(1) Link snow cover (2D) – snow amount (3D): MODIS images allow extracting detailed information on snow-covered area. This information is however purely two dimensional, i.e. a MODIS pixel provides exactly the same information if the snow thickness is 0.1 m or 2 m. In terms of water resources this is a huge difference! As much of the motivation of this paper is related to water resource management and hydrological forecasts, this is a crucial issue. Throughout the paper it is implicitly assumed that a high percentage of snow coverage corresponds to a high snow volume. This link is however not given a priori: For example, enhanced precipitation combined with higher air temperature might lead to an overall smaller snow coverage (due to melt at lower elevations), but larger snow volumes due to thicker snow at high elevations. Especially in winter (high snow coverage), the information content of MODIS images in terms of the snow amount is very limited. The authors should try to establish a link between the percentage of snow-covered areas and the snow amount if they want to relate their study to water resources management and discharge. The respective interpretations in the paper (see also detailed comments below) should be re-considered correspondingly.

We agree with the referee that the MODIS sensor provides only 2D information on snow extent. We also agree that though changes in snow cover (as depicted from snow depletion curves), somehow, provide information on various aspects of snowpack changes and thermal regime, however, these changes only provide an indirect measure of snow water resources (Brown 2000; Brown et al., 2003). In order to obtain water resources information from snow cover changes, these changes have successfully been statistically-correlated with the observed discharges (Gupta et al., 1982; Yang et al., 2003; Zhou et al., 2005; Forsythe et al., 2012) and/or have been used as input to the hydrological models for assessing snow melt processes/responses (Blo¨schl et al., 1991; Grayson et al. 2002; Parajka et al. 2007, Immerzeel et al., 2009; Tahir et al., 2011, Hakeem et al., 2014) and its forecast (Rodell and Houser, 2004; Andreadis and Lettenmaier, 2006), for parts of the study area and elsewhere. We will cite these studies and will discuss more in detail about such relationship in our revised manuscript.

On the other hand, the snowpack variables like snow depth and snow water equivalent (SWE), based on passive microwave sensors' estimates, feature a resolution of about 25km (Brown et al., 2003; Zhou et al., 2005) that is not suitable at all for the relief of the considered study area. The best possibility is the few field measurements obtained in the study region (e.g. Winiger et al., 2005). We will incorporate the information on related snow pack variables available from the literature, and elsewhere and will discuss them in detail in the revised manuscript. We will explicitly clarify that the high snow cover percentage does not necessarily corresponds to the high snow volumes, in the revised version of our manuscript.

(2) Snow cover – runoff: There is a lack in clarity regarding the authors' interpretations regarding the link of snow cover trends and stream-flow runoff. A trend in snowlines towards lower elevations is related to decreasing runoff volumes. The reasons for this should be discussed at a process-based level. And do decreasing SLAs really mean a decrease in water resources as implied by the authors? In fact, lower snowlines indicate positive glacier mass balances and thus enhanced water storage at high elevation which might represent an important future supply to water resources in a warming climate.

A descending tendency of end-of-the-summer snow line as a result of cooling summer effect (Page 13148, Line 2-4; Page 13150, Line 1-4) features a little less glacier/ice/snow surface area exposed to melting at higher elevations, relative to the normal conditions (Page 13162, Line 1-5 and Figure 8). This indicates two fold positive change in water resources of the area; the glaciers lose mass relatively less, the glacier/ice mass increases because of the remaining accumulated snow. In addition to that, the decreasing summer stream flows as observed (Khattak et al., 2011) and as noted from local perceptions (Gioli et al., 2013) within the region, corresponds well with a relatively less melting during the summer. We agree with the referee that the described situation indicates a positive change in the overall frozen water resources at higher elevations. We will clearly explain this in our revised manuscript.

As melt water largely contributes to the overall freshwater availability in Pakistan (Immerzeel et al., 2010; Hasson et al., 2014), less summer melt results in decreased melt water availability, indicating an alarming situation for the water resources management in the country. As the region yet not completely follows the climate change signal as observed globally or as projected by the present day climate models (increase in temperature), the findings based on modelling studies that initially the stream flow will increase due to increased melt and then it will abruptly decrease when glaciers will disappear (Rees and Collins, 2006) are quite misleading at present. We agree with the referee that an increased water storage at higher elevation will provide an increased melt water in a future warmer climate, possibly when the summer cooling phenomena will come to an end and the region will start following the warming signal, which is not yet the dominant case here in the study area.

We will clearly describe in more detail such link between changes in snow cover and corresponding changes in the stream flow and water resources of the study area under the prevailing thermal regime in the revised manuscript.

(3) Validation of snow cover products: I did not completely understand how the snow cover products were validated. What is the independent reference for judging the performance and the validity of MODIS snow cover and the applied cloud filtering methodology. A better explanation would be helpful.

Following studies (Minora et al., 2013; Hakeem et al., 2014), we had not validated the used snow cover products in the present study. The existing validation work done over the part of the study area (Hunza Basin in Karakoram by Tahir et al., 2011; Astore Basin in western Himalayas by Forsythe et al., 2012) and its neighboring region (Hindu kush Range by Gafurov and B´ardossy, 2009 and western Himalayas by Jain et al., 2008 and Chelamallu et al., 2013) suggest the use of MODIS snow products effective for mapping of snow cover under Himalayan conditions. Summarizing various studies, Parajka and Bl ¨oschl, (2012) report an overall accuracy of the MODIS snow products between 85% and 99%, under clear sky conditions. However, we agree with the referee and we will randomly validate the used MODIS snow products against the Landsat images, in view of the existing validation work done by Tahir et al., (2011) using ASTER images and Forsythe et al., (2012) using station observations. We will discuss the results of our validation in the revised manuscript.

For the validation of our applied cloud filtering technique, kindly see our response to comment # 2 of Referee # 3.

(4) Relation to glacier mass balance: End-of-summer snowlines are related to glacier outlines. If the authors intend to link observed snowlines with glaciers (which is important and interesting), a more detailed analysis and discussion is required. Instead of the median glacier elevation, the percentage of the glaciers covered with snow at the end of the melting season should be evaluated, corresponding to the so-called Accumulation Area Ration (AAR). For glaciers in High Mountain Asia often having particular hypsometries and considerable debris-coverage, the median elevation might be a bad indicator for the elevation of the equilibrium line.

We agree with the referee in general that the AAR is a good indicator of changes in the equilibrium line altitude. However, Dyurgerov et al., (2009), by analyzing data from 86 glaciers, report that majority of the glaciers show a good linear/non-linear relationship between AAR and mass balance. However, in several cases they did not find a statistically significant relationship between AAR and glacier mass balance, relating it to the complicated basin topography and the resulting complex glacier shapes. They also state that in case of a shorter time series, such relationship may not be reliable (e.g. Dunagiri and Changme-Khangpu glaciers in the Himalaya). In view of such limitations of AAR for high relief areas (Himalayas) and the short-length of data considered in the present study, we prefer our presented analysis. We will report in the revised manuscript that the AAR relationship is one of the alternate, and that, value of the balanced-budget AAR might fall below 0.5 due to avalanche-accumulation or topographic ‘concentration’ of precipitation, in such extremely high relief study areas (Kulkarni,1992; Braithwaite and Raper, 2009). We will put more emphasis on the limitations and the uncertainties of our technique and will discuss it in detail in the revised manuscript.

(5) Correlations to NAO: The correlation of snow cover to NAO is speculative and needs to be improved. Why did the authors choose to use the NAO (and only the NAO!) for

their analysis? The causal link between air pressure differences in the North Atlantic and the Indus Basin should be described in detail. Otherwise anything (!) could be correlated to the snow cover products. It is also unclear how the authors chose the different periods with varying lengths to perform the correlation analysis. Have there been any systematic statistical evaluations which months should be correlated with which ones, or is this based on physical relations in the climate system? More justification on the choices has to be provided and the lack in correlation for some basins needs to be better discussed. My major points (1) and (2) are most critical in this respect as the NAO is intended to be used to forecast runoff (i.e. snow melt QUANTITY), although winter snow percentage contains almost no information on snow depth.

A large portion of the Indus River flows comes from the snow and glacier melt from the Hindu kush-Karakoram-Himalaya (HKH) ranges, present in the northern part of the Indus Basin (Immerzeel et al., 2010). The northern Indus Basin mainly receives moisture under westerly disturbances, particularly during the winter season and mostly in solid form (Page 13147, Line 8-10), which together with the concurrent temperature regime, provides the melt-runoff during summer season (Hasson et al., 2014). Since the NAO controls the strength and position of the westerly jet, it is natural to correlate the snow cover with it. There is a sound meteo-climatic reason to such causal relationship between the Indus basin snow cover and NAO index. The correlation analysis is based on the corresponding time periods (2001-2012) of two variables. The reason to correlate winter season snow cover with a different set of seasonal NAO index is to explore a significant correlation between the two, identifying a reasonable lead time for the winter snow cover forecast. We will extend our aforementioned explanation, describing it in detail in the revised version of the manuscript.

(6) Figures: I had troubles to judge the Figures of the paper. In my printed version ALL axis labels consisted of symbols I was not able to read (probably Hindi. . .).

Labels of all axis will be improved to be readable.

Detailed comments:
(7) page 13154, line 22: How was the size of the filer determined? Was there some kind of optimization performed?

The size of the filter has been determined in order to rely on reasonable number of neighboring pixels for deciding whether the considered cloudy pixel will be replaced with snow or land class or will it remain unchanged. Here we intentionally avoid the greedy approach of taking decision based only on immediate neighbors. Secondly, Gurung et al. (2011) have also found the size of a 7x7 spatial window optimal for spatial filtering in order to remove/reduce cloud cover from the MODIS snow products.

(8) page 13156, line 22: "results have been improved significantly". This needs to be reformulated: first, "significantly" means that a statistical test has been applied indicating the enhanced performance. But against what has the quality of the snow cover product been evaluated? I agree that the filtered snow-cover product looks better. But without validation against independent data statements about the quality need to be put into Perspective.

We will replace 'significantly' with 'considerably'. For the validation of our cloud filtering technique against the independent data, other referees had similar comments. We have performed the validation of our cloud filtering procedure in the present study. The methodology is explained at Page 13155, Line 16-24, whereas results are summarized at Page 13156, Line 23-26 and Page 13157 Line 1-5; Table 1 and Figure 4. Additionally, the studies from which the applied technique has been adapted, also found it remarkably efficient in cloud reduction/removal from the MODIS snow products with few season-dependent tradeoffs, resulting snow maps in good agreement with the ground snow observations (Parajka and Blo¨schl, 2008; Gafurov and B´ardossy, 2009; Wang et al., 2009; L´opez-Burgos et al., 2013; Hüsler et al., 2014). We will clearly describe our applied validation procedure in detail and we will extend such validation to few more dates within the validation period of year 2004. We will also cite the aforementioned studies in our revised manuscript.

(9) page 13158, line 8: The presence of glaciers does not have any impact on snow cover variability. It is rather the particular topographical characteristics of ice-covered (high-elevation) basins that reduce the variability.

We agree with the referee that these basins feature low snow cover variability due to their topographic features and thermal regime corresponding to higher latitudinal extent and higher altitudinal surface areas, resulting in permanent snow and ice cover. We will clarify this statement in our revised manuscript.

(10) page 13159, line 13: "systematic underestimation". Why underestimation? . . ..

Such underestimation is mainly due to an inability of the MODIS sensor for detecting glacier/ice under debris cover, which is proportionate to the surface area of the debris covered part of the glaciers, lying within the basin. For example, the Hunza sub-basin, with a substantial glacier area under debris cover, feature larger underestimation of its total glacier area against the estimated minimum snow cover extent (page 13165, line 2-5). We will more clearly describe this in our revised manuscript.

(11) page 13160, line 1: positive / negative trends – provide a clarification for the reader what positive / negative trends imply (less / more snow-covered area; rising / decreasing snow lines altitudes). A figure showing these main results would be helpful.

A positive trend implies tendency for an increase in the snow cover area percentage while a negative trend means the opposite. We will clarify these terms for the reader in the revised version. We will add the figure showing snow cover area trends for each of the study basin.

(12) page 13161, line 1-13: More details are needed here. Average correlation coefficients should be also stated in the text. Reasons for choosing the considered periods should be provided. Furthermore, according to Fig. 8 there is very small year-to-year variability in snow line elevation for most basins. It is difficult to understand.

The correlation between NAO Index and the snow cover is based on the corresponding time periods (2001-2012). The reason to choose particular season is that the westerly disturbances mainly drop moisture over the region during winter season (Page 13147, Line 8-10). Therefore, the correlation analysis was performed between winter season snow cover and NAO-Index of different seasons (comprised of 3-4 months between September and December), first in order to explore a significant correlation coefficient, and second, to identify a possible lead time for the winter snow cover forecast. We will explain it in more detail in the revised version. We will also state the correlation coefficients in the text of the revised version.

The large variation in the snow line elevation is expected for the monsoon-influenced snow-fed basins, which are mainly lower latitudinal/altitudinal basins, extending into hotter climate. Such variable response is further susceptible to the erratic behavior of the monsoon as well as to the amount of its moisture deposited in a solid form. The small variations however correspond to cold climate conditions at higher elevations. We will mention this in our revised manuscript.

(13) page 13162, line 14: See substantive comment above. A snowline below the median glacier elevation does not directly indicate positive glacier mass balance. This might be a good occasion for citing Gardelle et al (2012, 2013).

We will add here 'such proxy finding, indicating a positive mass balance of existing glaciers, is further confirmed by Gardelle et al (2013), showing a possible slightly positive mass balance of the Karakoram glaciers for the last decade.'

(14) page 13162, line 17: "mass release of accumulated snow" – what does this mean?

We will replace it with the text 'at steeper slopes, where accumulated snow cannot stay longer'.

(15) page 13165, line 1-13: here in particular (and elsewhere): At several instances the authors use the terms "underestimation" which is unclear and wrong here. Why underestimation? This does imply that a bias is present. But relative to what?

The underestimation means that the estimated minimum snow cover extent from the MODIS snow product is less than the actual glacier area within the basin mapped in the considered inventory, which we expect to be the similar provided no debris covered glaciers were present. This underestimation is, therefore, not due to a bias but due to the inability of the MODIS sensor in detecting the debris covered part of the glaciers, which are quite common in the study area. We will now extend our explanation from Page 13165, line 2-5 for further clarification.

(16) page 13167, line 5-12: This paragraph is poorly connected to the rest of the paper and its statement are not very clear. It could be omitted.

We agree with the referee and we will remove this paragraph in the revised version of our manuscript.

(17) page 13167, line 15: "increased water storage capacity is needed". I think this statement is not correct. If snow line altitudes are decreasing this actually indicates that water storage in the Karakoram is increasing!

This is indeed. However, in a broader perspective of the freshwater water availability in Pakistan such statement is true. It is well known that a substantial amount of surface water, available through the Indus River System (IRS) in Pakistan, comes from the South Asian summer monsoon (July-September). The erratic behavior of monsoon often leads to too-little or too-much water situation in Pakistan. During wet years, an excess amount of water can be stored during monsoon season and carried over to the next snowmelt season in order to compensate the observed reducing melt-water availability from the Karakoram. However, the present water storage capacity in Pakistan is limited in such regards. In this context, we suggest that an increased water storage capacity may be needed in order to not only compensate the reducing melt-water availability but also to somehow regulate the large snow cover variability as well as the erratic behavior of Monsoon. We will clearly explain this at Page 13167, Line 13-onward, in the revised version of the manuscript.

(18) Table 2: referenced much too early - before Table 1 and before introducing the variables and results that are shown. What is the unit of the trend slope?

We will reference Table 1 and 2 in a sequence. The trend slopes for snow cover area are in percentage.

References:

Andreadis, K. M., and D. P. Lettenmaier (2006), Assimilating remotely sensed snow observations into a macroscale hydrology model, Adv. Water Res., 29, 872– 886.

Braithwaite, R. J. and Raper, S. C. B.: Estimating equilibrium line altitude (ELA) from glacier inventory data, Ann. Glaciol., 50, 127–132, 2009.

Blo¨schl, G., R. Kirnbauer, and D. Gutknecht (1991), Distributed snowmelt simulations in an Alpine catchment. 1. Model evaluation on the basis of snow cover patterns, Water Resour. Res., 27(12), 3171–3179.

Brown, R. D., 2000: Northern Hemisphere snow cover variability and change, 1915–97. J. Climate, 13, 2339–2355.

Brown, R. D., B. Brasnett, and D. Robinson, 2003: Gridded North American monthly snow depth and snow water equivalent for GCM evaluation. Atmos.–Ocean, 41, 1–14

Chelamallu, H. P., Venkataraman, G., Murti, M.V.R.: Accuracy assessment of MODIS/Terra snow cover product for parts of Indian Himalayas, Geocarto International, http://dx.doi.org/10.1080/10106049.2013.819041, 2013.

Dyurgerov, M., Meier, M.F., and Bahr, D.B.,: A new index of glacier area change: a tool for glacier monitoring. *J. Glaciol.,*
55(192), 710–716, 2009.

Forsythe, N., Fowler, H., Kilsby, C. G. and Archer, D.R.: Opportunities from Remote Sensing for Supporting Water Resources Management in Village/Valley Scale Catchments in the Upper Indus Basin, Water Resour. Manage., 26, 845–871, 2012.

Grayson, R. B., G. Blo¨schl, A. Western, and T. McMahon (2002), Advances in the use of observed spatial patterns of catchment hydrological response, Adv. Water Resour., 25, 1313–1334.
Gupta, R. P., Duggal, A.J., Rao, S.N., Sankar, G., and Singhal, B.B.S.: Snow-Cover Area vs. snowmelt runoff relation and its dependence on geomorphology – A study from the Beas Catchment (Himalayas, India), J. Hydrol., 58, 325-339, 1982.

Gafurov, A. and Bárdossy, A.: Cloud removal methodology from MODIS snow cover product,
Hydrol. Earth Syst. Sci., 13, 1361–1373, doi:10.5194/hess-13-1361-2009, 2009.

Gurung, D. R., Kulkarni, A. V., Giriraj, A., Aung, K. S., and Shrestha, B.: Monitoring of seasonal snow cover in Bhutan using remote sensing technique, Current Science, 101, 10, 2011.

Gardelle, J., Berthier, E., Arnaud, Y., and Kääb, A.: Region-wide glacier mass balances over the Pamir-Karakoram-Himalaya during 1999–2011, The Cryosphere, 7, 1263-1286, doi:10.5194/tc-7-1263-2013, 2013.

Gioli, G., Khan, T., and Scheffran, J.: Climatic and environmental change in the Karakoram: Making sense of community perceptions and adaptation strategies, Reg. Environ. Change, doi:10.1007/s10113-013-0550-3, in press, 2013.

Hüsler, F., Jonas, T., Riffler, M., Musial, J. P., and Wunderle, S.: A satellite-based snow cover climatology (1985–2011) for the European Alps derived from AVHRR data, The Cryosphere, 8, 73-90, doi:10.5194/tc-8-73-2014, 2014.

Hasson, S., Lucarini, V., Pascale, S., and Böhner, J.: Seasonality of the hydrological cycle in major South and Southeast Asian river basins as simulated by PCMDI/CMIP3 experiments, Earth Syst. Dynam., 5, 1–21, 2014

Hakeem, S. A., Bilal, M., Pervez, A., Tahir, A. A.: Remote Sensing Data Application to Monitor Snow Cover Variation and Hydrological Regime in a Poorly Gauged River Catchment—Northern Pakistan,
International Journal of Geosciences, 5, 27-37, 2014.

Immerzeel, W. W., Droogers, P., de Jong, S. M., and Bierkens, M. F. P.: Large-scale monitoring of snow cover and runoff simulation in Himalayan river basins using remote sensing, Remote Sens. Environ., 113, 40–49, 2009.

Immerzeel, W. W., van Beek, L. P. H., and Bierkens, M. F. P.: Climate Change will affect the Asian Water Towers, Science, 328, 1382–1385, doi:10.1126/science.1183188, 2010.

Jain, S.K. Goswami, A., Saraf, A. K.: Accuracy assessment of MODIS, NOAA and IRS data in snow cover mapping under Himalayan conditions, Int. J. Rem. Sens., 29:20, 5863-5878, 2008.

López-Burgos, V., Gupta, H. V., and Clark, M.: Reducing cloud obscuration of MODIS snow cover area products by combining spatio-temporal techniques with a probability of snow approach, Hydrol. Earth Syst. Sci., 17, 1809-1823, doi:10.5194/hess-17-1809-2013, 2013.

Khattak, M. S., Babel, M. S., and Sharif, M.: Hydrometeorological trends in the upper Indus River Basin in Pakistan, Clim. Res., 46, 103–119, doi:10.3354/cr00957, 2011.

Kulkarni, A. V.: Mass balance of Himalayan glaciers using AAR and ELA methods, J. Glaciol., 38, 128, 1992.

Minora, U., Bocchiola, D., D'Agata, C., Maragno, D., Mayer, C., Lambrecht, A., Mosconi, B., Vuillermoz, E., Senese, A., Compostella, C., Smiraglia, C., and Diolaiuti, G.: 2001–2010 glacier changes in the Central Karakoram National Park: a contribution to evaluate the magnitude and rate of the "Karakoram anomaly", The Cryosphere Discuss., 7, 2891-2941, doi:10.5194/tcd-7-2891-2013, 2013.

Parajka, J., R. Merz, and G. Blo¨schl (2007), Uncertainty and multiple objective calibration in regional water balance modelling - Case study in 320 Austrian catchments, Hydrol. Processes, 21, 435– 446.

Parajka, J. and Bl¨osch, G.: Spatio-temporal combination of MODIS images – potential for snow cover mapping, Water Resour. Res., 44, W03406, doi:10.1029/2007WR006204, 2008.

Rees, H. G. and Collins, D. N.: Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming, Hydrol. Process., 20, 2157–2169, 2006.

Rodell, M., and P. R. Houser (2004), Updating a land surface model with MODIS-derived snow cover, J. Hydrometeorol., 5(6), 1064– 1075.

Tahir, A. A., Chevallier, P., Arnaud, Y., and Ahmad, B.: Snow cover dynamics and hydrological regime of the Hunza River basin, Karakoram Range, Northern Pakistan, Hydrol. Earth Syst. Sci., 15, 2275–2290, doi:10.5194/hess-15-2275-2011, 2011.

Wang, X., Xie, H., Liang, T., and Huang, X.: Comparison and validation of MODIS standard and new combination of Terra and Aqua snow cover products in northern Xinjiang , China, Hydrol. Process., 429, 419–429, doi:10.1002/hyp.7151, 2009.

Winiger, M., Gumpert, M., & Yamount, H. (2005). Karakorum-Hindukush-Western Himalaya: Assessing High Altitude Water Resources. Hydrological Processes, 19, 2329–2338.

Yang, D., Robinson, D., Zhao, Y., Estilow, T., and Ye, B.: Streamflow response to seasonal snow cover extent changes in large Siberian watersheds, J. Geophy. Res., Vol 108, No.D18, 4578, 2003.

Zhou, X., Xie, H., Hendrickx, J.M.H., Statistical evaluation of remotely sensed snow-cover products with constraints from streamflow and SNOTEL measurements, Remote Sensing of Environment, 94, 214-231, 2005