Schneehydrologische Modellierung in den Berchtesgadener Alpen mit einer angepassten WaSiM-Version

Michael Warscher

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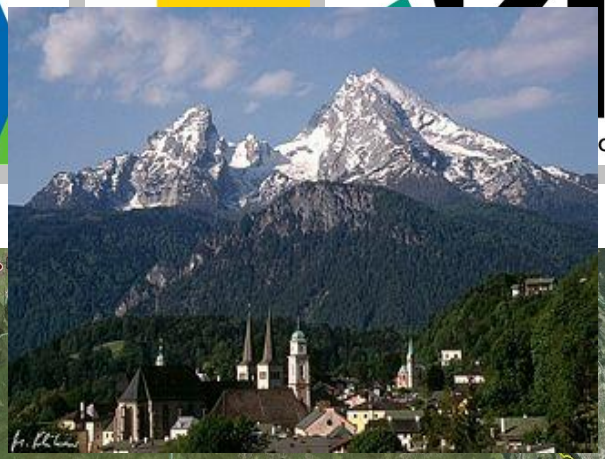
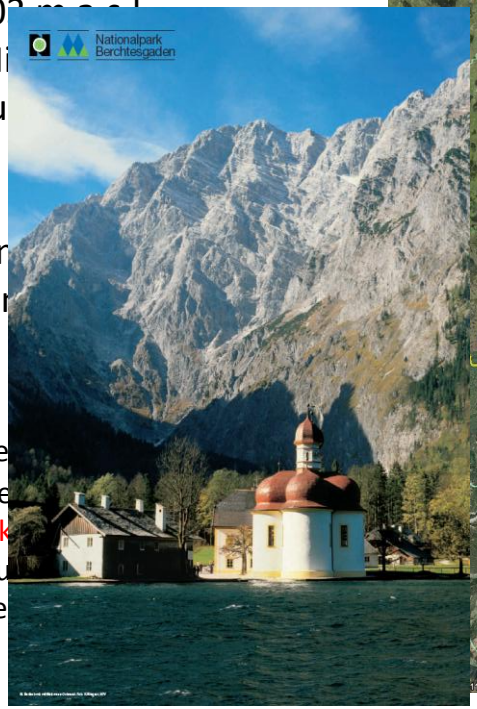
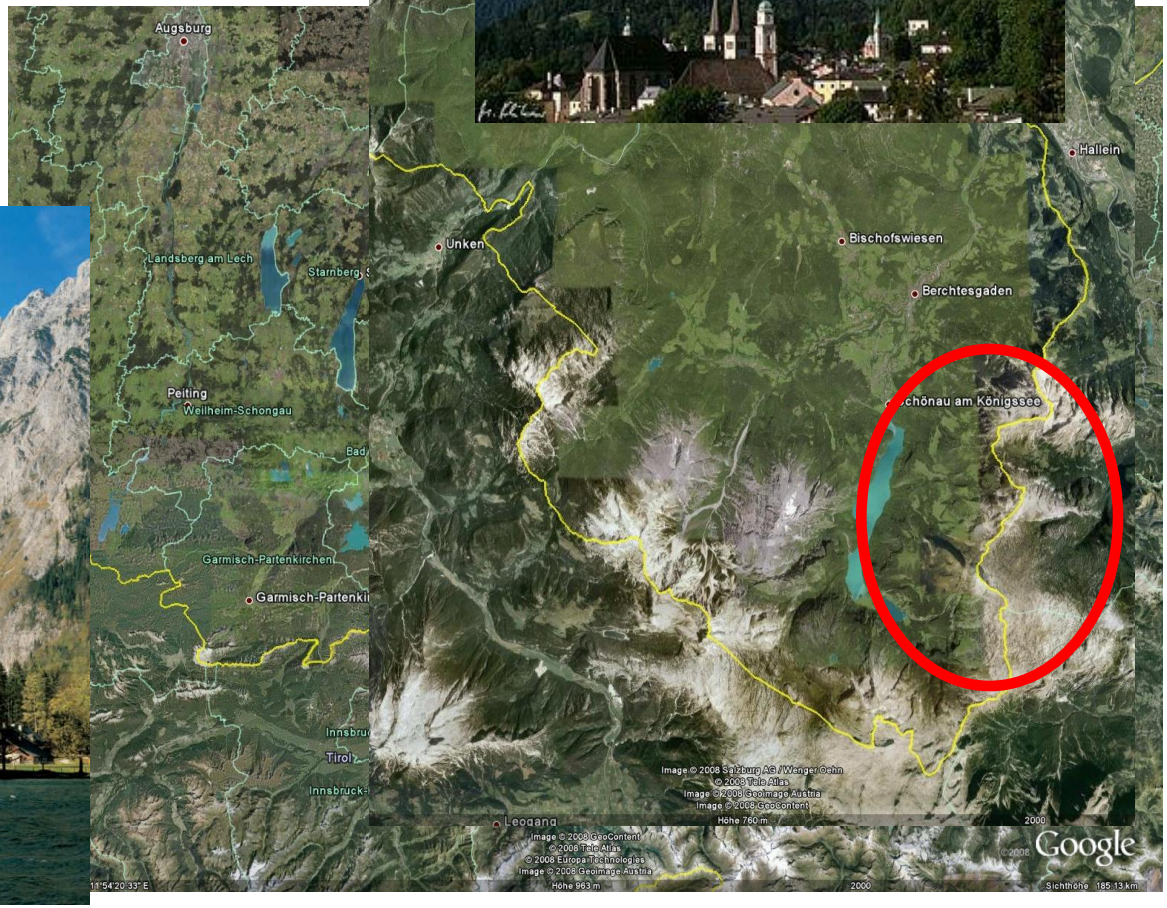
Berchtesgaden National Park

- National Park: 210 km²
  Catchment area: 433 km²
- Königssee: 60? m a.s.l.
  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







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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

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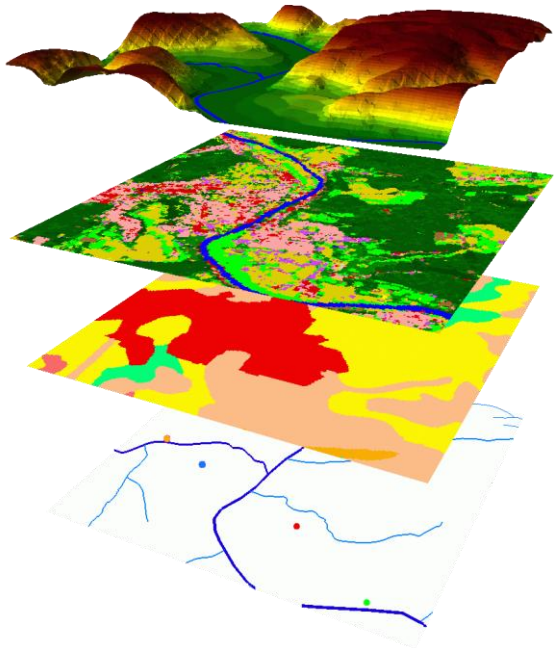
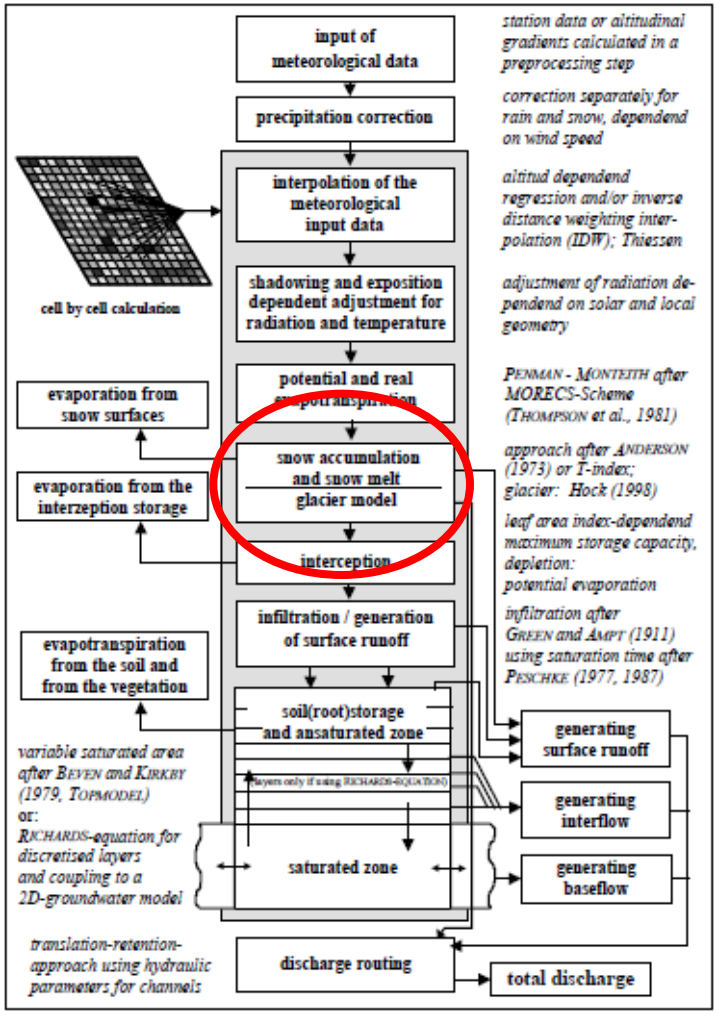
Distributed Hydrological Model

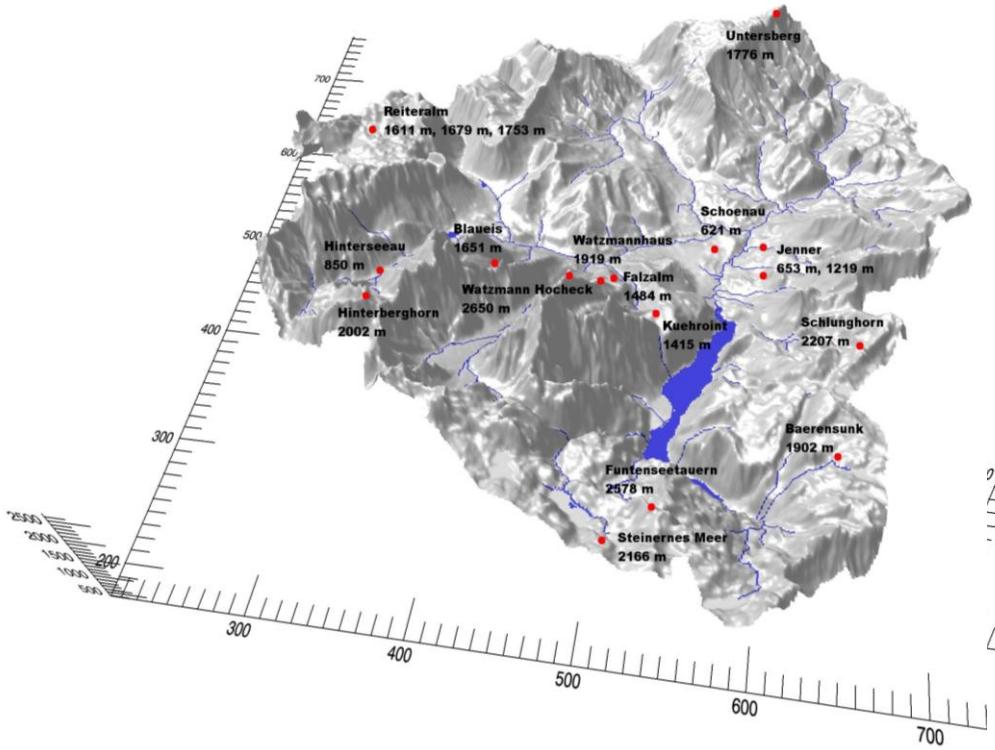
- **WaSiM-ETH** (Schulla and Jasper)





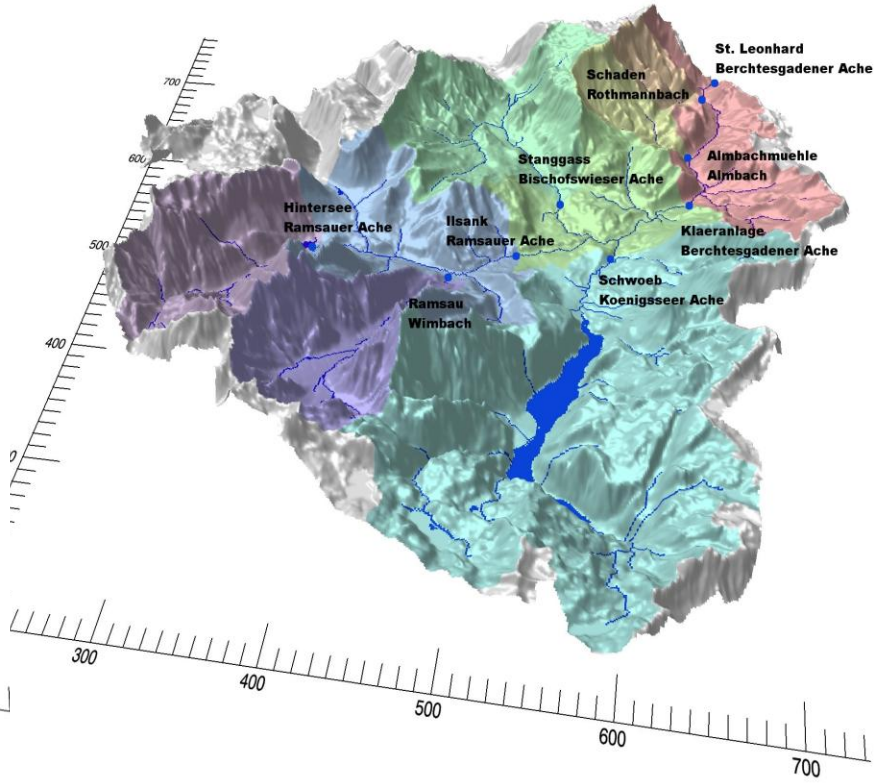
Input WaSiM-ETH

Meteorological measurements



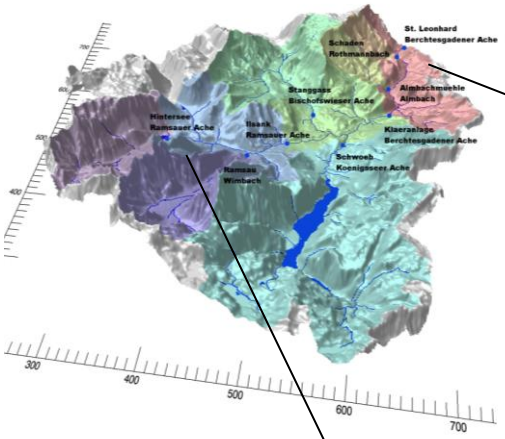
33 stations (19 automatic, 14 manual)
National Park administration, township Schoenau,
Bavarian avalanche service,
Central Institute for Meteorology and Geodynamics (ZAMG)

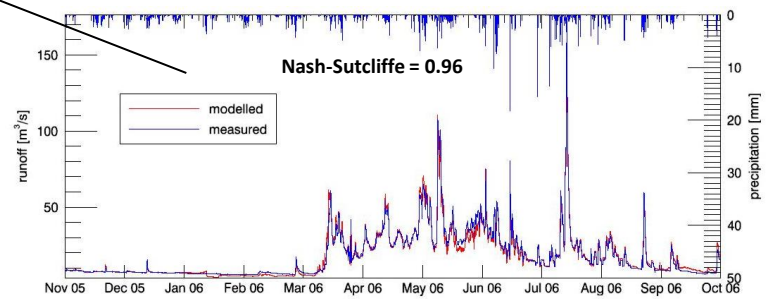
Gauges and subcatchments

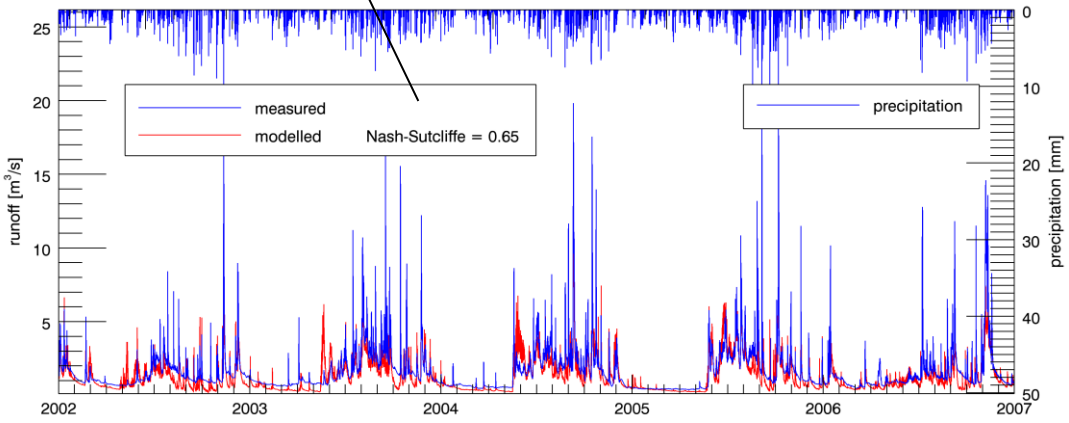


433 km²
9 gauges and subcatchments

Water balance







	annual mean (2002 - 2007)
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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

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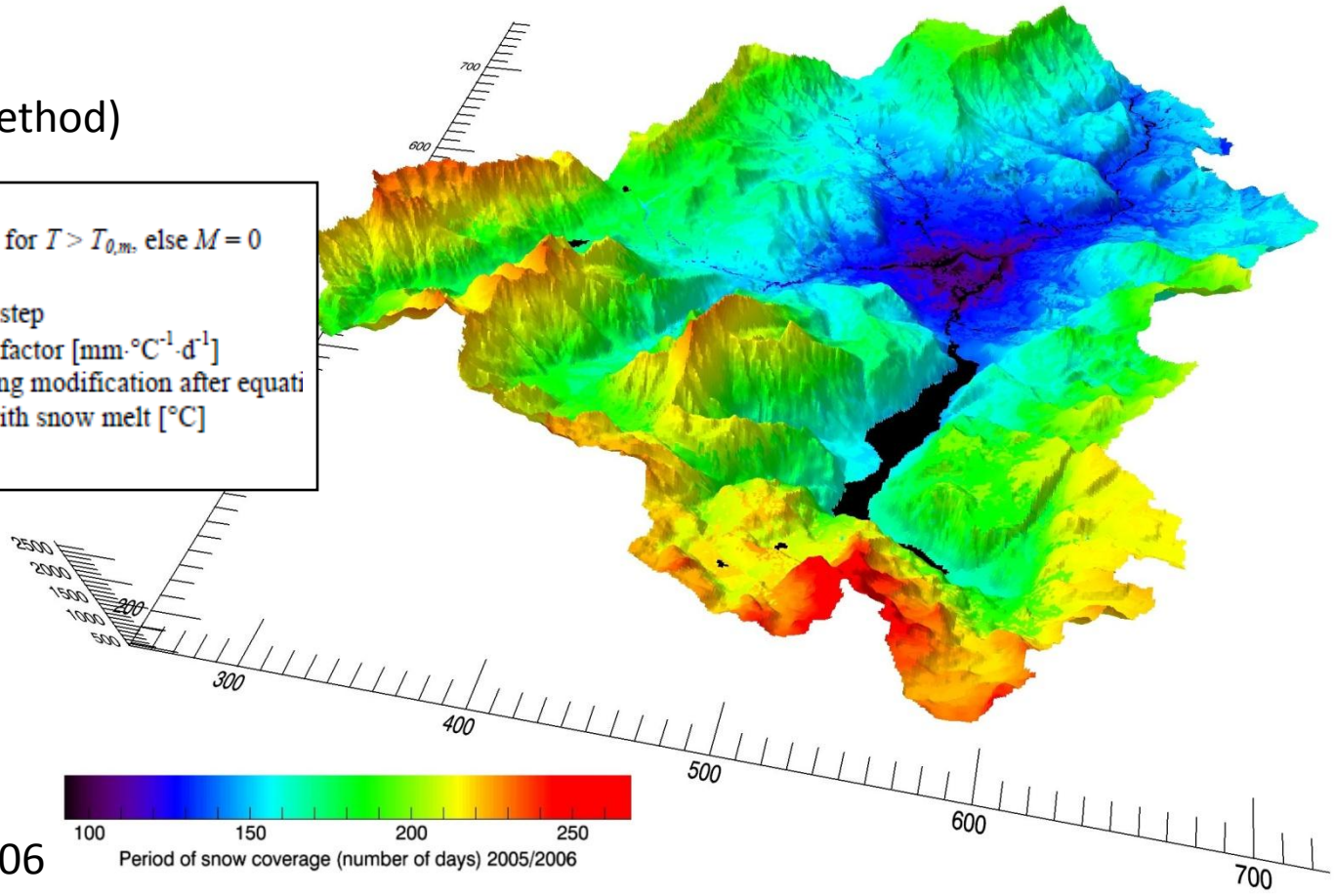
WaSiM-ETH Snow Module

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

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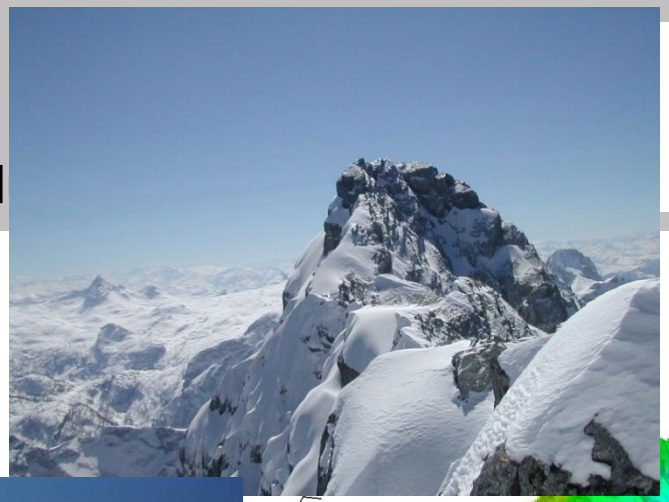
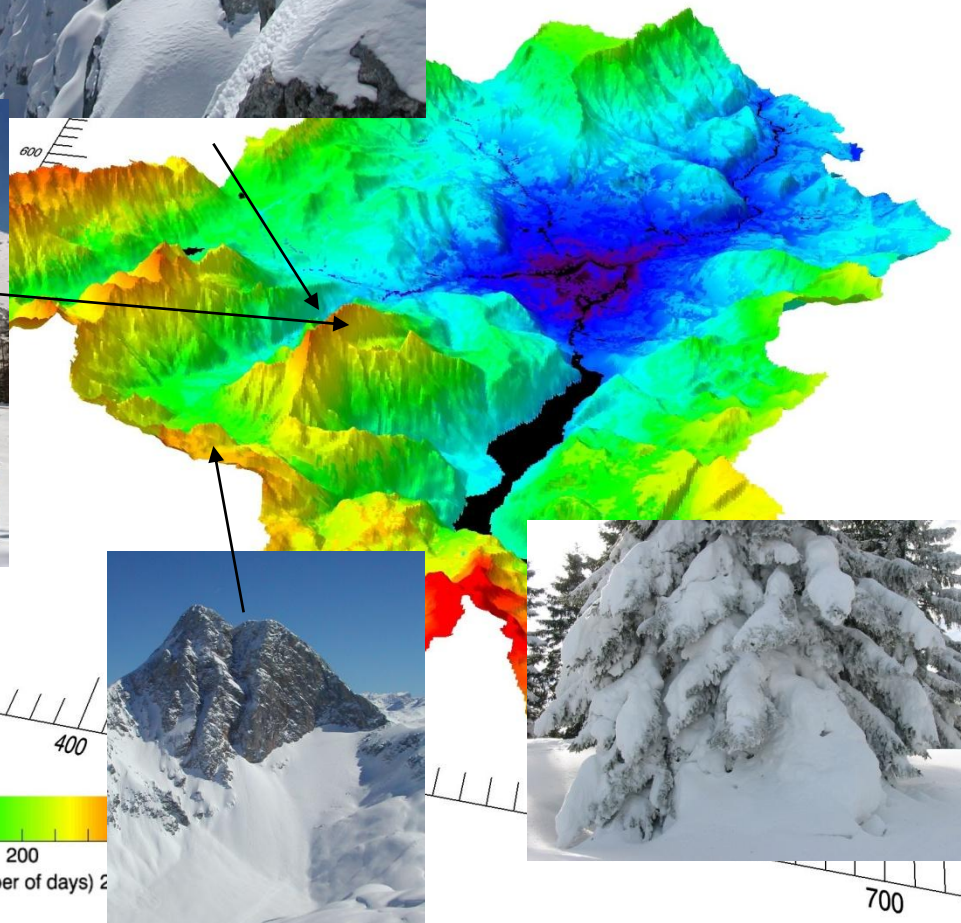
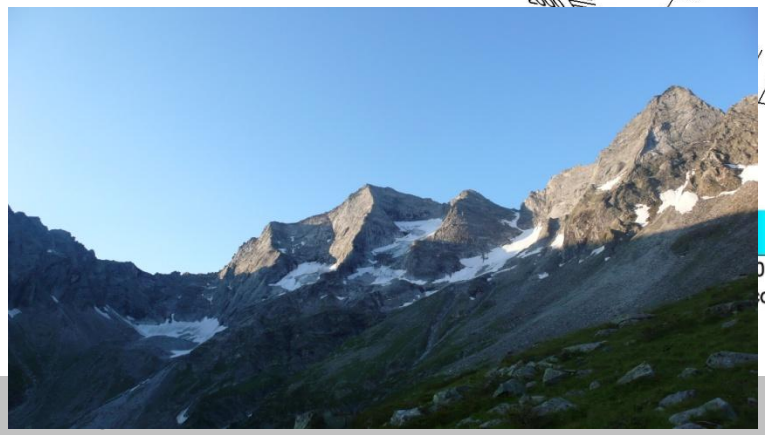
WaSiM-ETH Snow Mod







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Implementation of AMUNDSEN in WaSiM-ETH

What's new?

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

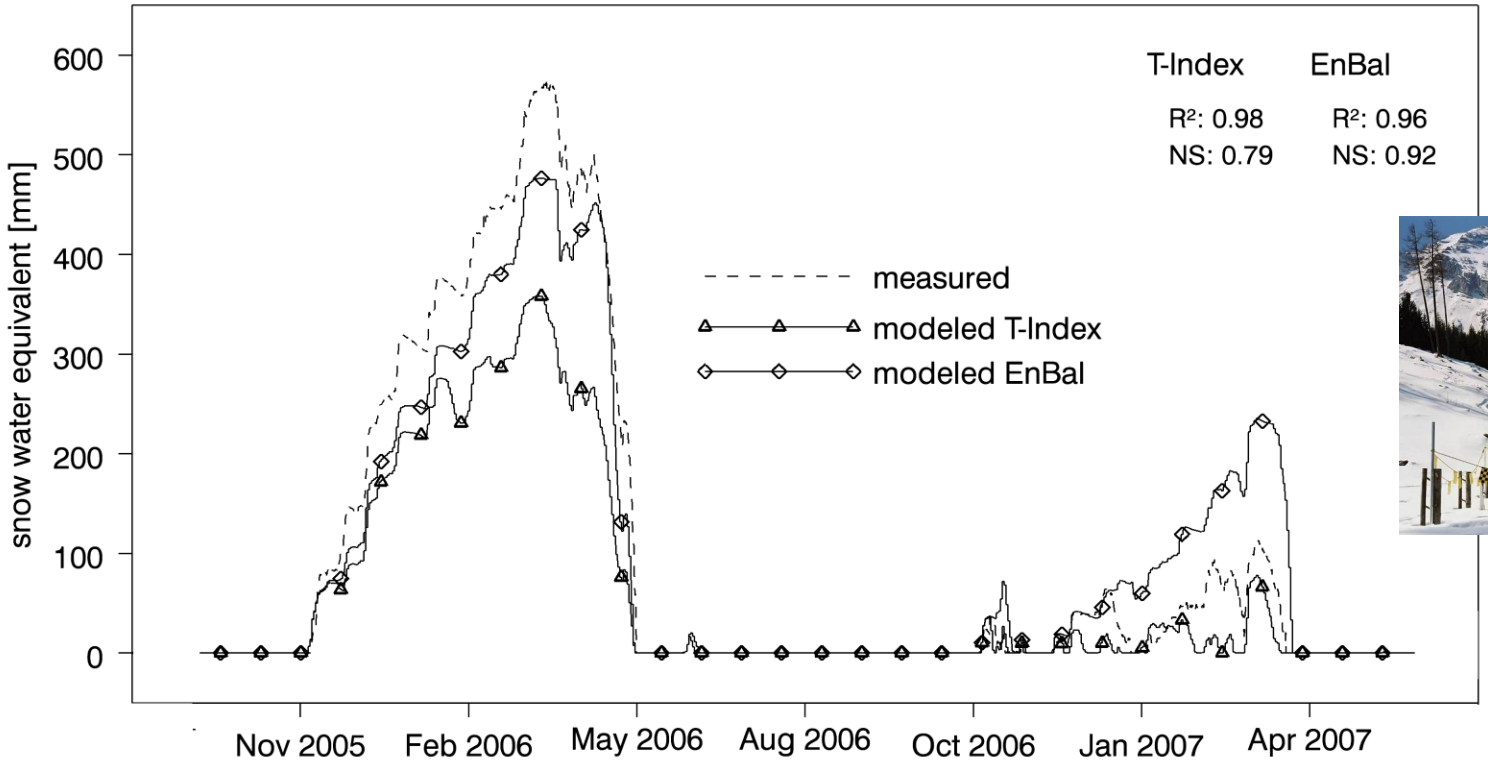
- **Energy and mass balance** of the snow cover
  (radiation balance, turbulent fluxes, advective heat flux, soil heat flux)

- **Lateral snow redistribution**
  (gravitational snow transport, wind-driven 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

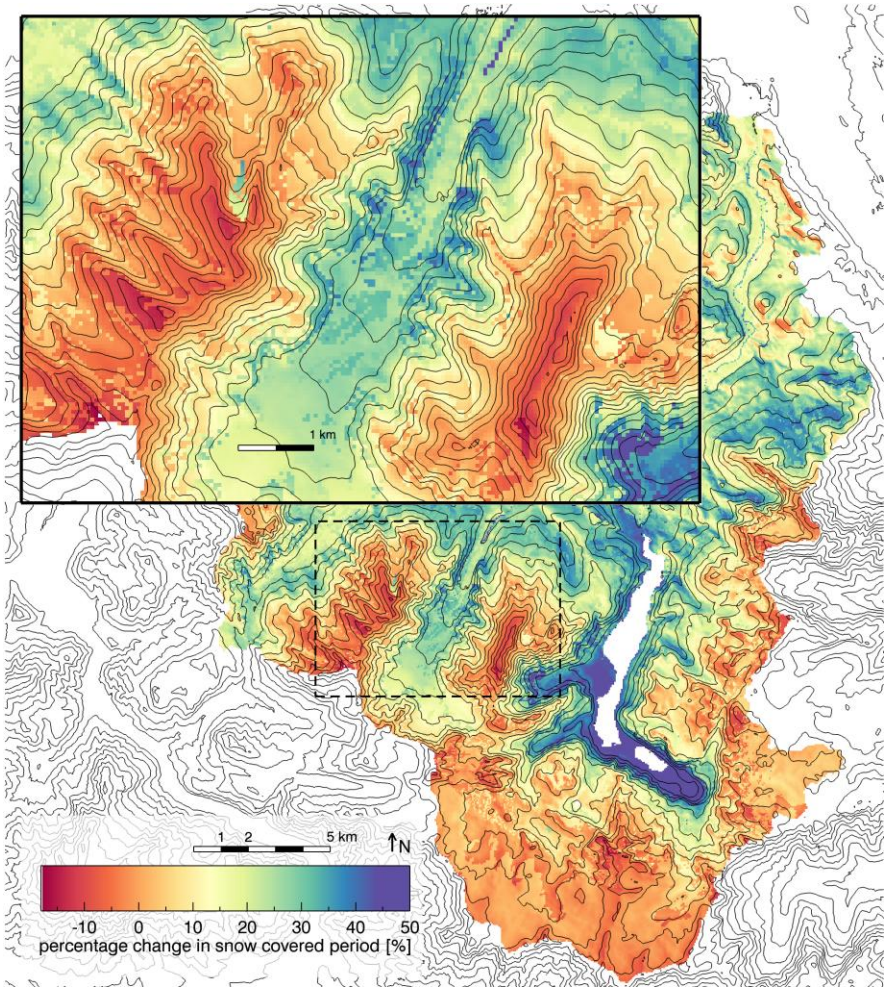


Snow water equivalent at the station Kühroint (1407 m a.s.l.)

Results – Energy balance

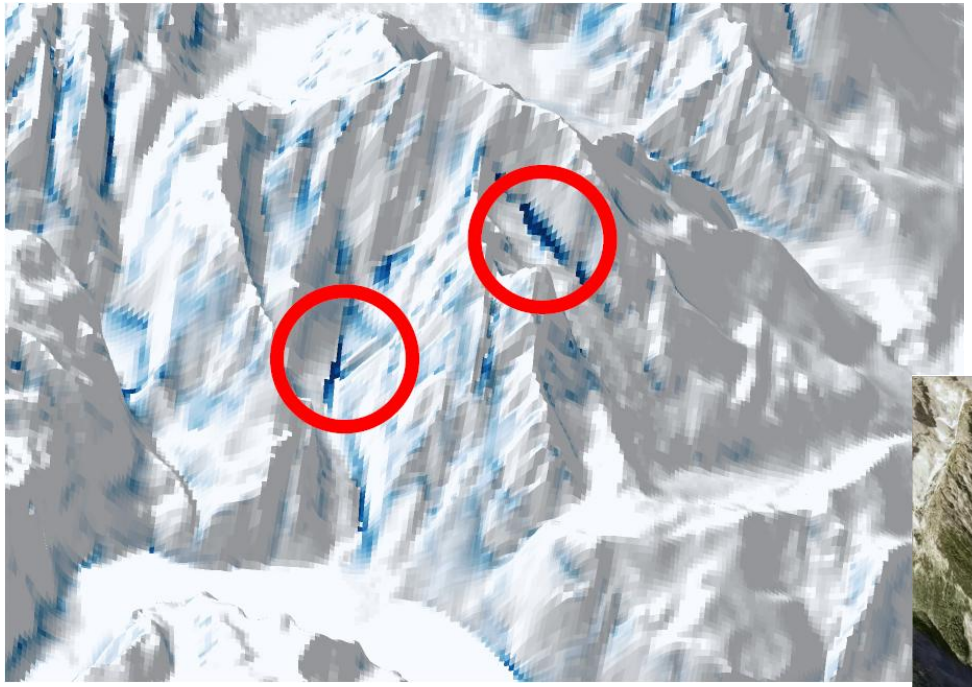
Changes in modeled snow cover duration due to

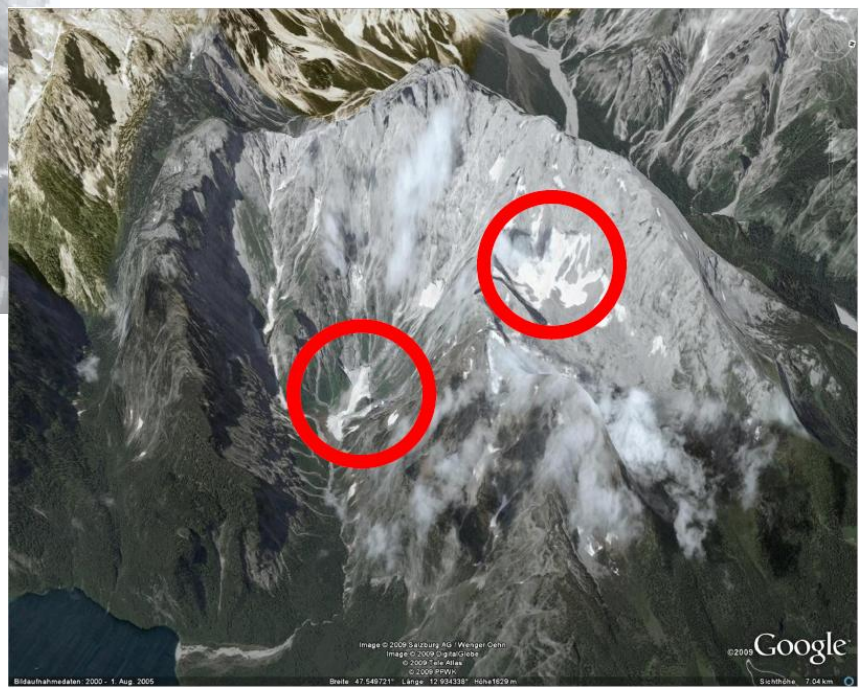
energy-balance method



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

Lateral snow transport

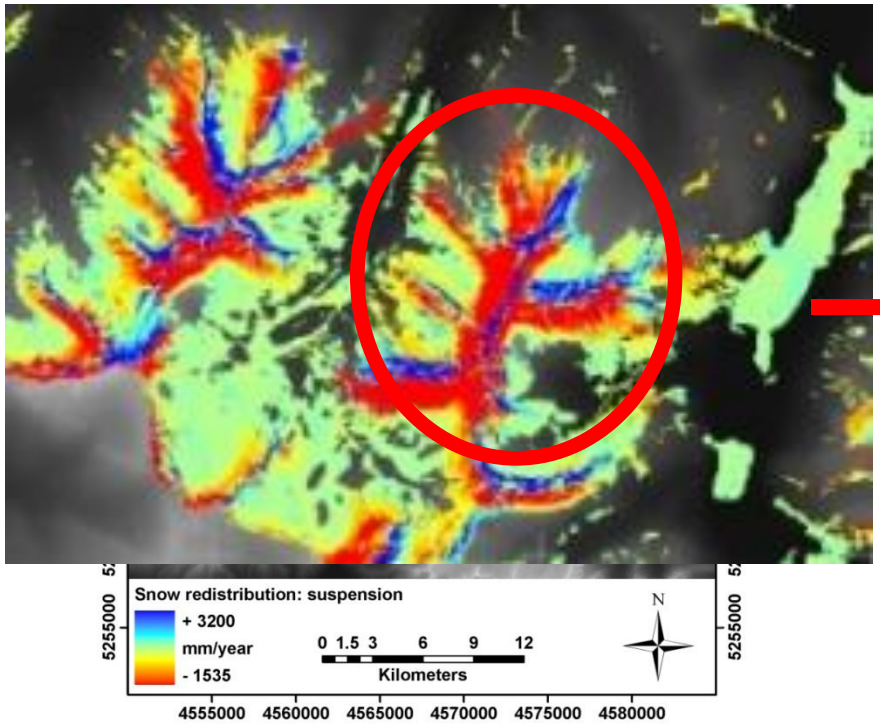




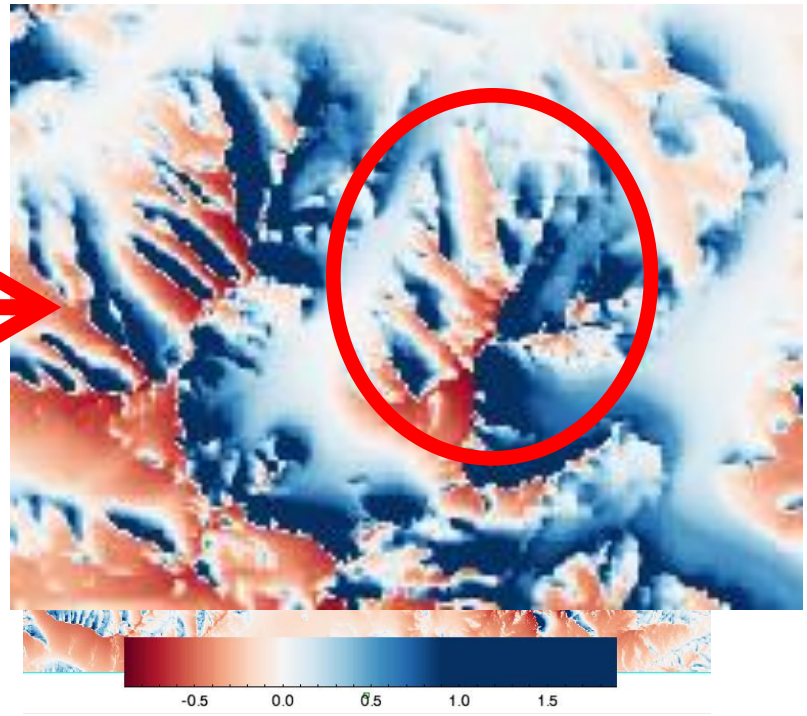
Locations of snow deposition by gravitational transport

Lateral Snow Redistribution

Coupled atmospheric / snow transport model



Parameterization (wind direction SW)

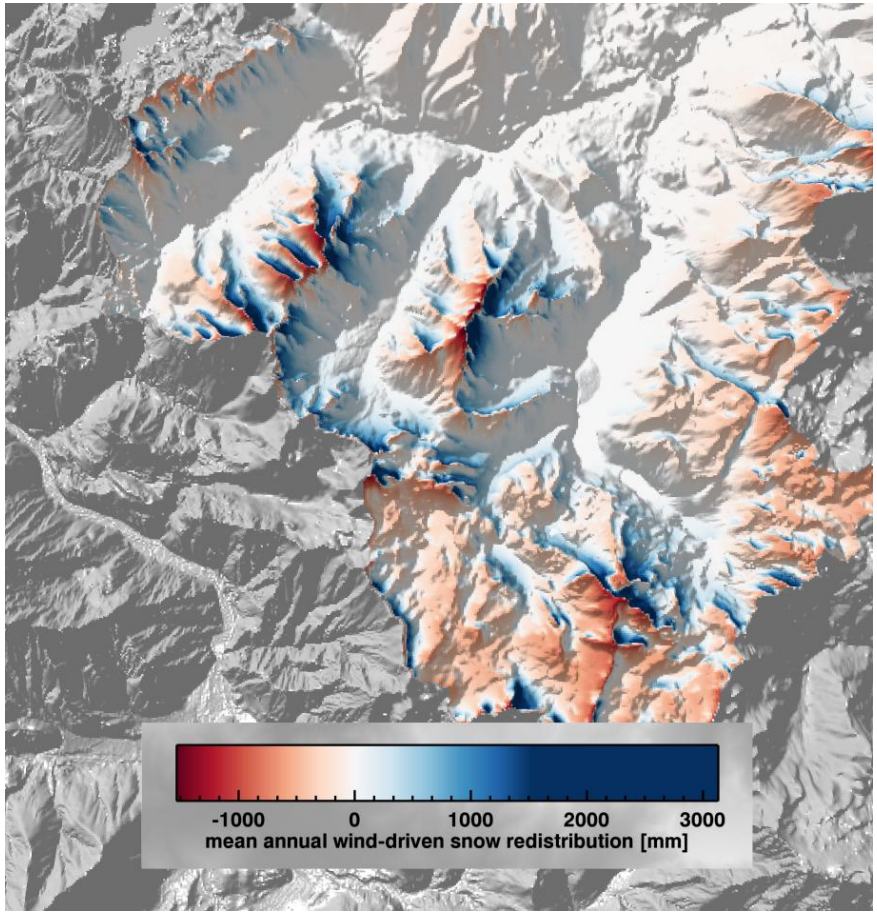


→ **Similar spatial patterns**

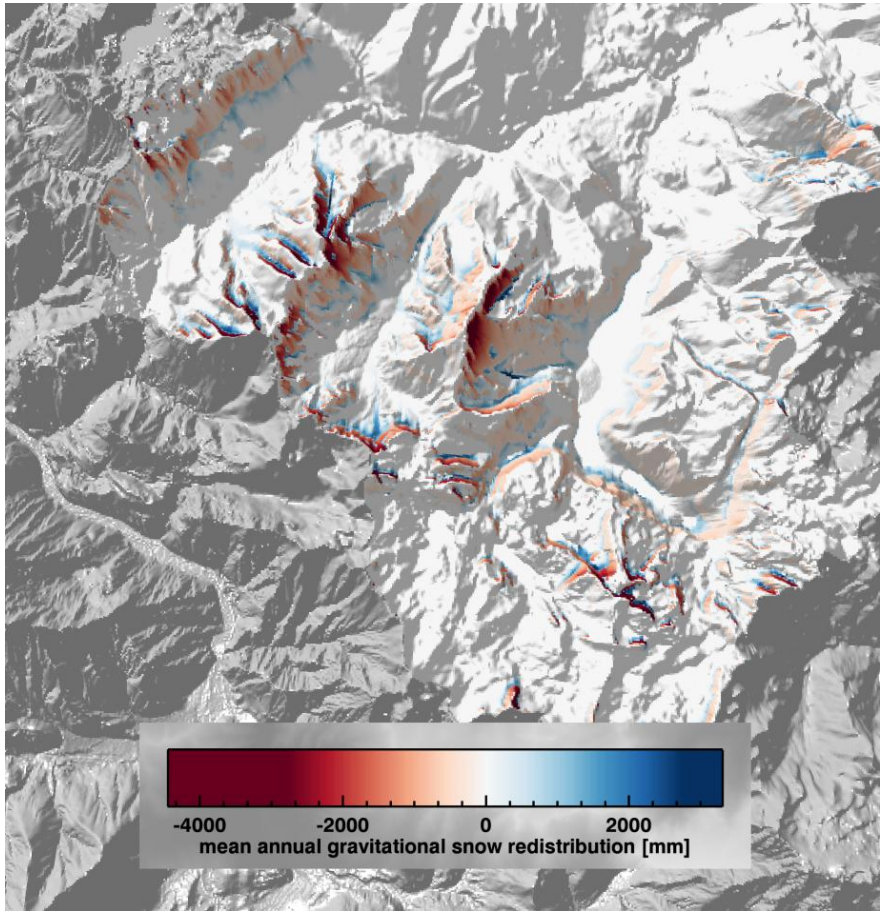
STRASSER (2008): Berchtesgaden National Park research report 55.

BERNHARDT ET AL. (2009): Hydrological Processes.

Lateral Snow Redistribution



Wind

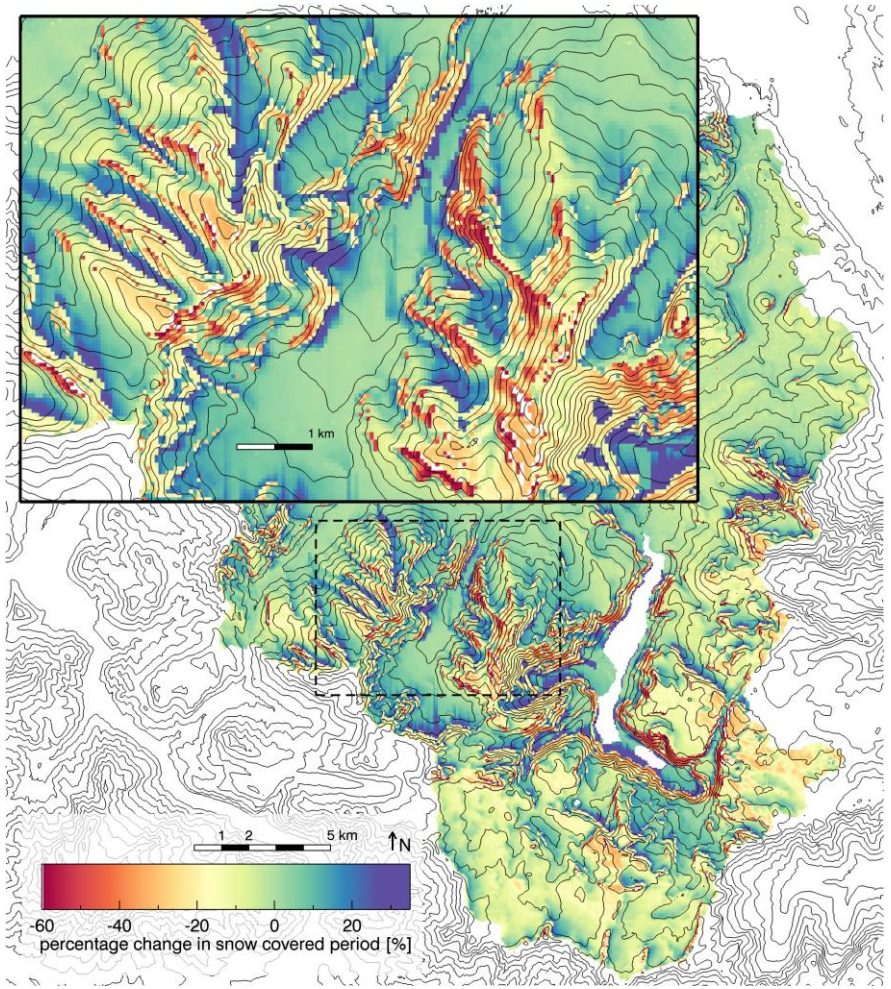


Gravitation

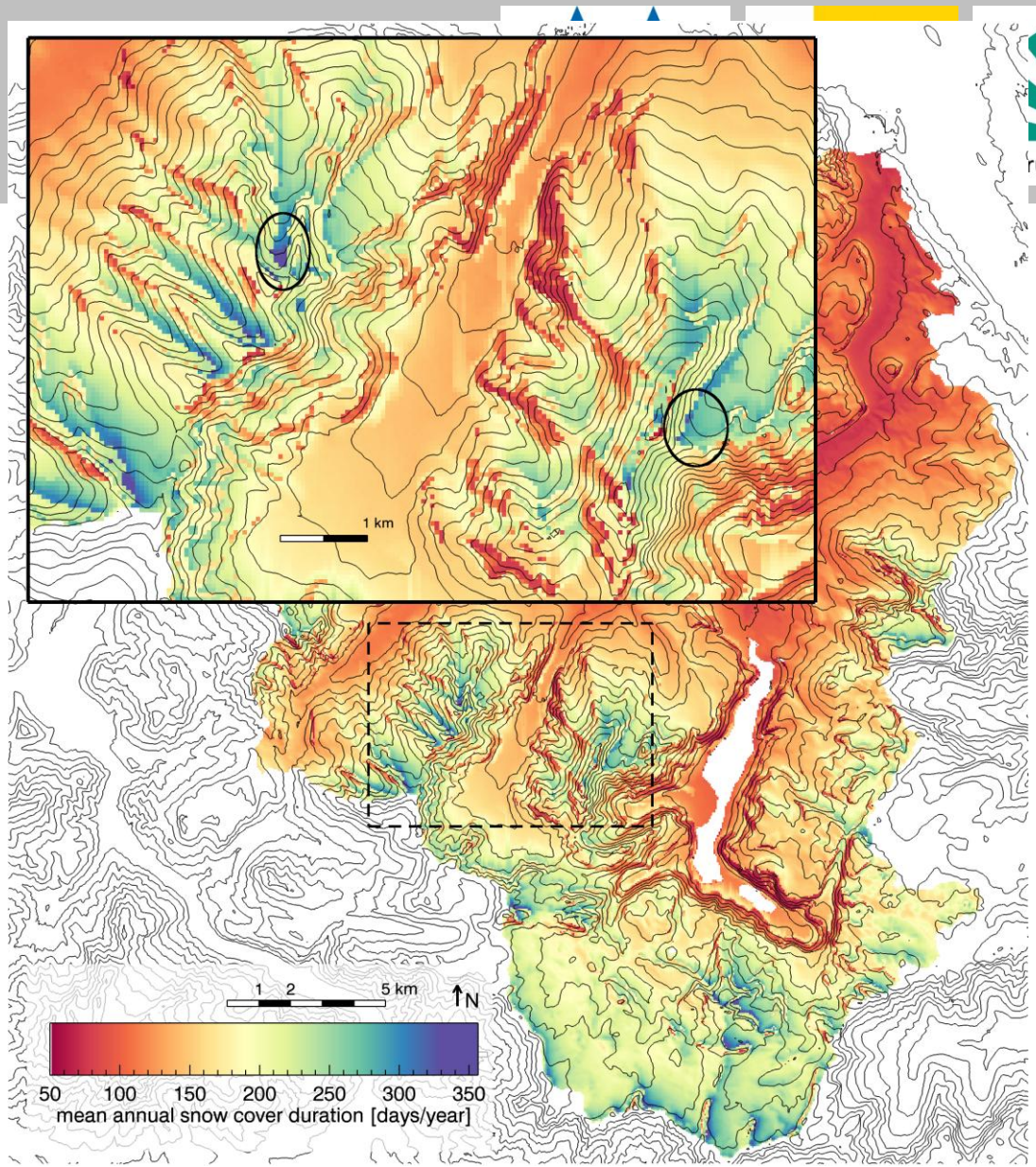
Lateral Snow Redistribution

Changes in modeled snow cover duration due to

lateral snow transport



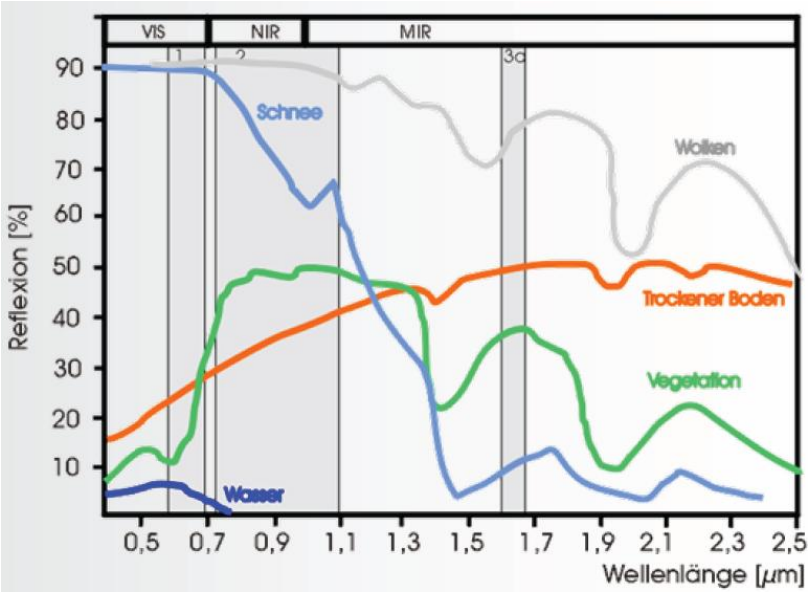
snowdays (without lateral transport) MINUS snowdays (with lateral transport)

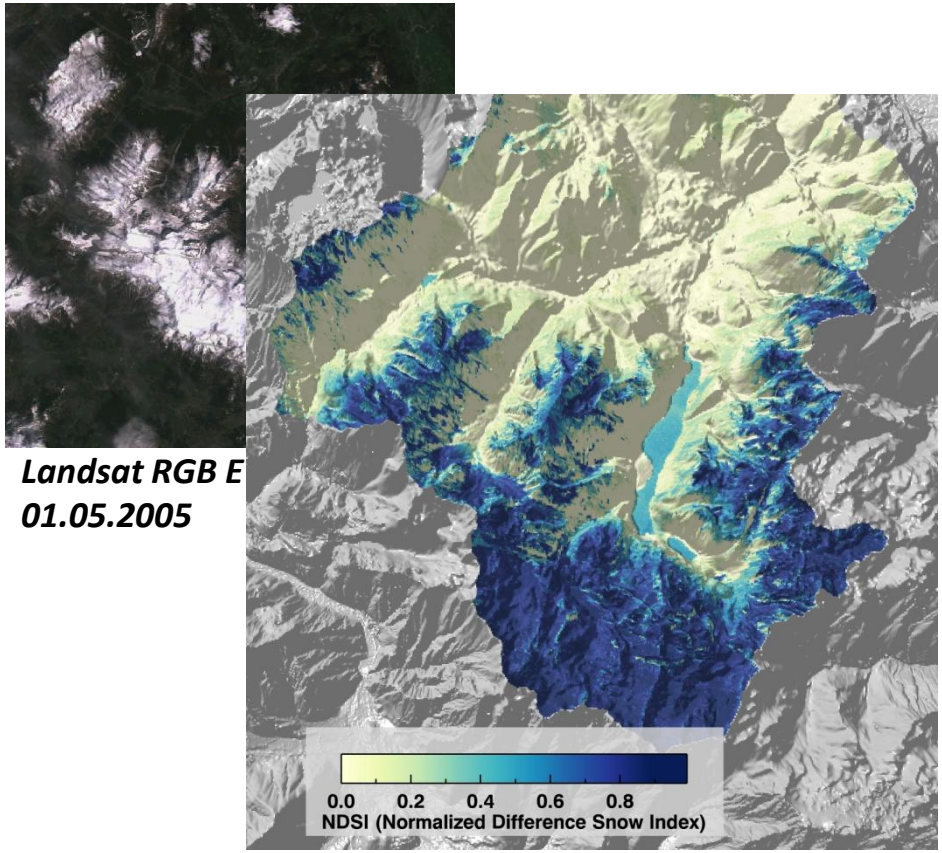


Modeled mean snow cover duration (2002 – 2007)

Normalized Difference Snow Index (NDSI)

$$NDSI = \frac{\rho_G - \rho_{MIR}}{\rho_G + \rho_{MIR}}$$





Landsat RGB E
01.05.2005

NDSI (not showing negative values)
01.05.2005

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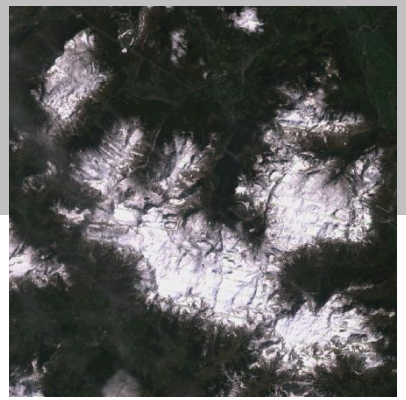
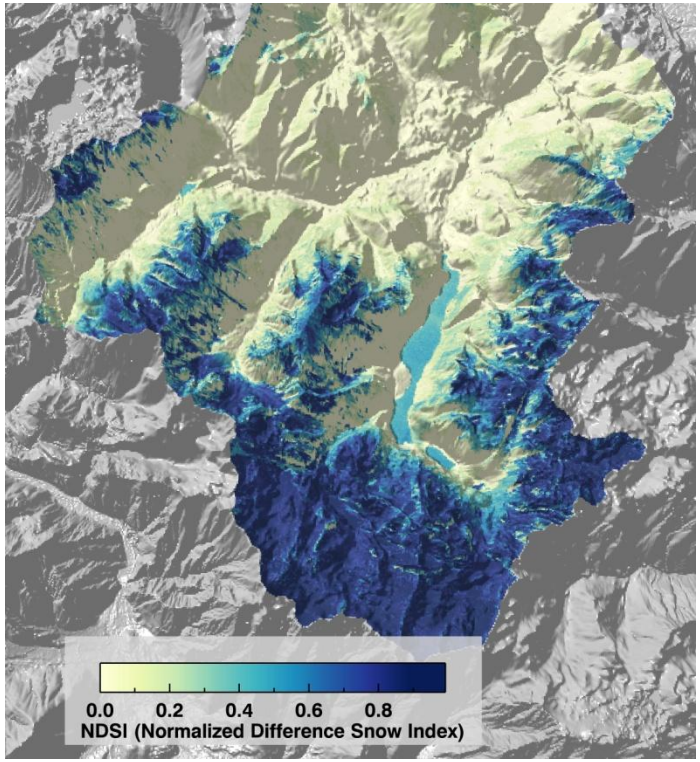
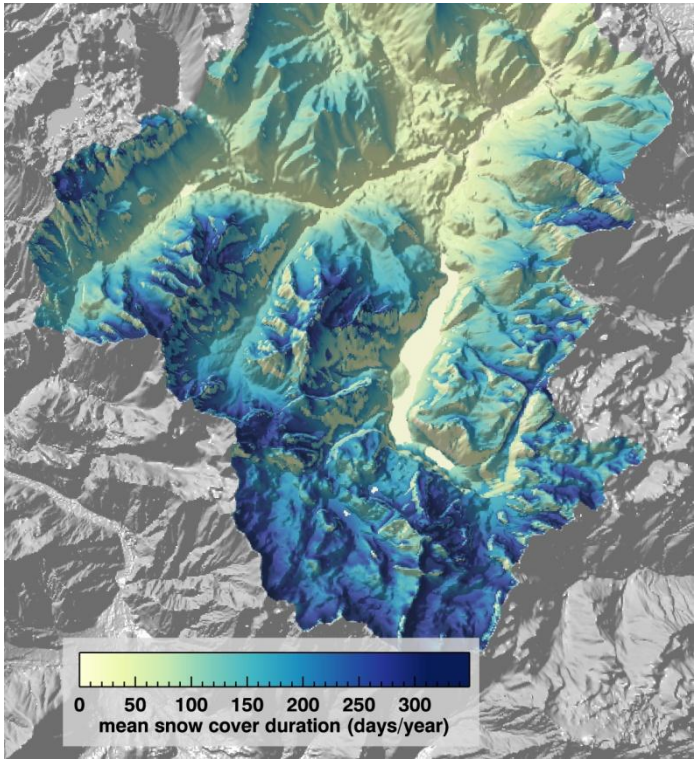


Landsat RGB ETM+
01.05.2005



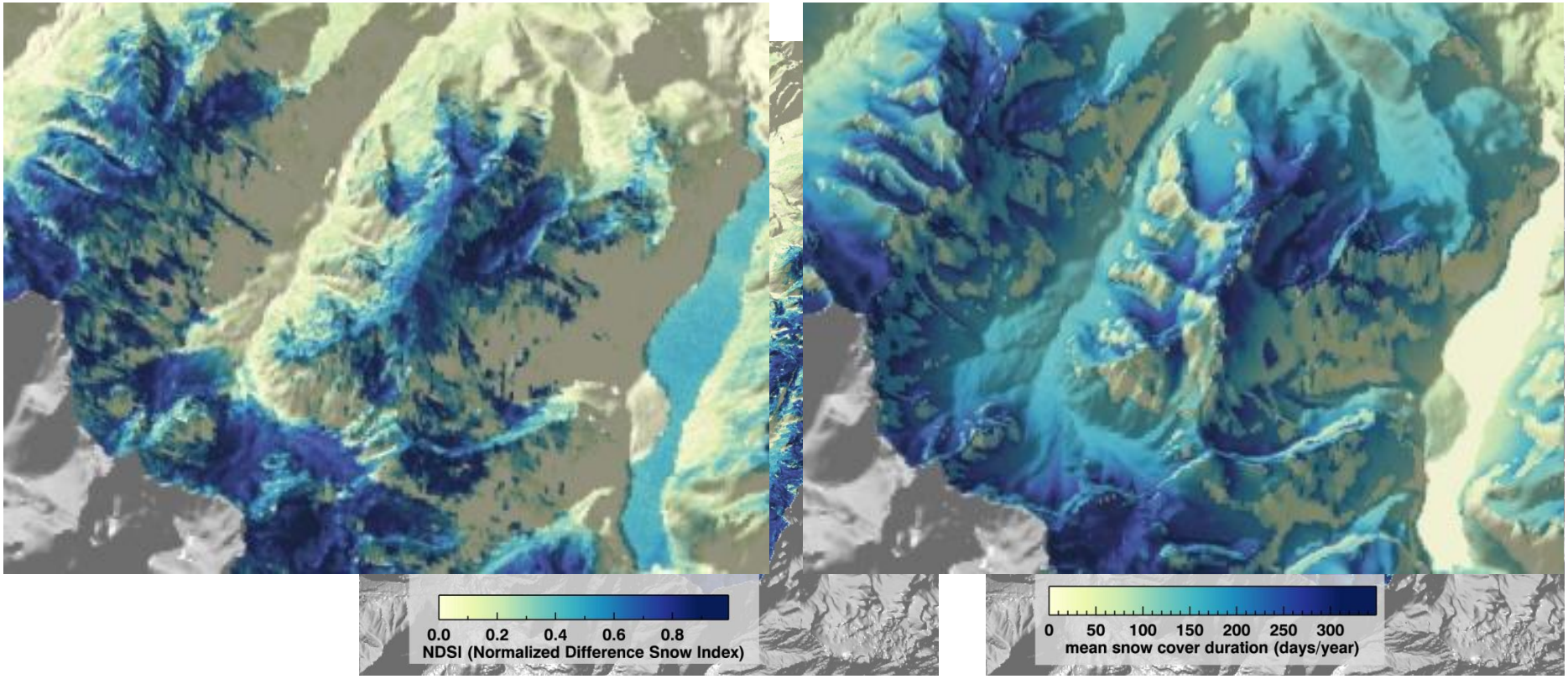
NDSI (not showing negative values)
01.05.2005



Modeled mean snow cover duration
2002 – 2007

Landsat ETM+

Model (WaSiM-ETH + AMUNDSEN)

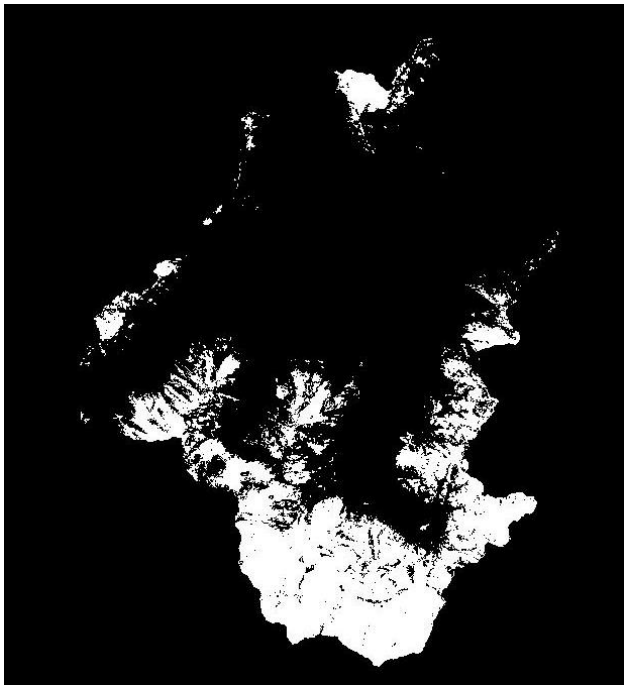


NDSI (not showing negative values)
01.05.2005

Modeled mean snow cover duration
2002 – 2007

Validation - Remote Sensing

Snow coverage 01.05.2005



Landsat ETM+ (NDSI ≥ 0.6)

WaSiM-ETH
Snow model: T-Index

WaSiM-ETH
Snow model: Energy-balance + snow slides + wind redistribution SW

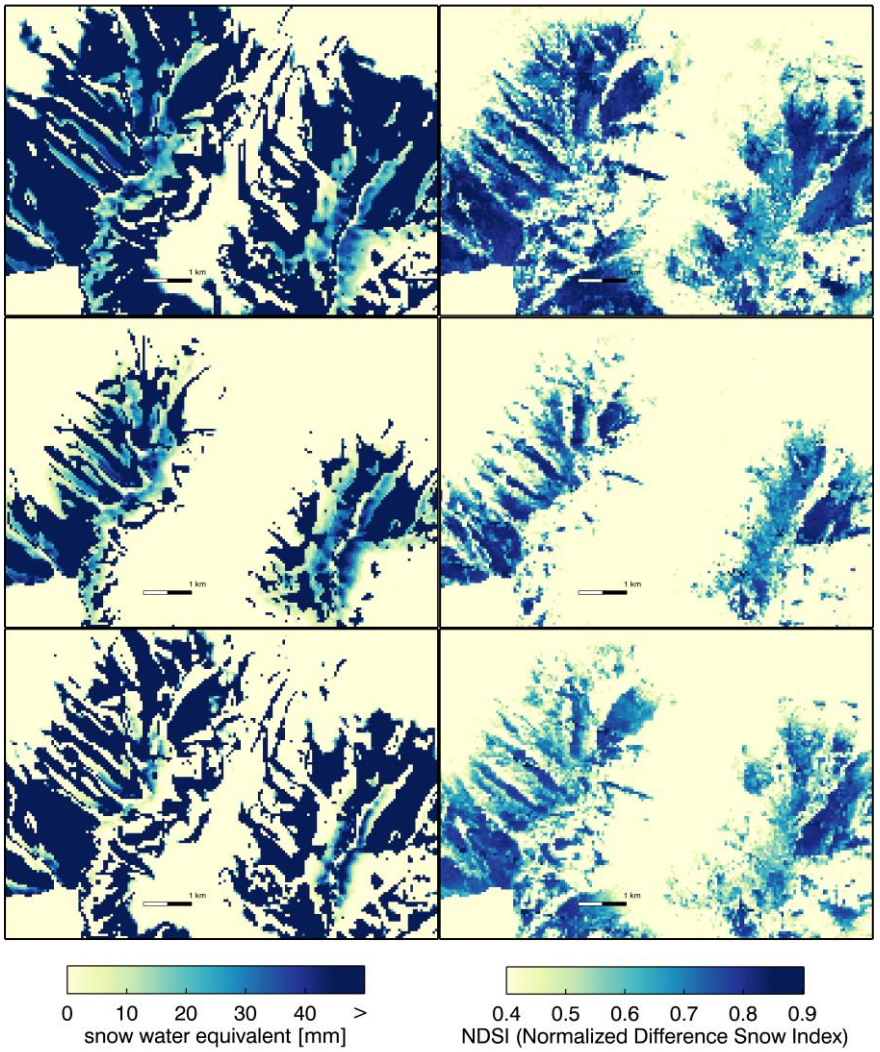
Validation - Remote Sensing

Modeled snow water equivalent (left) compared to NDSI (right) extracted from Landsat-ETM+ scenes.

April 07, 2002

May 30, 2004

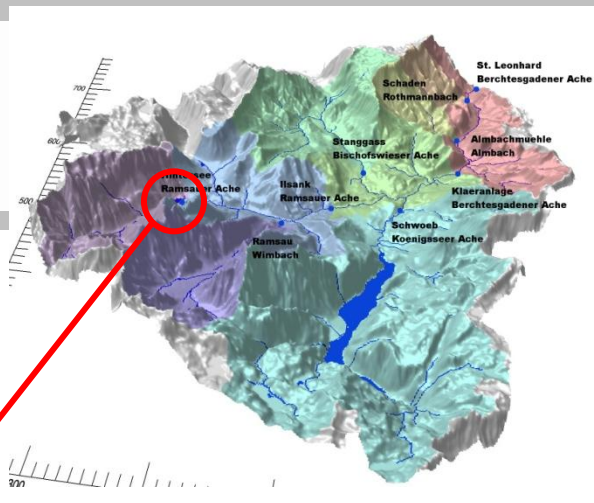
May 01, 2005



Matching pixel percentage [%]:

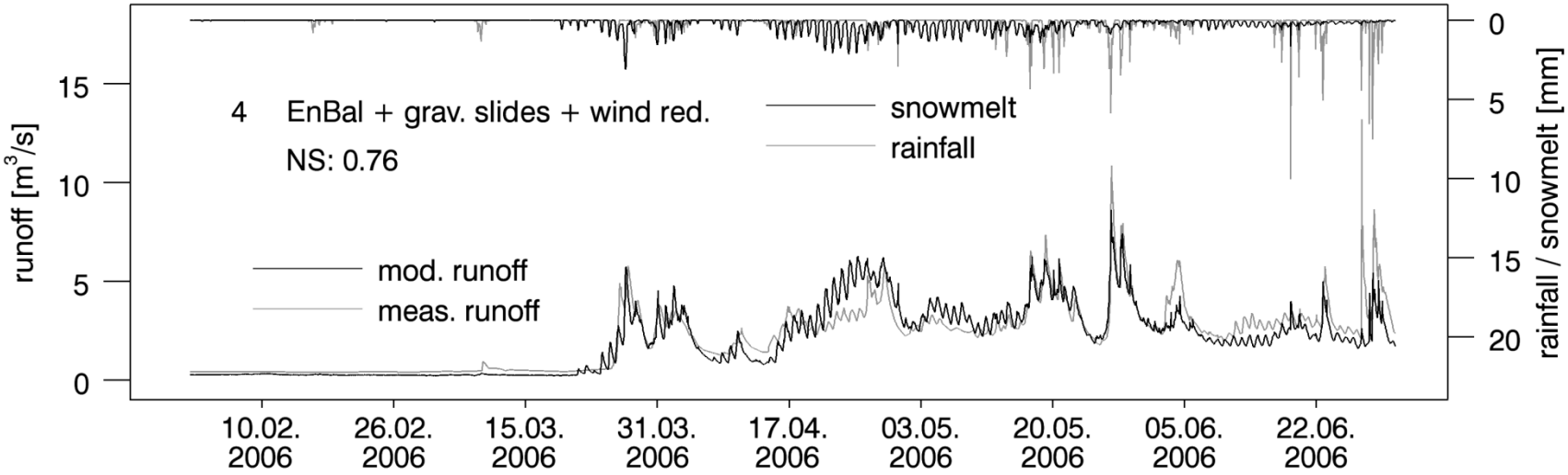
	summit section	total catchment
April 07, 2002	71.1	84.0
May 30, 2004	82.5	89.5
May 01, 2005	72.5	82.5

Snowmelt and Runoff



Do we need that within hydrological LSMs?

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



Snow module:	Day-Degree	Energy-Balance	E-Bal + Snowslides	E-Bal + Snowslides + Wind
	Nash-Sutcliffe = 0.52	Nash-Sutcliffe = 0.58	Nash-Sutcliffe = 0.69	Nash-Sutcliffe = 0.76

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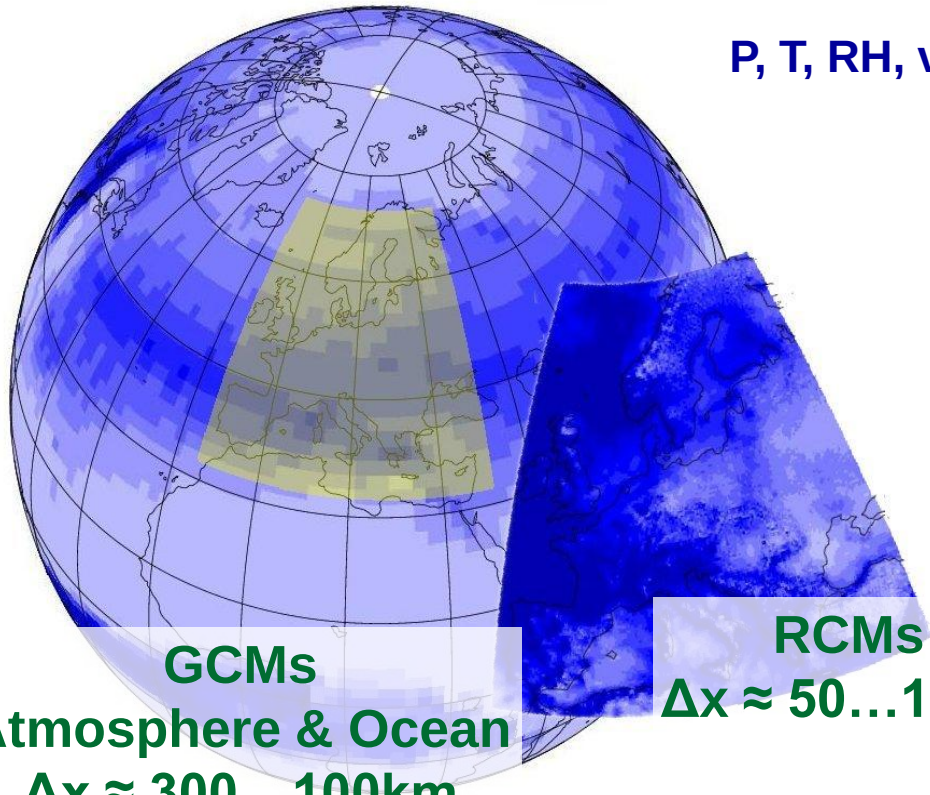
Climate Change Projections

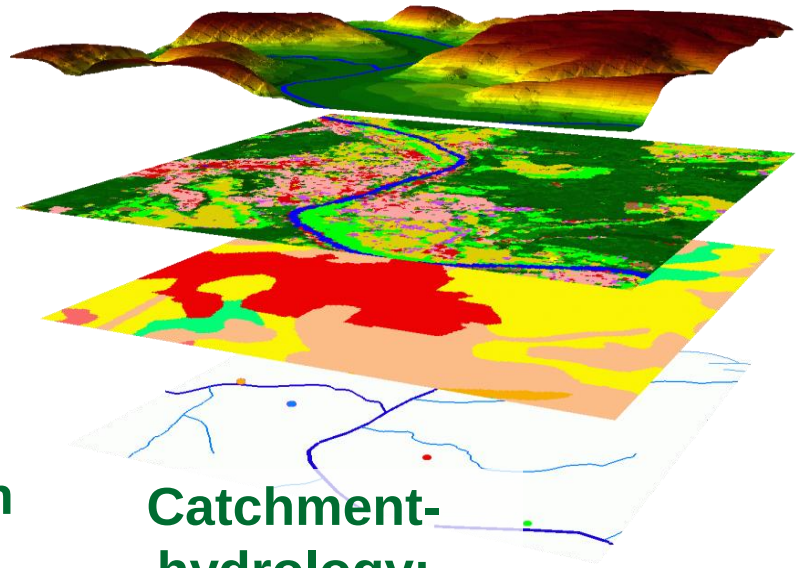


GCMs
Atmosphere & Ocean
Δx ≈ 300…100km

RCMs
Δx ≈ 50…10km

P, T, RH, v, R_n

WaSiM-ETH

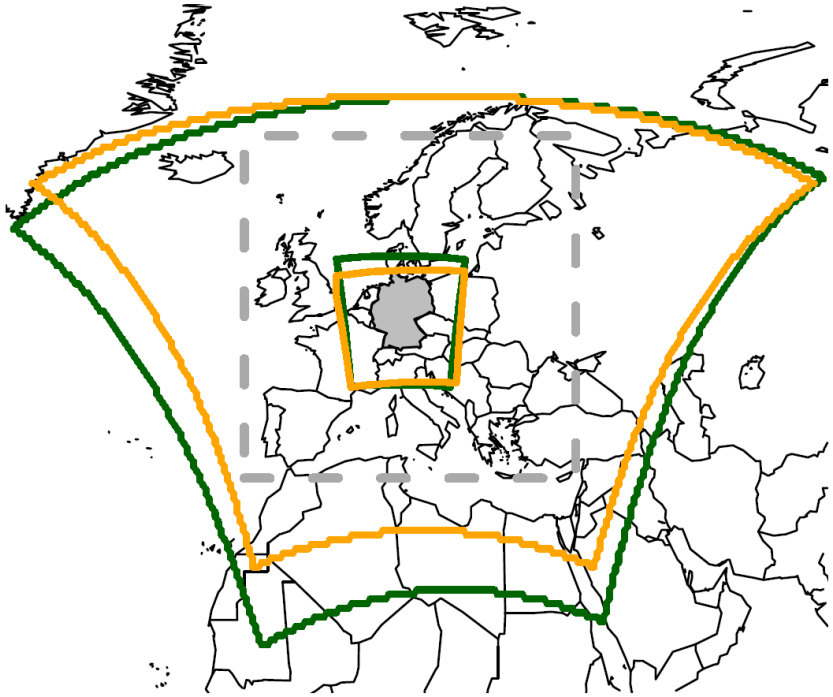


Catchment-hydrology:
Δx ≈ 1km…100m

Climate Change Projections

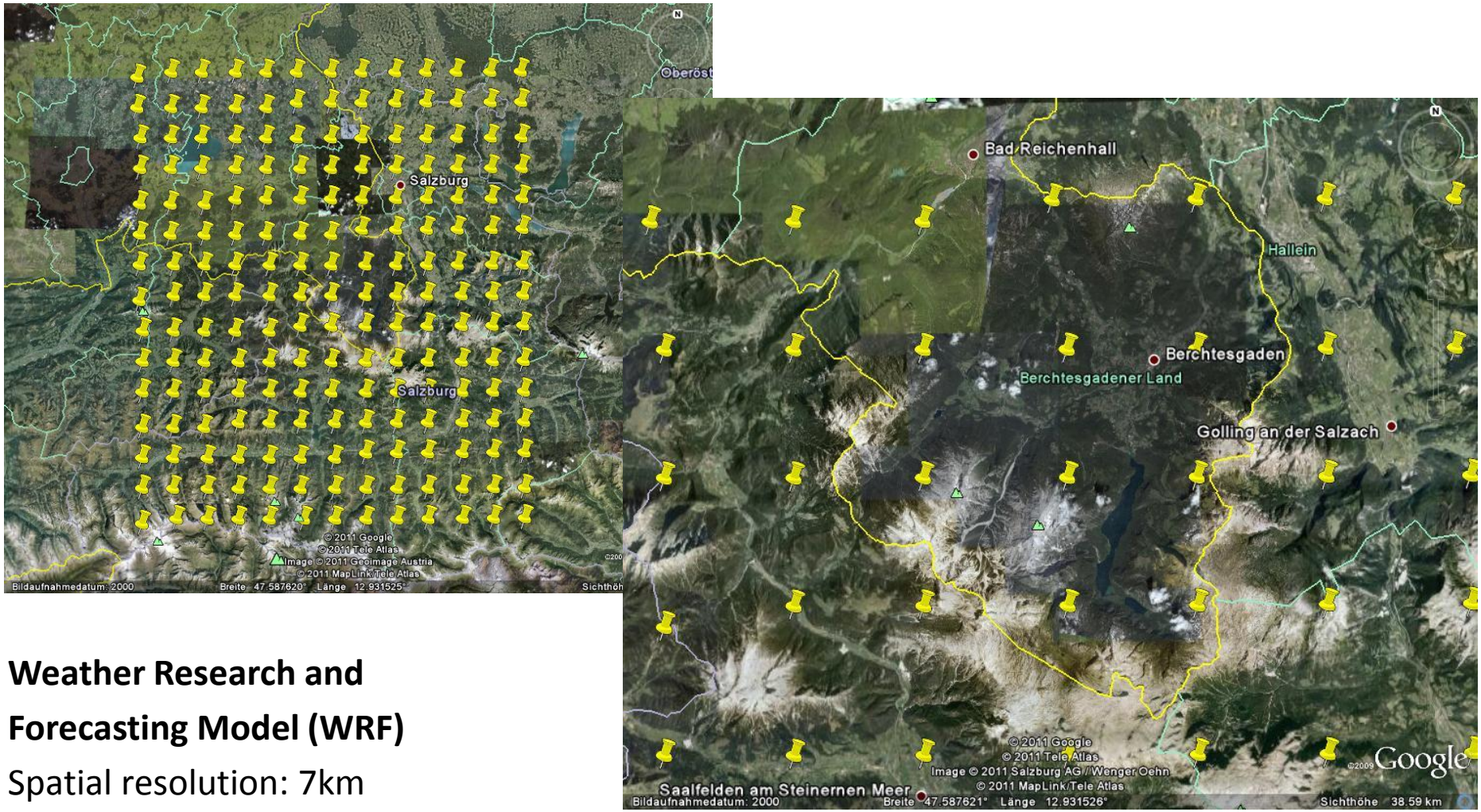
GCM	**ECHAM5-MPI/OM**	**T63 / L32**
RCM	**WRF**	**42 km / 7 km**
LSM	**WaSiM-ETH (+AMUNDSEN)**	**50 m**

Control	**1970 – 2000**
Scenario A1B	**2020 – 2050**



Berg et al. (2011)
Wagner et al. (2011)

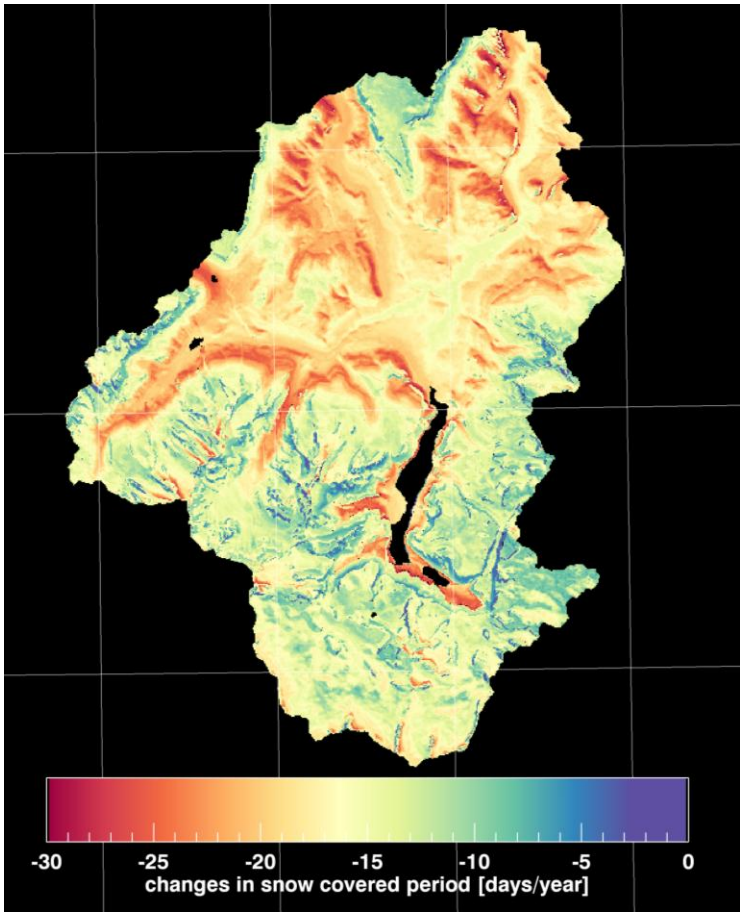
Climate Change Projections

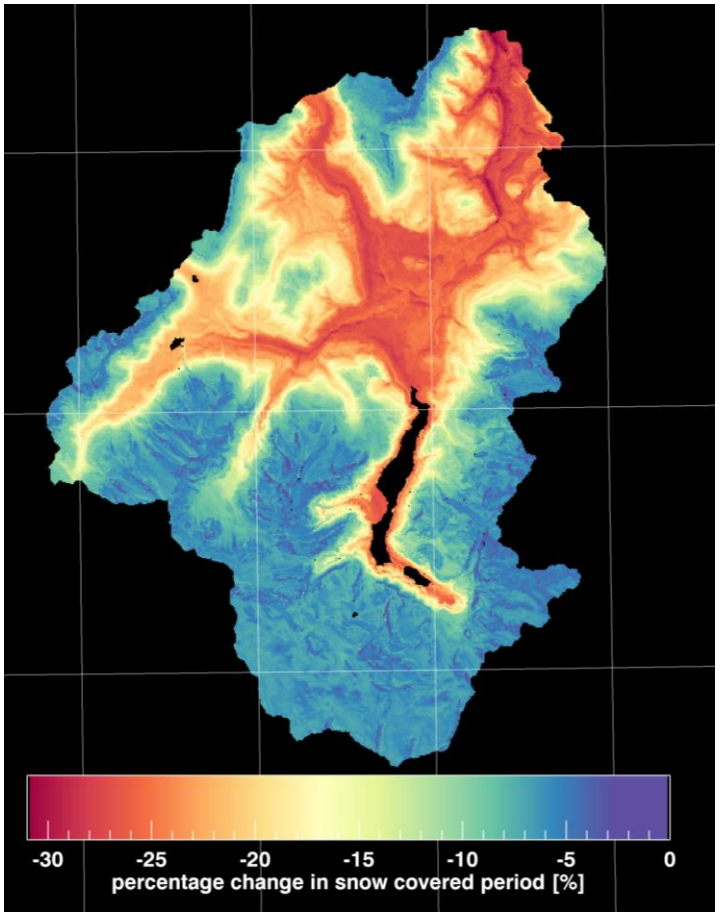


Weather Research and Forecasting Model (WRF)

Spatial resolution: 7km

Climate Change Projections

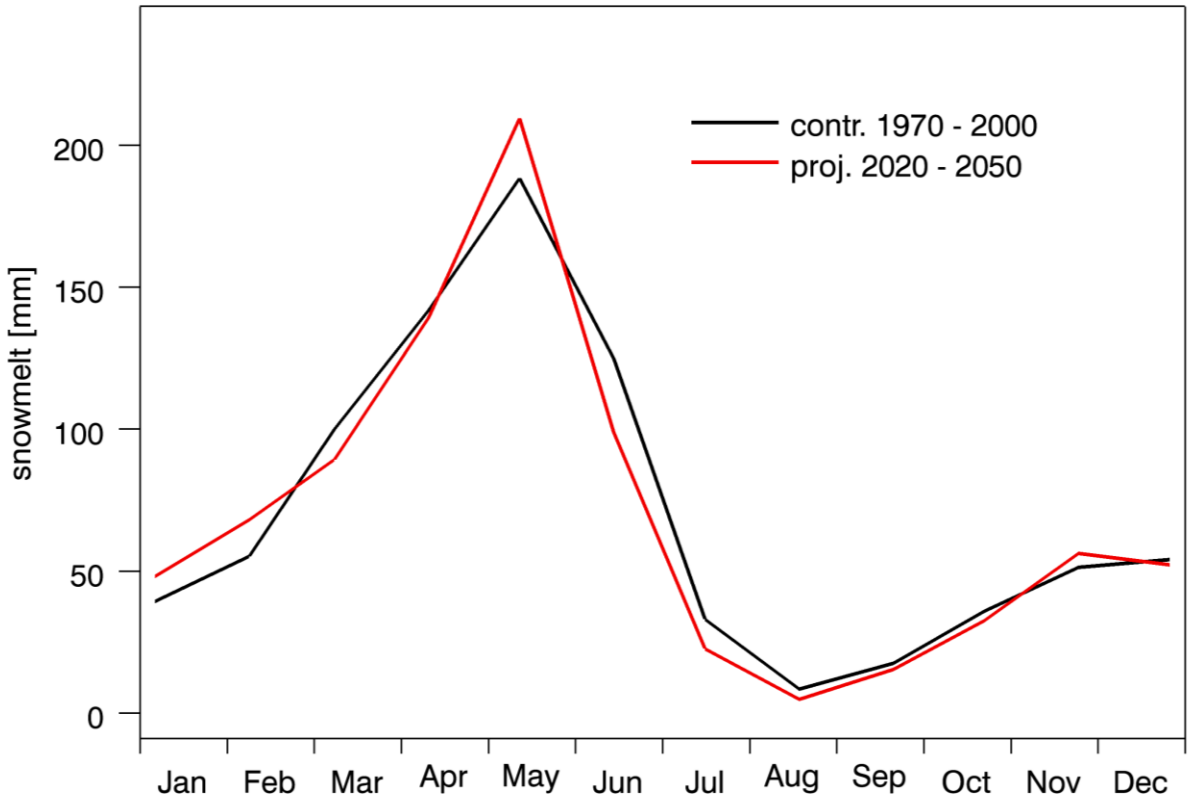




Difference in snow covered period 2020-2050 vs. 1970-2000

ECHAM5, Scenario A1B → WRF → WaSiM-ETH + AMUNDSEN

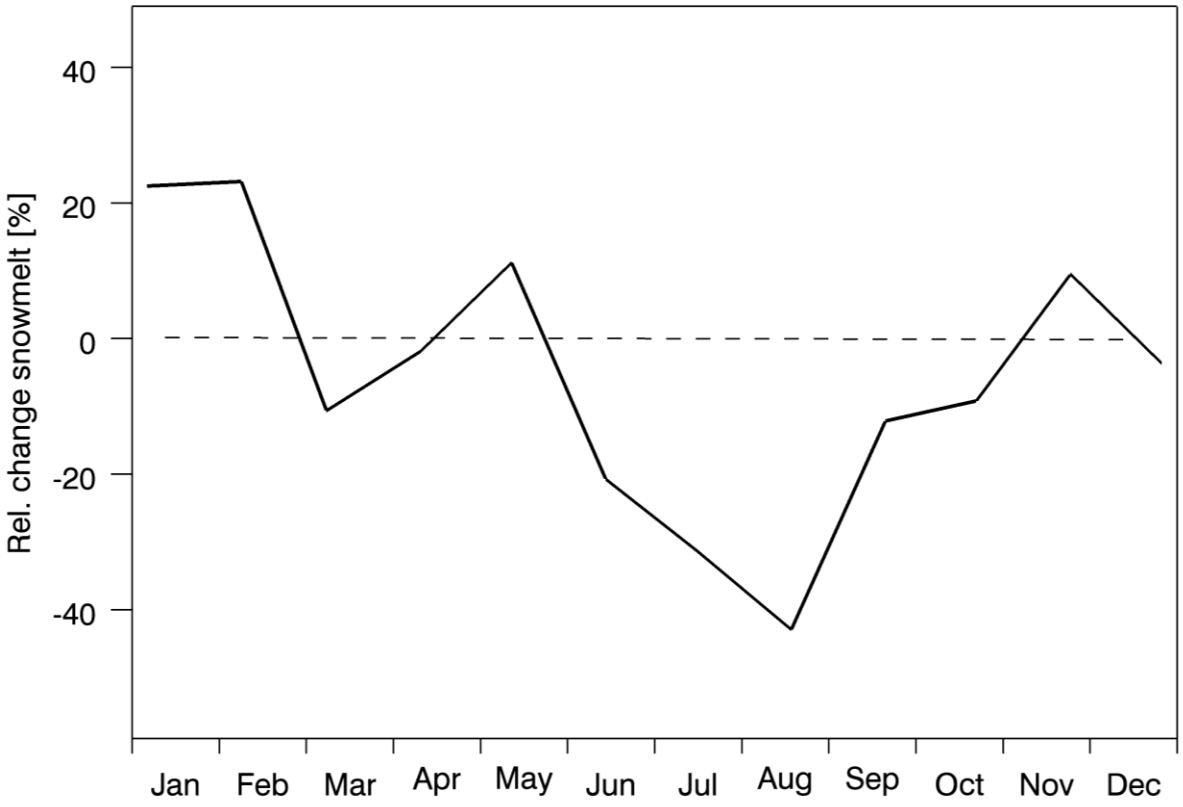
Climate Change Projections



Changes in snowmelt regime 2020-2050 vs. 1970-2000

ECHAM5, Scenario A1B → WRF → WaSiM-ETH + AMUNDSEN

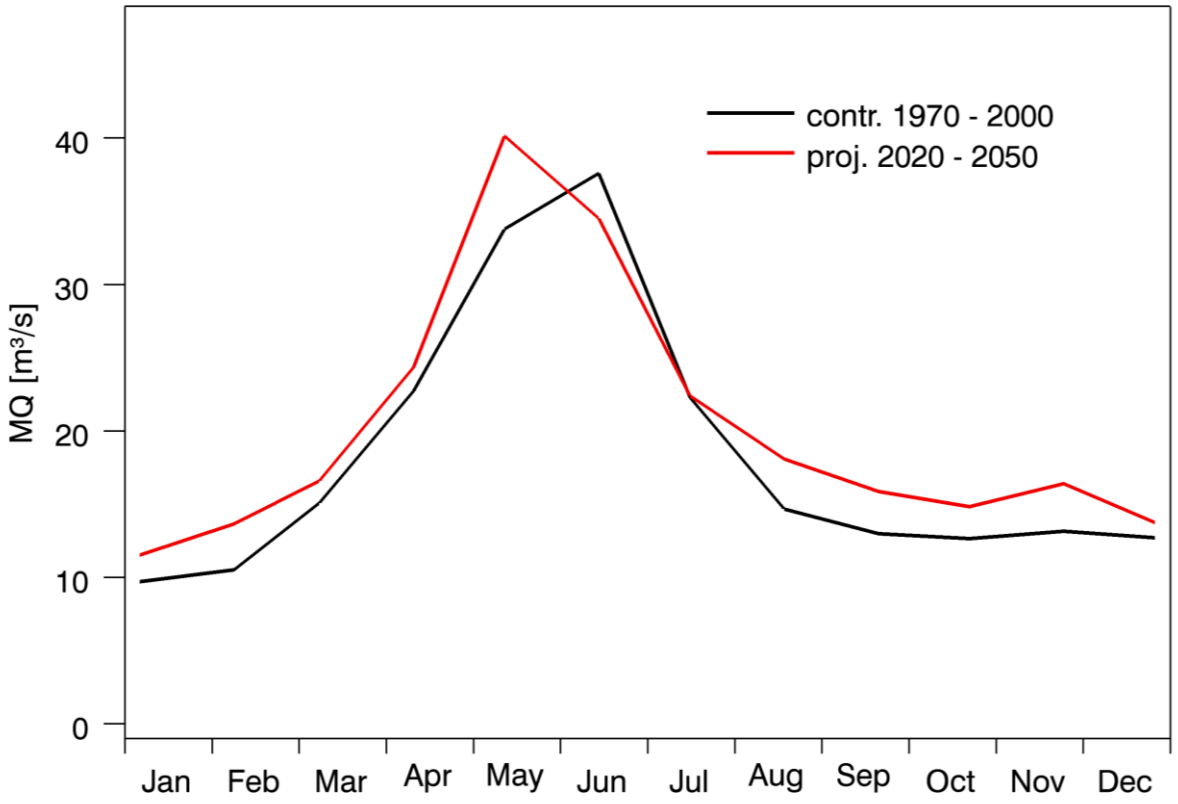
Climate Change Projections



Changes in snowmelt regime 2020-2050 vs. 1970-2000

ECHAM5, Scenario A1B → WRF → WaSiM-ETH + AMUNDSEN

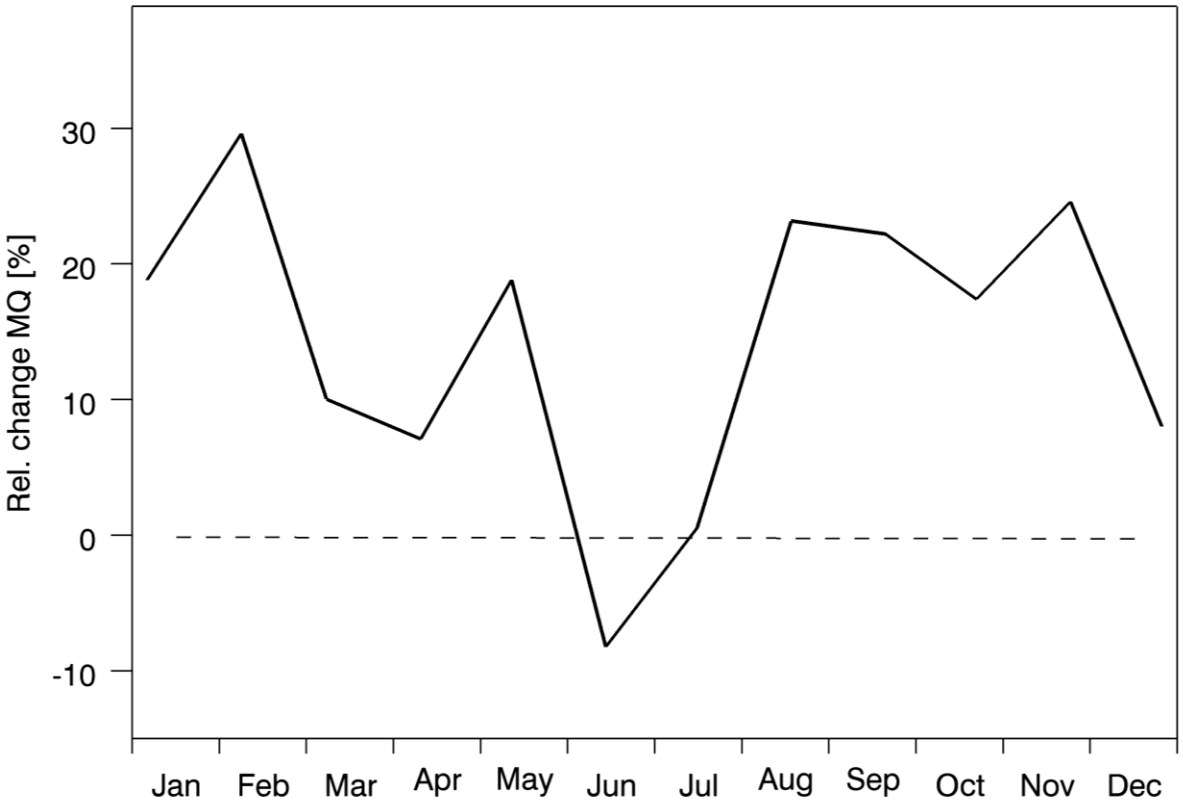
Climate Change Projections



Changes in mean monthly discharge 2020-2050 vs. 1970-2000

ECHAM5, Scenario A1B → WRF → WaSiM-ETH + AMUNDSEN

Climate Change Projections



Changes in mean monthly discharge 2020-2050 vs. 1970-2000

ECHAM5, Scenario A1B → WRF → WaSiM-ETH + AMUNDSEN

Thanks!