The Cryosphere Discuss., 4, C186–C195, 2010
www.the-cryosphere-discuss.net/4/C186/2010/

The Cryosphere Discussions

Interactive comment on "The role of glaciers in stream flow from the Nepal Himalaya" *by* D. Alford and R. Armstrong

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Received and published: 4 May 2010

1 General Comments

This manuscript (AA10) details an empirical study of glacier melt contributions to streamflow in the Nepal Himalaya. Estimates of ice melt contributions to runoff are generated from glacier hypsometries and an ablation gradient, whereas rainfall runoff values are estimated from basin hypsometries and a vertical precipitation gradient.

Major rivers in heavily populated regions of south Asia are sourced in the Himalayas. Streamflows in the region are sourced from a combination of snow melt, glacier melt, and rainfall, in addition to groundwater sources.

The authors state that empirical approaches are required in data-poor areas such as the Himalaya. While this may be partially true, there are several examples in the literature of distributed or semi-distributed hydrological models for Himalayan basins, yet the approaches and results of previous studies are not addressed at all.

Furthermore, there are numerous problems with the methodology presented in AA10 that need to be addressed, and the main conclusion of the study ("...neither stream flow timing nor volume of the rivers flowing into the Ganges Basin from Nepal will be affected materially by a continued retreat of the glaciers of the Nepal Himalaya", P471 L4-5) is not supported by the presented research. This study does not examine the timing of stream flow in the Nepal Himalaya, and the conviction of the conclusion is not warranted given the methodological issues adressed below.

Finally, AA10 lacks a proper review of previous studies on the topic of Himalayan glaciers and streamflow, factual statements and assumptions are not supported by references in many cases, the organization of the manuscript itself is confusing, and a major rewriting is required. This review provides general suggestions for improvements in these regards, and gives specific recommendations for the text.

2 Suggestions

- The approach used in this study hinges on prescribed values of temperature gradients, equilibrium line altitude (ELA) and mass balance gradients. While the authors indicate that "...an attempt has been made to select values from the literature for the mass balance processes.." (l. 19-20), they do not provide a range of possible values for these parameters, nor do they perform a sensitivity analysis which would provide bounds on the estimates of glacier contribution to streamflow. A sensitivity analysis testing a range of values for the ELA and the mass balance gradient would provide context for the results. Mass balance gradients and ELAs can be easily calculated from published mass balance data (Dyurgerov, 2002), and annual gradients can be used to provide a range of gradient values.

Furthermore, why is the mass balance gradient above the ELA assumed to be 0 (i.e. the winter accumulation is assumed to be 2.6 m for all elevation bands above the ELA)? Again, a proper examination of observed balance gradients would help resolve this issue, and provide more realistic values.

Finally, the reader is forced to assume that trial and error has been used to determine that "'...a value of specific annual accumulation of 2.6 m was required to balance the the annual mass loss resulting from melt in the ablation zone." (P477 L20-23). An assumption of zero melt above the ELA is difficult to accept. Again, this approach ignores realistic vertical gradients of accumulation and ablation that may strongly affect the results.

- The assumption that the ELA corresponds to the mean altitude of the summer 0 isotherm has no citation. What is this assumption based on? How sensitive is the model to this assumption? Are summer temperature records from low-elevation stations used to adjust the elevation of the ELA annually? Fitting the mean specific runoff to elevation (Figure 4) without accounting for interannual variability in ELA and changing glacier contributions to streamflow does not lend the conclusions much confidence. Work by Thayyen et al. (2005b) also demonstrated that temperature lapse rates vary seasonally, and this should be taken into account even in a generalized model.

- The article is missing significant papers regarding the contribution of glaciers to streamflow in the Himalaya (Braun et al., 1993; Singh and Kumar, 1997; Singh et al., 2005; Thayyen et al., 2005a; Rees and Collins, 2006) and in other alpine regions (e.g. Fountain and Tangborn, 1985; Hopkinson and Young, 1998; Stahl and Moore, 2006; Stahl et al., 2008). The interactive comment by M. Pelto on AA10

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points out several more recent examples specific to the Himalaya. While specific results are not transferrable between regions, methodologies can be transferred. A thorough review of relevant literature is recommended for this paper to help frame and inform this research.

- The values assumed for ELA (5400 m) and ablation gradient (1.4 m / 100m) suggest an ice-melt total of 30.1 m at an elevation of 3250 m (Table 3). Is this number realistic? A quick survey of reported mass balance values (e.g. Dyurgerov, 2002) might help constrain the parameters chosen for this study.

- As a means of justifying this study, the authors note that there is a view that "...a signficant volume of the annual flow of the Ganges River...may be derived from the melting of the glaciers of these mountains..." (P471 L8), however they provide no references for this statement.

- Organization: this paper requires substantial reworking. At a minimum, the authors should organize the text into clearly defined sections of (a) Introduction, (b) Study Area, (c) Methods, (d) Results, (e) Discussion, and (f) Conclusion. Currently, the introduction is lacking proper references (specific examples below), and a clear and simple statement of the objectives (i.e. "...to estimate the glacier contribution to streamflow in the Nepal Himalaya") is missing.

3 Specific Comments

- The abstract is wordy and rambling. What is "meaningful" research (P470 L7), or a "complete glacier system" (P470 L11), or a "disaggregated" data base (P470 L13)?

- "mesoscale variability..." of what (P470 L16)?

- Most of the text in the abstract (P470 L5 - 24) is more relevant as an introduction. The abstract needs to clearly and concisely state the methods and results.

- As a means of justifying this study, the authors note that there is a view that "...a signficant volume of the annual flow of the Ganges River...may be derived from the melting of the glaciers of these mountains..." (P471 L8), however they provide no references for this statement.

- The introduction needs to be focused: why is this study important, what do previous studies on this topic and region say, and what are the principal objectives. Most of the current material can be edited out, and material presented later in this manuscript can be moved to the introduction.

- Edit P473 L2-5: "The Nepal Himalaya range in elevation from xxx to 8000 m, covering a wide range of hydrological and meteorological environments. "

- "There are few reliable maps of the region" (P473 L5). Why is this here?

- Reference needed P473 L11-12.

- Remove "It is self-evident that" (P473 L12)

- Remove "It is a basic...credible" (P473 L18-19)

- Fix "This estimate, combined WITH all other..." (P473 L21)

- Text from P473 L26 - P474 L8 should be in a Study Area section

- A figure of the study area, with locations of gauging stations, climate stations, and basins discussed in this paper is needed. Reference it when the study area is first discussed.

- P474 L9: remove "elementary"

- P474 L15: reference needed
- P474 L18: “Orographic Runoff Model” is misleading, as it suggests that the model takes into account wind direction, mountain orientation, and windward and leeward aspects with regards to precipitation distribution and runoff generation. Suggest changing this to “Elevation Runoff Model”, as this it what it actually represents.
- P474 L15-17: Simplify. “Hydrological and climatological data available for this region are typically derived from low-elevation stations.” The phrase “...gross aggregate means..” is not helpful.
- A new methods section should simply expand on the list of bulleted points given on P475.
- P475 L5: ’orographic cuves’ : are these are just elevational gradients of precipitation and ablation? Again, not really orographic.
- P475 L10-13: This should be in a Study Area section
- P475 L14-P476 L2: This should be in the Introduction
- P475 L15-17: This sentence needs fixing.
- P476 L3 - L13: Study Area.
- P475 L19-23: This sentence makes makes no sense.
- P475 L14-15: This is a method.
- P475 L15 - 28: These are Results. Place in a separate section.
- P475 L28-29: Methods.

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- P475 L29 - P476 L3: Results.
- P477 L5 - 9: Introduction
- P477 L 10 - 23: Methods.
- P477 L 10 - 13: Rephrase: “Glaciers consist of zones of ablation, where annual net mass balance is negative, and zones of accumulation, where annual net mass change is positive. The glacier model used in this study assumes that the equilbrium line altitude (ELA) dividing the accumulation and ablation zones is determined by the mean altitude of the summer season (Jul - Sep) 0 isotherm. ”
- P477 L15: “...all melt water was produced from the ablation zone.” Does this refer only to glacier melt water, or snow melt water, or both combined? Throughout the paper the term melt water needs to made specific.
- It is unclear why the accumulation volume is assumed to equal the ablation volume (P477 L18). This would only be the case if the glacier is in steady-state, and no evidence has been presented to suggest that this is the case.
- P477 L23 - P478 L2: Results.
- P478 L5: ICIMOD - define.
- P478 L6: ELA is already defined. Also, from the manuscript Figure 6, which gives net mass balance data for the Yala Glacier, the ELA appears to lie around 5340 m. Why is 5400 m assumed in this study? Again, more examples from previously published mass balance series would lend credibility to the assumptions used in this study.
- P478 L9: lapse rates should be given in km^{-1}

- P478 L 17: "...gradient with latitude..." I assume this means altitude? And the text "...general trend of this..." should be removed.
- P478 Eq 1. and elsewhere: use italics for mass balance variables
- P478 Eq 1. don't mix units - use S.I. units (ie. metres) for all variables. Short-forms (mcm or km2) can be used for tabular summaries, but shouldn't be in the equations.
- P480 L27 - P481 L15. This entire paragraph is irrelevant to the study, and contains several problematic statements. To start, the authors appear to be referring to the fourth assessment of the IPCC Working Group II, which was reviewed. The "2035" error has been discussed in a letter to Science (Cogley et al., 2010), and the IPCC has issued a correction. However, the authors continue further to lift text directly from the IPCC WGII report without attribution: "...the Ganga, Indus, Brahmaputra and other rivers that criss-cross the northern Indian plain could likely become seasonal rivers in the near future..." (P481 L9-11, or IPCC WGII AR4 P493). This study does not examine the seasonal component of glacier streamflow, and the authors' suggestion that the IPCC should correct this statement as well is thus misguided.
- Table 1: italics for discharge quantities
- Table 2: italics, and table formatting. Enclose units in brackets: (m). It is unclear that this table is a comparison of two basins
- Table 3: italics again (Bw, Bs, bw). Remove "Column1", "Column2", etc.
- Figure 1: not relevant for Himalayan glaciers. Perhaps the data presented in Figure 6 could be expanded here instead to demonstrate Himalayan net mass balance gradients.

- Figure 2: not necessary
- Figure 3: Climate stations used in the analysis should also be indicated on this map. And where are gauging stations for the non-glacierized basins (e.g. Figure 4)?
- Figure 4: Could these points be stratified by glaciated and non-glaciated basins instead of east and west? Where is the curvilinear trend? What is its significance, error, etc.?
- Figure 8: These basins need to be identified in the study area figure.

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Interactive comment on The Cryosphere Discuss., 4, 469, 2010.