Sensitivity of alpine glacial change detection and mass balance to sampling and datum inconsistencies (TCD 7, 55-101, 2013)

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The paper addresses and important subject, which is that the datum surfaces to which digital terrain models are referred should be identified. It goes on to discuss four cases in which the horizontal datum either is or is not correctly identified and independently whether the vertical datum is or is not correctly identified. It considers data from three glaciers – Andrei, Bridge, and Peyto – in western Canada although detailed results are given for only Peyto.

The writing is very hard to follow. Each datum surface and each surface topography is a single-valued function of two horizontal coordinates. The subject, therefore, is eminently amenable to precise mathematical description and should be discussed in those terms. Introduction of a modest amount of mathematical notation would make the paper much more readable. Instead, it makes heavy use of vague terms such as inconsistency.

Table 6, which contains much of the quantitative information in the paper, defied over an hour of intense scrutiny because so much in it and in the text introducing it is ill defined. The paper takes up a highly technical subject and should not do so in such nontechnical language. To become comprehensible to glaciologists, it needs to be thoroughly rewritten. Terms such as residual error need to be defined explicitly. The slang "scenario" should be replaced by the standard word "case" throughout the paper.

Comments are identified by page and line number in the 17 January 13 manuscript.

58,8   Errors are intrinsic to all predictions, so it is just inadequate statement of uncertainties that will undermine planning.

58,16   Syntax of this sentence is disrupted.

58,25   "at discrete elevation bands" should be omitted.

60,1   What horizontal intervals are is unclear.

60,5   Syntax of this sentence is disrupted.

60,23   Two sentences are joined by a comma and need to be separated.

61,21   Between "-107 and 86 m" would be better.

62,1   Explain why the apparent difference between the two epochs cannot be corrected by the amount of the undulation.

63,1   More concise and precise than "bi-axial ellipsoid of revolution" is "oblate spheroid"

64,20   It would be helpful to indicate what similar endeavors are underway elsewhere,

64,24   Spirit leveling should be described, particularly its connection to other altimetry methods.

65,12   Locations of Bridge and Andrei are mixed up in Fig. 2.

66,15   Fig. 3 would be better were UTM coordinates used instead of Lat, Long.

66,22   What is meant by "even" should be explained.

68,12 Writing Eqn (1) as $U = E - G$ would be more readily understood, where U is the undulation, E height of the ellipsoid, and G height of the geoid.

68,16 "profile extents along the centre of the glacier margin" needs to be stated differently, for according to Fig. 3 the profile appears to be in the middle between the lateral margins.

68,21 The caption of Table 4 says geoid heights, not undulations, and should define the undulation as difference between ellipsoid and geoid, as Eqn. (1) should say.

68,23 Presumably geoid undulation is meant instead of geoid height.

68,25 According to Table 4, range for Andrei is 0.51

69,8 The exact date, not just the year, should be shown for each survey in Table 2. If surveys are made at about the same time each year, effects of seasonal variation are reduced. If not, an adjustment must be made taking into account the variation of the density of the upper layer of the glacier between spring and autumn.

69,10 This sentence is an example of where use of mathematical notation would achieve much greater readability.

69,13 Why analysis of difference of effects of using the two sampling schemes is not included should be explained.

69,26 Does the DEM give mean elevation over a 2.5-meter grid cell or does it give elevations at discrete points, albeit at 2.5-meter spacing in each of two horizontal directions ?

69,28 Under the assumption of Sorge's Law (Cogley et al., 2011), change of mass in a vertical column is caused by change in the ice component of the column.

In most geodetic determinations of mass balance over multi-year periods, change in the snow and firn components is usually neglected unless the time of year of each survey is known and change of those components is separately estimated for each. Otherwise, change is assumed to be solely in the ice component.

70,17 What is meant by "totalised" should be explained.

71,1 The error curve in Fig. 6 needs to be defined, whether it is some function of the two subsets of points on the elevation curve, and this should be done by introducing clear notation for the three.

Close inspection of Fig. 7 suggests this is true. Its error curve seems to have a point wherever there is a point on either of the elevation curves, each of which is taken to be a piecewise linear function passing through its points. At any point on either curve, the error is the difference between its elevation and the linear function representing the other curve.

The foregoing interpretation seems likely for Fig. 7 but it is not clear whether it is valid for Fig. 6.

71,13 Table 5 has maximum error 5.0 m for Peyto.

72,12 Eqn (2) would be better as $\Delta v = \Delta h \, \tan \alpha$, and the symbols v and h should be defined precisely as vertical and horizontal components respectively.

72,23 Why the change profile of Fig. 8A has a minimum at ≈ 800 m is worthy of comment, particularly if it is because the terminus receded between 1966 and 2006. See comment 98 below.

72,25 What is meant by "consistently transition" should be explained.

73,10 Why the relative error would have the most significant impact on accumulation estimates should be explained. The paper needs to make the case for why relative error is more important than absolute error.

73,25 The validity of assuming a spatially constant vertical datum error should be discussed as a function of glacier area. Presumably the effect vanishes as area goes to zero, but how it might scale with area should be described.

74,14 What is meant by errors being inconsistent should be defined. Explain why Table 5 has both H and V errors (Case 4) for Bridge and Peyto but not for Andrei.

74,16 Direction of the geoid height should be defined, for it seems that the height is a scalar function. Maybe the author means direction of its gradient, but the reader should not have to guess.

74,26 Instead of "play a critical role," the effect would be better described in terms of the inner product of the gradient of the glacier surface and the direction of the shift. Here it is that gradient that is pertinent, not the direction of glacier flow, although the two are generally very similar.

75,1 The datum inconsistency cannot introduce surface growth.

75,18 "$< 50\%$ of the change error" is unclear because change error is undefined and because < 50 is imprecise.

75,21 Why high melt rates are significant rather than large negative (or positive) annual balance should be explained. A reference should be supplied for high melt rates in the tropics.

75,27 Why detailed results are given for only Peyto (Table 6) should be explained.

84,8 Meier (1984) appeared in *Science* not *Nature.*

87 The second column in Table 1 is not the melt rate but rather is the negative of the average annual balance over the period. Were there no elevation change at all, there can still be melting, albeit counteracted by an equal amount of accumulation.

In view of the paper's emphasis on uncertainties, they should also be shown for the values in the last column of Table 1.

88 The reader should not have to look closely at Table 2 only to see that it is extremely repetitive. It should be replaced by two simple sentences:

"Photogrammetry for all three glaciers (1982 at Andrei, 1988 at Bridge, 1966 at Peyto) used NAD 27 for the horizontal reference system and CGVD 28 for the vertical. LiDAR was obtained in 2006 for all three glaciers using the NAD 83 for both the horizontal and vertical reference systems."

89 Table 3 and 4 should be combined.

90 In Table 4, −0.19 to 0.32 and −12.80 to −12.66 would parallel −10.54 to −10.50 in giving each range in increasing algebraic order.

"Ends of analyzed profiles" would be better than "extents of analyzed profile lines."

91 It seems the first three numerical columns are the mean, maximum, and minimum of the elevation change from the first survey until 2006 over the entire surface. Why it is called residual error is not clear. Meanings of +m and −m in the column headings are undefined.

92 The Table 6 caption should state the years over which the change occurred, 1966 and 2006. Does "subtraction statistics" mean volume change? Of the eight columns in the table, the relation between those in columns 6 and 7 is not obvious: how can the volume change Δ be greater than the volume? How can the water volume (column 7) be negative?

Notation in the column headings should be clarified. Does $-\Delta$, for instance, mean that all values in the column, which are shown as positive, are to be understood to be negative? Does "Water volume ($\times 10^6$ m^3) mean that all change in ice volume are converted to water equivalent? If so, why not use the standard m^3 w.e.?

"Consistent Horizontal and Vertical Datums" would be better as "Correct Horizontal and Vertical Datums," and "Inconsistent Horizontal Datum" would be better as "Incorrect Horizontal Datum and Correct Vertical Datum," and similarly for cases 3 and 4. (See note above concerning "scenario")

96 Fig. 4 should be identified as showing Bridge Glacier.

97 What the caption says would be the negative of the change from 1966 until 2006.

98 The origin from which distance along the profile is measured needs to be defined, and if it is from the terminus, including which terminus, 1988 or 2006. This obscurity needs to be remedied in many places in the paper.

A more manageable coordinate measures glacier length from the head of the glacier, because its position changes negligibly compared with change in terminus position.

100 What the curves are in Fig. 8B is unclear. The one labeled Residual Error appears to be the negative of the absolute error, incorrect minus true. The title mentions only ratio error, which apparently is that of the absolute error to the true change. The title mentions only ratio error.

101 So that the solid curve in Fig. 9B is noticed, it would be useful to say it has constant value (≈ 13 m), which is the difference between the two vertical datums (CGVD 28 and NAD 83, presumably) in the vicinity of Bridge Glacier. See also comment 73,25. It should be clearly defined that way, ideally with a more readily understood name than residual error.