

Author response to 'Review', Kenneth HEWITT, 20 Nov 2013

Reviewer comments in black; author response in red.

General:

Techniques for remote monitoring of glaciers hold great promise, especially in the rugged and extensive mountain regions of the HKH. As in several papers referenced, feature tracking and other satellite-based imaging have brought significant advances. The contribution here concerns technical innovations to identify and measure fast flow events, and pushes back the record to earlier, less high quality imagery for the Khurdopin Glacier. It is a welcome addition, as is the further potential indicated, and confirmation of Khurdopin's surge cycle.

I would request some clarification of interpretive remarks, and am disappointed by the limited view of Khurdopin and past work in the Karakoram, which could help bracket the arguments. In particular:

i) The title implies too much. There are no more than impressions of "Karakoram glacier surges" as a whole, and a largely speculative hypothesis about their frequencies and climate relations.

We agree that the title could better reflect the content of the paper and have amended it to "On the magnitude and frequency of Khurdopin Glacier surge events"

ii) Why so little information on Khurdopin Glacier, its dimensions, other studies that treat it as surge-type, and published reports of its behavior back to the 1880s?

We have augmented the first paragraph in Section 2 to include some further details. This section is necessarily succinct given the space restriction with a brief communication.

iii) Why pass so quickly over the relation of surges to Khurdopin-Virjerab ice dams and GLOFs? Arguably they are the most important aspect of this glacier's behavior, the focus of past work there, and main value of determining the scope and frequency of its surge activity. It is a pity because the authors have contributed to the topic elsewhere.

We have now included a section within the discussion that specifically considers the Khurdopin-Virjerab lake and its relationship with surge events.

I realize space is a big constraint in short submissions, but balancing discussion towards information and discussion for the specific case and Karakoram surge-type glaciers, as against broader, 'global' concerns, seems preferable. At least, greater use could be made of Supplementary for this purpose.

We have revised the discussion section considerably to tip the balance more in favour of the specific case and Karakoram surge-type glaciers. A more lengthy discussion (as suggested) would seem best placed in a full-length article (rather than as Supplementary material).

Points related to Khurdopin and other Karakoram glaciers

1. The specific contribution is a fast velocity profile for *one* surge event, in a small area of the lower tongue of *one* glacier (as stated, surely a tiny part of the surge event). The "frequency" is based on *one* other presumed surge (1999-2000). It does not show up as fast flow in the imagery available but is confirmed by other evidence. This is an important step in using the methodology. Khurdopin has a special place in Karakoram glacial events. However, the latter is hardly recognized and;

No response needed.

2. Mason (1930) deduced and presented an closely equivalent c.20-year cycle of thickening and thinning for the lower Khurdopin, one starting on or around 1905, the other 1925. His sources describe advance and thickening episodes lasting about 5 years, and 'quiescent' (Mason's "erosion")

periods of 15 years or so. I have problems with some of Mason's historical sources, but these two events are at least as well-supported as the 1979+, and 1999+ episodes. They seem to confirm the new findings. However, the "return period" is unchanged from the late LIA, despite a century of global warming. Might this not suggest insensitivity to the climate change (?). It seems to challenge the proposed relation to mass balance and to recent reports of a positive one in the Karakoram (p.6, 11 and 23-4).

This is interesting information and not something that we were previously aware of (we have been unable to source a copy of Mason's work from 1930). We have modified our text in both the introduction and the discussion to include these observations. The latter now reads: "*These data suggest that the thickening and thinning cycles on the lower Khurdopin Glacier previously reported by Mason (1930) were surge events taking place over an approximate cycle of 20-years. The return period of surges on this glacier therefore appears to be unchanged since the Little Ice Age despite climatic changes in the region.*"

3. The data from of 1905+ and 1925+ leave no doubt of a much thicker and more advanced lower Khurdopin then, than in more recent events. This seems relevant but, again, may challenge what is said in the paper. I am not clear just what is intended on p.6, (l. 1 and 7).

Again, thanks for this useful information. We have included it in the first paragraph of our discussion.

4. (p.2. 5 and 6. l, 6) The measured displacements at Khurdopin are not "*twice as large as any previously recorded*". Only feature tracking data prior to this publication had not picked up such fast flows (Copeland et al, Luckman et al., Mayer et al, Quincey et al. etc.,). However, a dozen other reports identify movement rates as fast or faster than the Khurdopin 1979 maxima (Shaw 1871; Mason, 1930, 1935; Todd, 1931, Visser; 1932; Kick, 1958, Desio, 1954; Hewitt 1969, 1998a and b, 2013; Goudie et al, 1984; Zhang, 1984). Since most others are based on terminus advances they are unlikely to be the fastest parts of those events.

We might argue that terminus advances are not representative of surge velocities given the lack of any downstream obstruction, but have removed the statement in both places to avoid confusion.

5. It is stated that, "return periods of Karakoram glaciers are almost unknown" (Abstract) and "little remains known about return periods" (3. L.13). I disagree, especially if we are talking, in fact, about indications from just two events per glacier. Past workers have been well aware that many more surge events must have occurred than been observed (p.5. l. 25). However, return intervals for a number of others are quite as "substantial and robust" as the Khurdopin material, but do not support a 20-year cycle, nor multiples of 20-year cycles; for example, at Karambar, Bualtar, Kotiah, Pasu, Balt Bare ...

There remains relatively little documented (published) evidence of Karakoram surge return periods other than historical observations of thickening and thinning, and some poorly constrained estimates (e.g. Drenmang – somewhere between 27-100 years (Hewitt, 2007, page 185)). We have adjusted the text to tone down our assertion.

In this regard, I am surprised there is no mention of the adjacent Virjerab. Difficult to find another glacier with so many similarities of form, size, nourishment, and location to Khurdopin, both classified as surge type by some studies -- but *no* parallels in the known extents, timing and rhythms of advance and retreat over more than a century.

Yes, considering the behaviours of the Khurdopin and the Virjerab would make a very interesting comparison. Unfortunately we do not have the space to include this in our discussion.

6. (p.3) Why not acknowledge previous work on Khurdopin? Much can be deduced from early work like Mason (1935) and Visser (1935-38), even if the notion of surge-type glaciers did not exist then.

The first publication to classify Khurdopin (and Virjerab) as surge-type seems to be Kotlyakov et al (1997; see also Alford 2001; Shroder and Bishop, 2010; Hewitt, 2000, 2006).

We have now included four references to previous work on the Khurdopin as a result of the changes made above. Thanks for the reference suggestions.

7. In general, a better idea of the dimensions and character of the Khurdopin would help, some sense of the 160 years of reports about other Karakoram cases, and comparison with them. I believe Khurdopin is the longest glacier with a confirmed record of surges (?).

We have given further information on the Khurdopin in the introduction. A comparison with other Karakoram surging glaciers is again not possible within the limits of the brief communication.

8. 6. I 24 "...other known surge glaciers in the region tend to be predominantly debris-free." Not so; rather the reverse. Most have heavy debris cover for many kilometers above the terminus – Hassanabad, Kotiah, Karambar, Bualtar, Barpu, Sughet, Skamri... I would not describe N. Gasherbrum as "debris-free". It lacks a complete cross-glacier coverage but there are huge quantities over the lower glacier. Superficial debris covers can be modified by steepness, crevassing and surge history.

Apologies, this was our error. We have corrected the text.

Matters for General Discussion

9. It seems implied that the c.20-year return interval at Khurdopin is indicative of a 'Karakoram cycle', or even 'HKH cycle', apparently reflecting snowfall regime? Quite a prediction, but on very little evidence and seeming contrary to existing theories of surge-type behavior (?). The introduction presents a more complicated scene (p.3 l.13-23). But what does "an indicative quiescent period of 25-40 years" mean, and what are the grounds for lumping into a single package the data in Copeland et al (2011)? My sources suggest Karakoram surge-type glaciers are never in phase with each other or give support to the idea of a common return interval, not even in adjacent and similar basins, or tributaries of the same glacier.

We did not mean to imply that the 20-year return interval should apply to other glaciers. Of course this would be contrary to existing theories and knowledge. The section referred to in the comment here has been removed as part of the manuscript revisions.

The use of expressions such as "an indicative quiescent period" stem from the fact we found it very difficult to get quantitative estimates of surge return periods. We have now removed this statement. Copland himself states "These observations suggest that the quiescent period averages 25–40 years for several glaciers in the Karakoram, although this may be as short as a few years or as long as a century or more", so that is where these specific (lumped) figures come from.

10. It is implied that these findings could help track mass balance changes in the whole HKH. Are there surge-types outside the Karakoram and Pamir?

We did not intend to imply this and intentionally started the sentence with 'Surge activity in the region' to try to avoid confusion. We now state 'in the Karakoram'.

11. Surge return intervals for Alaska and Svalbard are also all over the map (Jiskoot 2011, Table 1). They make it unsurprising that intervals for different Karakoram glaciers seem to range from 15 to over 110 years, also include 'minisurges', and a variety to other fluctuations.

Yes, we agree. There is also the view that a binary classification of surging and non-surging glaciers is inadequate, with all flow falling somewhere between these two end members on a wide dynamic spectrum.

12. Some very broad assertions or links are proposed to issues of mass balance, snowfall regimes and climate change. I cannot see any support, in the data provided from Khurdopin, for a connection, or to what Dowdeswell et al... etc. say about it in Svalbard and Alaska-Yukon. And if comparisons with Alaska etc., are valid, it would help to know how, if at all, they resemble

Karakoram conditions and ice masses. How does Khurdopin compare with Variegated, Bering, Trapridge, Monacobreen. Scobreen....glaciers pivotal to the ideas being cited? Clarification on these points, please.

We have removed this paragraph as part of the revised manuscript and instead focus on the specific case and other Karakoram surge-type glaciers.