GLOBAL RADIATION AND ALBEDO PARAMETERIZATION FOR COMPUTING GLACIER MELT IN HIGH ALTITUDE TROPICAL GLACIERS

Tohoku University / IHH-UMSA Student Member O Pablo FUCHS
Tohoku University Member Yoshihiro ASAOKA
Tohoku University Member So KAZAMA

1. INTRODUCTION

In high altitude glacial environments, incoming solar radiation and albedo play key roles in the underlying melt processes. Incoming solar radiation provides most of the energy used for melt while albedo determines the total shortwave radiation absorbed by the glacier surface and the changes in melt rates associated with the surface type (snow or ice).

Fuchs *et al.* (2013) applied an enhanced temperature-index model developed in the western Alps to the tropical Zongo glacier. This model includes shortwave radiation and albedo as relevant components for melt and considers the spatial variability of the melt rates for each elevation band delineated at given intervals (e.g. 250 or 500 meters).

Since global radiation is often missing or not observed, especially at high altitudes, a simple parameterization that requires minimal information is needed to overcome this problem.

Moreover, a better estimation of the spatial albedo throughout the ablation zone would certainly lead to a good estimation of the melt rates.

Therefore, the aim of this study is to test two widely known parameterizations of, respectively, the global radiation and the albedo for use in melt models.

2. STUDY AREA AND DATA

The study sites are located in the Huayna Potosi Massif (16°15'S, 68°10'W, Bolivia) at opposing orientations (**Fig. 1**).

Both glaciers are equipped with automatic weather stations (AWS) and hydrometric stations at the outlet of the glacier front. Additionally, a sonic ranging sensor in Huayna Potosi West site monitors changes in snow height.

3. METHODS

GLOBAL RADIATION PARAMETERIZATION

Global radiation was estimated using the model proposed by Thornton and Running (1999) which is basically a reformulation of the Bristow-Campbell equations. Observations of daily temperature, humidity, precipitation and radiation were used to feed the model. The following expressions illustrate the method to calculate the daily total global radiation on a horizontal surface:

$$R_{gh} = R_{pot} \cdot T_{t,max} \cdot T_{f,max}$$

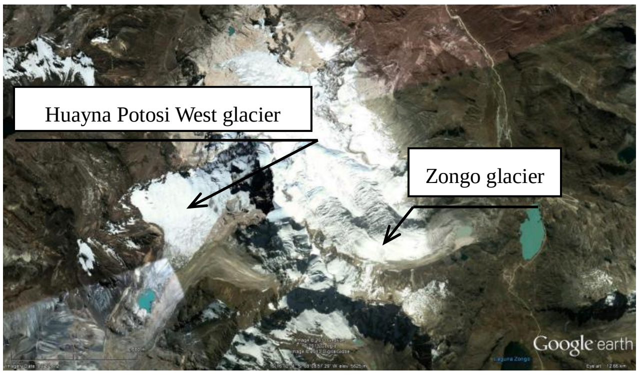

Fig. 1 Location of the glacier sites

$$T_{t,max} = \left[\frac{\sum_{s=sr}^{ss} R_{pot,s} \cdot \tau_{0,nadir,dry}^{(P_z/P_0)\cdot m_\theta}}{\sum_{s=sr}^{ss} R_{pot,s}}\right] + \alpha e$$

$$T_{f,max} = 1.0 - 0.9 \cdot exp(-B \cdot \Delta T^C)$$

$$B = b_0 + b_1 \cdot exp(-b_2 \cdot \overline{\Delta T})$$

Where R_{gh} is the daily global radiation [W m^{-2}], R_{pot} the daily top-of-the-atmosphere radiation on a horizontal surface [W m^{-2}], $T_{t,max}$ the maximum (cloud free) daily total transmittance, $T_{f,max}$ the proportion of $T_{t,max}$ realized on a given day (cloud correction), $R_{pot,s}$ the instantaneous potential radiation at solar time s [W m^{-2}], sr and ss are times of sunrise and sunset, $\tau_{0,nadir,dry}$ the instantaneous transmittance at sea level, at nadir, for a dry atmosphere, P_z and P_0 are the surface air pressures at elevation z and at sea level [Pa], m_θ the optical air mass at solar zenith angle θ, α a parameter describing the effect of vapor pressure e on $T_{t,max}$ [Pa^{-1}], B and C are parameters describing the effect of diurnal temperature range ΔT on daily transmittance, $\overline{\Delta T}$ a 30 day moving average of ΔT, and b_0, b_1, and b_2 are empirical parameters controlling the shape of the relationship between $\overline{\Delta T}$ and B.

R_{pot}, sr, ss, m_θ, and P_z were calculated using standard methods while α, $\tau_{0,nadir,dry}$, b_0, b_1, b_2, and C were estimated by optimization.

Thornton *et al*. (2000) showed that the parameters used to estimate $T_{t,max}$ should not vary with climate or latitude and that those of $T_{f,max}$ have significant climatic variation. We reached a similar conclusion and identify b_0 as the most sensitive parameter.

ALBEDO PARAMETERIZATION

The albedo scheme used here requires daily albedo,

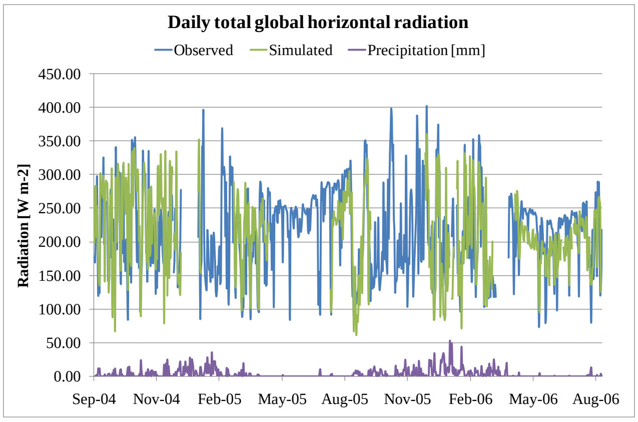

Fig. 2 Global radiation and precipitation at Zongo

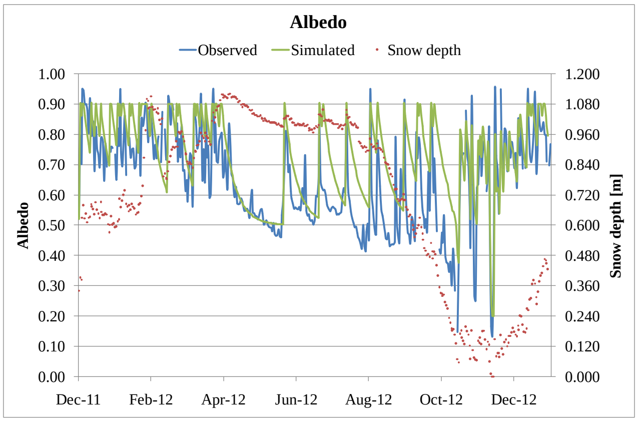

Fig. 3 Albedo and snow depth at Huayna Potosi West

snow depth and dates of snowfall events as input data and the determination of five control parameters: albedo of fresh snow (α_{frsnow}), albedo of firn (α_{firn}), albedo of ice (α_{ice}), e-folding constant for effect of ageing on snow albedo (t^*) [days], and e-folding constant for effect of snow depth on albedo (d^*) [cm w.e.] (Oerlemans and Knap, 1998). The albedo of the snow-covered glacier surface at day *i* is calculated as:

$$\alpha_{snow}^{i} = \alpha_{firn} + \left(\alpha_{frsnow} - \alpha_{firn}\right) \cdot exp\left(\frac{l-i}{t^*}\right)$$

In this equation *l* is the number of the day on which the last snowfall occurred. When snow depth *d* is small, a smooth transition to the characteristic ice albedo is required. This is achieved using the equation:

$$\alpha^{i} = \alpha_{snow}^{i} + \left(\alpha_{ice} - \alpha_{snow}^{i}\right) \cdot exp\left(\frac{-d}{d^*}\right)$$

4. RESULTS AND DISCUSSION

First, the parameterization of the global radiation was evaluated at Zongo from 01 September 2004 to 31 August 2006. A correction for obstructed horizons was introduced to account for the effect of shading by the surrounding terrain yielding a mean absolute error (MAE) and bias for the predictions of 39.56 and 1.35 [W m^{-2}], respectively (**Fig. 2**).

Although biases are small, they show a general overestimation of radiation. However, during the dry season the model underestimates radiation that could be attributed in principle to multiple reflections between the high-albedo snow-covered area and the atmosphere which increase the diffuse component of global radiation (Meek, 1997) and produces negative prediction biases.

Secondly, we applied the albedo parameterization to the meteorological conditions of the Huayna Potosi West site using the available information from 23 December 2011 to 14 January 2013. The control parameters were optimized until a minimum root mean squared (RMS) difference was found. The optimized values are: α_{firn} = 0.50, α_{frsnow} = 0.90, α_{ice} = 0.20, t* = 10 days, and d* = 2 cm w.e. The correlation coefficient between observed and simulated albedo was 0.73.

While we have a good agreement still some problems are apparent. For example, days with light snowfalls or sudden changes of albedo cannot be accounted for by the model (**Fig. 3**).

Further study incorporating the parameterizations of global radiation and albedo to the Zongo glacier site for filling the gaps in the missing information and study the spatial albedo will allow us to investigate the performance of the glacier melt model with these parameterizations as well as the transferability of the models within the study region.

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