The Cryosphere Discuss., 6, C2010–C2032, 2012
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The Cryosphere Discussions

TCD

6, C2010–C2032, 2012

Interactive Comment

Interactive comment on "The recent retreat of Mexican glaciers on Citlaltépetl Volcano detected using ASTER data" *by* J. Cortés-Ramos and H. Delgado-Granados

J. Cortés-Ramos and H. Delgado-Granados

jorge@geofisica.unam.mx

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Dear Dr. Andrew Klein,

The authors thank the anonymous reviewer for the useful comments, recommendations and error corrections to this contribution. We concur wit the reviewer when he mentions that publications about glaciers in places like Mexico are rare. It is also important to emphasize that the dynamics, energy and mass balance variability, as well as the shrinkage of these glaciers have not been described completely and the knowledge about their behavior is still under study. The retreat of Citlaltépetl Volcano's glaciers had not been documented until now in spite of being the largest glacier system in

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Mexico. The physics of this glacier had not been analyzed until the work of Ontiveros-González (2007). The relationship between net radiation and ablation processes on glacier's surface is a conclusion of that study. Ontiveros-González concludes that net radiation is the main parameter affecting the energy balance. An important point of our study is to pull the readers' attention on our observations on the retreat of the Citlaltépetl's glaciers also indicating that the glacial retreat is strongly influenced by the energy balance, which at the same time depends on the net radiation distribution. Our observations support the conclusion of the work by Ontiveros-González (2007), a study that will appear elsewhere. Our observations and those of Ontiveros-González (2007) are part of a continuous study of our working group. In a first version of our submitted paper we included the paper submitted by Ontiveros-González et al., but we withdrew the reference due to the policy of The Cryosphere in regard to referencing literature under submission process. So, we included the thesis by Ontiveros-González (2007) as a valid reference. The Universidad Nacional Autónoma de México gives access to anyone around the world to the thesis of our students so, anyone can access our libraries with a large freedom for these materials. To make the access to this thesis easy to foreign researches, in the meantime the Ontiveros-González et al. paper is accepted for publication in an international journal, we include the link where they can access the thesis (http://132.248.9.195/pd2008/0627305/Index.html). In the next paragraphs we address the referee's criticism and explain how we addressed the comments and suggestions, and the way we expanded several parts of the paper following the referee's recommendations.

General Comments

About the dynamics of the glacier (glacier flow), it is only limited to retreat movements of the glacier front, where accumulation is minimal and quickly removed by radiative and thermal processes. Even if there is an outstanding accumulation on the surface, our observations indicate that this new mass does not remain enough to cause downward movement. It is important to notice that the glacier dynamics is dominated by the

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energy exchanges on the surface air temperature variability, the snow/ice cover and accumulation/ablation on the glacier, as the referee comments. However, in the absence of mass balance data we rely our interpretations about the behavior of the glacier dynamics on our field observations and measurements. For decades visual observations indicated that most of the ablation occurs during the dry season on the glaciers of this latitude (Delgado Granados et al., 2007). However, no instrumental data existed for long time, mainly due to inaccessibility and performance of measurements with high altitude meteorological stations due to the logistic and technical challenges. It was not until the first data was available that we were able to support the visual observations with instrumental data. Ontiveros-González (2007) shows a dry season with a peak in February. The observations shown in that work lead to the conclusion that this season is characterized by ablation. In Ontiveros-González et al. (submitted) this conclusion is extended with more observations. So, we reinforced the conclusion that net radiation is the main factor producing melting over the glacier surface. Nevertheless, the information and conclusions mentioned above came from a single point over the glacier surface. So we considered important to study the distribution of the net radiation over the glacier's surface. in this paper we focus on the capability of ASTER images to get the net radiation distribution over the surface and, at the same time, calculate the glacier limits. This approach allowed us to qualitatively establish the zones prone to retreat due to ablation exposure based on the values of net radiation for the dry season. We had access to the complete ASTER catalog. Unfortunately, there are very few useful images for this purpose (free of cloud cover or completely covering the area of interest). We included in the submitted version a set of processed images for the dry season of a three-year period, because it is also the time when the glacier boundaries are clearly seen (free of cloud cover and absence of snow cover). Now we are also including additional three images for a non-dry (i.e. rainy) season. These new images show the same pattern as observed in the dry season: the net radiation distribution shows the same although less enhanced pattern. Below, please find our answers to the referee's criticism beginning with the letter "A".

Answers to specific comments and suggestions

1) "Realising a more extended study of glacier surface-area change using Landsat images, freely available on the USGS website, and analyse the results in relation with meteorological data available in the region, and/or reanalysis data, and/or climate indices like SOI, STT..."

A: We included glacier surface-area data using Landsat images as suggested. (see Figure 3 and Table 2 on supplements).

Figure 3. Glacial shrinkage on Citlaltépetl Volcano from 1973 to 2010. Outlines from 1973, 1989, 1999, 2000, 2006, 2009 and 2010 were delimited using Landsat data of the sensors MSS and ETM+. The rest of the outlines are from ASTER data (Figure 2).

2) "Adding a description of the climate seasonnality and the mass balance seasonality in this region of the world."

A: Ontiveros-González (2007) and Ontiveros-González et al. (submitted) tackle this issue so we don't get into this. The reference of Ontiveros-González (2007) can be accessed at http://132.248.9.195/pd2008/0627305/Index.html

3) "Presenting in detail the seasonnal and annual cycle of the meteorological data measured at the AWS since 2006 on and close to the glacier (SWin SWout, LWin, LWref, albedo, Rnet, T , humidity, accumulation, etc...) instead of quoting a Master tesis work (Ontiveros-Gonzalez, 2007), impossible to find for a foreign researcher."

A: See our answer at 2.

4) "Working on the net radiation maps computed from the ASTER images. The authors claim that their results of net radiation distribution on the glacier for a single date per year are representative of the energy balance in the rest of the year, but this point is doubtful when one sees the annual cycle of Rnet shown in Figure 4. One first thing to do is to compare the albedo and surface temperature values given by the satellite data with the values given by the AWS on and out of the glacier."

A: The dates included in this paper are the best in the USGS catalogue for ASTER data. We studied 55 images among which only 6 are without cloud cover and only 3 of them are close to the dry season, the best time for determination of areal glacier cover. We are including now 3 more images of non-dry season and 1 of dry season confirming that the pattern persists around the year. (See Figure 6). Figure 4 is now renumbered as Figure 5 that contains the variation of the net radiation.

Figure 6. Net radiation distribution over Glaciar Norte's surface derived from ASTER imagery. The highest values are observed in February 2003 and March 2007. In almost images is possible to observe the strongest values of net radiation on the western part of the glacier.

5) "Finally, the Abstract, Introduction and some other parts of the paper would gain of being reviewed by an english native speaker."

A: An English native speaker revised this paper. Melinda M. Brugman kindly read the amended manuscript as stated in the acknowledgements.

6) "Abstract: P. 3150, L. 2: replace "elimination" by "disappearance". "

A: Done and amended at a new version of this discussion paper: "tc-2012-69_new.pdf" on supplements.

7) "P. 3150, L. 9-10: replace "would be gone" by "might have disappeared"."

A: Done

8) "P. 3150, L. 10-12: The sentence "The net radiation from ASTER images and the energy fluxes calculated via the meteorological data at the glacial surface show the close relationship between glacial shrinkage and surface energy balance", is not demonstrated in the paper! There is no analysis of the surface energy balance, even if a AWS is apparently available on the glacier since many years..."

A: P. 3160, L. 10-12: We refer the work by Ontiveros-González (2007). At P. 3160, L.

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15-18 we describe how Ontiveros-González (2007) concluded that net radiation is the principal component on the energy balance and then he relates net radiation with mass loss on the glacier surface. We relate this influence of net radiation with the pattern of mass loss but in a spatial form. This is described in P. 3161, L. 3-7. Here, we use the premise of albedo influence described by Mölg and Hardy (2004) but using the net radiation. It is important to notice that the albedo is close related with the net radiation where low albedo means high values of net radiation. So, if net radiation is closely related to the energy balance and the energy balance is related to the gain or loss of mass (if this is negative or positive respectively), net radiation should be related to the mass loss or gain. Then, we relate the zones at the image where the net radiation is high and determine which zones are prone to retreat. We showed one example of this in Figures 2 and 6.

Figure 2. Ice-coverage changes of Glaciar Norte between 2001 and 2007 obtained from ASTER images. Figure 2e shows changes of the glacier boundaries through that period. The ellipses make evident the glacial shrinkage. a) 20 October 2001; b) 3 February 2003; c) 23 November 2005; d) 18 March 2007.

9) "P. 3150, L. 12-13: The last sentence "The magnitude of changes... glacial retreat in Mexico" can be removed from the abstract as this point is not demonstrated in the paper."

A: This is one of the main results from the processing and analysis of the ASTER images. On P. 3163, L. 23 – P. 3164, L.6 we discussed this statement, the high values of net radiation makes the surface more exposed to melting and if this values are low as happened for Glaciar Oriental, this surface retreats lower than the other surfaces on the glacier.

10) "Introduction: P. 3150, L. 20: replace "understanding" by "knowledge"."

A: Done

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11) “P. 3150, L. 22: replace “Mexico” by “the surrounding areas”.”

A: Done

12) “P. 3151, L. 1: replace “it is possible there could be water shortages” by “it is possible that water shortages may occur”.”

A: Done

13) “P. 3152, L. 4: “algorithms were developed to”. The used equations already existed before the study was realised, so that you should write, “were used”.”

A: Done

14) “P. 3152, L. 6: “in this work the relationship between net radiation and glacial retreat was established or the entire glacier surface”. I can’t see in this paper any relationship established between these parameters.”

A: In this study we obtained radiation values from the ASTER data. The net radiation obtained from these images allowed the determination of the net radiation spatial-distribution during each year’s dry season for the studied period. Then, using the net radiation-energy balance relationship established by Ontiveros-González (2007) and Ontiveros-González et al. (submitted) we document a spatial link between the net radiation and glacial retreat. This assertion is developed on the Results and Discussion sections.

15) “Glaciers of Citlaltépetl Volcano

A: P. 3152, L. 21-22: A reference is missing for the advances of the glaciers during the early Holocene, and furthermore how these advances were dated??” Done.

16) “P. 3152, L. 23: remove the paranthesis (5000-100 yr before present). Do you consider these dates as the time limits of the Neoglacial? Were does it come from?”

A: Done.

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17) “P. 3152, L. 26-27: “the LIA ended in Mexico during the mid 19th century”. How the moraine were dated? I can’t find the quoted references by Heine.”

A: Done.

18) “P. 3153, L. 7: replace “during” by “in”. “

A: Done

19) “Last paragraph beginning P. 3153, L. 19: instead of quoting the work of Ontiveros-Gonzalez which is a student tesis, imposible to find for a foreign researcher, you should better describe the regional seasonnality of climate. And it is the same thing everywhere in the paper when you quote this reference to mention the works on surface energy balance realized on the glacier (see “general comments #3).”

A: This reference is valid. The Universidad Nacional Autónoma de México gives access to anyone around the world to the thesis of our students so, any “foreign researcher” can access our libraries with a larger freedom than at many other large universities around the world for the same material. To make it easy to the referee, in the meantime the Ontiveros-González et al. paper is accepted for publication in an international journal, we include the link where any “foreign researcher” can access the thesis (http://132.248.9.195/pd2008/0627305/Index.html). We also annotated the link in the reference list of the new manuscript (tc-2012-69_new.pdf).

20) “P. 3153, L. 21-22: “Furthermore, the net radiation on the surface impacts this seasonality”. I assume “this” is used for “local weather” which appears in the former sentence. How can the net radiation at a glacier surface impacts the local weather?”

A: The glacier surface and the atmosphere are linked by the energy exchanges present at that interface. The radiation coming from the sun and the radiation fluxes varying on the surface are part of these energy exchanges. The variability of these parameters like sensible and latent heat, and net radiation determine variability of the energy balance. Then, the energy balance results from the energy exchanges on the surface. Thus, the local weather is related with the energy balance on the glacier surface and also the local variations. Following the conclusion of Ontiveros-González (2007) work, if the net radiation dominates the energy balance on the surface it should impact the seasonality of the local weather.

21) "P. 3153, L. 24-28: this sentence has to be re-written. It is because, the region of interest is far from pollution sources and because the volcanic activity is low, that you can assume that climate change is the main cause of glacial retreat."

A: Done.

22) "3.1 Meteorological data The location of the two AWS could be shown on the map (Fig. 1)."

A: Done. Find a modified Figure 1.

Figure 1. Location of Citlaltépetl volcano and extent of its glaciers as documented in 1958 (Lorenzo, 1964; grey area) and 2007 (this work; contour in blue). Shaded relief of 1:20,000 DEM from SIGSA (Sistemas de Información Geográfica S. A.). MC: Mexico City; C: Citlaltépetl Volcano.

23) "More details are needed about the NARR data (resolution of the grid, method of interpolation, coordintate of the grid cell(s) used in this study, etc....)"

A: Added.

24) "What about the meteorological data after the 15th of october 2009. The paper has been submitted in May 2012!"

A: Due to the inaccessibility to the AWS, maintenance has been a problem due to extreme weather conditions at the high altitude, and most recent data was lost. Currently, the AWS are out of order.

25) "3.2 Glacier mapping from ASTER What are the Path/raw of the used images? What are the dates of the used images? What is the accuracy on the ground control

points? What is the resultant error on the glacier surface-area computed?"

A: Done. Please find Table 1 in the supplement attached.

26) "3.3 Spatial distribution of the net radiation P. 3156, L. 25: remove "it" after "were made"."

A: Done

27) "P. 3156, L. 27: replace "moment" by "date"."

A: Done

28) "P. 3156, L. 28: remove "it" after "is made"."

A: Done

29) "P. 3157, L. 2: remove "a" after "and"."

A: Done

30) "P. 3157, L. 11: replace "Stephan" by "Stefan" and write it like it: Stefan-Boltzmann. Stefan is not the first name of Boltzmann, his first name was Ludwig! But Stefan the family name of Jozef Stefan, the austrian physicist, thesis director of Ludwig Boltzmann."

A: Done

31) "P. 3157, L. 14: replace "Boltzmann constant" by "Stefan-Boltzmann constant"."

A: Done.

32) "P. 3158, L. 15: remove the "s" for the word "regression"."

A: Done

33) "P. 3158, L. 23: replace "Stephan" by "Stefan"."

A: Done

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34) “P. 3159, L. 11: replace “Stephan” by “Stefan”

A: Not found.

35) “4.2 Surface distribution of the net radiation This part has to be completely changed, and reorganised, see general comments #3 and #4.”

A: See the response for comments #3 and #4.

36) “P. 3160, L. 10: It would be more usefull to describe the energy balance at the glacier surface than given the reference of a Master Thesis (Ontiveros-Gonzalez, 2007) impossible to find.”

A: This description is a matter of another paper (Ontiveros-Gonzalez et al., submitted); the referencing policy of The Cryosphere does not allow the use of references under submission process. The reference of the Masters thesis is available at: http://132.248.9.195/pd2008/0627305/Index.html.

37) “P. 3160, L. 12: “Those values ... lead us to calculate” Why “lead us”... Where these results are presented in the current paper??? There should be!”

A: Amended

38) “P. 3160, L. 16 and 18 and 21: replace “on” by “at”.”

A: Done

39) “P. 3160, L. 20: replace “where” by “when”.”

A: Done

40) “P. 3160, L. 20-21: “This period is accompanied by an increasing of net radiation values on the glacial surface”. Due to what?? Explain.”

A: The reason why the net radiation reaches high values on the glacial surface is because this period is the driest season of the year, so there are no clouds during the day. Strong incoming short-wave radiation has a role in this increase.

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41) “P. 3160, L. 24-25: “A strong sublimation occurs due to the intense radiation in spite of the prevailing cold temperatures of this season”. Where does it come from? The sublimation is not a consequence of the radiation but of the turbulent fluxes and so of the temperature and humidity gradient between the glacier surface and the air. Furthermore, there is no relationship between cold temperature and sublimation. You can have sublimation with negative temperature! In other words, cold temperature do not prevent sublimation to occur.”

A: Agreed, sublimation can occur with negative temperature. Furthermore: sublimation occurs at temperatures and pressures below a substance’s triple point. Snow and ice sublimation is slower below the melting point temperature. If the temperature of the surface is far below the melting point (far below the triple point) the sublimation is inhibited. Then the only energy source for sublimation to occur is the radiation coming from the sun. The sentence was amended.

42) “P. 3161, L. 1-2: “That means an absence of sublimation that may enhance the effects of radiation making the mass balance more negative.” How can the absence of sublimation that enhance the effects of radiation?? What does it mean?”

A: Amended.

43) “P. 3161, L. 6-7: “the more vulnerable zones for glacial shrinkage (mass loss) are those where the net radiation has the highest differences”. What does “the highest differences” mean??? Differences with what? Are you talking about spatial variability?”

A: Amended.

44) “P. 3161, L. 10: remove the “s” at “decrease”.”

A: Done

45) “P. 3161, L. 15: replace “difference between” by “higher from”.”

A: Done

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46) “P. 3161, L. 16-18: “Since the images were selected into the driest month of the year in Mexico, this could be considered as representative of the ablation season in a balance year.” How can you say that!! This has to be demonstrated!”

A: The driest season is for Mexican glaciers the most representative ablation season during the year. Also, these glaciers show ablation in the whole year, then, we can approximate the ablation of these glaciers from the driest season of the year on a yearly comparison basis. Accumulation of snow could happen at the same time but it cannot remain for much time as is evident after the field campaigns and visual observations. See response for comment 4. We have included the net radiation distribution for non-dry season to reinforce this (see Figure 6).

47) “P. 3161, L. 18-19: “net radiation is then the controlling factor for ablation on the glacial surface”. This point is largely known for tropical glaciers... you should almost quoted a reference, which are not missing, see the papers of Kaser, Wagnon, Favier, Sicart, Molg, etc...”

A: Done.

48) “P. 3161, L. 19-20: “The net radiation values for 2007 are in agreement with the values measured on the same day of the year by the Glaciar AWS”. Interesting to read, but you have to mention the values given by both the AWS and the satellite!”

A: Done.

49) “5 Discussion and 6 Conclusions The discussion session has to be completely changed. This part is full of inaccuracies, generalizations not supported by the results, inconsistencies, etc. Just one exemple: the authors mention that March 2007 was the highest values of Rnet, they conclude that a strong ablation was occuring on the glacier, but this same year, they mention that the retreat was very reduced... this is inconsistent with their hypotesis that the glacier retreat is linked to the distribution of Rnet (which is a wrong hypothesis because of the time-lag in the response of the glacier surface-area

changes to the changes in mass balance). The conclusion has also to be changed!"

A: The calculation of the glacial limits with the ASTER images could show an effect of growth of the glacial surface if there is snow present on the scene that can mask the real limits of the glacier and enlarge the area value. Although overestimation is just one factor for a reduction of the retreat rate, there are other reasons that can support glacier growth and be consistent with the surface distribution of net radiation. As an example: El Niño phenomenon could change the actual pattern of this glacial retreat rising or decreasing retreat rates, which has not been evaluated yet. According to the referee suggestion, new data were added from Landsat scenes. Variations of glacial retreat can be seen for some years and are discussed in this section. However, retraction of Citlaltépetl Volcano's glaciers is evident in spite of those variations.

50) "Figures Figure 1: The map showing the glaciers extension in 1958 could be in color and adding the contour line of the glaciers in 2007 to show the retreat over the 50 yrs. What is the source of the DEM used in the background?"

A: Done.

51) "Figure 3: The X-axis should be changed to be proportional to time."

A: We amended the figure, including additional ASTER and LANDSAT data as suggested by the referee. Please find Figure 4. The gap between 1958 and 1973 of the first LANDSAT image is large as well as other gaps in between those images and the yearly sequence of the ASTER images so, for the sake of clarity we prefer to maintain the axis format.

52) "Figure 4: The authors say P. 3155, L. 1., that the data are available over the period from 2006/09/17 to 2009/10/15, but only present the data for the period Sept 2006 to July 2007. The analysis of the seasonnal and annual variation of Rnet at the glacier surface would gain by presenting all the data. Also, what about the data after 2009? We are in 2012."

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A: Due to the inaccessibility to the AWS, maintenance has been a problem due to extreme weather conditions at the high altitude, and most recent data was missed. Currently, the AWS are out of order. Nonetheless, the complete data is presented in Ontiveros-González et al. (submitted) (Figure 5 attached).

53) "Another important point: the peak in early March 2007 reaching about 500 m/w2 looks more like an error of measurements! Apparently, the data presented on this graph are daily average (it should be mentioned). And reaching such a value for a daily average of Rnet is impossible."

A: Graph corrected. The "Y" axis is Average Net Radiation (see Figure 5 attached). For this period the instrumentation was new and calibrated, so the data is correct. There are several high values that on average throw this peak. Furthermore, the peak appears as part of an increase-decrease tendency.

54) "Figure 5: The scale must have intermediate graduation (not only the min and max values), to help the reader to better understand the spatial distribution of Rnet."

A: Done. Please find Figure 6.

55) "Figure 6: As for Fig. 3, the X-axis should be proportional to time. Also, where does the values for 1945, 1971/1975, 1988 and 1994 come from?? The used data to obtain these values should be presented in the text. Also, what is the dating of the LIA maximal extent, and how the dating was made?"

A: Graph was amended including the data obtained from additional ASTER data and LANDSAT images as suggested by the referee. Please find Figure 7 in the supplement attached. As in Figure 4 we prefer to maintain the same graphing style for clarity. The caption was corrected for better clarity on the sources of the data that do not belong to this study. Further details on the age of the Little Ice Age can be found in Palacios and Vázquez-Selem (1996).

Figure 7. Altitudinal evolution of the glacial front since the end of the LIA. The alti-

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tudes of 2001 to 2007 were calculated from ASTER imagery; values for L.I.A., 1945, 1971/1975, 1988, and 1994 were obtained from Palacios and Vázquez-Selem (1996).

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Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/6/C2010/2012/tcd-6-C2010-2012-supplement.zip

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Interactive comment on The Cryosphere Discuss., 6, 3149, 2012.

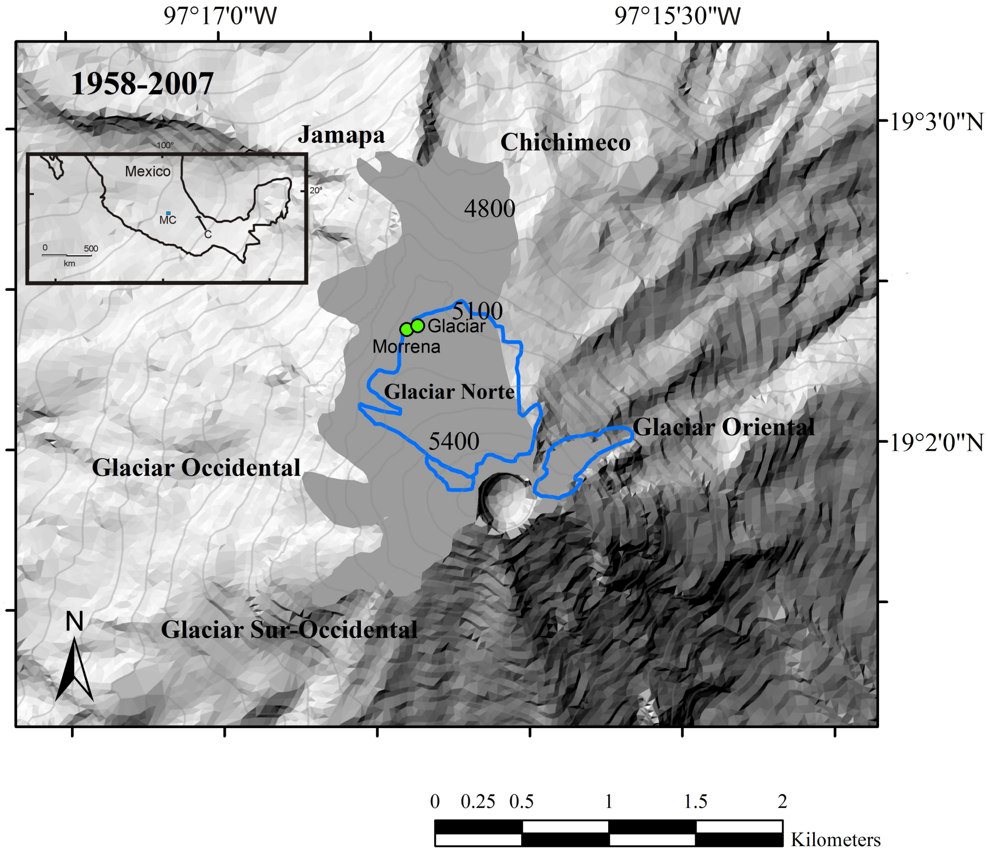

Fig. 1. Location of Citlaltépetl volcano and extent of its glaciers as documented in 1958 (Lorenzo, 1964; grey area) and 2007 (this work; contour in blue). Shaded relief of 1:20,000 DEM from SIGSA

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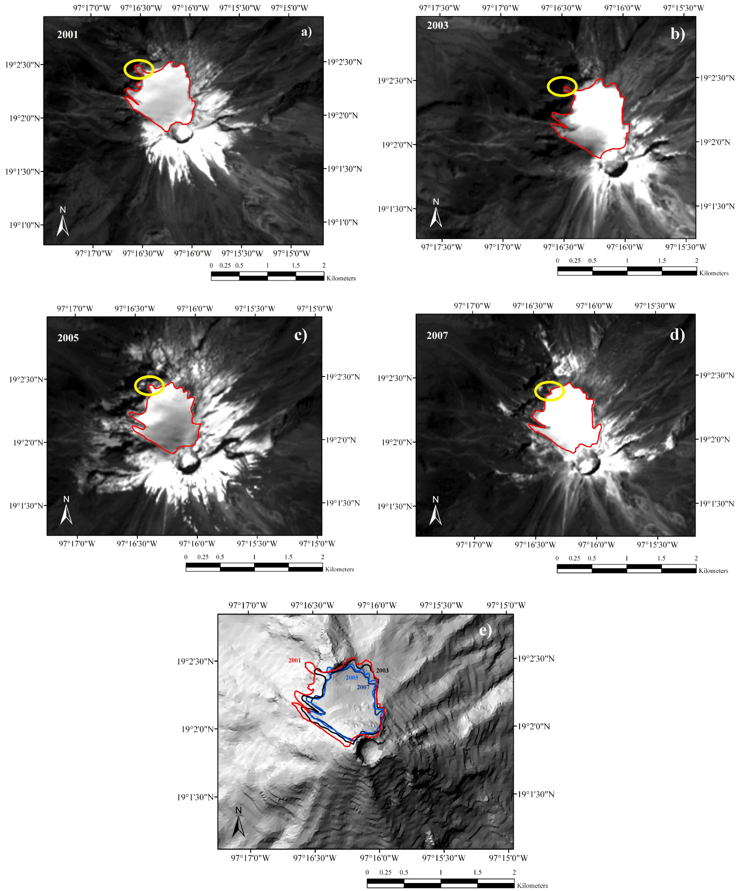

Fig. 2. Ice-coverage changes of Glaciar Norte between 2001 and 2007 obtained from ASTER images. Figure 2e shows changes of the glacier boundaries through that period. The ellipses make evident the glacial

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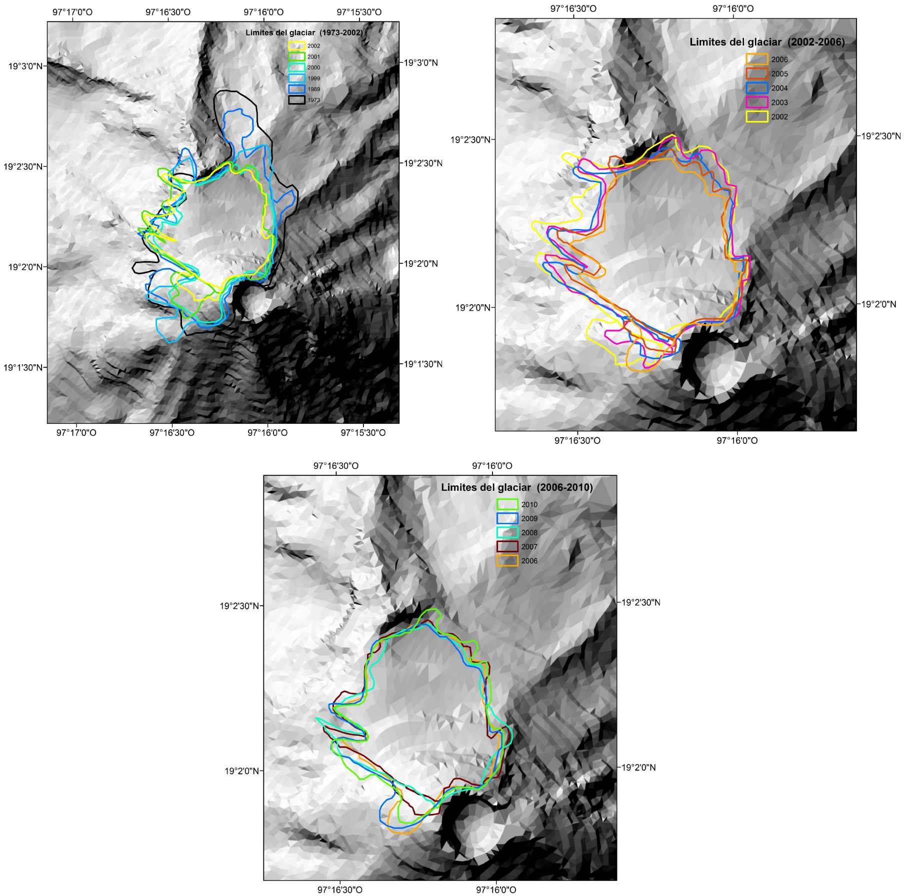

Fig. 3. Glacial shrinkage on Citlaltépetl Volcano from 1973 to 2010. Outlines from 1973, 1989, 1999, 2000, 2006, 2009 and 2010 were delimited using Landsat data of the sensors MSS and ETM+. The rest of the

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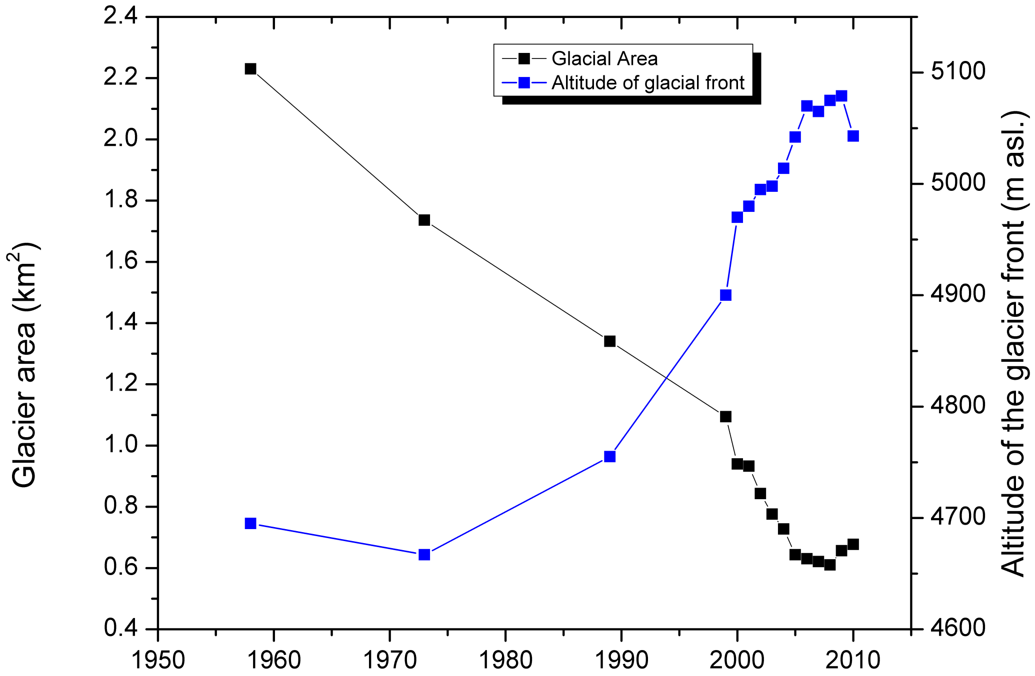

Fig. 4. Glacial area and altitude changes for the period 1958-2007.

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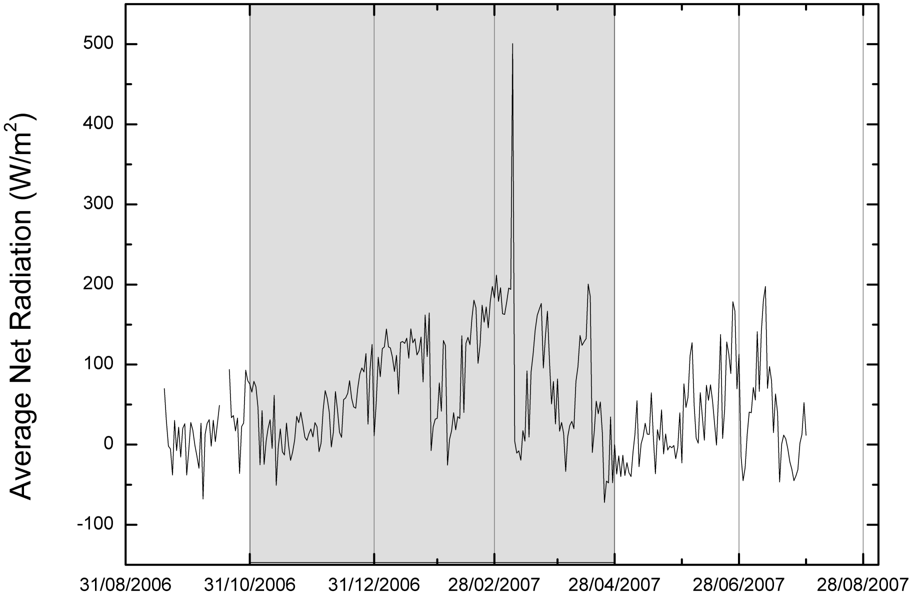

Fig. 5. Net radiation variability of the Glaciar-AWS data from September 2006 to July 2007 (after Ontiveros-González, 2007).

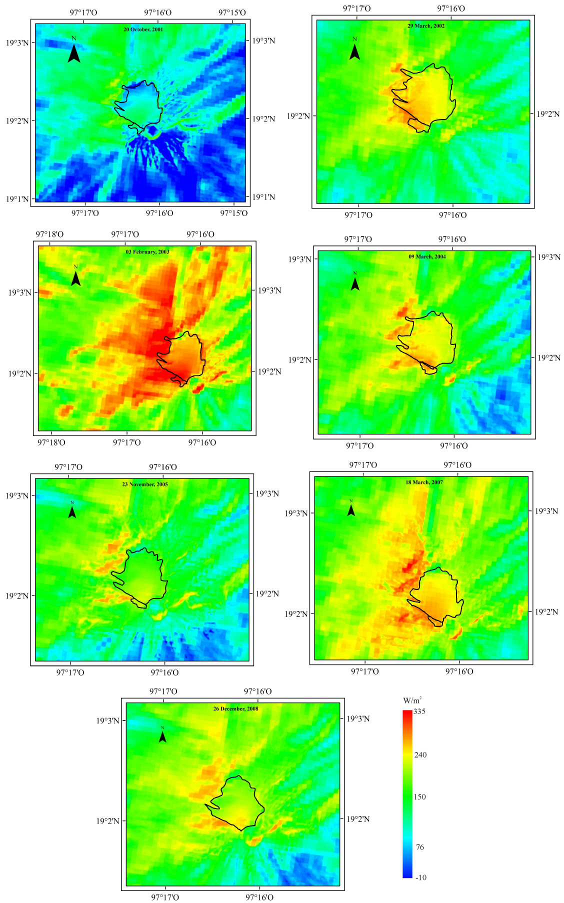

Fig. 6. Net radiation distribution over Glaciar Norte's surface derived from ASTER imagery. The highest values are observed in February 2003 and March 2007. In almost images is possible to observe the

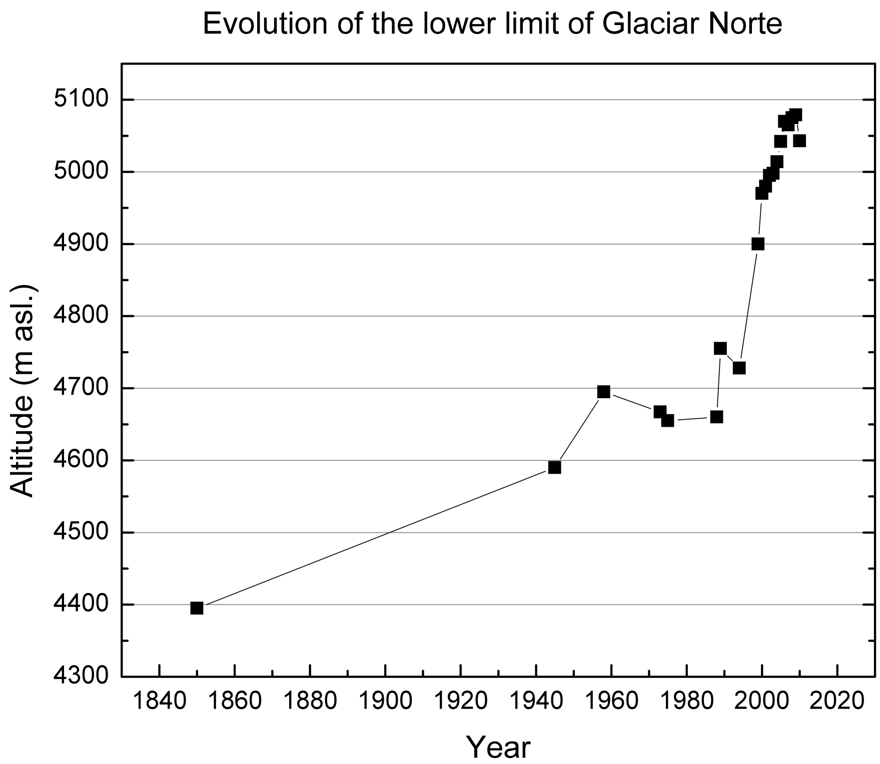

Fig. 7. Altitudinal evolution of the glacial front since the end of the LIA. The altitudes of 2001 to 2007 were calculated from ASTER imagery; values for L.I.A., 1945, 1971/1975, 1988, and 1994 were