Final response : 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

Thayyen and Dimri

We thank the reviewer for very insightful comments. Our response is provided to each of the reviewer comments as follows:

C: The study is facing several major problems that need further attention. First, comparison of results from only two valleys, i.e., from only one altitudinal profile in each glacio-hydrological regime, does not allow to draw general conclusions.

Response : Systematic and consistent year to year variation of SELR in the two valleys in association with dominant meso-scale atmopheric weather systems of the region indicate that the observed variability is a regional phenomena driven by these weather systems. Comparable SELR variations in the cold-arid and monsoon regimes during the winter months owing to the presence of the winter monsoon in both the regimes underline this fact. Moreover, as mentioned in the introduction, the study by Kattel et al. (2013) using the data of 56 stations and an elevation range of 72 to 3920 m a.s.l. for a signifiacntly long period (1984-2004) has also shown a similar response of near surface temperature lapse rate over the monsoon dominated regions of the Nepalease Himalaya. These give credence to the region – wide response of temperature lapse rates in response to the major weather systems. A paragraph on SELR linkage to the dominant weather systems of the region is added to address the concern raised by the reviewer. It is emphaised here that general role of regional climate and orographic – weather interaction is not debated in the present set of the paper. Present study is an attempt to provide physical basis for such a regional response of temperature lapse rate and hope that further studies in this direction will help in refining the regional extent of glacio-hydrological regimes.

C: Second, the first problem is further aggravated by the fact that the two profiles are from different altitudinal ranges that do almost not overlap. Thus, the authors cannot exclude the possibility that limited availability of moisture is strongly influenced by altitude-dependent effects not related to glacio-hydrological regimes.

Response : The existance of distinct glacio-hydrologic regime in the Himalaya is governed by the mountain topography including altitude. A key factor determining these major climate & hydrological regimes is how predominant weather systems of the region is distributing the moisture across the region. We have illustrated this in the introduction “ As these two systems negotiate the Himalayan region from opposite directions, topography regulates these flows and produces seasonal moisture surplus and deficient zones across the Himalayan arc forming distinct regional climate and hydrological zones.” Ladakh region is part of elevated Tibetan Plateau and the distinction between these two systems are shown by comparing the temperature and precipition of these two regimes at same altitude range (Fig.3). In both the regimes, the stations are designed for better understanding of the headwater nival-glacier system. High elevation of the glaciers are characteristics of Ladakh range (>5200 m a.s.l.) and the snow cover in winter months extend to the valley bottom at ~3400 m a.s.l. Hence the high elevation of stations in Ladakh is a topographical constraint and characterisitcs of the cold-arid regime. The role of weather systems is evident in the similar winter SELR in response of the two regimes under the influence of WD's and lower lapse rates observed at higher altitude section of the both the regimes.

C: Third, the description of data and methods for analysing humidity data is by far insufficient.

Response: We will improve the data and methods for humidity data analysis and a new section on specific humidity variation will be included. The methodology section will be strengthened by giving further details of the instrument and station characteristics.

C: Fourth, it remains unclear, why moisture shall be the most important factor, since other factors were not analysed by the authors.

Response: It is to bring to notice that moisture play a dominant role over these two regions. Specific role of orographic – weather interaction does modulate the precipitation regime. But the present context of the paper is primarily to deal with moisture and associated changes. Further, both cold-arid and monsoon regimes receive moisture from Indian Winter Monsoon during the winter months and experience similar lapse rate across the altitude range. During summer months monsoon regimes receive moisture from Indian Summer Monsoon and the observed lapse rate follow the theoretical Saturated Adiabatic Lapse rate as shown in the Fig.6. The moisture deprived cold-arid system experience dry adiabatic lapse rate and severe instability during the same period. It is being supported by the model results as well. Consistency in seasonal variations in lapse rate through the observation years is another factor underlining the major systematic response of lapse to the moisture influx/absence. As we could attribute most of the lapse rate variations with that of presence or absence of moisture, we feel it is prudent to conclude that the presence or absence of moisture is an important factor in determining the lapse rate in mountains.

C: The authors also state that simple interpolation of near-surface air temperature would be 'extremely untenable'. This statement is, however, not substantiated by any kind of analysis how errors would propagate into glaciological or hydrological models.

Response: We have not stated interpolation of near surface lapse air temperature would be untenable. We have stated that" the arbitary use of temperature lapse rate to extrapolate temperature to the higher Himalaya is extremely untenable". We have drawn the line of standard environmental and dry adiabatic lapse rates of monsoon and cold-arid regimes respectivily in Figure-9 to highlight the seasonal deviations of observed lapse rate. We have also shown distinctly different lapse rate regime at the higher elevations. Assessing its impact on glacio-hydrological models in the Himalaya is not within the scope of the present work, which we will take up separatley. However, the discussion related to the near surface lapse rate and model sensitivity is available in the literature (Immerzeel et al 2014 and Gardner and Sharp,2009) we will cite these reference to butteress this point.

2. Specific comments

C1. I would suggest to change the term SELR in near-surface air-temperature lapse rate, since this term is also used in the scientific literature. The word 'slope' is particularly misleading, since altitude effects are also present over non-sloping surfaces like valley bottoms or glacial terraces.

Response: We have considered number of existing terminologies including near surface air temperature lapse rate before deciding on the term SELR. The present analysis suggests that the temperature lapse rate of the mountain slopes are governed by the process associated with orographic uplift facilitated by the mountain slopes rather than surface characteristics of the mountain slopes. The limited role of the surface conditions in determining the lapse rate is highlighted by previous work as well (Kirchner et al., 2013). The term near surface air temperature lapse rate thought to be echoing a dominant surface control on near surface temperature and non- reflective of orographic processes controlling the near surface temperature. De Scally (1997) used the term "slope lapse rate" of air temperature to distinguish the role of mountain slope with the environmental lapse rate of the free atmosphere. We are of the opinion that the term "slope lapse rate" is more reflective of the processes driving the temperature lapse rate of the mountain slopes as suggested in the paper. The term Environmental lapse rate of temperature represent the free atmosphere and by prefixing the term "slope" to the "environmental lapse rate" effectively distinguish it from the free atmosphere and indicate that mountain slope processes are the governing factor for the temperature lapse rate along the mountain slopes. Hence we are strongly inclined to use the term "Slope Environmental Lapse Rate (SELR) in the present paper. This also provide an effective acronym of SELR in the same genre such as SALR, DALR and ELR.

C2. I would also recommend to use the unit K per km instead ◦C per km. The SI requires to specify temperature differences always in Kelvin! Unfortunately, this mistake is frequently found in the scientific literature, but it nevertheless is not conform to the SI.

Response: Units have been changed to Kelvin as suggested

C3. Instead of using ERA-Interim data, I would recommend using gridded data that is able to better resolve the complex topography of the study region. The authors may check, if data from the High Asia Refined Analysis (HAR) would be suitable in this respect (see Maussion et al., 2014). This data set is publicly available at www.klima.tuberlin.de/HAR.

Response: Authors has added results from regional climate model which are driven by ERA-Interim. This will provide better representation of the regional climate as suggested. With reference to HAR: It does not provide 3-D temperature distribution and hence is not used as suggested.

C4. Relative humidity, which is analysed by the authors, is strongly depending on air temperature. Thus, it would be much better to analyse variables like specific humidity or water-vapour mixing ratio. These variables do not only better characterise atmospheric water vapour but are both not depending on air pressure (as e.g. absolute humidity). I would also check if data on precipitable water are available. Then, it would be possible to take phase changes within clouds into account.

Response: We partially agree with the reviewer's observation. A section on Specific humidity variations in both the regimes are introduced as suggested. However, humidity is still a critical factor in determining the SELR response. In both the systems, moisture content in the air is lower in winter months than in summer. But winter lowering of SELR is common in both the regimes due to extremely low temperature and higher saturation in winter. Contrary, moisture available in the cold-arid region atmosphere in summer period is larger than its winter equivalent, but represented by steep SELR under very warm conditions. Section 2M and 2A has generally experienced reduced moisture content than the lower altitude but have sustained lower SELR due to higher humidity regimes. To distinguish this, a new figure is added to show the monthly variations in specific humidity, humidity and temperature of two stations each in both regimes. Since precipitabale water content is secondary derivative calculated based on the specific humidity and hence not added in the present manuscript.

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