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The Cryosphere Discussions

Interactive comment on "Monitoring ice shelf velocities from repeat MODIS and Landsat data – a method study on the Larsen C ice shelf, Antarctic Peninsula, and 10 other ice shelves around Antarctica" *by* T. Haug et al.

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In this paper the authors describe an exciting new approach for the application of low-resolution optical satellite imagery (MODIS) to monitor ice shelf dynamics in Antarctica. This offers and is described as an opportunity for the observation of average large-scale ice dynamics and is therefore complementary to existing methods for high resolution and short-term velocity mapping. The applied methods are explained in detail and the error analysis is thorough. The achievable accuracy is found to be about one fourth of a pixel, which sounds reasonable compared to other optical image sen-

sors. The performance of the applied methods (feature tracking using normalized cross correlation of image templates in the image domain and orientation correlation – OC - in the frequency domain) are compared to high resolution optical satellite imagery (Landsat, with data voids after 2003). OC shows in general better and satisfying results. The method is applied to several ice shelves around Antarctica and sheds new light on ice shelf flow variability suggesting a need for further investigation.

The scientific significance aside, there are some flaws in the scientific quality. Large-scale changes in surface features (especially for ice selves under change) over the very long period of time may result in flawed velocity measurements. As the same method (tracking of features) is applied for similar sensors (optical imagers) over similar periods of time, this might lead to the same (but flawed) results. This would require a completely independent measurement to proof the results. The test of performance of different sensors is performed by comparing the low- with the high-resolution result. An elegant way to test the theoretical performance of a low-resolution sensor might be to sample high resolution data down to lower resolution and to compare the results from data of the same sensor. This might be especially interesting in narrow shear zones. A bit more consideration might be useful for the selection of end-members of the tracking results, and the angular quality of the velocity measurement. It is not entirely clear what is assumed to be a statistically significant result (p. 45, line 1). Most importantly, I do not agree with one of the main results, which is the deviation between streamlines and flowlines at Larsen C (illustrated in Fig. 10, but not recognizable to me). This needs either an improved figure and/or a better description in the text, or reconsideration. The results for other ice shelves beside the Larsen C a kept very vague, e.g. it would be interesting to know which small glacier at Ross Ice Shelf is accelerating. When putting the velocity increase at Larsen Ice Shelf into context, it would be interesting also to include the calving events (and possibly the morphological change) during the observation period into consideration.

The main shortcomings are in the presentation quality. The references seem not to

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be complete or are missing, some references are outdated (especially important in relation to the performance of sensors), one not yet published (manuscript in preparation). Many of the citations are wrong or imprecise. Some of the equations need to be checked. Explanations need sometimes more precision, and the text could be more concise which could also shorten the paper. For example, as this paper concentrates on the velocity measurements, the aspect of ice shelf thinning could be significantly shortened in the introduction, as it is described in the discussion of the results. It would help to have path and row numbers of Landsat scenes in the Tables and in the Figure, and to have some of the Figures besides each other for better comparison (e.g. combine Fig. 4 and 8). Although I am not an authority in English language, this aspect needs to be improved. For all these points author and co-authors are asked to put more effort into the presentation quality.

Please see below some more detailed comments.

Comments in detail

Abstract, p. 32:

Line 8: The OC method needs to be mentioned, as this is a major outcome of the study. Line 9: less than 70m could be anything. Why not 'about one fourth of the pixe size', as in the text. Otherwise 'about 70m'. Line 15: reword according benefits (fewer mismatches, able to match Landsat after 2003, faster). I assume for glaciological applications the speed does not play the most important role.

page 33 Line 5: . . . SAR image acquisitions. . .

Line 8: In this context, I would use 'coherence' only in relation with coherent imaging systems, and therefore 'decorrelation time'.

Line 18: I have used and published the correlation method on the Larsen Ice Shelf (Rack et al., 1999, Ann. Glaciol., 29, 261-266).

Line 27: MODIS and MERIS. Write out acronyms when used the first time.

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page 34: Line 9: (3) correlation time. . . Line 15: higher spatial resolution does not necessarily provide higher signal-to-noise ratio (this is correctly mentioned further below).

page 35: Line 3: Although not done here, cross correlation technique can also be applied in the frequency domain. Vice versa, orientation correlation could also be applied in the spatial domain.

page 6: Ice shelves haven't experienced a rise in air and sea temperature, but a rise in air and ocean temperatures have impacted on ice shelves. Line 9: Turner (2005) found that the air temperature at the western Antarctic Peninsula rose by 0.56 deg./decade, not on the whole Ant. Peninsula. Furthermore, this trend was measured at Faraday/Vernadsky. Meredith and King (2005) refer to the ocean west of the Ant. Pen. Line 12: Cook and Vaughan (2009) are imprecisely cited: As many as seven ice shelves 'have either retreated significantly or have been entirely lost'. Line 14: The first observation of glacier speed up of inflow glaciers after ice shelf break-up is published by Rott et al., 2002. , Ann. Glaciol. 34, 277-282. Line 21: . . .loose. . .

page 36: Line 1: Rack etal (1999, see above) describes the velocity increase just before the Larsen A collapse.

Line 6: see also Rott et al. 2002

Line 13: the last sentence of this paragraph does not explain what the thickness of Larsen C has to do with the thinning of Larsen B. The first paragraph of p. 36 needs revision.

Line 15: triggering

Page 37:

Line 8, 9: data download site is mentioned in Acknowledgement and can be removed from here.

page 38: Line 1: Can the elevation differences also be neglected for the matching of the

images using stable points on higher elevated ground and different imaging geometry?

Line 9: . . . a sub-window of this image. . .

Line 11: You need to check equation (1), as I think that indices got mixed up.

page 39: Line 2: The explanation how convolution and correlation is related is not really helpful. This needs either an additional sentence for explanation, or (better) citing of a signal analysis book or previous work.

line 9: . . . at time t=2, and choosing a complex representation, the orientation . . .

page 40: Line 3: Why not keep using the words 'reference' and 'search' window from before? Line 4: I would rather write: . . . where G* is the FFT of the complex conjugate of g.

Line 10: Check equation 6 and 7 (brackets in denominator missing)

Line 16: . . . the OC images are low pass filtered . . .

Page 40:

Line 2: u,v? Line 7: . . .is found from the position (xm, ym) in the correlation surface P. Line 16: Is a specific FIR filter design used? Clarify.

Page 41:

Heading: I suggest 'Locational Accuracy'

An introductory sentence would be helpful saying that this chapter tries to quantify the (i) errors from co-registration and (ii) the errors in those areas where no ground control is available.

Line 10: Do you really mean 'displacement measurements over stable ground' (which is a contradiction) or 'matching points over stable ground?

Line 11: change 'displacements' to 'shifts' (I assume this is what you would like to say.

Line 14: . . .the measured pixel shifts. Line 15: . . . of the pixel shifts of stable ground. Line 18: include path 217/row 106 in Table/Figure. Line 20: They overlap with some of the . . .

Line 20/21: Contradiction? Is the overlapping area either/or/and grounded/ice shelf?

Line 22: . . . using stable rock. [bedrock is not visible]

Again Line 22: grounded/not grounded/ice shelf? See comment above.

Page 42: needs revision

Line 12:

check reference (old)

The actual geometric accuracy of Landsat prior to the failure of the ETM+ SLC is better than the pre-launch requirement. See Lee et al., 2004, Four Years of Landsat-7 On-Orbit Geometric Calibration and Performance, IEEE Trans. Geosc. Rem.Sens., 42 (12).

Is there information available about the performance after this time?

Line 23: . . . approximately SNR > 5 . . .

Page 43:

Line 15: what are obstacles on the ice shelf? Clarify. Line 23: . . . the average pixel shift is 33.5m. Line 26: Which numbers from above are used to obtain 117m?

Page 45: Line 1: how did you define statistically significant?

Page 46:

The selection of end members is clearly a general problem in feature tracking. Forward tracking in combination with backward tracking might be used for a more objective selection.

Page 47:

Line 4: I cannot recognize (from the yellow and blue dots) that the streamlines deviate significantly from flowlines. It seems pretty well aligned in the image. Or do I need to compare the arrows? How many kilometers is the deviation, and where exactly? As you have measured an acceleration in the north, shouldn't there be a deviation in the north?

Page 48:

Line 18-23: what is the measured magnitude of these velocities, or the change in %? Line 19: which is the (small) accelerating glacier?

Page 52:

Line 12: For the remaining Larsen B, intensified rifting and the change in ice shelf geometry due to the calving event in February 2006 could also have played a role in the observed velocity change. The northern Larsen C also changed its configuration due to a calving event. After a regular calving event one might expect stabilization, which backs your interpretation that thinning plays a role for acceleration in this part.

Line 20-22: This is in contradiction to your own observation (see also my comment p.47) and your interpretation of Figure 10. Clarification is necessary.

Table 1:

I suggest to include path and row for Landsat, and acquisition time for MODIS.

Table 3:

Either write 'velocity difference' (what it is), or change the unit to acceleration [ma-2]. The latter needs adjustment of the numbers (divison by about 3.5) as the center values (year) for the velocity measurements are about 3.5 years apart (2004 and mid-2007).

Figure 1: path/row into the Figure; include all Landsat frames.

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combine Figure 4 and 8, and use the same scale for arrow length in Fig. 4 and 8.

References: Check references (include doi's if available)

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