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## ***Interactive comment on “Probabilistic estimation of glacier volume and glacier bed topography: the Andean glacier Huayna West” by V. Moya Quiroga et al.***

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Dear editor and reviewers, We deeply value the comments received greatly, as they pointed out a number of issues to be addressed in order to improve the article. The replies to the comments are detailed in the following paragraphs. After general comment 7 we replied all the minor comments. Besides, we provide a shorter but improved manuscript with all the changes and also the new features such as:  $\checkmark$  Monte Carlo analysis of the volume estimations  $\checkmark$  Comparison and discussion of the V-A volume estimations using different coefficients  $\checkmark$  Glacier thickness estimation according to the mass turnover ice-flow mechanics approach We think that the following improve-

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ments improve the manuscript and we hope that it now satisfies the standards for a publication in The Cryosphere. Thank you very much for your kind consideration.

General Comment 1: Thank you for the comments. We realized that unfortunately, our main idea was not properly explained and led to confusion. The Glabtop is a practical approach for estimating glacier volume and glacier bed topography. Its main uncertain parameter is the basal shear stress. Although there is a practical suggestion for estimating BSS as a function of the glacier elevation range, such suggestion is based on mid-high latitude continental glaciers. Tropical glaciers tend to have extremely high mass balance gradients, causing correspondingly high mass turnovers and shear stresses for a given elevation range; thus, higher BSS is expected for the same elevation range. Our main objective was to estimate the glacier volume and glacier bed topography of the tropical glacier Huayna West. For such purpose, we estimated the BSS of a tropical glacier by analysing the whole range of possible BSS values. For such goal we made two assumptions: \*The use of the GlabTop approach with the correct BSS should provide a good estimation of the glacier volume. \*The use of V-A with correct coefficients should also provide a good estimation of glacier volume. This volume should be equal to the volume estimated by GlabTop. We agree with the reviewer that maybe the word probabilistic is not the adequate. We also agree that distribution of the V-A relations is not a relevant finding. Thus, in the new manuscript we improve our approach. \*First, we performed a Monte Carlo analysis of the volume estimations over the whole range of possible BSS. \*Then, we compare the different confidence of volume estimations with volume estimations from V-A, and discuss why some confidence intervals are related to some V-A coefficients. \*Then, assuming that V-A coefficients suggested for tropical glaciers provide a good estimation of the glacier volume, we estimate the BSS that provides such volume. This is the most probable BSS and we reduce the range of possible BSS values. \*Besides that, we also include glacier thickness and volume estimation according to the mass turnover ice-flow mechanics (MTIFM) approach. We calibrate the approach also considering that the V-A suggestion for tropical glaciers provide a reasonable estimation of the volume.

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Comments 2 and 3. We think that the reviewer is right, and the log-normal distribution should not be a surprise. Initially we wanted to make a differentiation between errors assuming normal distributions and log-normal distribution (in log-normal distribution the t-student is not suggested). However, we realized that those differences are very small compared with other uncertainties. In the present manuscript we perform a Monte Carlo analysis of the volume estimated considering whole range of possible BSS values. Then, we compare the different confidence of volume estimations with volume estimations from V-A, and discuss why some confidence intervals are related to some V-A coefficients. (New Manuscript Pg7Ln18-Pg8Ln12) Maybe a better title would be: “Glacier volume and glacier bed topography estimation of the tropical glacier Huayna West” Comment 4. Our density depth relation was based on density measurements at different depths between 0 and 35 m (Ginot 2001). We consider that 35 m is a considerable depth. However, since the volume difference considering constant density and variable density is low and is not the main objective, we will remove this section in order to avoid miss understanding Comment 5. We truly apologize for such mistake. In the new version we carefully reviewed that all quantities have their corresponding units Comment 6 Actually we do not state that V-A relation is different than thickness area. We think that the confusion of the reviewer is due to a wrong use of the word method. We were using the word method for each pair coefficients of the V-A estimation. We agree that in general terms V-A and thickness are the same. Moreover, we agree that two V-A estimations using different coefficients are also the same approach, just with different coefficients. In the manuscript we misused the word method in order differentiate between two V-A estimations using different coefficients are also the same approach. However such use of the word “method” led to confusion. In the new manuscript we overcome such mistake stating that we use different coefficients of V-A method. We also state the currently there is a debate about the uncertainty of V-A estimations (Bahr et al., 2012; Farinotti and Huss 2013). Nevertheless the method is still in use as a first estimation of glacier volume (Baraer et al., 201). Besides, it is also used for validation and comparison of

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volume estimations (Farinotti et al. 2009). Actually the V-A coefficients for tropical glaciers have a difference about 1.2%. Nevertheless, in the new manuscript we state the fact that V-A estimation has an ill-posed boundary and may easily induce errors about 40%. However, the discussion of V-A errors is a new topic with few publications. Since the main objective of the present study is the volume estimation and glacier bed topography in a tropical glacier considering the uncertainties of the basal shear stress, we assume that V-A coefficients suggested for tropical glaciers provide a good estimation of the glacier volume. General comment 7: The sections mentioned by the reviewer were removed and written with a better explanation. In the new manuscript we compared the volume estimations of each V-A estimation with the volume estimation according to GlabTop. Then, we explained Specific comments: Pg3932 Ln9-17. The abstract was rewritten. (New ManuscPg1Ln11-27) Pg3932 Ln1; Ln14-15: Ln15-17. Same as above Pg3932 Ln24. The sentence was reduced to a concise introduction that glaciers are retreating. (New ManuscPg 2 Ln4) Pg3933 Ln3. The objective of the sentence was not the exact amount of sea level rise, but to state some consequences of glacier retreat. (New ManuscPg2 Ln5) Pg3933 Ln9. We thank the reviewer for the correction. (New ManuscPg2Ln8-9) Pg3934 Ln1-2. The phrase was rewritten. (New ManuscPg2 Ln12-15) One popular and practical approach is the volume area (V-A). V-A assumes a power law scaling relation between glacier area and glacier volume, and is based on ice dynamic constraints due to ice rheology and typical climatic-topographic conditions of glacierized areas (Bahr et al., 1997). Pg3934 Ln12-13. We only wanted to reference a study that applied such approach. The reference was removed. Pg3934 Ln16-25. Those citations were included just to stress the importance of predicting glacier bed topography. They were reduced to some references about the importance of glacier bed topography (New ManuscPg2 Ln19-22) Pg3934 Ln24-fw. We stressed the GlabTop due to its rising popularity. In the new manuscript we also estimate glacier volume and GBT according to the MTIFM approach. (New ManuscPg3Ln7-14; Pg6 Ln4-15) Pg3935 Ln19-21. In the present manuscript we perform a Monte Carlo analysis of the volume estimated

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considering whole range of possible BSS values. Then, we compare the different confidence of volume estimations with volume estimations from V-A, and discuss why some confidence intervals are related to some V-A coefficients. (New Manuscript Pg7Ln18-Pg8Ln12) Pg3935 Ln23-24. In the new manuscript we state the sensibility of GlabTop to local slopes. Thus, we included a threshold slope. Besides, we compare results from GlabTop with results from MTIFM. (New manusc Pg8 Ln13-20) Pg3935 Ln25. The area of the glacier is included in the introduction. (New manusc Pg3Ln28) Pg3936.Ln19. The figure was removed Pg 3936. Ln26-27. The sentence was removed Pg3936 Ln27. We only wanted to make reference to other studies that used GlabTop using the surface slope. In the new manuscript the sentence was removed Pg 3937 Ln5. The TauDEM algorithm computes surface slope. We did not put in the manuscript because the details of the algorithm (popular in America) are the reference. Pg 3937 Ln6-8. The figure was improved. We included the whole basin for a better visual effect and the glacier flowlines. Besides, in the results we compare the glacier volume as an equivalent water layer over the whole basin. (New manusc Pg 9-Ln17-27) Pg 3937 Ln18-20. The new manuscript has a better explanation (New manusc Pg5 Ln1-13) The values of DH are in table 1. Pg3937 Ln22-25. We mean the BSS estimated with Eq2 Pg 3938 Ln11. The density section was removed from the manuscript Pg3938 Ln20. The density section was removed from the manuscript Pg3938 Ln23-24. We made a new interpolation assuming a boundary with zero thickness. (New manusc Pg5Ln15) Pg3939 Ln2-3. Thank you for the correction. We made the correction. (New manusc Pg5 Ln17) Pg3939 Ln4-6. The confusion of the reviewer is due to our incomplete explanation of the BSS estimation. The new manuscripts improves such description. (New manusc Pg5 Ln1-11) Pg3939 Ln14-15 Thank you for the correction. The V-A is now better explained. (New manusc Pg2 Ln12-20) Pg3939 Ln21-23. The data is the mentioned reference. We did not include to avoid copyright problems. In the new manuscript we removed such reference in order to avoid confussion. Pg3939 Ln24-25. This sentence led to the confusion between V-A and thickness – Area relationships. We agree that they are the same. In order to avoid confusion the sentence was

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removed. Pg3939 Ln27-f Same as above Pg3940 Ln5. In the new version we reduced the number of V-A estimation. All of them and their details are in one single table (Table 4) Pg3941 L1-11. In the new manuscript the statistical analysis was removed and replaced by a Monte Carlo analysis of the possible volume estimations. Besides, there is a discussion of why some confidence volumes are related to some V-A estimations. (New manusc Pg7 Ln11- Pg8 Ln12) Pg3941 Ln12-14. Same as above Pg3942 Ln5-6. Same as above. Pg3942 Ln21. Same as above. Pg3942 Ln25-26. We just wanted to explain all the variables. A simpler explanation was included. (New manusc Pg6 Ln20-21) Pg3943 Ln2-5. In the new version we performed a Monte Carlo analysis of the possible volume estimations. Then, we assumed that the volume estimation that provides the volume according to the V-A estimation for tropical glaciers is the most probable one. We used the BSS that provides such volume. Pg3943 Ln7-8. The result was improved. In the new manuscript we provide the BSS that provides the most probable volume estimation. (New manusc Pg7 Ln2-9) Pg3943 Ln8-10. The sentences were removed. Pg3943 Ln10-20. The variable density was removed Pg3943 Ln26. The new manuscript has a better discussion of the V-A estimations. (New manusc Pg7 Ln10-Pg8Ln12) Pg3943 Ln28. We truly apologize for the mistake. The new manuscript we carefully checked that all the units are in the manuscript. Pg3944 Ln17. The statistical approach was replaced by a Monte Carlo approach. (New manusc Pg7 Ln10-13; Table3) Pg3945 Ln5-6. Same as above Pg3945 L13. The new manuscript has a better discussion of the V-A estimations. (New manusc Pg7 Ln10-Pg8Ln12) Pg3945 L13-20. The new manuscript has a better discussion of the V-A estimations. (New manusc Pg7 Ln10-Pg8Ln12) Pg3945 L22. Initially we wanted to differentiate GBT and GBTE. However, such differentiation is unnecessary. In the new manuscript we do not repeat the definition. (New manusc Pg6Ln16) Pg3946 L8-10. Thank you for the note. The conclusion was corrected. New manusc(Pg10 Ln13-30) Pg3946 Ln11. Same as above. Pg3946 Ln12-13. In the new manuscript we include a sensitivity of local slope. In the conclusion we state such sensitivity (New manuscPg10 Ln21-23) Pg3947 Ln12-13. The sentence was removed. All tables and figure were improved.

Please also note the supplement to this comment:

<http://www.the-cryosphere-discuss.net/7/C2246/2013/tcd-7-C2246-2013-supplement.pdf>

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Interactive comment on The Cryosphere Discuss., 7, 3931, 2013.

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