Point to point reply (in red) to anonymous reviewer by Azam et al.

Major comments:

This study presented a point-scale surface energy balance analysis using in-situ meteorological data from the ablation zone of Chhota Shigri Glacier over two separate periods. The impact of Indian summer monsoon on Chhota Shigri Glacier mass balance also assessed. However, there are several misconceptions have given in the manuscript. Most important issue is related with Bhunter meteorological data. Authors used meteorological data (Tair and precipitation) of Bhuntar as the representative for the 2012/2013 hydrological year because this station is about 50 km from the Chhota Shigri Glacier. However orographic barrier separate the Beas basin (Bhuntar meteorological station) and Chandra basin (Chhota Shigri Glacier) (Fig 1). Effect of orographic barrier on vegetation distribution and geomorphic process in both basins (Chandra and Beas basins) suggests that Chandra basin is located in monsoon arid zone (monsoon rain shadow area) and Beas basin in monsoon dominated region (Bookhagen et al. 2005; Collins and Hasnain 1995; Srivastava et al. 2013). Thus, is it scientifically correct to use summer monsoon dominate station metrological data as a hydrological representative for Chhota Shigri Glacier which is located in monsoon–arid transition zone? Authors also mentioned on Page 2877, line 16-21 'the winter westerlies predominantly undergo orographic capture at higher elevations in the orogenic interior providing high precipitations at Chhota Shigri Glacier (79% of annual precipitation) compared to Bhuntar meteorological station in windward side (49% of annual precipitation). Thus, Chhota Shigri Glacier seems to be a winter-accumulation type glacier receiving most of its annual precipitation during winter season.' If the precipitation pattern by ISM and MLW is highly variable between Chhota Shigri base camp and Bhuntar meteorological stations (i.e inside the airport, and just 4 kilometers from the confluence of Beas and Parbati Rivers) then the question rises here, how valid is **the re-constructed mass balance for Chhota Shigri Glacier** (monsoon–arid zone) using meteorological data of Bhuntar station (monsoon dominated region) (**Azam et al. 2014 AoG paper**)? Authors have also hid orographic barrier on map in Azam et al. 2014 TCD and Azam 2014 AoG. We believe this is questionable and this can mislead the readers. Fig1. Orographic barrier (watershed divide) between Chandra and Beas basins.

We thank this anonymous reviewer for her/his comments. We completely agree that there is an orographic barrier between both locations as clearly stated in our initial manuscript or previously in Azam et al, AoG, 2014:

TCD paper P 2877, lines 7-14: *"The different precipitation regimes in this region can be explained by the location of the orographic barrier which ranges between 4000 and 6600m in elevation (Wulf et al., 2010). ISM, coming from Bay of Bengal in the south east, is forced by the orographic barrier to ascend that enhances the condensation and cloud formation (Bookhagen et al., 2005) thus, provides high precipitations in the windward side of the orographic barrier at*

Bhuntar meteorological station (51% of the annual precipitation) and low precipitations in its leeward side at Chhota Shigri Glacier (21% of annual precipitation).".

Azam et al, AoG, 2014, section 5.1: "*Moreover, during these events which are probably triggered by the orographic effect (Bookhagen and Burbank, 2010), precipitation amounts measured at Bhuntar Observatory are not always representative of those occurring on the glacier."*

Since in both the papers this orographic effect has been mentioned and discussed, it is clear that we did not hide this fact. Nevertheless, we agree that the question is still reliable, and that using meteorological data collected on the windward side of the range to apply them on its leeward side can be questioned.

The main problem comes from the availability of the data. There is a meteorological station at Keylong located on the leeward side of the range, and closer to the glacier, with long term data available since 1985, but actually, we could not get access to this dataset. However, this dataset is shorter than Bhuntar (available since 1969) and might not be the good option to reconstruct the long term mass balance series for Chhota Shigri Glacier but it could be used to have a better understanding of the distribution of precipitation in leeward and wind ward side. Some studies even showed that the precipitation at near-by stations is less correlated with the glacier mass balance than the stations located farther because local stations usually located in valleys are influenced by local micro-meteorology due to their position at the bottom of valleys (Stuefer, 1994). As a consequence, the only dataset that we could use for this present paper (Fig 4 and 5), and also for Azam et al AoG, (2014) was Bhuntar dataset.

Without additional dataset, we thus could not accurately assess the meteorological differences between Bhuntar and Chhota Shigri Glacier as mentioned in Azam et al (AoG, 2014):

"Nevertheless, additional measurements (e.g. systematic comparisons between precipitation at Bhuntar and at the glacier elevation) are still required to explain in detail these discrepancies between modelled and observed MBs."

Though, Chhota Shigri Glacier is located at 50 km (aerial distance) from Bhuntar, it is not true that meteorological data at Bhuntar are completely decoupled from those at the glacier. Wulf et al. (2010) did a thorough study using the precipitation data of 80 stations from the northwest Himalaya including Chhota Shigri Area and concluded that in Baspa Valley (~100 km southeast to Chhota Shigri Glacier):
"*The two most prominent 5-day-long erosional events account for 50% of the total 5-year suspended sediment flux and coincide with synoptic scale monsoonal rainstorms. This emphasizes the erosional impact of the Indian Summer Monsoon as the main driving force for erosion processes in the orogenic interior, despite more precipitation falling during the winter season*."

It is true that the amount of monsoonal precipitation on the windward side of the mountain is higher than on the leeward side, and we extensively discussed and quantified this point in our present manuscript (it was not possible to quantify this difference in Azam et al, AoG, 2014, because our Geonor sensor had not been installed at that time). We also believe that if 2012/13 is an average year in terms of meteorology at Bhuntar (section 2.4.3), we can assume that it is also the case on the glacier. In order to be clearer, we supported our analysis (section 5.1) with the study of Wulf et al. (2010) and added a small paragraph in section 5.1 in the revised manuscript:

"As already discussed in section 2.4.2, Bhuntar meteorological station and Chhota Shigri Glacier are separated by an orographic barrier and consequently the precipitation distribution is different at both sides. In agreement with the present analysis between mass balance and ISM snow falls, Wulf et al. (2010) already did a thorough study using the precipitation data of 80 stations from the northwest Himalaya including Chhota Shigri area and concluded that in Baspa Valley (~100 km southeast to Chhota Shigri Glacier) "The two most prominent 5-day-long erosional events account for 50% of the total 5-year suspended sediment flux and coincide with synoptic scale monsoonal rainstorms. This emphasizes the erosional impact of the ISM as the main driving force for erosion processes in the orogenic interior, despite more precipitation falling during the winter season."

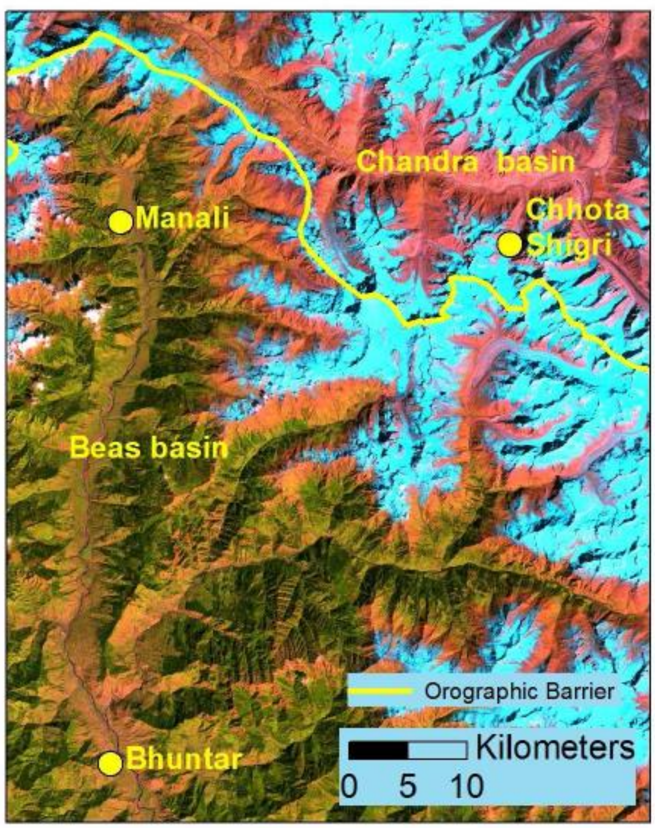

Fig1. Orographic barrier (watershed divide) between Chandra and Beas basins.

Other comments

1. Page 2868, line 1-2 'Recent studies revealed that Himalayan glaciers have been shrinking at an accelerated rate since the beginning of the 21st century.' But studies on Chhota Shigri Glacier show 4 years positive mass balance during 2003-2011.

   Figure A (below) shows the annual as well as the cumulative mass balances of Chhota Shigri Glacier between 2002 and 2013 (Azam et al., under preparation). Although the glacier showed four years of positive (generally close to balanced conditions) mass balance as pointed out by the reviewer, , this glacier lost a cumulative mass of –6.45 m w.e. over the last 11 years corresponding to an average annual mass balance of –0.59 m w.e. yr^{-1}. Comparing all the available mass balance series, including the Chhota Shigri Glacier mass balance between 2002 and 2010, from the Himalaya and Karakoram region over the last five decades, Bolch et al. (2012) concluded that the glaciers are in an accelerated mass loss especially after 1995. Consequently the four years of slightly positive mass balance should not be misunderstood with the regional picture of mass loss. In the revised manuscript, we re-phrased the sentence to avoid any misunderstanding. Now it is:

   "Some recent studies revealed that Himalayan glaciers have been shrinking at an accelerated rate since the beginning of the 21st century."

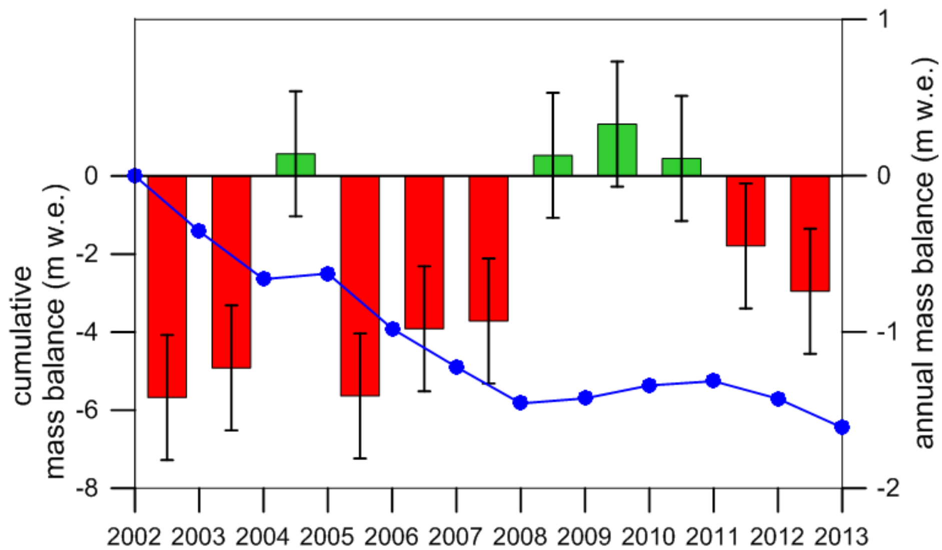

Fig. A. Cumulative (blue line) and annual glacier-wide mass balances (red and green histograms) of Chhota Shigri Glacier between 2002 and 2013. Black error bars represent the uncertainty in annual glacier-wide mass balance.

2. Page 2868, line 5-8 'In this study, a point-scale surface energy balance analysis was performed using in-situ meteorological data from the ablation zone of Chhota Shigri Glacier over two separate periods (August 2012 to February 2013 and July to October

2013) in order to understand the response of mass balance to climate change.' As per the IPCC definition (2011) of climate change a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Authors used about one year meteorological data how they understood the response of mass balance to climate change. This needs to be clarified.

We agree with the reviewer and replaced “climate change” with “climatic variables” in the revised manuscript.

3. Page 2868, line 5-8 'The impact of Indian summer monsoon on Chhota Shigri Glacier mass balance has also been assessed. This analysis demonstrates that the intensity of snowfall events during the summer-monsoon season plays a key role on surface albedo, in turn on melting, and thus is among the most important drivers controlling the annual mass balance of the glacier.' What impact? It delays the melting? Or enhance the melting? This needs to be clarified in abstract.

   Done. The revised sentence is:

   ‘The impact of Indian summer monsoon on Chhota Shigri Glacier mass balance has also been assessed. This analysis demonstrates that the intensity of snowfall events during the summer-monsoon season plays a key role on surface albedo (melting is reduced in case of strong snowfalls covering the glacier area), and thus is among the most important drivers controlling the annual mass balance of the glacier.”

4. Page 2869, line 4-7 'Some recent studies have found negative mass balances over Himalayan glaciers (e.g., Azam et al., 2012; Bolch et al., 2012; Kääb et al., 2012; Gardelle et al., 2013), with the fact that the Himalayan glaciers (22 800 km2) have been shrinking at an accelerated rate since the beginning of 21st century (Bolch et al., 2012; Azam et al., 2014).' Azam et al., 2012; 2014 references are based on single Chhota Shigri Glacier whereas authors have given statement on whole Himalayan glaciers. There are many other references on single Himalayan glacier mass balance. So should include other references on single Himalayan glacier mass balance or omit Azam et al., 2012; 2014.

   Done, Azam et al, 2012 and 2014 have been omitted.

5. Page 2869, line 11-13 'Unfortunately, data on recent glacier changes are sparse and even sparser as we go back in time (Cogley, 2011; Bolch et al., 2012) and, thus, the rate at which these glaciers are changing remains poorly constrained (Vincent et al., 2013).' This statement doesn't show authors are explaining glacier changes are sparse for Rockies/Andes/Alps or Himalaya.

   Done. We revised the sentence to make it clearer to the reader. Now it is:

"Unfortunately, data on recent glacier changes in the Himalayan region are sparse and even sparser as we go back in time (Cogley, 2011; Bolch et al., 2012) and, thus, the rate at which these glaciers are changing remains poorly constrained (Vincent et al., 2013)."

6. Page 2869, line 13-20 'The erroneous statement in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007) about the future of Himalayan glacier has highlighted our poor understanding of the behavior of the region's glaciers to climate. However, the IPCC Fifth Assessment Report (IPCC, 2013) stated "Several studies of recent glacier velocity change (Azam et al., 2012; Heid and Kääb, 2012) and of the worldwide present-day sizes of accumulation areas (Bahr et al., 2009) indicate that the world's glaciers are out of balance with the present climate and thus committed to losing considerable mass in the future, even without further changes in climate".' In a first statement authors criticized the work of IPCC without any citation and in second statement they referred IPCC Fifth Assessment Report as one of the authors paper was cited in this report. This needs to be corrected.

   Our intention was not to criticize the work of IPCC (2007) and if it has been understood as such, we sincerely apologize for this to IPCC. As also suggested by reviewer 2, the sentence has been revised as follow: The revised sentence is:

   "The erroneous statement in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (Solomon et al., 2007) about the future of the Himalayan glaciers dragged the attention of the scientific community towards the behavior of the these glaciers in relation to climate. However, the IPCC Fifth Assessment Report (Stocker et al., 2013) stated "Several studies of recent glacier velocity change (Azam et al., 2012; Heid and Kääb, 2012) and of the worldwide present-day sizes of accumulation areas (Bahr et al., 2009) indicate that the world's glaciers are out of balance with the present climate and thus committed to losing considerable mass in the future, even without further changes in climate."

7. Page 2870, line 18 'Chhota Shigri Glacier is one of the best studied glaciers in Indian Himalaya.' In terms of what?

   In terms of mass balance. Indeed, with more than one decade of continuous annual mass balance data, Chhota Shigri Glacier is one the most studied glacier in the Himalayas.

   The sentence has been revised for better understanding:

   "In this paper, we present a SEB analysis for Chhota Shigri Glacier, Western Himalaya. This glacier is one of the best studied glaciers in Indian Himalaya, in terms of mass balance."

   Page 2870, line 8-9 'Unfortunately glacier SEB studies from Indian Himalaya (covering Western, some Central and Eastern parts of Himalaya) are not available. Here what is "some" mean? Is that the area covered in Indian Himalaya or the SEB studies commenced over some part of the Central Himalaya? Need to be clarified.

Here "some" means the glacierized area covered by Indian Himalaya. In the revised manuscript, we rephrased the sentence to make it clearer:

"Glacier SEB studies from Indian Himalaya (covering Western as well as parts of Central and Eastern Himalaya) are not yet available."

8. Page 2870, line 19 to 30 and Page 2871, line 1 to 7 purely literature review. What is the output of this paragraph? There is need to be improved.

   This paragraph is a review of the work done on Chhota Shigri Glacier. We do believe this kind of review is helpful for the reader to get a quick but basic knowledge about the glacier and should be part of the paper.

9. Page 2871, line 18-21 'It involves two main objectives: (1) the glacier's microclimate is analyzed' As per WMO climate is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over at least 30 years of time. Authors used about one year meteorological data how they analyzed the glacier's microclimate. Use correct terminology. Also the objectives defined here and the statement at page 2868, line 5-9 "In this study, a point scale surface energy balance analysis was performed using in-situ meteorological data from the ablation zone of Chhota Shigri Glacier over two separate periods (August 2012 to February 2013 and July to October 2013) in order to understand the response of mass balance to climate change" is not perspective to each other. See comments for Page 2868, line 5-8 above.

   Done. The word "microclimate" is replaced with "micrometeorology" in the revised manuscript.

   We feel that there is some confusion. In fact we used data from two AWSs. AWS1(less than one year of data) at the glacier surface that is used to conduct SEB study and AWS2 (four years of data between 2009 and 2013 and not just one year as stated by the reviewer) that is used to analyze the micrometeorology of the glacier. We invite the reviewer to read the section "2.1 Study site and AWSs description" in the manuscript.

10. Page 2871, line 26 'It lies ~25 km from the nearest city of Manali.' Aerial distance?

    Yes, it is the aerial distance. Specified now in the revised manuscript

11. Page 2872, line 9 'The equilibrium line altitude (ELA) for a zero net balance is close to 4900ma.s.l. (Wagnon et al., 2007).' Why used equilibrium line altitude (ELA) for a zero net balance based on 4 years data? Why not used Azam et al. 2012 JoG; Ramanathan (2011) mass balance data to calculate ELA0 and AAR0.

    Thanks for this point. In fact in our upcoming work dealing with the mass balances of Chhota Shigri Glacier we have done this based on the 11 years of annual mass balance data between 2002 and 2013. Still the equilibrium line altitude (ELA) for a zero net balance is close to 4900 m a.s.l. As this paper is not even communicated we prefer to keep the same reference here.

12. Page 2876, line 23-25 'Surprisingly, the months with minimum precipitation was July to November (mean value of 16 mm) and those with maximum precipitation were January and February (183 and 238mm, respectively).' Why authors feel surprise? This is fact that Chhota Shigri Glacier is located in monsoon–arid transition zone. Authors knew this and mentioned in several places. See Dobhal et al. (1995); Azam et al. 2014 TCD Page 2872, line 10; Azam et al. 2014 AoG Page 70; Ramanathan (2011) page 13; 73; 78.
    Yes, we know that Chhota Shigri Glacier is located in monsoon–arid transition zone and mentioned this in our previous studies. But in the present study, for the first time, we compared the precipitations amounts at glacier base camp and Valley Station at Bhuntar. Given the difference in regimes it is quite surprising because Chhota Shigri is located in a transition area between monsoon and westerlies and seems to receive precipitation (79%) mainly from westerlies. However as suggested above in the reply of major comments, we need more data from glacier to get better picture of precipitation regimes.

13. Page 2877, line 5 "this station is only about 50 km from Chhota Shigri Glacier.' Aerial distance?
    Yes, it is the aerial distance. Specified now in the revised manuscript

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