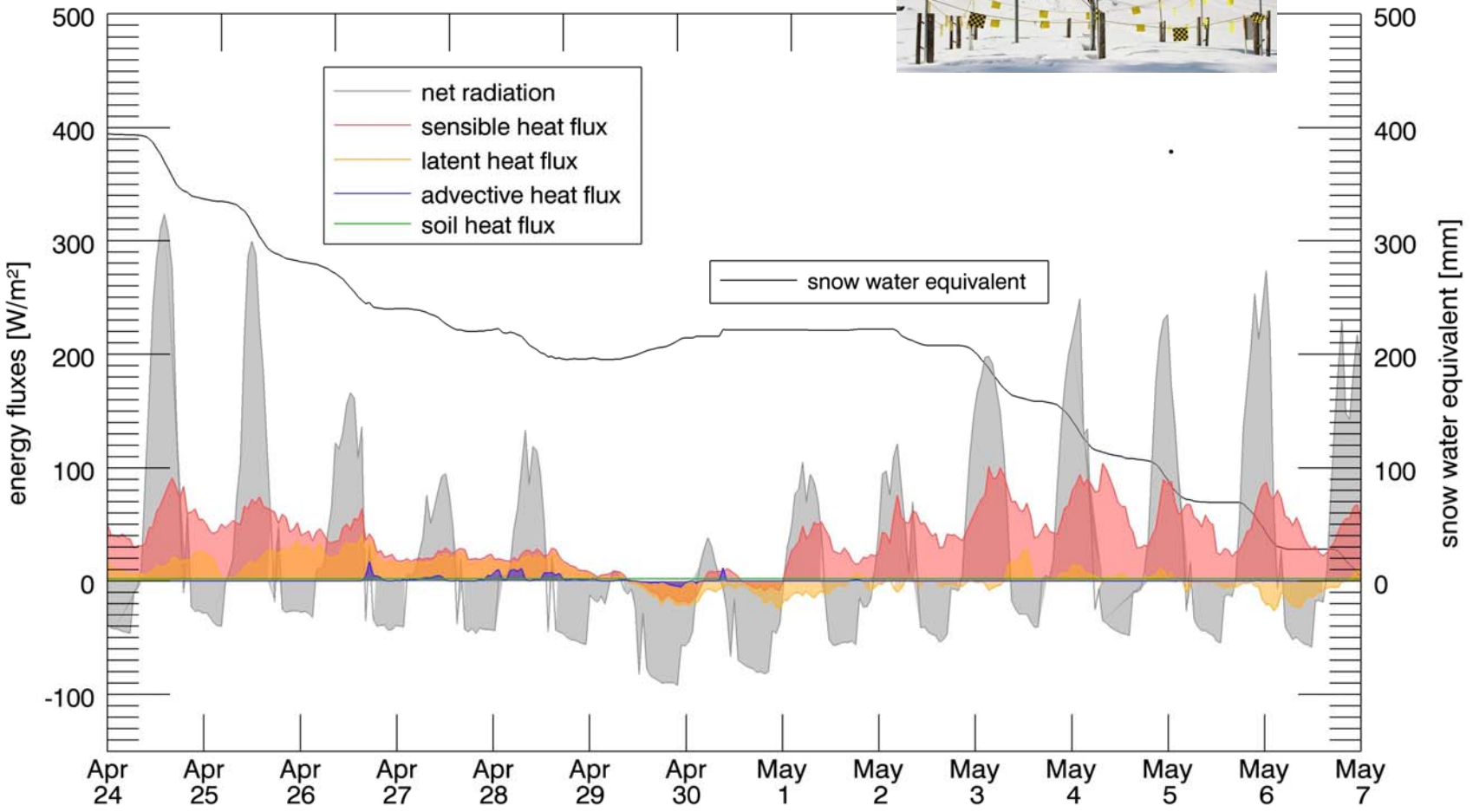


What's new?

- **complete energy and mass balance** of the snow cover (radiation balance, turbulent fluxes, soil heat flux)
- Interaction **vegetation** – snow (processes of interception and sublimation, micrometeorological conditions)
- **Terrain-dependent radiation processes** (shading, reflections from surrounding slopes)
- **Gravitational** snow **transport** (snow slides)
- **Wind-driven redistribution** of snow

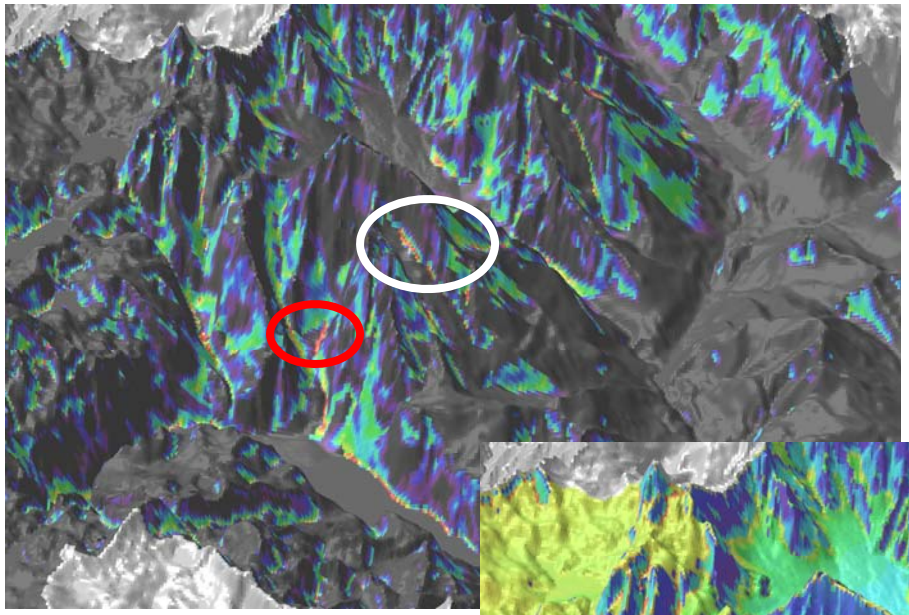
High alpine terrain

Results – Energy balance

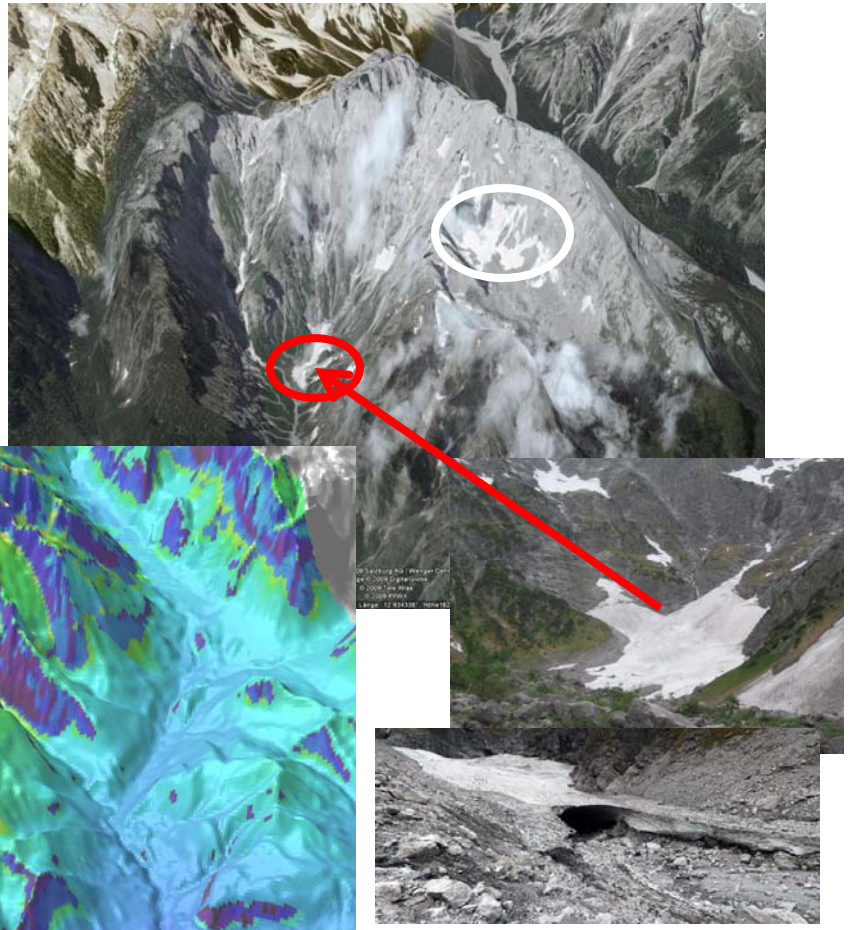


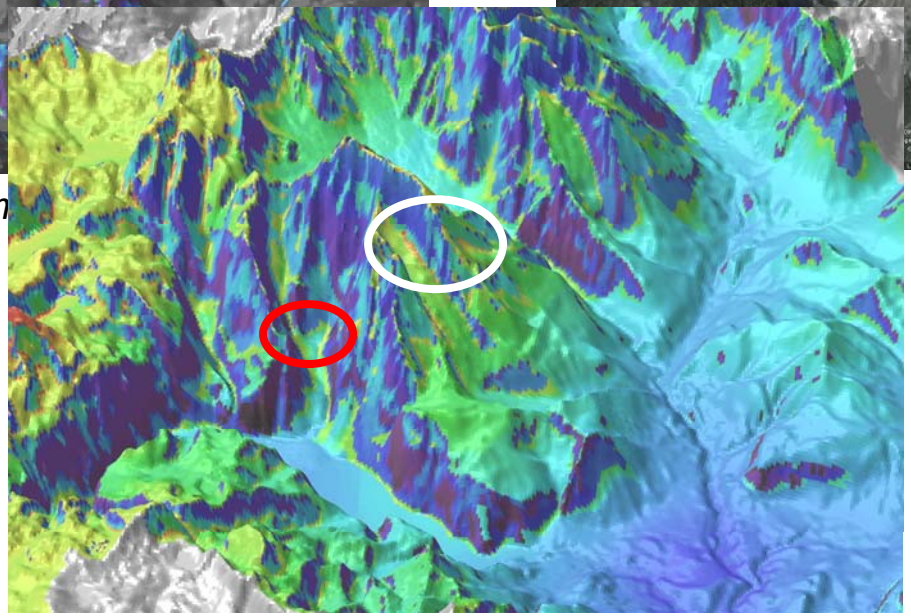
Modelled energy fluxes on the snow cover (Kühroint winter 2005/2006)

Results – Snow slides

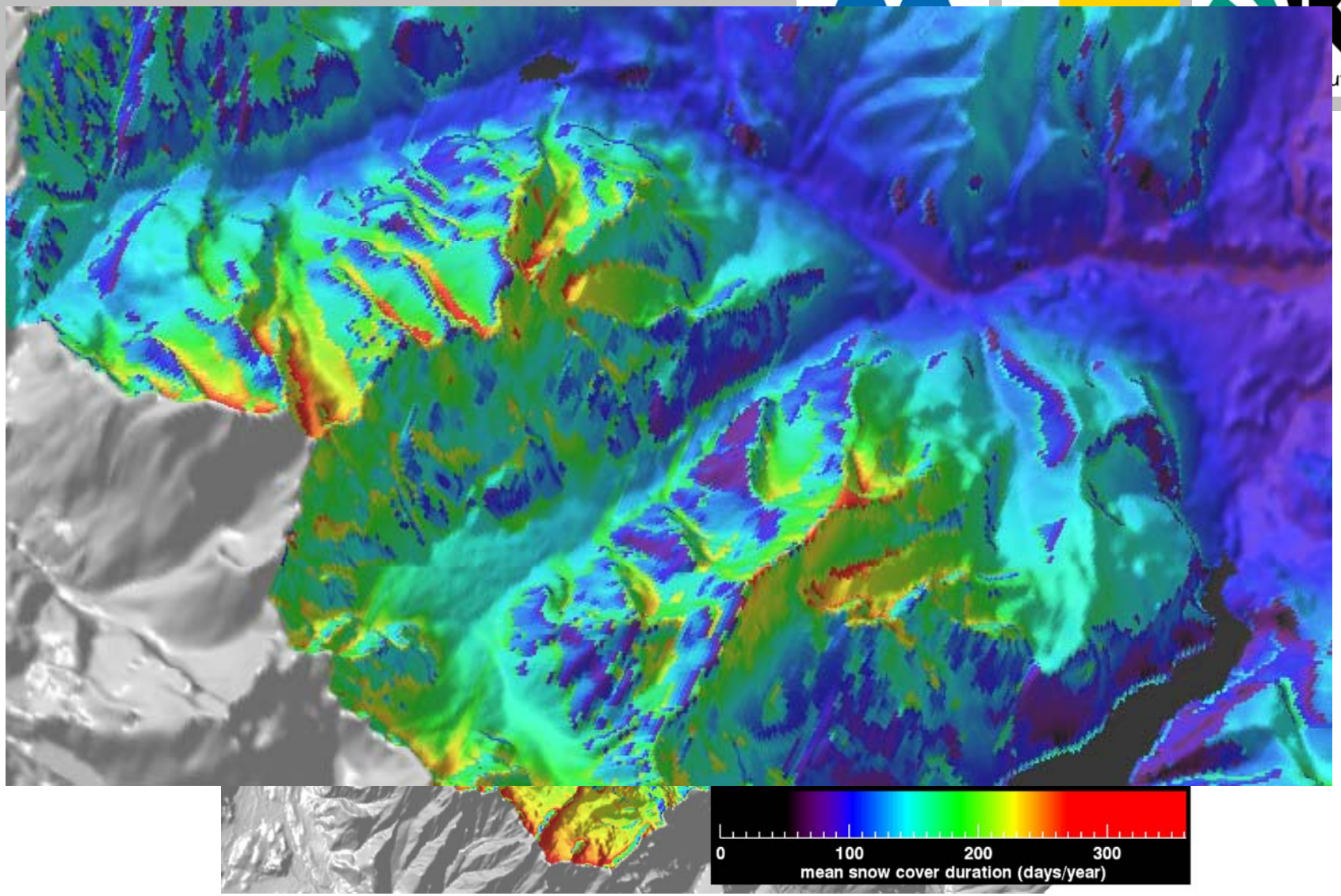


Snow deposition during win





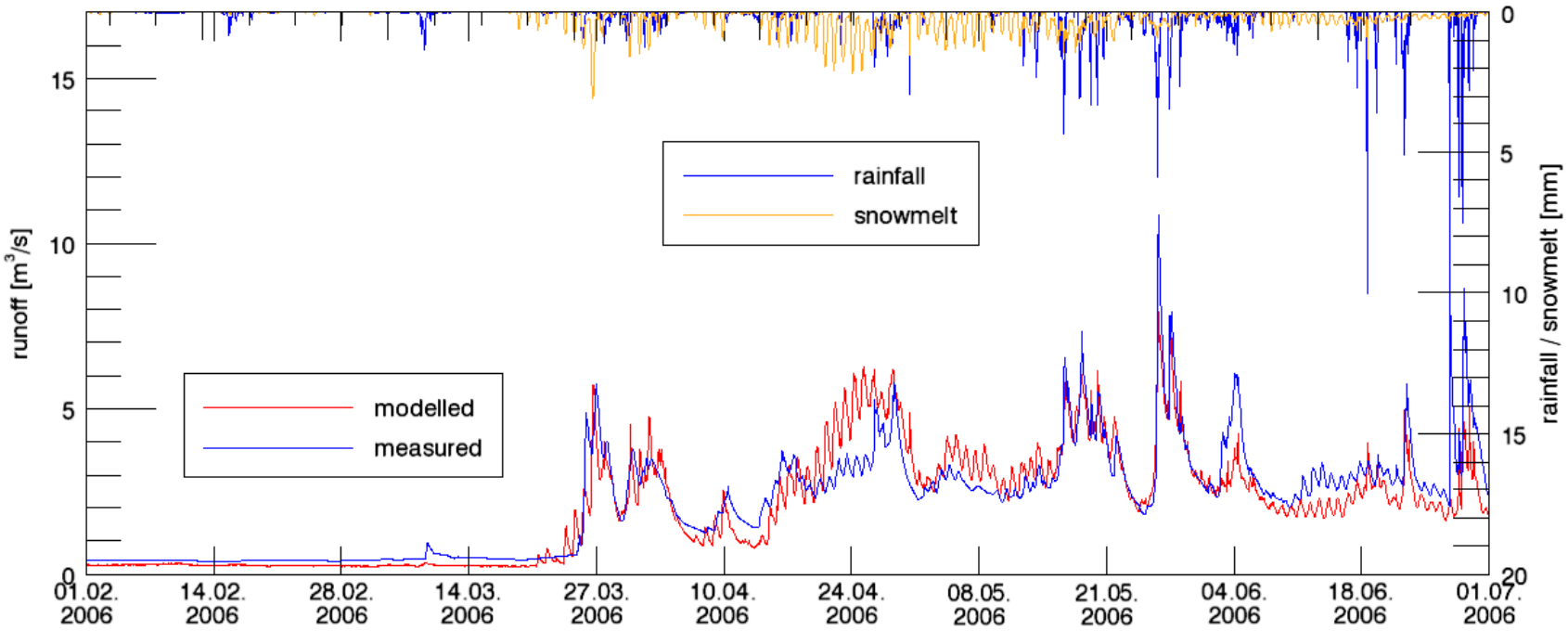
Days with snow coverage (winter 05/06)



Modelled mean snow cover duration (2002 – 2007)

Snow melt and runoff dynamics

Runoff at gauge Hintersee (melting period spring 2006)



Day-Degree
Nash-Sutcliffe = 0.52

Energy-Balance
Nash-Sutcliffe = 0.58

E-Bal + Snowslides
Nash-Sutcliffe = 0.69

E-Bal + Snowslides + Wind
Nash-Sutcliffe = 0.76

Summary and outlook

- **Enhanced snow module significantly improves the discharge modelling in alpine catchments (snow melt periods)**

- **Further important processes:**

  - **Snow-canopy processes (interception, sublimation, melt unload, micrometeorology)**
    Algorithms available and tested within AMUNDSEN (Strasser 2008)

- **Systematic subsurface water redistribution is identified**

- **Climate change scenarios and impact analysis**

Thanks!