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# *Interactive comment on* "Climate change implications for the glaciers of the Hindu-Kush, Karakoram and Himalayan region" *by* A. J. Wiltshire

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## Overview

The manuscript by A. J. Witshire describes the present status and future changes in air temperature, precipitation, and snowfall along the Hindu-Kush, Karakoram and Himalayan mountains projected by two GCMs, which are downscaled using a high resolution regional climate model. Although this manuscript does not deal with energy and mass balances over glaciers, the two drivers are mainly projected and discussed in detail, air temperature as a proxy of glacier ablation and snowfall amount as a proxy of glacier accumulation. Some previous studies have projected changes in glaciers and/or

associated glacier runoffs using GCM outputs as boundary conditions for their mass-balance or runoff models. However, those previous studies have not depicted how the input drivers affected the calculated changes in glaciers or runoffs. This manuscript by Witshire therefore helps us to understand the climate conditions, which are the driving force for changes in glaciers, in this high mountain region where the basic information is scarce. On the other hand, it is unclear how the author deals with altitudes of individual sub-regions, which affect both air temperature and snow accumulation. I request the author to make this point clear.

Major comments

Altitude information

Altitude settings affect air temperature and thus snow accumulation. Each sub-regions discussed in this study should have different altitude distribution, but no relevant information was given. Average, minimum, maximum, distribution, and representative altitudes have to be provided in detail. In particular, the "representative altitude" is important because air temperature and snow accumulation depicted in this study should be calculated at a given altitude for a sub-region. As the author mentioned in the discussion paper that the impact of warming on "positive degree days" differed along the altitude, it is important to disclose which altitude is dealt with.

Besides altitude settings of RCM, the author can analyze the hypsometry (altitude-area distribution) of each sub-region using the Randorph glacier inventory together with high resolution digital elevation models (gap filled SRTM-v4.1 or ASTER-GDEM2). It is important to provide information how the altitude distributions modeled in this analysis are different from/consistent with the latest glacier distributions.

Present climate

More detailed descriptions of present climate (Figs. 6 and 7) and its implications for the present glacier distributions are appreciated.



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Climate changes at different altitudes

Some studies asserted that the higher altitude, the more rapid warming. It will affect future changes in glaciers if it is real. If such phenomena are found in the models in this study, which mechanisms drive it? How much degree? If not, what is the author's idea?

Does larger PDD imply more sensitive glacier?

As the author cited, Fujita (2008a, b) discussed the sensitivity of glacier mass balance, in which glacier mass balance will more sensitively respond to the same degree of warming if the glaciers are situated in the summer accumulation environment. Because the regions analyzed in this discussion paper cover wide regions in terms of precipitation seasonality (summer accumulation in the Himalaya to winter accumulation in the Karakorum), I suppose that the degree of changes in PDD associated with warming cannot be simply implicated to that of glacier sensitivity. Any discussion is required about it.

Other but non-minor points

P3729L12: I do not understand how this degree-day factor was obtained. Need more detailed description.

Minor comments

Chapter structure

"1.1 Baseline regional climate" does not seem Introduction because this part consists of the modeled results.

In the earlier part of "2 Methods", definitions of sub-regions ("2.2" and altitude information too) have to be presented. The relevant figure is too unclear to find those sub-regions.

I request for the author to reconsider the order of chapters.



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Snow to rain probability

It is appreciated how the GCMs/RCMs calculate phases of precipitation, snow or rain.

Reference list incomplete

Scherler et al (2011), Hewitt (2005, 2011), Matsuo and Heki (2010), Bhutiyani (1999), and Fujita (2008a, b) are not found in the reference list. Copland (2011) and Kääb (2012) seem to be just missed "et al", but Cogley (2010) is cited for glacier inventory but Cogley et al (2010) in the reference list does not provide any glacier inventory.

By the way, Scherler et al (2011) concluded that the terminus changes in heavily debris-covered glaciers were equivocal, but they did not dealt with changes in glacier mass. I suppose that it is unnecessary to cite this study so many times in this study. In this regards, Bolch et al (2011) and Nuimura et al. (2012) revealed that the thinning rate of debris-covered glacier surface have been comparable to that of debris-free glacier surface.

Bolch T, Pieczonka T, Benn DI (2011) Multi-decadal mass loss of glaciers in the Everest area (Nepal Himalaya) derived from stereo imagery. Cryosphere, 5, 349–358.

Nuimura T, Fujita K, Yamaguchi S, Sharma RR (2012) Elevation changes of glaciers revealed by multitemporal digital elevation models calibrated by GPS survey in the Khumbu region, Nepal Himalaya, 1992–2008. Journal of Glaciology, 58(210), 648-656.

Positive degree days (PDD) is generally used than the just degree days (DD).

P3719L19: I do not catch why the author can say "and thus" here. If the author wants to say "and thus", aridity/humidity or precipitation contrast or contrast of melt and precipitation seasonality along the catchment have to be described in the earlier part, and then the author can emphasize the importance of glacier meltwater contribution.

P3720: "Karakorum anomaly" seems to be mentioned too many times. I suppose that



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the author can make this part more simple. Matsuo and Heki (2010) did not particularly mention the "Karakorum anomaly".

P3721L22-: I do not catch where this "possibility of future mass increase" comes from even under the current trends observed worldwide. We have to keep it mind that the Karakorum glaciers are currently slightly gaining mass, but it is unnecessary to persist this phenomena because the many other glaciers are shrinking in the Himalayan range.

P3723L9-: I do not catch the feature of precipitation gradient in Figs. 5, 6 and 7. Please rethink the presentation.

P3724L14: Ohmura (2001) is more appropriate than Hock (2003).

Ohmura A (2001), Physical basis for the temperature-based melt-index method, J. Appl. Meteorol., 40, 753–761

Misc

Capital letters have to be used appropriately in the reference list. I found TRMM, GCMs ERA-Interim, IPCC and others are written in small letters. Please check carefully.

P3721L4: Need any reference for avalanche contribution, Hewitt (2011) for instance.

P3721L16: Radić

P3721L27: Please rethink the word "Himalaya Hindu-Kush".

P3722L18: "degree C" after "zero".

P3722L19: I do not catch the written feature in Fig. 2. Fig. 1?

P3723L4: Is Fig. 4 really needed? This is an impressive and beautiful picture, but providing little information.

P3723L5: I do not catch the written feature in Fig. 5.

P3724L26: general circulation models?



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P3728L29: I do not catch the greater winter warming in Fig. 10.

P3729L8: HKKH?

P3729L23: Sentence incomplete. "across the."?

Table 1: Need descriptions what the scenario ab is. Kääb (2012) should be Kääb et al (2012). What is the last "scenario ab"?

Figs. 1 and 5: Depicted domain is too wide. The same domain in Fig. 2 seems more appropriate.

Please rethink color bars in many figures because the current version is too difficult to see.

Fig. 2: Definition of sub-regions has to be depicted in more simple way. No Cogley (2010) is found in the reference list, which should be different from Cogley et al (2010).

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