Final respponse : Factors controlling Slope Environmental Lapse Rate (SELR) of temperature in the monsoon and cold-arid glacio-hydrological regimes of the Himalaya by Thayyen and Dimri

R.J Thayyen and A.P Dimri

We thank the reviewer for his/her constructive comments. Our response is provided to each of the reviewer comments as follows:

C: Chapter 3: The authors present and use lapse rates from daily averaged temperature. However, at least at some stations and for some periods, hourly temperature records are available. What is the impact of using daily temperatures? How strong to the lapse rates vary during a 24-hour period? This certainly depends on the conditions. Nevertheless, the authors should check the high-resolution lapse rates to estimate the uncertainty of the daily lapse rates.

Response: Hourly SELR show higher variability as very localised and temporal factors viz., local clouds, wind etc. could highly influence the instantaneous temperature values. Daily mean temperature reflect daily aggregate weather and more stable SELR. SELR variability reduces from hourly to daily and monthly time step and better represents the regional climatic characteristics which is the main focus of this paper. As per the suggestion we have calculated the standard deviations of the available hourly SELR and discussed along with daily and monthly SELR variability for the monsoon and cold-arid regimes. These changes will be included in the revised manuscript at suitable places.

C: Chapter 4.2: The authors discuss precipitation data without any description of how these data was obtained. The measurement of precipitation in mountainous regions and in regions with a high fraction of solid precipitation is still challenging. What is the uncertainty of the presented precipitation data? Later on, the authors also show relative humidity (Fig. 7c). Again, no information on the measurement methods for the humidity is given in the manuscript. Finally, since the authors claim that moisture is the major driving force, why is the precipitation data necessary? Isn't the moisture a much more important parameter that should be discussed in chapter 4.2 instead of the precipitation?

Response: It is very important, firstly, to understand and know regional climate. Thus precipitation data is presented to distinguish the general climatology of the two distinct glacio-hydrological regimes. As pointed out by the reviewer, precipitation data is not used

anywhere in the modelling. We fully agree with the reviewer's observation regarding the high uncertainty associate with the measurement of solid precipitation in the mountain. Solid precipitation is collected in the standard rain gauges and measured as water equivalent after melting following India Meteorological Department (IMD) standard procedure. We agree with the reviewer that the paper discusses about the importance of the moisture in controlling the SELR under orographic conditions. As suggested we are now providing a discussion on the specific humidity variations in the respective glacio-hydrologic regimes. A new figure is added to describe this variability in the revised manuscript to extend this discussion. In addition, the section of data collection is also being revised thoroughly.

C: Chapter 4.3 and 4.4: In many (all?) cases the ranges of the daily SELR given in the text do not correspond to the values in the corresponding figures. For example, the authors claim that in section-1A the SELR in the core winter months range from 5.8 to 7.5 ◦C/km. However, the SELR shown in Fig. 4a vary between 2 and 10 ◦C/km. The given ranges should be verified and made consistent with the data displayed in the figures.

Response: The figure 4 presents five day moving average of daily SELR. Hence the SELR ranges given in the text will not tally with the smoothened figure. Originally we have submitted the daily SELR plots which was changed to daily pentad as per the advice of the handling editor. We could revert back to the original daily SELR figures in consultation with the handling editor.

C: Chapter 4.3: The authors claim that the SELR in September and November in section1M decreases only "occasionally" to the low range of 4.9 to 5.8 ◦C/km observed during the summer. However, Tab. 1 shows that in September only in two years (out of six) the average SELR was higher than 5.8 ◦C/km, in November this was the case in only one year (out of five). This is not consistent with the statement in the text.

Response: The statement "September and November" has been corrected as September and October as November is already considered as a winter month. The statement is restructured as follows "Monsoon transition month of September continue to experience predominantly lower lapse rate whereas post monsoon month of October experiences predominantly higher (>5.8^{o} K/km) lapse rate."

C: Chapter 4.5: The authors use the ERA-Interim data set to calculate the SELR from reanalysis data in comparison to the observed SELR. However, it is well known that the coarse-resolution re-analysis data do not well capture many features over the rough

topography of the Himalayas. However, results from regional climate models for the Himalaya region are also available (e.g. M. Ménégoz et al., Hydrol.Earth Syst.Sci. 17, 3921-3936, 2013; A.J. Wiltshire, The Cryosphere 8, 941-958, 2014). Wouldn't it be better to compare the observations to the results of the RCM simulations?

Response: The present paper is prepared to discuss the highly distinct SELR of two glacio-hydrological regime of the Himalaya and the role of moisture in controlling temperature with the help of observations. In due course handling Editor asked for inclusion of ERA-Interim data. It is well known to the authors as well that this data set is at very coarser resolution particularly over the highly variable topographic and landuse heterogeneous regions. But the idea is to present large scale influence in reanalysis which in fact is seen up to certain extent in the reanalysis data. Now the corresponding simulations from RCM (RegCM4) driven with ERA-Interim initial and boundary conditions is introduced in the revised figure as instructed by the reviewer with very brief modelling reference; as modelling aspects are felt not to the within the scope of the present work.

C: Chapter 5: The authors discuss the influence of moisture on the SELR in terms of relative humidity. Wouldn't it be better to use absolute humidity? The authors claim the importance of moisture on the SELR. Did the authors correlate the SELR with the observed humidity? Do exceptional dry days during the summer period show high SELR and vice versa for humid days during the winter period? If that is the case this would support their conclusion that the moisture is a very important factor.

Response: We fully appreciate the reviewer's observations. We have introduced a section discussing the specific humidity variations. Mainly we have based our emphasis on moisture control of SELR on the significant SELR difference between cold-arid and monsoon regimes. A figure of specific humidity variations in both the hydrologic regime is added to buttress this point. We have also investigated the specific humidity-SELR variations as suggested by the reviewer which showed expected relationship of negative correlation between specific humidity and SELR in summer and a slightly positive relationship in winter signifying the importance of the moisture in determining the SELR variations.

C: Chapter 5, page 5666: The authors state that their analysis provides a "a significant advancement in our understanding of the process governing moisture–temperature interplay at the higher Himalaya and the SELR variations in two distinct glacio-hydrologic regimes of the Himalaya". A similar statement can be found in chapter 6, page 5667. I find these

statement to far-fetched. The proposed equations and coefficients certainly provide a step forward in describing the SELR in this distinct regions providing valuable information to be used in further applications. Nevertheless, I am missing a detailed discussion on how these observations have advanced our understanding. In my opinion a discussion of the validity of the derived parameter is further missing. The authors show that they represent reasonably well the SELR during the investigated periods and the two valleys. However, a conclusion of how the parameters can be extrapolated to other valleys or regimes or to other periods in the past or even in the future is absent.

Response: This paper brings in few critical information hitherto unknown.

1. Huge difference in the SELR of cold-arid and Monsoon regimes

2. Comparatively lower lapse rate of higher Himalayan region than the lower elevations

3. The SELR variability is mainly governed by the moisture variability which reflected in monsoon lowering and

4. Modelling of SELR for both glacio-hydrologic regimes

In an important cryospheric system like the Himalaya, where temperature lapse rates are used arbitrarily and little is known about the factors controlling the temperature of the mountain slopes; we certainly believe that the insight provided in the present paper certainly brought a "significant advancement" in our knowledge about these systems. This paper further underlines the need to appreciate different glacio-hydrologic regimes of the Himalaya and its various manifestations. Thayyen and Gergan (2010) discussed about hydrological characterisation of these glacio-hydrologic regimes of the Himalaya. The present paper illustrate another significant distinction between the two regimes. This is possible only due to the efforts put in to collect systematic data from the data sparse cold-arid regime since 2010. We fully appreciate the need for developing better criteria's for deciding which indices to be used and where. However, these requires significant further effort to build data and research in these data sparse regions. What we are suggesting now is to experiment with the derived indices in each of the glacio-hydrologic regimes and similar altitude regimes rather than using the arbitrary lapse rate values. We feel that it is a significant step forward. Efforts are being made to develop similar kind of data set from other valleys and regimes to address the issue flagged by the reviewer.

C: Chapter 6, page 5666: The authors claim that “the single most important factor determining the temperature of the higher Himalayan mountain slopes including snow/glacier regime is the moisture.” Has this actually been tested? This is actually the only factor at which the authors have looked in detail. The manuscript gives no further information which other parameters were studied.

Response: This statement is primarily driven by the huge difference between the SELR of cold-arid regime and monsoon during the summer months and similarity in winter months. Figure -6 also shows that the most of the SELR variability is explained by the moisture forcing. Steeper lapse rates during pre and post monsoon period is explained in terms of LCL variations. The model response (Eq-2) during the monsoon months is also very close to the observed lapse rate suggesting the strong control of moisture. We are only suggesting that the moisture is the most important factor in determining the SELR of the mountain slopes. (Deleted “Single”)

C: Figure 4: All four x-axes begin with different months making a comparison very difficult? This should be made consistent. Also in Fig. 7 and 9. In Fig. 8 the x-axes are completely missing. Figure 7a and b: I don’t understand the claim of the authors that the SELR and LCL in Fig. 7a shows a better correlation than in Fig. 7b. This is not obvious from the graphs. Figure 7c: This is not a good title for a figure.

Response: All changes in the figures are made as per the reviewer’s guidelines.

Figure & 7a &b coefficient of correlation is added in the caption

References

1. Thayyen, R. J., and Gergan, J. T.: Role of glaciers in watershed hydrology: a preliminary study of a "Himalayan catchment", The Cryosphere, 4, 115-128, doi:10.5194/tc-4-115-2010, 2010.