# SNOWMELT RUNOFF SIMULATION IN A MOUNTAIN WATERSHED TUNI, BOLIVIA

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## 1. INTRODUCTION

In the last years, glaciers in South America have shown a generalized retreat and wasting, in agreement with the global trend. Small glaciers are particularly vulnerable to wasting, several of them having disappeared since the Little Ice Age (LIA) and many others being in the final stages of complete wasting (Ramirez et al., 2001).

Glaciers in South America are critically important for water resources, including domestic, agricultural and industrial uses, particularly in equatorial, tropical and subtropical latitudes. Enhanced melt should cause runoff increase in the short term but decreased availability in the long term (Casassa et al., 2007).

Andean countries, such as Bolivia or Peru, rely to a great extent on fresh water from glaciated basins during the dry season. Mountain glaciers act as a critical buffer against highly seasonal precipitation and provide water for domestic, agricultural or industrial use at times when rainfall is low or even absent.

## 2. STUDY AREA AND INPUT DATA

The Tuni Condoriri system (**Fig. 1**) is located on the Andes mountain chain (16°12'S; 68°13'W, Cordillera Real, Bolivia). It provides important water resources to two major cities of Bolivia (La Paz and El Alto).

The Tuni glacierized basin has a surface area of 9.78 km$^2$ and ranges from 5300 to 4400 meters above sea level (asl). The observed mean air temperature and annual precipitation are 5.2°C and 681.9 mm, respectively.

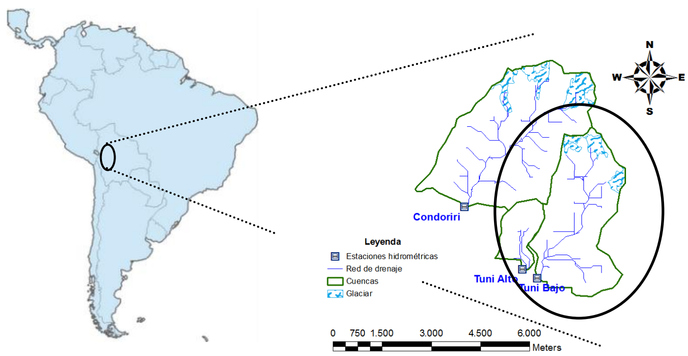


**Fig. 1** Location of the study basin

In order to determine the flow at the outlet, the model requires temperature, precipitation and snow cover area at a daily resolution as input variables, as shown by Martinec and Rango (2008).

The simulations were conducted for two periods: the 2001-2010 years for calibration of the model and the 1999-2001 years for validation.

**Table 1** Meteorological and hydrological stations

| Station | Lat | Lon | Alt. | Type | T. Res. |
|---|---|---|---|---|---|
| Laycacota | 16.50 | 68.12 | 3632 | Met. | Daily |
| El Alto | 16.51 | 68.18 | 4072 | Met. | Daily |
| Chacaltaya | 16.35 | 68.13 | 5188 | Met. | Daily |
| Condoriri | 16.22 | 68.26 | 4520 | Met. Hydr. | Hourly |
| Tuni Alto | 16.23 | 68.24 | 4655 | Hydr. | Hourly |
| Tuni Bajo | 16.23 | 68.23 | 4475 | Hydr. | Hourly |
| Tuni Huayna | 16.28 | 68.19 | 4735 | Hydr. | Monthly |

Lat = latitude [°]; Lon = longitude [°]; Alt. = altitude [masl]; Type: Met = meteorological; Hydr. = hydrological; T.Res. = temporal resolution.
The meteorological information (excepting for Condoriri) was provided by SENAMHI (Servicio Nacional de Meteorologia e Hidrologia), while the hydrological data was given by IRD (Institut pour le recherche et le developpement). Laycacota and El Alto stations historical data extends since as early as 1945. Chacaltaya data is available during the June 2003-August 2007. The IRD program started on 1999 and is still ongoing.

Parameter optimization was carried out in two stages. On the first stage, observed and simulated discharges were compared; the second stage consisted on the quantification and validation of the annual melt rates with respect to measured ablation from stakes installed on the Zongo glacier (16°15'S; 68°10'W).

## 3. MODEL STRUCTURE

MELT ESTIMATES

Many studies have shown considerable improvements on snowmelt runoff modelling by incorporating shortwave solar radiation and albedo in modified temperature index models (Li and Williams, 2008 and all references therein). Based on SRM model (Martinec and Rango, 2008) and following Li and Williams (2008), an enhanced temperature-index model was used to calculate melt rates:

$$M = \begin{cases} m \cdot R \cdot (1-\alpha) \cdot (T_d - T_0), T_d > T_0 \\ 0, T_d \le T_0 \end{cases}$$

Where $M$ (cm/day) is daily snowmelt, $T_d$ (°C) is daily mean temperature, $\alpha$ is surface albedo, $R$ (Wh/m$^2$day) is the daily total shortwave solar radiation, and $m$ (m$^2$cm/Wh°C) is a composite parameter. Daily discharge from an elevation zone is calculated as:

$$V_i = (M_i \cdot S_i + c \cdot P_i) \cdot A_i \cdot \frac{10000}{86400}$$

Where $V_i$ [m$^3$/s] is the average daily discharge from the ith zone, $S_i$ is snow cover percentage, $c$ is precipitation runoff coefficient, $P_i$ (cm/day) is daily precipitation, and $A_i$ is the size of the ith zone in km$^2$.

SOLAR RADIATION

The solar-radiation model developed by Fu and Rich (1999) was used in this study because it is readily available in a geographic information system (GIS) environment and accounts for typical atmospheric conditions, elevation, surface orientation, and influences of surrounding topography. This model assumes clear-sky conditions and does not account for differences in solar radiation caused by cloud cover.

SNOW ALBEDO

Albedo is defined as the fraction of the incident shortwave radiation that is reflected:

$$\alpha = \frac{SW \uparrow}{SW \downarrow}$$

Since the study basin does not have daily measurements of albedo, we use the information of Zongo glacier which is closer to the study area and has historical series of albedo.

RUNOFF ROUTING

This model uses the same method in SRM to route both snowmelt and rain water to the watershed outlet:

$$Q_{n+1} = V_n \cdot (1 - k_{n+1}) + Q_n \cdot k_{n+1}$$

The recession coefficient “k” indicates the decline of discharge in a period without snowmelt and rainfall, and is assumed to vary inversely with discharge.

## 4. RESULTS

All model parameters are set as explained in Martinec and Rango (2008), except for “m” and “c”. These parameters were determined by optimization.

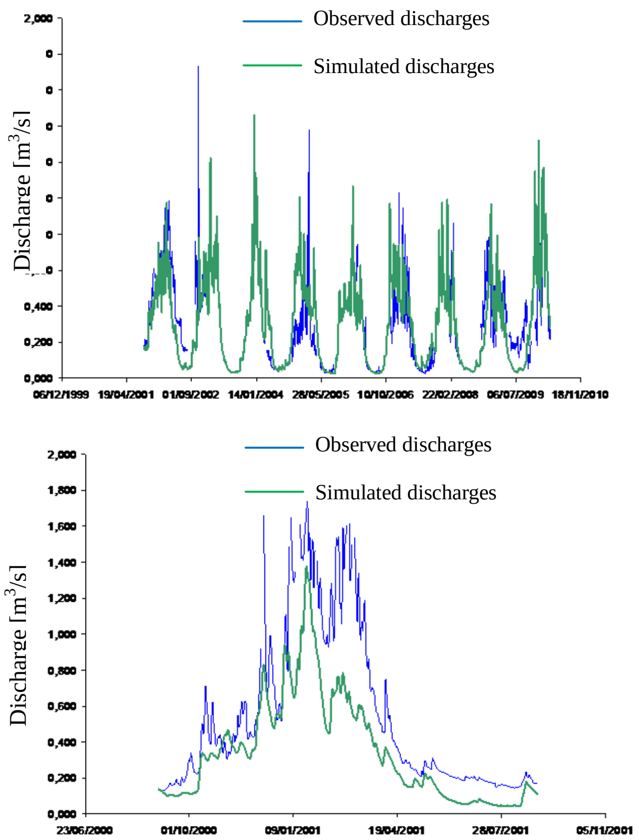


**Fig. 2** Simulated and observed discharges at the outlet for the calibration (upper graphic) and validation (lower graphic) periods.

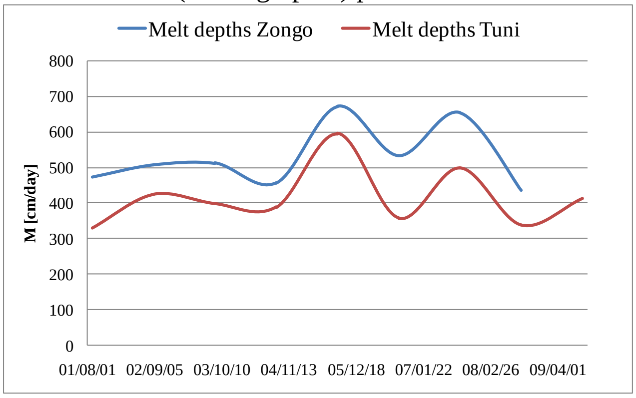


**Fig. 3** Annual melt depths measured in Zongo glacier and simulated in Tuni glacier. The melt rates in Zongo are higher because of the areal extent and snow covered area ratio of this glacier (1.860 $km^2$, >90%) compared with Tuni glacier (1.493 $km^2$, ~25%)

## 5. CONCLUSIONS

The research carried out at Tuni glacier shows that an enhanced temperature-index model can be successfully used to simulate the daily flows in a mountain basin with limited hydro-meteorological data. While the discharges obtained at the outlet during the calibration and validation phase proved to be inaccurate ($R^2$ = 0.367 and 0.558, respectively), the resultant hydrographs seem to be reasonable in terms of the seasonal trends reproducibility and the simulated melt depths.

## ACKOWNLEGEMENTS

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