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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 addresses, in order to improve the article. The responses to the mentioned 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 3. Thank you very much for your kind consideration.

Comment 1:

a) The number of data used to train the artificial neural networks (ANN) is an important factor. ANN that are too large tend to over-fit, while ANN with too few data do not contain enough processing elements to correctly model the input data set and tend to under-fitting the data. Both of these situations result in poor generalization (Barnard & Wessels, 1992).

Bauer and Hausler (1989) reports that the minimum number of training examples (N) is directly proportional to the number of weights (W) and inversely proportional to the accuracy parameter (e). Hu C. (1996) explains such relation by stating that with an error of 10%, the number of training data should be at least 10 times the number of weights. In the present study, the number of training data is much longer that the number of weights, hence, fulfilling this requirement.

It is also important to mention that in theory, longer data set should provide better ANN model, since it provides additional knowledge, thus considering more possibilities when training the model (Hertz et al., 1991). This is certainly true to the extent that if a sufficient amount of information representing critical decision criteria is not given to an ANN, then the ANN (or any other modeling technique) cannot develop a correct model of the domain. However, the presence of too many input variables may poor generalization due to noisy and unnecessary data leading tend to overfitting (Walczak & Cerpa 1999).

In order to avoid overfitting, it is important to validate the model against other data sets (validation data set). In the present study we verified the ANN model by the cross validation method, which performs better than the traditional hold out methods, as it was explained in the present paper (from 9470 line 6 to page 9471 page 10). Additionally, if the reviewer and editor consider appropriate, it could be possible to perform a new training using just 75% of the total data and then to compare the results. The number 75 % was selected, since the cross validation process uses 4 cross validation sets, i.e., total data divided into 4 set of 25 % each one.

The above mentioned explanation will be included in the new version.

b) This ANN model emulates the energy balance based on solar radiation, temperature and relative humidity. Then it allows estimating a potential melting rate per square meter. Thus, for total melting it would be required to multiply the potential melting rate by the total glacier area. Nevertheless, since this model is point based one (i.e., for the point of te meteorological station), it does not consider the possible spatial variation of the input data, e.g., Montes de Oca (1995) and US flight standards service (1975) reported a lapse rate (decrease of temperature with elevation) about 0.55 C per 100 vertical meters. This problem may be easily approached by applying elevation ranges of 100 m, and applying the ANN model to each elevation range independently; that would allow us to get melting rates for each elevation range. Actually we did it such analysis, but the first idea was to present such analysis in a different publication (not submitted yet). If the reviewer and editor consider important, it could be included in the present one.

Besides, is important to consider that this ANN model was developed focusing on its applicability to glacier area. An increase in temperature will rise the elevation of the equilibrium line altitude (ELA); thus, more area will be exposed to melting, as stated by other studies (Condom et al., 2010; Carrasco et al., 2012; Wei et al., 2009). It is also important to consider that the temperature near glacier cannot rise up to much, since once it exceeds 0 deg C the glacier cools the near ground air (Hock 2010). Thus, it is reasonable to assume that the ELA will have the same temperature but a different altitude, and the glacier exposed to melting (near and below ELA) will have temperatures within the melting ranges. Temperature outside the temperature used in the training process are expected to occur in lower areas that are not covered by glacier, so they will have no influence in the glacier melting.

The above mentioned explanation will be included in the new version.

c)The data used is the only data set within the catchment for this measurement period.

Although we installed a new meteorological station, it is located at different location, and the data set period is much shorter.

We have already evaluated the influence of input data such as different melting temperatures o lapse rate. However, it was not included in the present paper, since the original idea was to dedicate this paper just to the development of the ANN model, and a next publication would have been dedicated to the data uncertainties. Nevertheless, if the reviewer and the editor consider important, we could include it in the present paper.

Comment 2.

Analysing the reviewer statement, we agree in the importance of comparing the developed ANN model against a different approach, in order to verify its usefulness. Since the mathematical comparison between ANN and multiple linear regression were already done, and already demonstrated that ANN are better approximators than multiple linear regression (Agha and Alnahal, 2012; Arulsudar et al., 2005), we consider that in the present case it would be better to compare the present model against temperature index models (considering that the objective is to develop a melting model that performs better than temperature models, using simple data such as solar radiation and temperature). Besides, when analysing the effect of using different melting temperatures, or possible lapse rates, we found that the new melting rates are not linearly related to the temperature. Actually this linearity is one limitation of temperature models. Such analysis of the temperature could be included in the present paper.

The Zongo melting could be estimated also with temperature models, and then to perform a comparison between temperature models and the present ANN model, using the results from the energy balance as the base for comparison.

Comment 3: Minor comments

a) We agree that it could be removed. Considering the previous explanation (response number 1) about energy model, such figure does not provide much information. Moreover, the suggested comparison against other melting approaches would be more useful for the present paper.

b) Thank you for the correction, the term will be changed

c) We were referring to uncertainty in input data; For instance, uncertainty in the melting temperature to be considered, uncertainty due to the lapse rate (decrease of temperature with elevation), censored data (low measurements outside the range)

Additional references to be included: * Barnard, E., & Wessels, L. “Extrapolation and Interpolation in Neural Network Classifiers”, IEEE Control Systems, Vol. 12 No. 5, 1992, pp. 50-53.

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