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Hydrology and Earth System Sciences Discussions

Interactive comment on "Snow glacier melt estimation in tropical Andean glaciers using Artificial Neural Networks" *by* V. Moya Quiroga et al.

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Dear editor and reviewer,

We value the comments received greatly, as they pointed out a number of issues to be addressed, in order to improve the article. The responses to the mentioned comments are detailed in the following paragraphs. The number of the answer is related to the number of the comment. Minor comments were numbered as number 6. The additional references that will be included in the new version are at the end.

Thank you very much for your kind consideration.

Comment 1: The main objective of the ANN model was to emulate the nonlinear relation between the incoming short wave radiation (SW) and temperature (T) at different months and hours with the total energy budget and the potential melting rate, so that it was possible to estimate melting rates at different time using SW and T. The data from the meteorological station was assumed as representative of the glacier. Considering the glacier area (2.4 Km2) and that the station (5050 meters above sea level (masl)) is located near the mean equilibrium line (5150 mosl) (WGMS, 2011; Condom et al., 2007; Wagnon 1999), and the fact that previous studies at other locations used data collected near the equilibrium line at one point as representative for the glacier (Hock and Holmgrem 2005), it was assumed that the data from the meteorological station could be representative of the area. Different surces of uncertainties such as the lapse rate (temperature variation with elevation) are analysed in the next stage of this research.

The above mentioned comments were added to the new version of the paper

Comment 2: This comment was divided in three parts; a), b) and c)

a) The study of Pellicoti et al. (2005) was not mentioned, because it was applied to high latitude glaciers, and in the present study we wanted to emphasize tropical glaciers. Besides, its performance was not suited for the present study as it will be explained in point 3. Nevertheless, considering its importance and improvement for temperature methods, it is included in the new version of the manuscript.

b) Relative humidity (RH): Previous studies demonstrated that melting is related to RH (Thompson et al., 2009; Molg et al., 2008; Khun 1987). Besides, previous studies concluded that there is a correlation between RH and cloud cover (Yi et al., 2004; Walcek C. 1994). Moreover, considering that cloud cover affects the long wave radiation and its relation to seasonality, it may be assumed that long wave radiation and albedo are related to RH (Juen et al., 2007).

c) Bare ice and snow were not differentiated, since it is assumed that ice and snow have the same latent heat of fusion (LHF). The relation between snow LHF and ice LHF depend on the amount of liquid water in snow; while some studies state that latent heat of fusion of snow may be little lower than the one from ice (Sing and Vijay 2001), other studies reported that snow LHF is little higher than ice LHF (Guttmann L., 1907). However, the differences are too low that usually they are assumed as having the same value (Hock, 2005).

The above mentioned comments were added to the new version of the paper

Comment 3: The main reasons for not comparing with the mentioned models were:

a) Both models consider only short wave radiation (SW). The mentioned models (Pellicoti and Hock) are suitable for high latitude glaciers, but not for tropical glaciers, since they don't consider long wave radiation (LW) which is a key variable for the energy balance in tropical glaciers Sicart (2005). Although the present model does not consider LW explicitly, it does consider other parameters such as RH, T or the month. Considering that Molg et al., (2008) reported that LW may be parameterized as a function of T and vapour pressure (which depends on RH), it may be assumed that those parameters (and the present ANN model) implicitly represent LW and seasonality.

b) Both models require albedo data which is not available at the Condoriri station. In order to obtain albedo it would be necessary to use a second pyranometer. Such additional sensor would highly increase the cost of any station measuring SW (Almost twice the cost of a station measuring incoming SW). This additional cost would be a strong limitation for developing countries.

c) There is no other published work with clear analysis of the hourly variation of melting rates. Actually this study is a pioneering in detailed analysis of hourly melting rates.

Comment 4: This comment was divided in two parts; a) and b)

a) The energy balance model has a strong physical background already validated by other studies, that it could be used even without any physical validation (Molg et al.,

2008; Cullen N., et al., 2007; Molg T. and Hardy R. 2004; Wagnon P., et al., 1999). The highest uncertainties of the energy balance model are from the roughness parameters, but in the present study we used the values for the present study area suggested by Sicart et al., (2011) and Sicart et al., (2005) (Page 9465, lines 1-13). Besides, we reported that Van As (2011) and Sicart et al., (2005) concluded that both latent and heat fluxes play a minor role in the energy balance and their errors may be assumed as negligible (Page 9465, lines 11-15).

b) The only way to validate the energy model is comparing with glaciological measurements using ablation stakes. The melting rates cannot be compared with runoff since only part of the melt water goes to runoff, while some of the melt water is stored due to glaciological sub processes: For instance, Hannah and Gurnell (2001) demonstrated that there are interaction between melt water generation, storage and discharge. Liu et al., (2010) showed that water can be stored within a glacier either in surface snow, crevasses, englacial pockets, subglacial cavities or englacial and subglacial drainage networks. Swift et al., (2006) reports that melt water routing through the glacier depends on the evolution of melt water sources and subglacial drainage systems. Hence, different methods were developed for estimating glacier melt runoff as function of glacier melt considering correction factors (Zhenniang Y., 1995), water balance and one dimensional conservation equations (Baisheng Y., and Kegong C., 1997), linear reservoirs (Hannah D., and Gurnell A., 2001), parallel linear reservoirs or glacier reservoirs (Hock 1998).

Although the energy balance could have been used without validation (as stated in point 4a), in the present study we preferred to show a comparison with of the total yearly glacier loss compared with the glaciological estimations, which is the only available data. The study of Perroy et al., (2007) may be not available online, but is available at the IRD, at the Bolivian university of La Paz (UMSA) and the Bolivian meteorological service (SENAMHI)

Comment 5:

a) Actually we stressed the limitations of ANN and the limits of the data used for training the ANN (table 2 and page 9469 lines 3-4). We also included the suggestion that before using any ANN model is important to check the limits of the data to be used. Moreover, we stated the limits of reliability of the ANN and suggested that results above a threshold limit (8 mm/h) should be carefully analysed (Page 9473, lines 2-4).

b) The proposed model may not represent high latitude glaciers, but it does tropical glaciers specially the outer ones. The paper of Hettiarachi et al., (2005) was referenced as the use of ANN for hydrological studies (Page 9468, lines 17-18). Actually Hettiarachi et al., (2005) does not criticize ANN, but suggest the use of the probable maximum event (an event with a very small, but not negligible probability of exceedance) along with a logaritmic transformation, as a second stage of ANN in order to overcome extrapolation problems. The study of Hettiarachi was about rainfall-runoff, an area where there are already estimations of probable maximum precipitation. Defining the Probable Maximum Temperature and Probable Maximum Radiation is a statistical analysis that would deviate the main objective of the present paper.

Comment 6 (Minor comments):

a) The initial statement of "Any human activity relates somehow to water, but unfortunately is not a renewable resource . . ." was used to introduce the importance of the water problem which is becoming a serious issue. By stating water is a renewable resource we mean that there is a given amount of water (either liquid solid or vapour), and no additional water can be created. However, in order to avoid possible confusions, that first statement may be removed in the new version.

b) The references to Vrugt et al., (2003) and Vrugt et al., (2008) about Gauss and uncertainty, were to indicate that there are different sources of uncertainty that will be discussed in the next stage of this research. However, they may be removed in the version of the manuscript

c) We agree that it would be interesting to compare those figures with published work;

unfortunately, up to date there is no published work with hourly melting rates. Besides, the main objective of the present paper is to present a new approach based on ANN that will allow obtaining detailed melting rates with easy to obtain data. We consider that any additional comments on the energy model would deviate from the main objective of the paper.

d) Figures 8-12 were included to show graphically the correlation of the different models and have a visual explanation about which model performs the best and which the worst. Besides, the suggested upper limit of melting rate that can be estimated with the present ANN approach can be visualized in such figures and not on the summary table.

e) Actually, we agree that the figure is redundant. In the final version redundant figures are eliminated.

Additional references:

Baisheng Y, Kegong C (1997) A MODEL SIMULATING THE PROCESSES IN RESPONSES OF GLACIER AND RUNOFF TO CLIMATIC CHANGE A Case Study of Glacier No . 1 in the IJriimqi River , China ∼. Chinese Geograpical Science 7(3): 243–250

Guttnzann LF (1907) On the latent heat of fusion of ice. J. Phys.Chem 11(4): 279–282. doi:10.1021/j150085a002

Hannah DM, Gurnell AM (2001) A conceptual , linear reservoir runoff model to investigate melt season changes in cirque glacier hydrology. Journal of Hydrology 246: 123–141

Juen I, Kaser Georg, Georges C (2007) Modelling observed and future runoff from a glacierized tropical catchment (Cordillera Blanca ,Perú). Global and Planetary Change 59: 37–48. doi:10.1016/j.gloplacha.2006.11.038

Condom T., Coudrain A., Sicart J.E., Théry S., (2007) Computation of the space and time evolution of equilibrium-line altitudes on Andean glaciers (10°N–55°S), Global and Planetary Change, Volume 59, Issues 1–4, October 2007, Pages 189-202, ISSN 0921-8181, 10.1016/j.gloplacha.2006.11.021.

Cullen NJ, Molg T, Kaser G, Steffen K, Hardy D. (2007) Energy-balance model validation on the top of Kilimanjaro , Tanzania , using eddy covariance data. Annals of Glaciology 46: 227–233

Liu W, Ren J, Qin X, et al. (2010) Hydrological Characteristics of the Rongbuk Glacier Catchment in Mt . Qomolangma Region in the Central Himalayas , China. J. Mt. Sci. 7: 146–156. doi:10.1007/s11629-010-1069-4

Molg T and Hardy D. (2004) Ablation and associated energy balance of a horizontal glacier surface on Kilimanjaro. Journal of Geophysical Research 109: 1–13. doi:10.1029/2003JD004338

Molg, T., Cullen N, Hardy D, et al. (2008) Mass balance of a slope glacier on Kilimanjaro and its sensitivity to climate. International Journal of Climatology 892(August 2007): 881–892. doi:10.1002/joc.

Pellicciotti, F., Brock, B., Strasser, U., (2005) An enhanced temperature-index glacier melt model including short wave radiation balance: development and testing of haut d'Arolla, Geneva, Switzerland. Journal of glaciology 51 (175): 573-587 Singh P, Vijay P (2001) Snow and glacier hydrology Kluwer Academic Publishers, Dortrecht; Boston

Swift DA, Nienow PW, Hoey TB, et al. (2005) Seasonal evolution of runoff from Haut Glacier d ' Arolla , Switzerland and implications for glacial geomorphic processes. Journal of Hydrology 309: 133–148. doi:10.1016/j.jhydrol.2004.11.016

Thompson LG, Brecher HH, Mosley-thompson E, et al. (2009) Glacier loss on Kilimanjaro continues unabated. PNAS 106(47): 19770–19775

Walcek. (1994) Cloud cover and its relationship to relative humidity during a springtime midlatitude cyclone. Monthly weather review 1021-1035 WGMS (2011) Glacier Mass

Balance Bulletin No. 11 (2008–2009) Zurich, Switzerland

Wagnon P, Ribstein P, Kaser Georg, et al. (1999) Energy balance and runoff seasonality of a Bolivian glacier. Global and Planetary Change 22: 49–58

Yi Y, Minnis P, (2004) Re;ationships between meteorological conditions and cloud properties determined fromARM data. Fourteenth ARM science team proceedings. Albuquerque. New Mexico, 1-18

Zhenniang Y (1995) GLACIER MELTWATER RUNOFF IN CHINA. Chinese Geographical Science 5(1): 66–76

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