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A dynamic Energy Balance Model to compute supra glacial debris thickness on a glacier in Langtang valley, Nepal Himalaya

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1 Introduction

A significant proportion of Himalayan glaciers is debris covered. Knowing the thickness of the debris cover is essential to obtain accurate estimates of melt rates. Collecting field measurements of debris thickness for a large number of glaciers is not possible. For this reason, previous studies have proposed an approach based on computing the energy balance at the debris surface using surface temperature from satellite imagery together with meteorological data and solving for debris thickness. These studies differ only in the way they account for the nonlinearity of debris temperature profiles and the heat stored in the debris layer, but assuming the same profile for all grid cells. In our study we aim to 1) assess the performance of three existing models, and 2) develop a **method for calculating the conductive heat flux within the debris, which accounts for the history of debris temperature profiles at each grid cell** by solving the advection-diffusion equation of heat.

2 Site and data

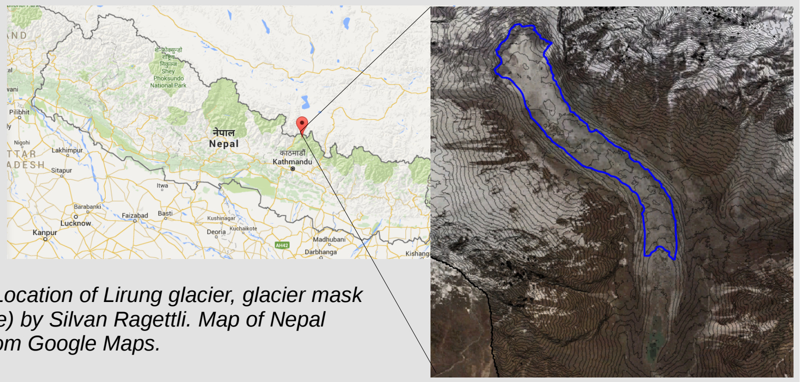

Fig. 1 : Location of Lirung glacier, glacier mask (blue line) by Silvan Ragettli. Map of Nepal taken from Google Maps.

The study is carried out on Lirung glacier in the Langtang valley, Nepal Himalayas. The tongue of Lirung glacier is 3.5 km long and is situated between 4000 and 4300 m.a.s.l. Meteorological data has been measured on Lirung glacier from spring 2012 until autumn 2015, and on-site debris thickness measurements have been made in 2012 and in 2015.

Five Landsat 7 and Landsat 8 thermal satellite images for the years 2012, 2013 and 2015 were used. All images were taken in the post-monsoon season when the climate and the debris layer is driest.

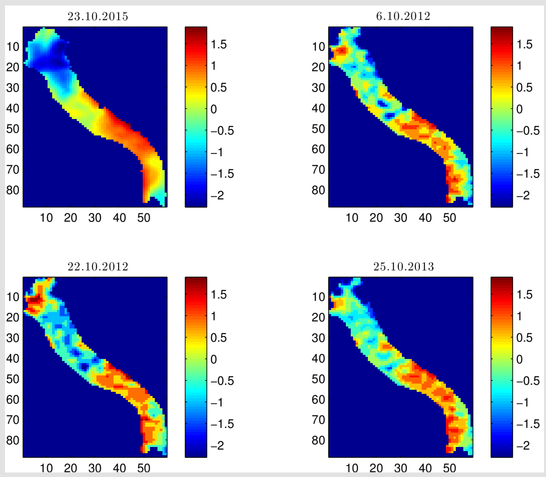

Fig. 2 : Normalized surface temperature obtained from four Landsat satellite images.

3 The methods

A) Current methods :

Reconstruction of debris thickness via inversion of the energy balance, with use of thermal satellite images and meteo data.
Different ways of dealing with **heat storage** and **non-linearity** of debris temperature profile :

- **Foster et al. (2012)** → constant heat storage factor F = 0.64
- **Rounce and McKinney (2014)** → 'Gratio' to correct for non-linearity of temperature profile
- **Schauwecker et al. (2015)** → heat storage factor F dependent on debris thickness (data from several publications)

B) New time-integrating method :

1. Assume 'kick-off' debris thickness d = 0.5 m
2. Discretize using a layer thickness Δz

For each time step **t** and for each satellite image pixel **j**... :

3. Compute the energy fluxes at the debris surface for each time step
4. Compute the debris temperature profile
5. Obtain debris surface temperature Ts after T_tot = 7 days (= 24 x 7 time steps corresponding to the time scale needed for the heat to penetrate across the debris layer down to the glacier ice)
6. Compare **Ts_computed** vs. **Ts_satellite at time of satellite overpass**
7. (a) d too small if Ts,comp < Ts,sat (not enough insulation from ice)
   (b) d too large if Ts,comp > Ts,sat (too much insulation from ice)
8. Next iteration with corrected debris thickness d

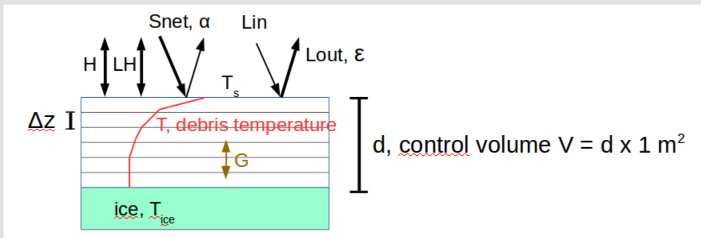

Fig. 3 : Design of the dynamic model : Energy balance at the debris surface, solved at each time step t for each satellite image pixel j.

Energy balance for the entire debris layer, for time step t :

$$c\cdot\rho\cdot\int_0^d \frac{\partial T(t,z)}{\partial t}\,dz = \underbrace{S(t)+L(t)+H(t)+LH(t)}_{Q(t)} \underbrace{-K(z)\cdot\frac{\partial T(t,z)}{\partial z}}_{\text{Ground heat flux } G(t)}$$

For the numerical computations we use :

$$c\cdot\rho\cdot\frac{\partial T(t,z)}{\partial t}\cdot\Delta z = Q(t) - K(z)\cdot\frac{\partial T(t,z)}{\partial z}$$ Topmost debris layer

$$c\cdot\rho\cdot\frac{\partial T(t,z)}{\partial t}\cdot\Delta z = -K(z)\cdot\frac{\partial T(t,z)}{\partial z}$$ Internal debris layers

5 Results and Conclusions

- Existing models…
  - do not give reliable estimates of debris thickness and often underestimate debris thickness
  - are sensitive to thermal conductivity K, incoming shortwave radiation SWin and albedo
- A time-integrating model…
  - can represent non-linear debris temperature profiles
  - is computationally intensive and requires hourly meteo data for a time period of several days
  - remains sensible to thermal conductivity, albedo and incoming shortwave radiation
  - can only make accurate predictions for debris thickness smaller than 0.5 m

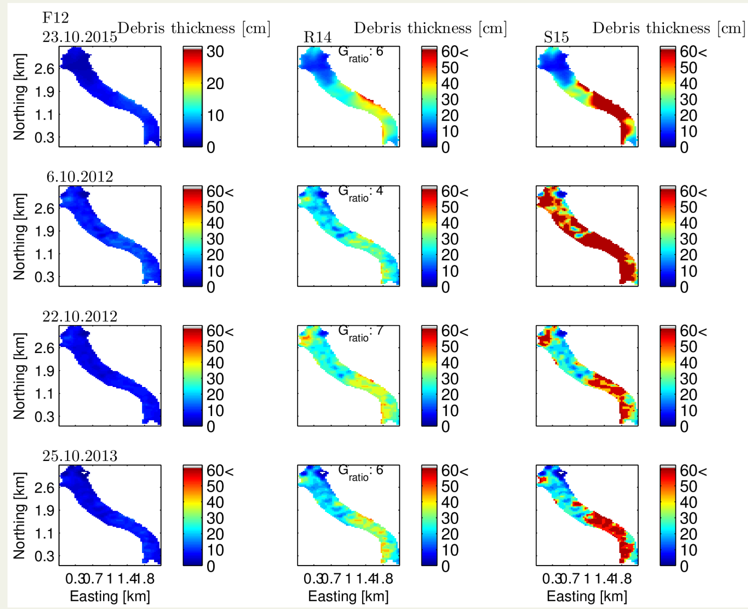

Fig. 4 : Debris thickness computed with three different methods for four different satellite images.

Methods :
***F12** is Foster et al. (2012)*

***R14** is Rounce & McKinney (2014)*

***S15** is Schauwecker et al. (2015)*

6 References

1) LA Foster, BW Brock, Mark EJ Cutler, and F Diotri. A physically based method for estimating supraglacial debris thickness from thermal band remote-sensing data. Journal of Glaciology, 58(210):677–691, 2012.

2) TD Reid and BW Brock. An energy-balance model for debris-covered glaciers including heat conduction through the debris layer. Journal of Glaciology, 56(199):903–916, 2010.

3) DR Rounce and DC McKinney. Thermal resistances in the everest area (nepal himalaya) derived from satellite imagery using a nonlinear energy balance model. The Cryosphere Discussions, 8(1):887–918, 2014.

4) S Schauwecker, M Rohrer, Ch Huggel, A Kulkarni, A Ramanathan, N Salzmann, M Stoffel, and B Brock. Remotely sensed debris thickness mapping of bara shigri glacier, indian himalaya. Journal of Glaciology, 2015.