Dynamic response of glaciers on the Tibetan Plateau to climate change - Development and evaluation of a 1-D snowpack model for estimating energy fluxes and mass balance changes over the Tibetan Plateau

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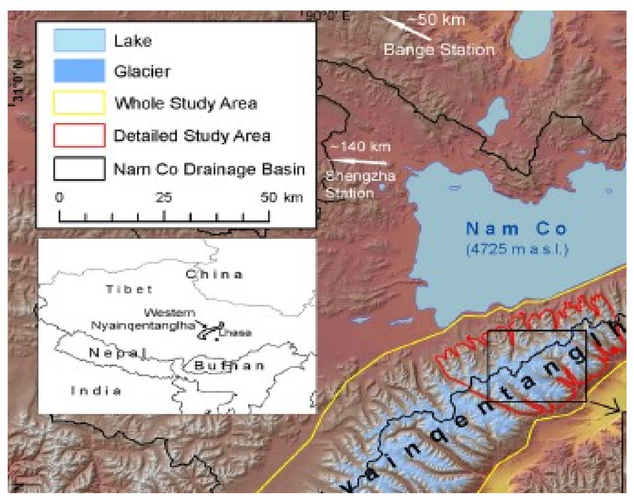
Introduction

The model that we have attempted to develop has a rather straight forward aim of being able to predict the melt generated from the snow pack overlaying the polythermal Zhadang glacier in Tibet. The aim of the project may be summarized as follows:

- To compute the melt generated, estimate the refreezing and hence study run off and the evolution of the snow-glacier system.
- To develop a computational tool and create a windows-based tool-box.
- To use the developed module for studying the influences of large-scale atmospheric forcing on the time evolution of the glacier.

Ultimate aim of the project is to have at hand, a tool-box which may be utilized to analyze AWS measurements and downscale atmospheric parameters to predict the glacier evolutions over the entire Tibetan Plateau.



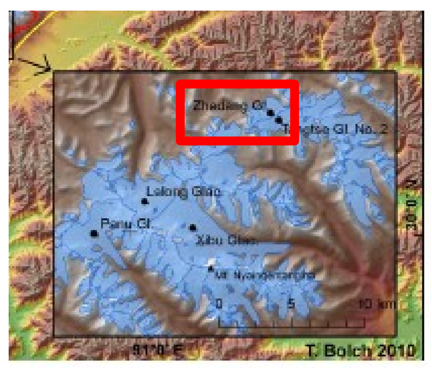


Fig. 1: Overview of the study area (modified from Bolch et al. 2010)

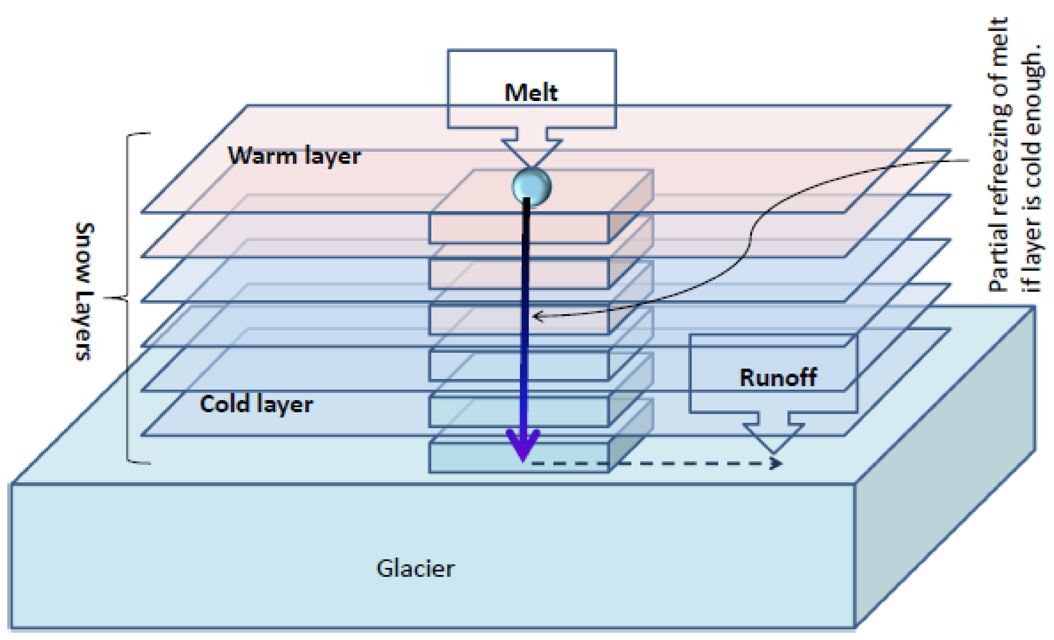


Fig. 2: Schematic representation of the physical processes as considered in the model

Model Description

- Physically based one-dimensional (only depth at a point) model driven by meteorological parameters measured at weather stations.
- The snow surface temperature is estimated from energy fluxes (UEB Model, *Tarboton & Luce 1996*).
- The temperature profile in the snow pack is estimated by solving the heat equation for 2 cm layers of snow; snow depth beyond 2 cm is not resolved.
- A mean glacier temperature of -5°C at 10 m below the ice surface is assumed (from data set spanning April 2009 - August 2009).
- Snow is considered to be homogeneous i.e., the various physical parameters like snow density and heat conductivity do not change from layer to layer.
- It is assumed that melt percolates only downwards from layer to layer and refreezes where a layer is cold enough; horizontal movement of melt is not accounted for.
- Amount of refreezing in each relevant layer depends on the cold content of the layer.
- The only effect of refreezing is assumed to be in raising the temperature of the concerned layer; it is assumed to have no effect on the physical parameters of the layer.
- When the resulting melt reaches the snow-glacier interface, it is estimated to be the run off.

Modelled Parameters

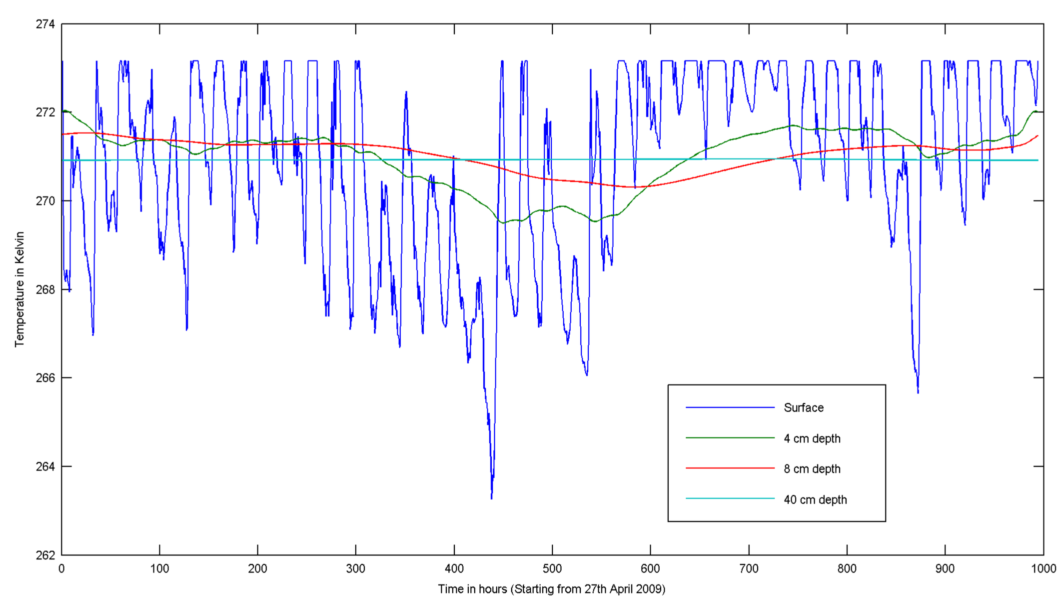


Fig. 3: Snow pack temperature at different depths

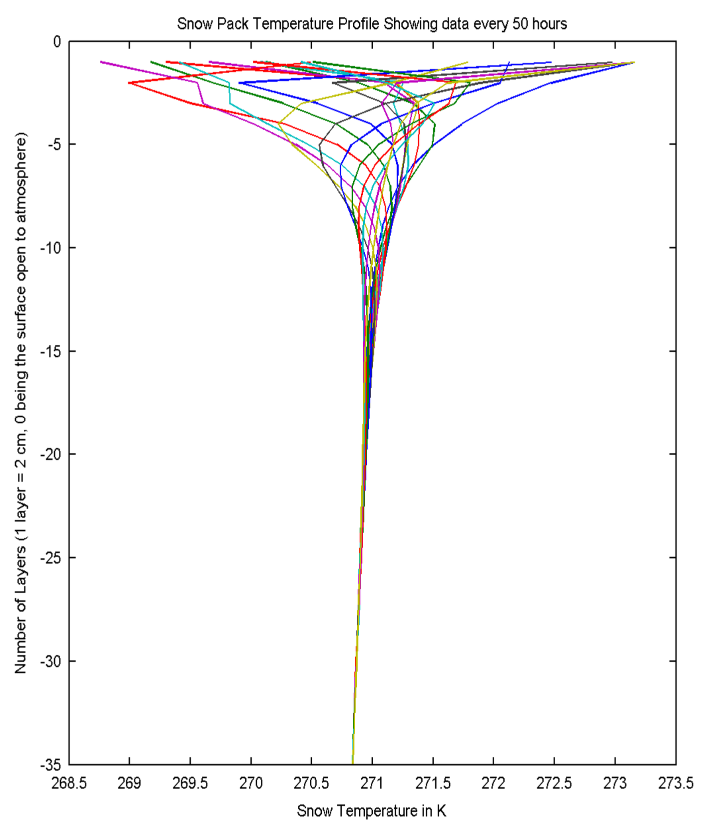


Fig. 4: Snow pack temperature profile April-August 2009

Cold Content: the heat required per unit area to raise the snow pack temperature to 273:16K. This gives a measure of the amount of melt that will refreeze in every layer.

$$H_c = \rho_s C_p d(273.16 - T)$$

Water equivalent (W_c) of the cold content is then the equivalent amount of water needed to raise the snowpack temperature to 273:16K.

$$W_c = \frac{H_c}{\rho_w L}$$

where,
ρ_w: Density of water
ρ_s: Density of water
L: Latent heat of fusion of water
d: Thickness of the snow layer
T: Mean temperature of the snow layer in Kelvin
C_p: Specific heat capacity

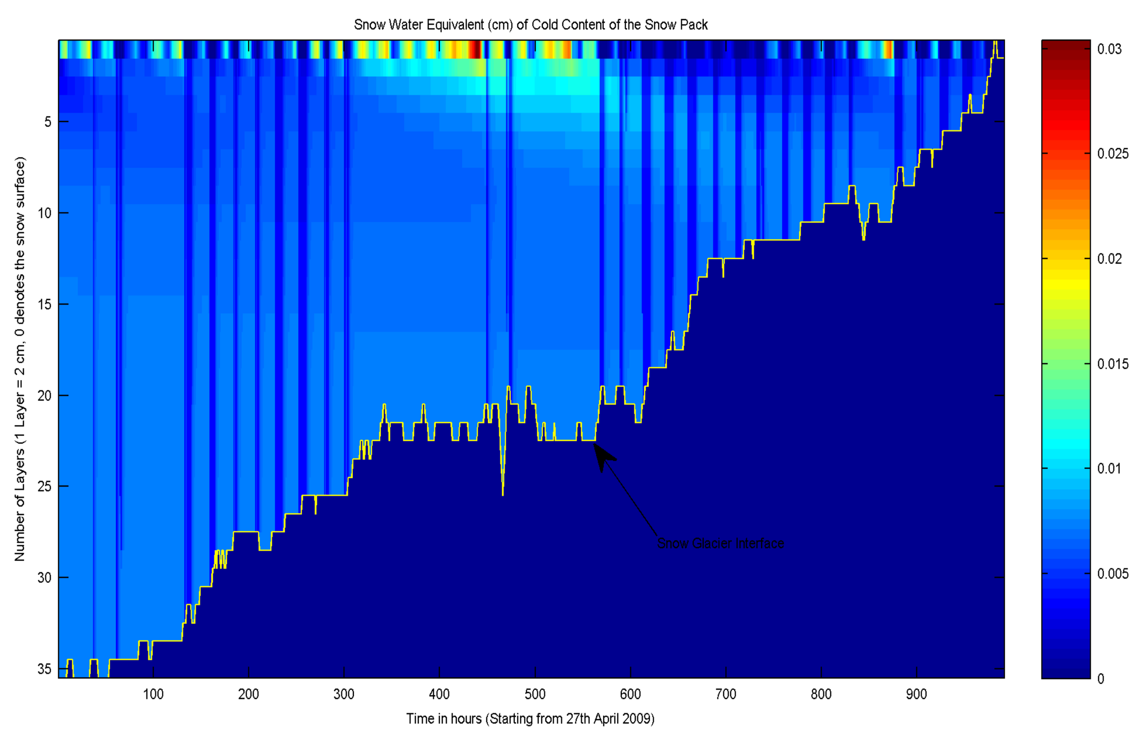


Fig. 5: Plot of the water equivalent W_c of the cold content of the snow pack

Initial Results

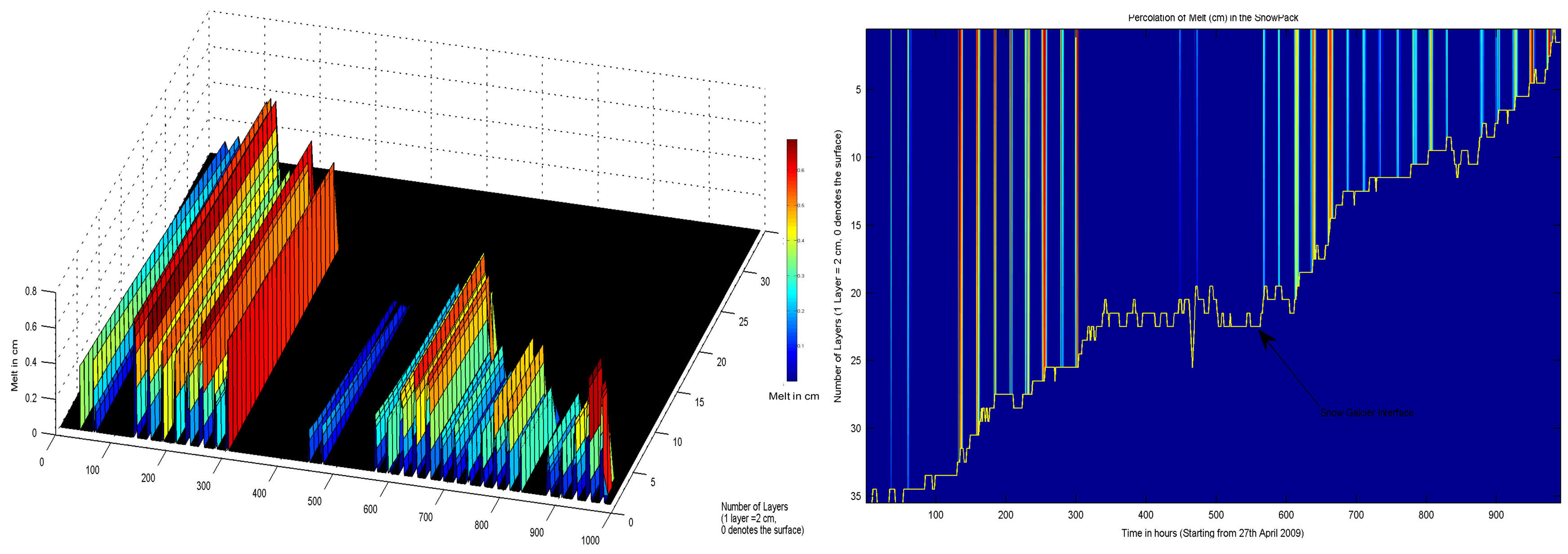


Fig. 6: Plot showing how the melt estimated from the energy balance percolates down the layers, refreezes if cold enough and runs off on reaching the snow-ice interface. This indicates that in case of cold snow packs, only a fraction of the melt generated at the surface is obtained as run off. The rest refreezes and is retained in different layers.

As an initial estimation, refreezing of melt water is found to have a definite impact on the run off at the Zhadang Glacier. It is expected that consideration of the alteration of snow density upon refreezing will lead to a better match between the modeled and the observed snow melt.

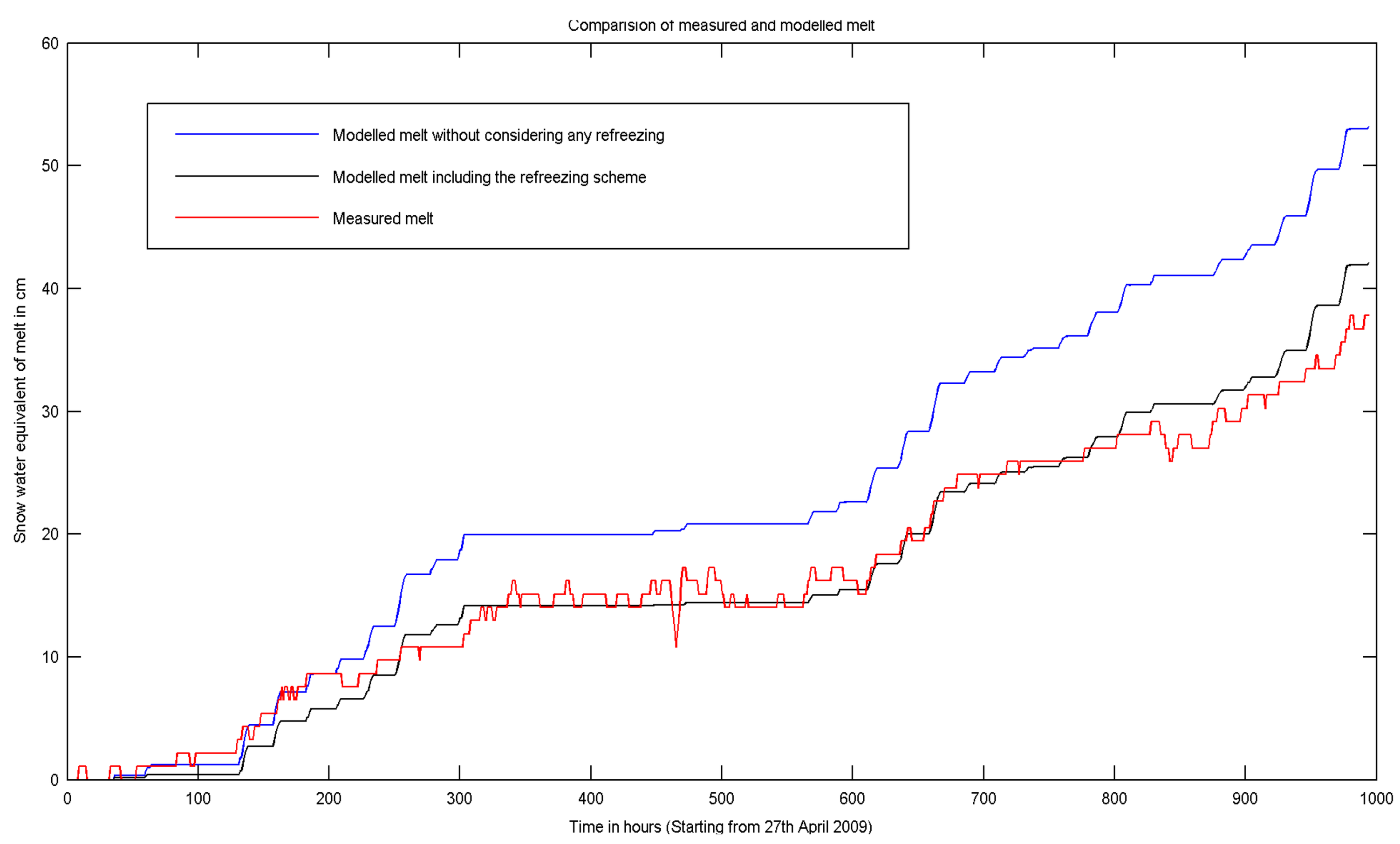
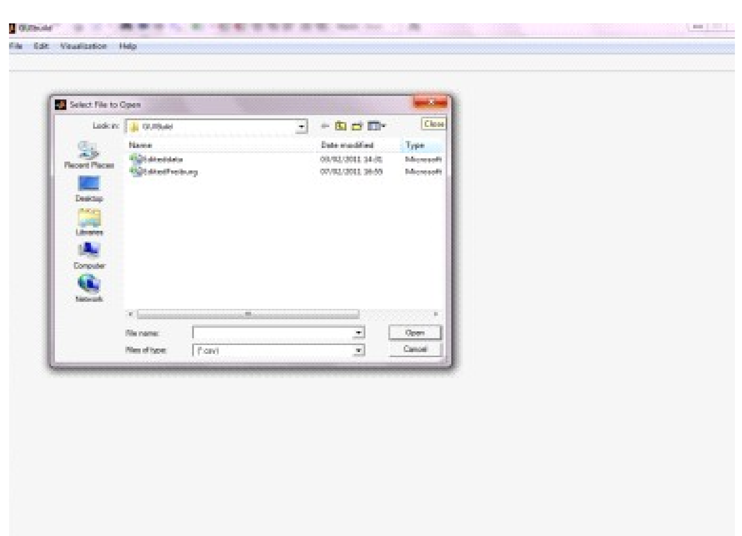


Fig. 7: Plot comparing the snow water equivalent of the measured snow depth changes, the initial melt estimation and net melt after consideration of refreezing

GUI Tool-box

A windows-based GUI (graphical user interface) is being developed for easy handling of multiple model runs. This will provide the user a simple way of visualizing, manipulating and analysing the data without having in-depth programming knowledge.



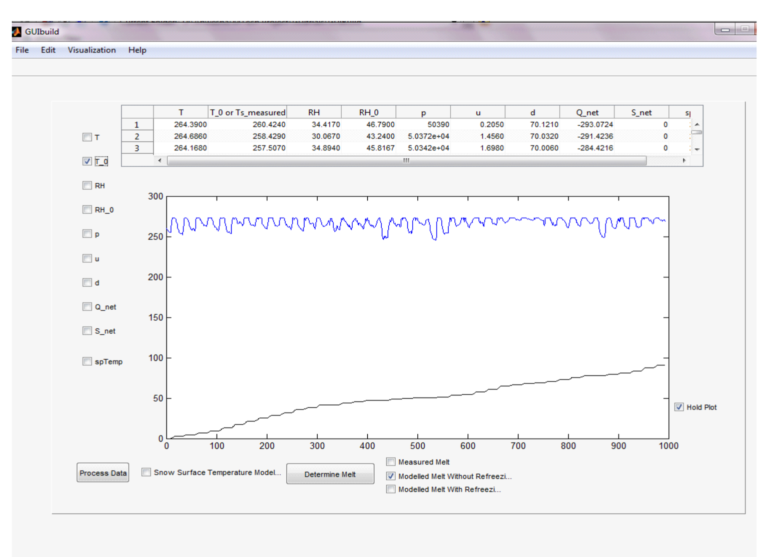


Fig. 7: Screen-shots of the tool-box in its current state of development

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