Creation of an Empirical Energy Balance-Based Snow Module Simulating Both Snowmelt and Snow Accumulation for Mountain Hydrology

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Context

Snow models are usually designed to simulate snowmelt and river discharge when coupled to a rainfall runoff model, **but few of them simulate correctly the snow water equivalent (SWE) at point scale**. Tackling this flaw could have several advantages: Improving the model reliability and performance for short-term and long-term prediction, spatial regionalization, and performing data assimilation using observed snow measurements.

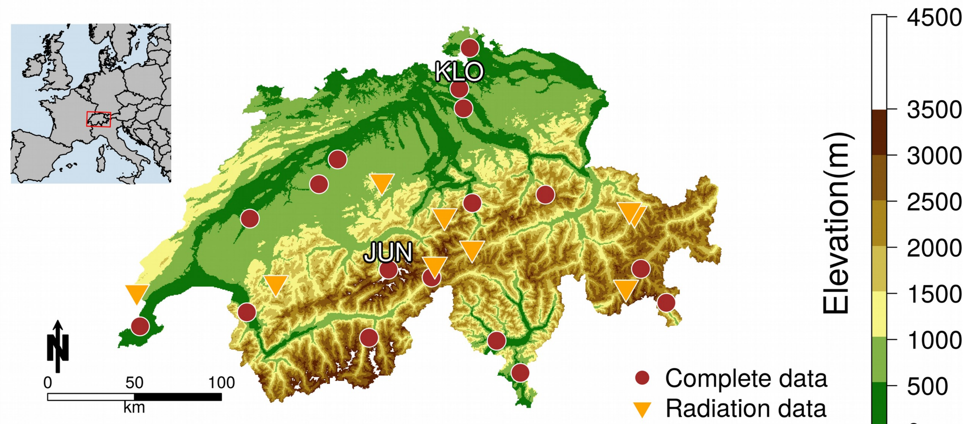
The model developed in this study has to have the following characteristics :

1. Be parsimonious and be coupleable to different hydrological models, using only temperature and precipitation as inputs
2. Be able to simulate the state of the snow pack without worsening discharge simulations when coupled to a hydrological model.
3. Have state variables directly comparable to observations.

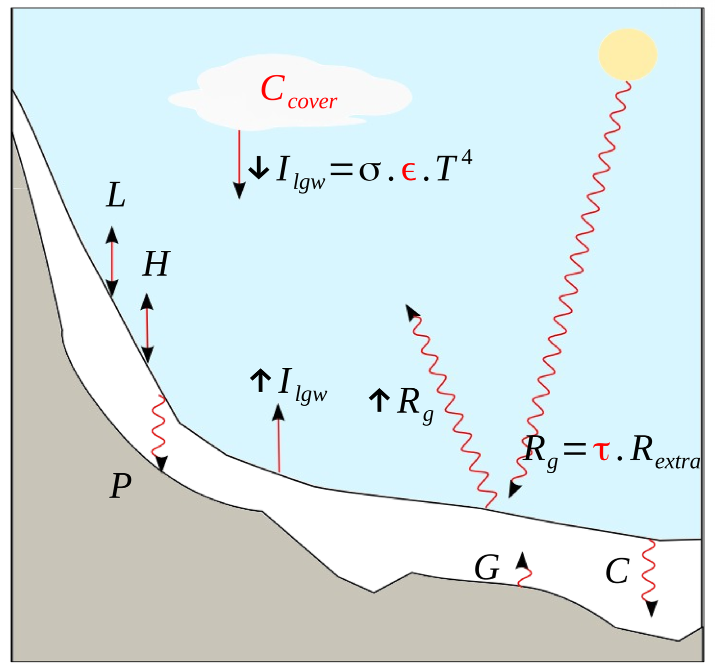
The first step for creating that model is to parameterize incoming shortwave and longwave radiation for energy balance modeling

Method and datasets

- 26 meteorological stations with temperature, radiation, precipitation and humidity observations.
- 17 also have cloud cover observations
- Wide data availability on large range of elevations in Switzerland



Locations of meteorological stations



Schematic representation of energy balance for snow

Objectives of this study:
- Modeling radiations for all elevation areas
- Parameterizing transmissivity and emissivity
- Using cloud cover parameterization for a better constrain

For building a complete downward radiation model, we have tested
- 4 transmissivity formulations
- 4 emissivity formulations
- 3 cloud cover formulation

The performance of the radiation model built is compared to Walter (2005) snowmodel which used parameterizations formulas from the literature

Improving downward radiation parameterization

Combined calibration

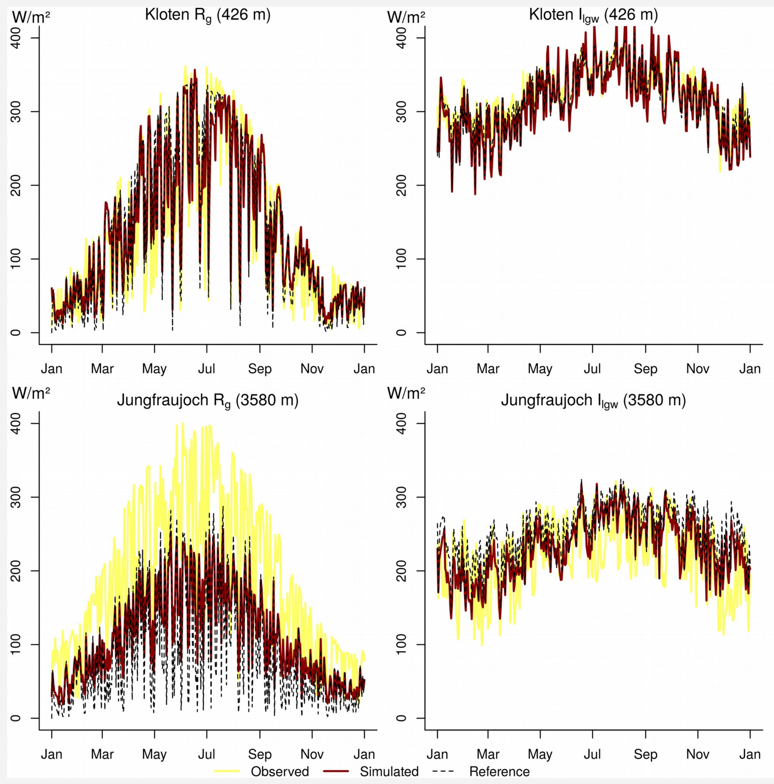
Multiple calibration strategies have been tested, all calibrations have been made using the jackknife method and the KGE' optimization criterion.

$$KGE' = 1 - \sqrt{(r-1)^2 + (\beta-1)^2 + (\gamma-1)^2}$$

The KGE' uses the correlation coefficient, the bias ratio and the ratio of variability.

Name	Calibration Type	Variable used for optimization
st1	Independent	$\tau, \epsilon, C_{cover}$
st2	Combined	$\tau, \epsilon, C_{cover}$
st3	Combined	τ, ϵ
st4	Combined	R_g, I_{lgw}, C_{cover}
st5	Combined	R_g, I_{lgw}

Setting up of the different calibration experiments



Simulations of solar and infrared radiations for Kloten and Jungfraujoch meteorological stations

Improving parameterization for high elevation areas

- Based on the Bristow and Campbell (1984) equation, this new transmissivity parameterization has been developed

$$\tau_{max} = \tau_{max,low\ z} + (1 - \tau_{max,low\ z}).(1 - \exp(\frac{-z}{z_{ref.1}}))$$

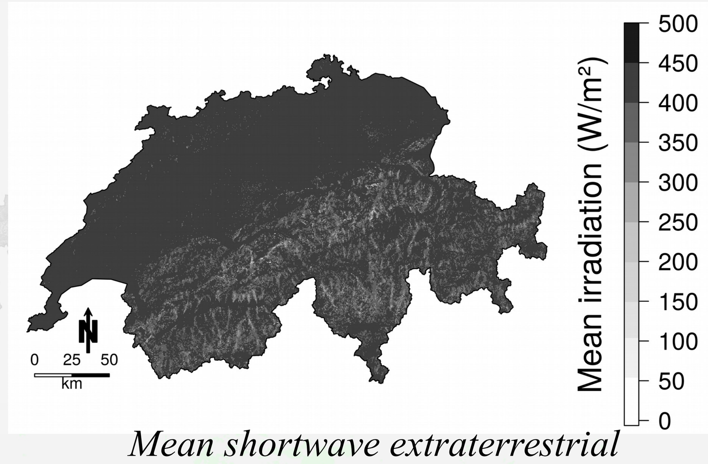
$$\tau = \tau_{max}.(1 - \exp(\frac{-\Delta T}{\Delta T_{ref}} - (\frac{z - z_{ref.2}}{z_{ref.3}})^2))$$

- Impact on transmissivity parameterization
  - Increase of maximal transmissivity with elevation
  - Decrease of transmissivity range with elevation

Adding extra data

Extraterrestrial Radiation with topographic shadowing

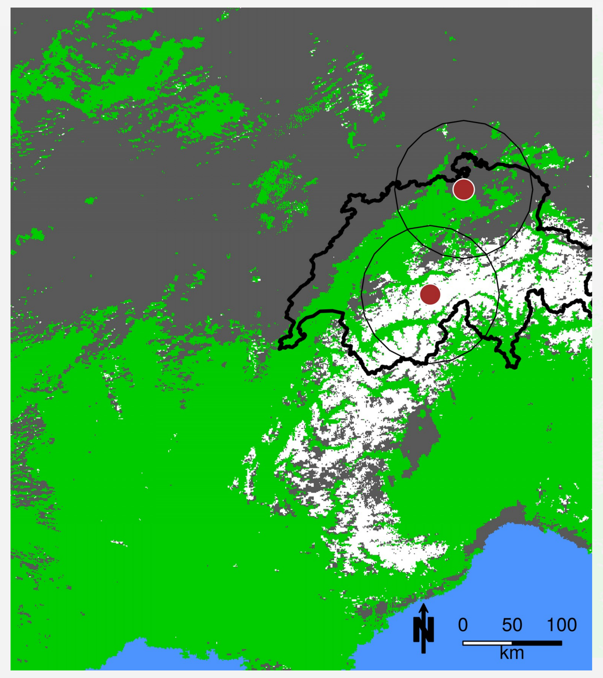
- Using DEM and Grass GIS script r.sun (Suri and Hofierka, 2004) allowed a daily mean R_{extra} computation
- Taking into account topographic shadowing gives a great increase of model performance



Mean shortwave extraterrestrial insolation for July 28th

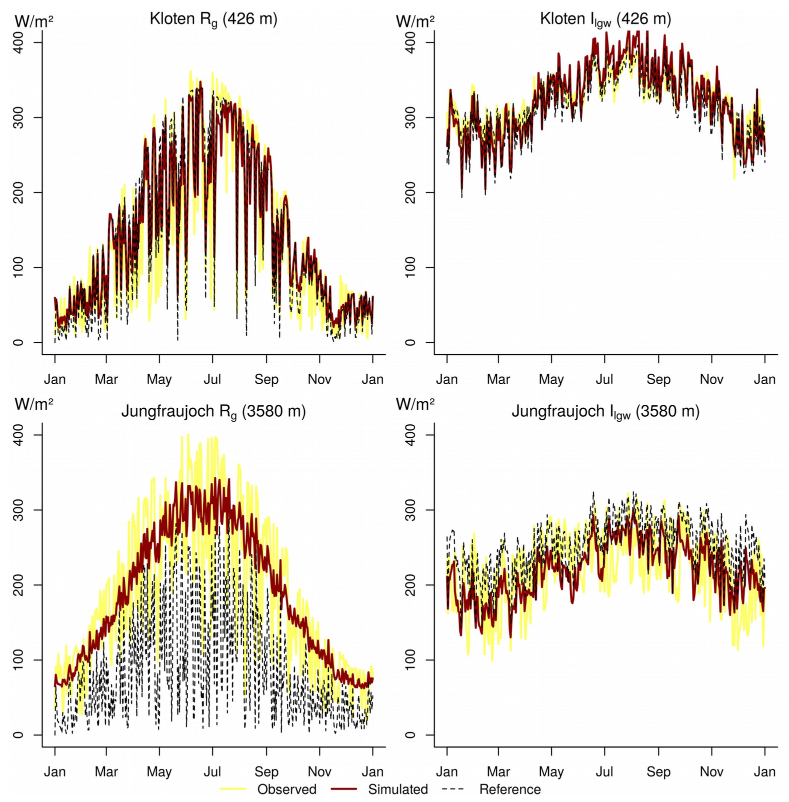
MODIS observed cloud cover data

- Radiation modeling benefits from using cloud cover parameterization.
- Unlike cloud cover observations, MODIS satellite observations are spatially widely available

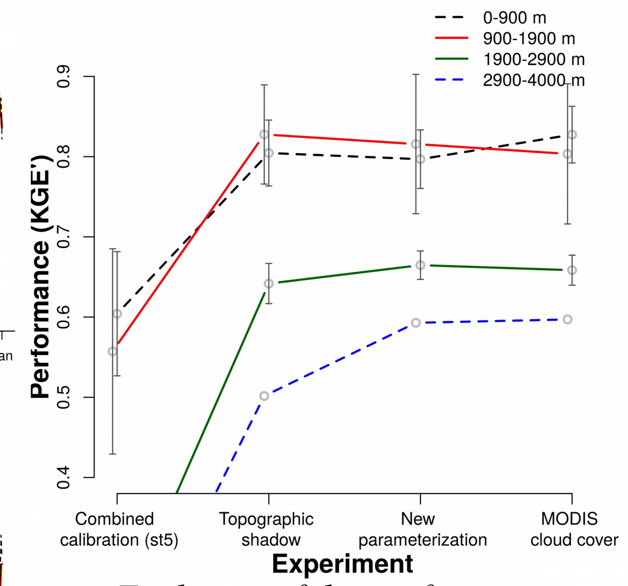


MODIS image from March 10th 2011 showing cloud cover (gray), snow (white), snow-free land (green) and water (blue) areas

Results



Simulations of solar and infrared radiations for Kloten and Jungfraujoch meteorological stations after the experiments



Evolution of the performances after successive experimentations for different elevation classes

- The experiments undertaken in Switzerland showed an increase of performances of the radiation model.
- Large increase of performances in high elevation areas.

Conclusion and perspectives

During the remaining PhD work, the downward radiation model will be coupled with a snowpack model. It will simulate the conductivity fluxes into the snowpack, the change in albedo and density of the snow with time and the snow surface temperature.

The complete snow model should run at basin scale, using snow and discharge measured data for calibration

References

Bristow, K. L., and G. S. Campbell (1984), On the relationship between incoming solar radiation and daily maximum and minimum temperature, Agricultural and Forest Meteorology, 31(2), 159–166.

Suri, M., and J. Hofierka (2004), A New GIS-based Solar Radiation Model and Its Application to Photovoltaic Assessments, Transactions in GIS, 8(2), 175–190,

Walter, T., M., E. S. Brooks, D. K. McCool, L. G. King, M. Molnau, and J. Boll (2005), Process-based snowmelt modeling: Does it require more input data than temperature-index modeling?, Journal of Hydrology, 300(1-4), 65–75.

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