

Interactive comment on “Quantifying changes and trends in glacier area and volume in the Austrian Ötztal Alps (1969–1997–2006)” by J. Abermann et al.

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Referee comments by Ian S. Evans, Durham University.

GENERAL COMMENTS This is a very useful study of area and thickness change in most of the glaciers in the largest glacier region of Austria, starting from three inventories so that the very important question of acceleration of loss can be addressed on a regional basis. The authors go on to relate these changes to annual time series of length and mass balance on several of the glaciers. The attempt to measure acceleration is the most innovative approach but the paper is worth publishing also for the straightforward data on glacier area and volume changes since 1969, including

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use of a 2006 LIDAR DEM to bring the record up to date. Changes are presented in both absolute and relative terms and related to altitude and glacier size. This study of regional change makes use also of change data for individual glaciers to improve temporal resolution.

SPECIFIC COMMENTS : MAIN POINTS Most comparisons of inventories refer to change over different time periods, and one must expect less change over longer time periods because of the greater averaging involved. This is inconvenient when we want to conclude whether change has accelerated or not. Covering the period 1969-2006 poses the problem of how to deal with the important phase of mass gain and advance that interrupted the general wastage and recession of glaciers, especially in the Alps. Data for 16 Ötztal glaciers show that on average advance started in 1976 and had been nullified (the same average length had been reached) by 1989. Mass balance data for three of these glaciers (3 of the 6 largest of the 16, Table 1) shows an onset of mass gain in 1973, with the cumulative gain nullified by 1985. The authors use this information to reduce the duration of the 1969-1997 28-year period of net loss by 12 and 11 years respectively (I make this 13 and 12 years, but this depends on how the bounding years are treated? Yet there are 14 symbols between the two vertical lines on Fig.2!). Although the sampling basis (16 and 3 glaciers, originally selected for convenience rather than by random or regular sampling) for this adjustment is very limited, the use of these reductions does make rates of recession per year more comparable, as only phases of recession or mass loss are considered. Thus the two periods of recession compared are 16 or 17 years (in two phases) and 9 or 8 years long respectively. I disagree with referee 1's "main point 1": it might apply to annual balances and length changes, but the authors have correctly used cumulative balances and changes. It is true that these vary considerably between glaciers, but it is reasonable to take the average so long as the duration of 'non-wastage' is approximately applicable to the regional total. Ideally there would be inventories for c.1976 or c.1989 but, given the data available, the approach used here is useful for considering acceleration of loss. For this purpose it would be misleading to compare a 28-year period which included

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gains/advances with a 9-year period which did not. Schicker, Lambrecht and Rott (2006 AGM Munich abstract) showed that 117 Stubai glaciers lost 1.35% of area 1969-85, but 13.2% in the 12 years 1985-97: coming from an adjacent area, this supports the way the present authors subdivide the 1969-97 period. To address the acceleration question directly, the authors define four “scaling parameters”, F. I suggest replacing this broad term by the more precise ‘acceleration factors’. It is interesting that these are greater for thickness and volume than for area and length. Fig. 7 shows that the four acceleration factors differ considerably for glaciers <100 ha, but are fairly similar for larger glaciers: comment on this could be extended. Also the notion that separation of two formerly coalescent glaciers affects the rate of loss needs fuller explanation (and critical thought). From Fig.4 I infer that absolute annual loss has accelerated below 3100 m altitude, but hardly above. I agree with Pelto that relative loss curves would be useful, and more consistent with the discussion here. Fig.6 shows that % area losses are more evenly distributed across glacier size classes in the second period, and that annual rates accelerated for all except the smallest (<10 ha) glaciers. I would emphasise that the deceleration for the smallest is from a very high rate of area loss (4.3 % a⁻¹) to a still considerable one (-1.9% a⁻¹). It would be useful to compare the changed situation for smallest glaciers, before and after 1997, with studies of glacier change elsewhere. The authors cite no climatic data. As this is one of the few mountain areas with decent data, an obvious addition to the value of the paper would be to give relevant climatic statistics for each of the two periods, 1969-97 and 1997-2006. Reference to the work of Schöner, Auer and Böhm might be useful, e.g. *Annals Glaciol.* 31, p. 31-38 (2000) and 46, p. 161-9 (2006). I find it strange that other papers on Ötztal glacier change (1969-92) are not cited; Paul, F. 2002 *Int J Rem Sensing* 23, p. 787-799; also *Eos* 83 (23), pages 253, 260, 261. As acceleration of wastage is the most important theme of the paper, some reference should be made to other authors who have discussed this, notably Haeberli and colleagues, e.g. 1999 *Geogr. Ann.* A 81, p.585-591. At present we can infer acceleration from the limited sample of glaciers with annual mass balance or length data. My hope is that we may soon be able to assess

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acceleration on a regional basis by comparing three equally spaced inventories. The paper should be accepted for TC after some rewriting.

DETAILS & TECHNICAL COMMENTS: Although the English is comprehensible, there are some repeated errors, such as use of the wrong prepositions, and under-use of the simple past tense. I suggest quite a few improvements, some important and some rather petty;

p416 line 22 'past 40 years' is 1969-2009. But the post-1973 mass gain, followed (as detailed later in the paper) by 12 years before the mass of Austrian glaciers fell back to that level, is not a 'minor exception'! - not globally, and certainly not in Austria: so reword.

p 417 lines 5 & 6 simple past tense; 'was', not 'has been' [twice].

line 10 delete last 'the'

lines 18-19 delete 'trends of' ?

line 28 'decades' [plural]?

p418

line 1 replace 'comparably' with 'relatively'

line 3 delete or reword 'higher resolved trends of'

lines 4-5 replace 'to relate' with 'relating'

line 12 replace 'exposition' with 'aspect'. [Although there is a rare word 'exposition' in English, it has other meanings (e.g. 'I made an exposition on misuse of the German language'). Used in this sense, it is a French word, not an English one. This is a not uncommon linguistic error, but the fact that it is printed in journals does not make it right.]

line 19 replace 'of' with 'from'

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lines 20-21 simple past tense; 'was', not 'has been' [twice].

p419 line 4 I suggest '...cases can errors exceed...' [accuracy is inversely related...]

line 9 I suggest '...LIDAR from flights undertaken...'

line 11 replace 'well' with 'closely'

line 12 'DEMs used'

line 13 'remarks on glacier boundary delineation from DEMs'

line 20 replace 'are' with 'have been'

line 24 replace 'temporal course' with 'time series'?

p420 line 18 replace 'renamed' with 'relabelled'

line 20 replace 'accuracies' with 'errors' [again, errors are 'bad' and we want to avoid them; accuracies are 'good!']

line 24 '...by the mean area for...'

p421

line 4 replace 'accuracy' with 'error'

line 5 Please state whether +/- is 95% confidence interval, or standard error.

line 7 'annual length and area'

lines 12-14 '...1969 by 2003...', and reorder the sentence...

line 20 I made it 28-13 = 15, not 16...

line 20 state that area change is assumed to correlate highly with length change, over time.

line 21 'net area (and probably length) reduction.'

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line 22 ‘...2006 continuous length loss...’

line 23 delete ‘a’

line 24 is misleading unless space is inserted between 9 and the formula.

p422 line 14 ‘...years had been lost by 1985, after several negative...’

line 17 ‘only one year (2001) showed a positive sum of specific mass balance...’

line 21 ‘lengths’

p423 line 2 replace ‘parameters’ with ‘variables’ or ‘attributes’ [parameters are in models, or statistics fitted to data – not the data themselves]

line 3 replace ‘have been’ with ‘were’

line 10 replace ‘has risen’ with ‘rose’

line 12 replace ‘of’ with ‘for’

line 14 delete ‘due to’

line 21 replace ‘a similar ’ with ‘the’

line 22 delete ‘has occurred’

line 22 replace ‘as it was’ with ‘is similar to that’ [clumsy indirect expression; sentence remains a little verbose]

p424 line 3 begs the question, ‘how?’...Please explicate. I doubt if WFF received much support (buttressing) from RMF.

line 19 etc. I suggest F = ‘acceleration factors’ rather than ‘scaling parameters’.

lines 21-25 These equations are clumsy; could be improved by using ‘annual change in area...’?

p425 line 4 ‘...and permit trends...change to be contrasted...’

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lines 5-6 ‘...to the periods of net retreat...’

line 10 usually we compare later period with earlier...

line 16 not ‘critical’. Perhaps ‘doubtful’?

line 17 ‘to, which...’

line 18 ‘between the two periods.

line 23 CUT: because in Table 2 no F values show a deceleration trend, only one steady FA (all) = 1.0..

p426 line 4 replace ‘changes’ with ‘losses’

line 5 replace ‘changes’ with ‘reductions’

line 18 ‘...information such as annual length...’

line 24 ‘...inventory: rather, longer-...’

line 27 delete ‘different’

p427 line 4 ‘that for the...) retreat has decelerated in terms...’

lines 5-6 delete ‘they used to be’

line 9 ‘at low....increased more than at high elevations (Fig. 4b)...’

line 12 ‘at low’

line 14 ‘...supply to glacier...’

line 16 ‘Comparison of scaled parameters reveals that those connected...’

line 20 delete brackets

line 22 ‘at low’

line 24 ‘tongue around 2700 m a.s.l.; and up to 150 m for larger...’

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line 25 NOT 'constellation...' May be 'arrangement'?

line 28 replace 'that are within' with 'between'

line 29 replace 'has not changed' with 'did not change'

p428 line 2 delete 'have'

line 3 'lose'

line 3 'within a few'

p429 line 22 insert page numbers.

p430 line 1 insert page numbers, as this is now published

line 13 insert page numbers.

p433 Does Table 2 show overall change per size class (not average of changes per glacier)? - there is a difference...(If so, perhaps the 3 disappeared glaciers should be included?). Do the size classes refer to 1969, and do glaciers remain in the same class even if their area crosses a class boundary? Usually I ask for more rounding, but in this case, annual rates in km² a⁻¹ might benefit from an extra decimal place (i.e., use ha a⁻¹, losing the decimal point and initial zero...); acceleration factors too need one extra decimal place. Is -1.9% a⁻¹ correct for glaciers <0.1 in 97-06? I make -11.8% in 9 years = -1.3% a⁻¹.

p. 434 Table 3 As in Lambrecht and Kuhn 2007 p.181, thickness (height) change is related to initial area. I suggest that a 'wedge model' is more appropriate; a more representative glacier surface height change is obtained by dividing the volume loss by the mean of initial and final areas. This gives the actual lowering over the surviving glacier surface, assuming that the slope of the deglaciated areas is linear (draw a cross-section!).

p435 The caption implies that grey v. red shows changing glacier extent, but it shows

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mainly the more limited survey coverage in 2006, so please reword the caption.

p436 The point symbols are heavy (spreadsheet?) splodges; a more refined symbol (cross or open circle) is desirable.

p437 Fig 3 caption line 2; delete comma

Interactive comment on The Cryosphere Discuss., 3, 415, 2009.

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3, C125–C133, 2009

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