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The Cryosphere Discussions



# *Interactive comment on* "Worldwide widespread decadal-scale decrease of glacier speed revealed using repeat optical satellite images" *by* T. Heid and A. Kääb

**Anonymous Referee #1**

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Heid and Kaab applied feature tracking to Landsat imagery to measure glacier regional velocities and their change between two different time periods. The technique is applied to 6 different regions, 5 of them having experienced negative mass balance and one of them without any mass balance measurements but with some indirect evidences that the glaciers may have recently gained mass. A strong decrease in velocity is observed for regions where mass losses occurred whereas a heterogeneous increase in speed is measured in the Karakoram.

To my knowledge and as correctly stated by the authors, it is the first time that regional velocity changes are observed for glaciers. The relationship of velocity changes with

the sign of the glacier-wide mass balance is an expected finding (according to textbook glaciology and field measurements) but, here, is first verified at a regional scale and clearly will stimulate others similar studies. The paper is generally well-written (could be better organized though) and I recommend publication in the TC. The comments below are some recommendations mainly aimed at improving the paper, making it more accessible/concise (by shortening it) and more convincing (by adding intermediate velocity fields).

General Comments

1/ A long paper. The studies is based on a well-know technique that has already been applied numerous time to optical imagery including Landsat (starting as early as 1991, see [Bindschadler and Scambos, 1991]). It would really give the paper more impact if all the technical details (and multiple references) are skipped. The whole digression about INSAR is useless. The authors just need to briefly present the technique using some classical references. In this paper, it does not really matter to the reader which correlation algorithm was used. So the introduction and the method section really need to be reworked and shortened (and thus I only provided a few technical comments for these sections). Even the abstract could be more concise and thus attractive (for example the first 2 sentences are not really useful). On the other hand, more details are needed on the method that is used to compare velocity from two time period (from individual vectors at different locations) because it is not so straightforward. For example, how do you treat a glacier for which one part accelerated and another slowed down?

2/ I do not have anything against the choice of the regions but can the authors better justify their choice. Availability of Landsat imagery? An attempt to capture a great variety of climate influences? Regions where features tracking works best? Obviously the availability of glacier mass balance measurements was not really a driver.

3/ The conclusions are based using only the comparison of two time periods, two snapshots of the velocity for each region. Importantly, those velocities measurements



TCD

5, C1522–C1529, 2011

are annual (or for two years) so they should not be (or very little) affected by any short-time, seasonal variations in speed. However, the paper would really gain some strength if, at least for one or two regions, an additional time period was added. Pamir would be a good candidate given that the signal is very large (43% decrease per decade). Possible to go back in time before 2000 for Pamir? Or add a velocity field for ca. 2004-2005 (from ASTER imagery maybe?)

4/ The readers need to have a better sense of where the velocity variations are measured. Are the measurements mostly in the ablation area (as I suspect because this is where good correlations can be observed over a one-year period)? Is it close to the glacier front? Close to the ELA? From mass conservation, it is expected that the slow down due to negative mass balance will have different amplitude depending on the location on the glacier (larger but delayed relative change close to the front). Can different locations along the longitudinal profile explain the varying signal between the different regions? Simply, the authors could compare the mean altitude of their measurement with the mean altitude of all glaciers in the region. An alternative suggestion: If the authors have the outlines of each individual glacier, they could try to normalize the velocity changes by the total length (see [Arendt et al., 2006], 5.2 Method B: Normalized Thickness Changes to understand what I have in mind here). I understand that this is a significant amount of work. It is not mandatory for paper acceptance (although I think it would make the comparisons within each region or between different regions more robust and meaningful).

5/ Karakoram. The authors should make it clear that there are no mass balance measurements in this mountain range to date, except an hydrological mass balance in the late 80s [Bhutiyani, 1999]. There are only some indirect evidences that the glaciers are actually gaining mass (frontal stability, some glaciers have thickened, Baltoro accelerated, etc...). In the submitted manuscript, it is as if mass balances measurements were available and shown the glacier to be gaining mass. From existing inventories of surging glaciers from [Barrand and Murray, 2006; Copland et al., 2009] and maybe oth-



TCD
5, C1522–C1529, 2011





ers, do you think it is feasible to exclude the well-known surging glaciers and provide a velocity analysis restricted to the non-surging ones? I have the feeling that this is going to be difficult given the complex pattern observed in Figure 3... just a thought.

6/ Structure It seems that the velocity data from the Karakoram region was added afterwards (the authors will tell in their reply if my guess is right or wrong). There are various places in the paper where only 5 regions (instead of 6) are mentioned (e.g., Table 3). The Karakoram velocity data are shown in Figure 3 (whereas logically it could have been also shown in Figure 1 and 2 with other regions). The authors needs to make sure that they treat this region in a consistent manner with others

7/ Title: Worldwide seems a bit strong (suggest a study covering all glaciarized regions)

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Technical comments.

P3026. L16. As if something was missing at the end of this sentence. Do you imply that the changes in speed are less meaningful in the Karakoram?

P3028. L1. The glacier does not need to be in a state of balance for the fluxes at a cross section to equal the upstream mass balance. This is also true in case of imbalance (for negative mass balance the ice fluxes will decrease to adjust).

P3028. L18. “Indicative positive mass balance” is a strong statement. I would rather say that climate trends are “consistent with a possible positive mass balance”. I do not think they “indicate” it. If large scale modelled climate data (re-analysis) provided useful glacier mass balance without any calibration on actual measurements, we actually would not need to measure their mass balance. . .

P3028. L25. Clarify what the opposite is? An acceleration during a period of positive mass balance? Or an acceleration during a period of negative mass balance?

P3028 L3029. Your definition of regional scale is not clear. There have been some



TCD

5, C1522–C1529, 2011



other studies measuring basin-scale velocities such as [Berthier et al., 2005] from SPOT5 images for the whole Mont Blanc area (Alps) or [Quincey et al., 2009] for the whole Everest region from satellite radar interferometry and feature tracking (ERS 1 and 2) or [Bolch et al., 2008] for part of the same region (from Ikonos and Aster imagery). None of those studies had the same extent as the one quoted here ('large regions') but they are also "regional" and should be cited if you want to have a comprehensive list (another probably better option is to refer just to one/two paper relevant to your present word preceded by e.g.,)

P3029 L15-20. If you do not use ASTER you do not need to describe the sensor in detail (source, attitude etc. . .).

P3031 L13. Not five but six regions

P3032 L1. Clarify stress transfer or skip. Unclear as it is.

P3032 L8. For the final velocity comparison do you use the 3 by 3 low pass filtered field or the raw vectors (with outliers excluded)?

P3033 L12-18 and L20-22. These parts need to be in the Method section.

P3033 L26. A reference for surges in Pamir (textbook?) and, a few lines below, in the Alaska Range?

P3035 L6-10. [Span and Kuhn, 2003] suggest no more than a one-year lag for the velocity changes. You should better discuss the fact that the timing of the velocity response to an anomaly in the mass balance will depend on where on the glaciers (ELA, front) the changes is measured (see kinematic wave theory from text books).

P3035 L27. Surge of lower magnitude. Any reference? Do you have in mind the sort of behaviour that were described by [Frappé-Sénéclauze and Clarke, 2007]? Otherwise another reference?

P3036 L17. Flow instability is vague. It is rather descriptive and not really clarifies what

are the causes of those events.

P3037 L5. I do not think the positive mass balance of Baltoro is proved. It is rather guessed from modelled climate data (and surface velocity change). “proposed” would be more accurate than “found”

P3037 L6. In Figure 3 it seems that Siachen is decelerating and not accelerating. . .

P3037 L8. [Quincey et al., 2011] probably needs to be also cited regarding surge activity in this area.

P3037 L20-23. needs to be in the results section (in general, try if possible to better separate the description of the velocity change in the results and their interpretation in the discussion).

P3037 L25-onward. Here I am geographically lost. What is east, northwest, Central North Karakoram. Maybe show those regions on the map?

P3038 L11. “which is an area of positive mass balance”. Reference to a published positive mass balance in this region? For example the existence of the “Karakoram anomaly” was stated recently as “controversial” [Cogley, 2011]. If no reference showing mass gain, downplay your statement.

P3038 L21. We did not really see how you tried to test the relationship velocity/mass balance. Did you expect the relationship to be linear? Do you really have the data to test it (I do not think so, it would require mass balance for individual glaciers)

P3039. Maybe stress in the conclusion, that those findings would be even more robust if annual velocity measurements could be derived every year to really avoid “aliasing” the velocity change. –> future glacier monitoring strategy. To support your choice of having just two snapshots of the velocity, you could examine (qualitatively) published estimate of the long term annual velocity of some glaciers. [Span and Kuhn, 2003] is the reference I have in mind but there must be other such series elsewhere in the Alps.



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5, C1522–C1529, 2011

Table 1. I would put as Titles of the column Raw 1 Period 1 / Period 2 Raw 2 1st image 2nd image 1st image 2nd image

Table 2. Karakoram missing here.

Figure 0. What about a global location map as figure 1? Or in Inset on each velocity change regional map?

Figure 1. I would favour one figure for each region (thus 6 figures showing map of velocity change) to make them large enough for visibility (space is probably not an issue in TC as far as I understand because this is only published online)

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