Sensitivity of Glacial Change Detection on Bridge Glacier to Horizontal Datum Transformations

TRISTAN GOULDEN[1,2], CHRIS HOPKINSON[2,1] & MICHEAL N. DEMUTH

1Process Engineering and Applied Science, Dalhousie University, Halifax, Canada
tgoulden@dal.ca
2 Applied Geomatics Research Group, NSCC Annapolis Valley Campus, Nova Scotia, Canada
3 Glaciology Section, Geological Survey of Canada, Ottawa, Ontario, Canada

Abstract To chronicle the change of alpine glaciers analysis of historical data and comparison with modern observations is necessary. This is typically performed by observing profile lines along the glacial surface with GPS, extracting elevations of the observed profile from a historical topographic map, and comparing the elevations. GPS observations and the historical topographic map are typically referenced to separate horizontal datums. This research demonstrates the sensitivity of glacial change detection to the horizontal datum considerations through a case study of Bridge glacier in Western Canada. To simulate the procedure of observing the glacial surfaces, profiles along the centreline of Bridge Glacier were derived from Digital Elevation Model (DEMs) in obsolete and current horizontal datums from historical and contemporary observations of Bridge Glacier. The change was determined both when 1) the horizontal datums were correctly reconciled 2) the horizontal datums were not correctly reconciled. It was concluded that the effects of disregarding datum considerations propagated significant error (up to 40%) in the change detection results which may cause incorrect conclusions to be drawn about the fate of the glacial system.

Key Words: Glacial Change Detection, Datum Transformation, Error

INTRODUCTION

Alpine glaciers are a common climate change indicator used to establish the evolution of global temperature patterns (Oerlemans, 1994). Current research indicates that a there is a recent raise in global temperatures causing net losses to many alpine glacial systems over time (Barry, 2006). There is a need to carefully monitor these systems as inputs to climate change models and for quantification of water resources. One technique of monitoring the change in a glacial system is through direct observations of *x,y,z* coordinate locations along the glacial surface and developing a representative profile. A current and historical profile can be subtracted to yield the change in the surface. Often directly observed historical profiles do not exist and can be established from historical topographic maps. Contemporary observations can be acquired through traditional surveying techniques such as with GPS (e.g. Mark and Setzer, 2005). Often historical topographic maps will have been produced in obsolete horizontal datums. Transformations between historical and modern datums are essential if time-variant geospatial data are going to be compared (Daniels, 2001). In glaciology, reconciliation of modern and historical datums is critical, given subtle patterns of net surface growth and downwasting can occur on the same glacier over decade time scales (e.g. Hopkinson *et al*., 2010).

This research demonstrates the sensitivity of glacial change detections to errors that typically occur when horizontal datums are not properly reconciled. A horizontal datum is characterized by three-dimensional bi-axial ellipsoid with a defined centre, scale and orientation. All coordinate observations will be consistent if they are made with reference to the same datum definition. For most of the 20th century, the North American Datum of 1927 (NAD27) was the official datum definition in Canada. Throughout the past century, increases in technology and computing power have necessitated a modification of the datum definition, and in 1990 the Canadian government officially adopted the North American Datum of 1983 (NAD83).

The study site for the research is Bridge Glacier, located in the Canadian Coast Mountain chain. Today, GPS observations are often observed in the WGS84 or NAD83 datum. Therefore, any historical observations used prior to 1990 must be transformed in to the current datum before comparisons can be made.

METHODS

'Historical' data for Bridge Glacier exists in the form of a DEM derived from an aerial photogrammetric survey performed in 1988. A 'contemporary' DEM was obtained from a Light Detection and Ranging (LiDAR) survey in 2006 by the Applied Geomatics Research Group (AGRG). The DEMs can be integrated in a GIS platform and profiles digitized on their surface to simulate the acquisition of *x,y,z* locations along the glacial surface. All profiles were drawn beginning at the highest elevation areas of the glacier toward the lowest. When generating profile lines from a historical topographic map, a horizontal line is physically drawn on the map and elevations are extracted on the intersection of the horizontal line with the map contours. To properly simulate this activity, the historical observations were sampled at 10 metre contour intervals from the DEM. When acquiring contemporary GPS observations on the glacier surface observations are likely to be made at a regular horizontal spacing. To simulate this procedure, contemporary profiles obtained from the DEM were sampled every 100 m horizontally. To determine the effect of the datum transformation profiles from the historical dataset were obtained in both the NAD27 and NAD83 horizontal datums. These were subtracted from the profile obtained from the contemporary data set obtained with reference to NAD83. This produced two change profiles, a correct one in which both profiles were referenced to NAD83 datum and an incorrect one in which the historical datum was incorrectly referenced to NAD27. From this, the error introduced within the incorrect profile is quantified.

RESULTS

To display the different sampling techniques and difference in horizontal datum reference, the surface of the glacier as it existed in 2006 was sampled with reference to NAD27 on the 10 metre contour interval ('x' in Fig 1) and with reference to NAD83 sampled at even 100 metre intervals horizontally ('+' in Fig 1). The prominent difference in the sampling interval occurs in areas characterized by large changes in elevation as well as flat areas with little change in elevation. When samples are taken on even 10 metre contours areas with large changes in elevation are densely sampled, while sampling every 100 metres horizontally results in sparse samples. Conversely, sampling at even 100 metre intervals will represent flat terrain well while sampling on even contour intervals cannot. Fig 1 also demonstrates the error introduced when horizontal datums are not properly reconciled (solid circle). The change shown is from the same temporal surface meaning the error is strictly due to different datum definitions and not influenced by the change in the glacial surface over time. Errors of nearly 20 metres exist which are difficult to identify from only analyzing surface profiles because of the scale of the elevation change on the glacial profile.

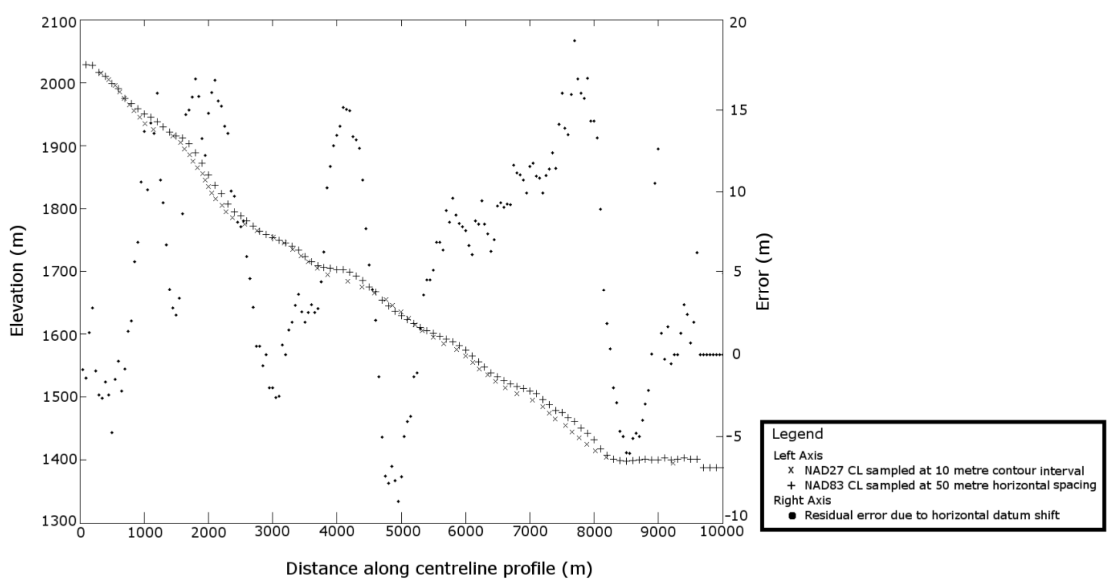

Fig 1 Profile line from the 2006 DEM. Profile shown with '+' is referenced to NAD83 and sampled at 100 metre intervals horizontally. Profile shown with 'x' is referenced to NAD27 and sampled at 10 metre intervals vertically. Solid circles represent the difference between the profiles.

Fig 2 shows profiles of the change in elevation on the glacial surface when the historical dataset was incorrectly referenced to the NAD27 datum and the contemporary dataset was referenced to the NAD83 datum, represented with the 'x' symbol. The second profile shows the change in elevation when both the historical and contemporary dataset are correctly referenced to the NAD83 datum, shown with the '+' symbol. The correctly referenced profile shows a consistent and expected increase in downwasting as the profile moves from the higher elevation to lower elevation areas. The incorrect change profile shows a more inconsistent pattern of downwasting which is likely caused by natural peaks and valleys in the glacial surface no longer being spatially coincident. When the surface profiles are subtracted the observed change is a result of the combination of true glacial decline and the difference between the separate locations on the glacier. This results in a more erratic and random change profile as it is dependent on the natural variation in the glacial surface as well as the decline. It should be noted that along the flat area at the end of the profile line the observed change is consistent. This occurs because no error is introduced if a flat area is shifted only by a horizontal translation, as the elevations are unchanged. This should remind users that examining change profiles for errors due to incorrect horizontal datum choices cannot be done on flat surfaces.

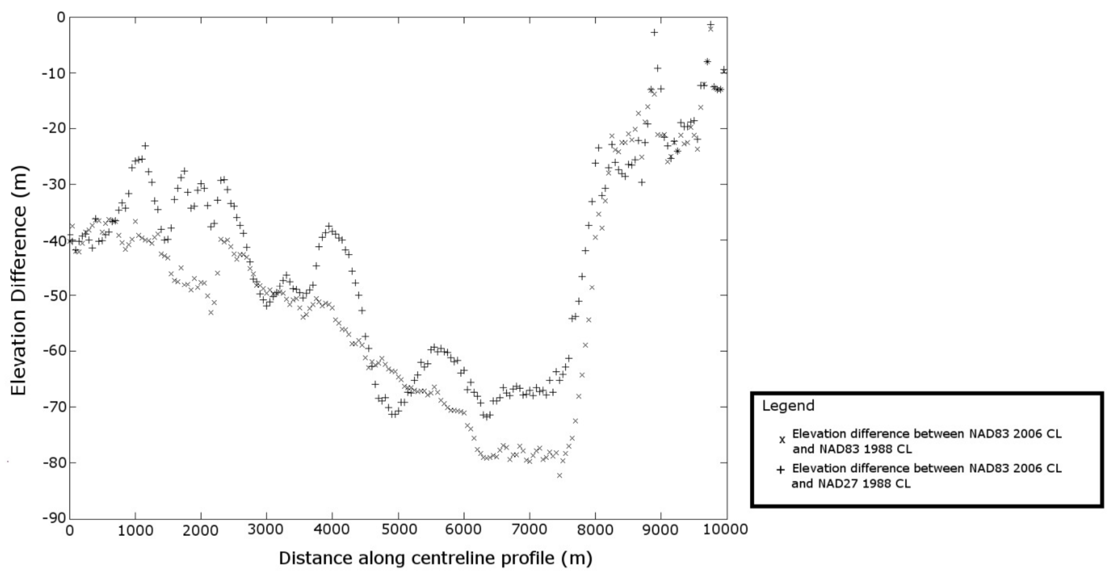

Fig 2 Profile lines showing elevation change between the 1988 DEM and 2006 DEM. Profile shown with '+' is change between the 1988 data set referenced to NAD27 and the 2006 dataset referenced to NAD83. Profile shown with 'x' is the 'true' change between the 1988 data set referenced to NAD83 and the 2006 dataset referenced to NAD83.

Fig 3 displays the amount of error that exists between the correctly referenced change profile and in the incorrectly referenced change profile. The magnitude of the error is represented on the left axis with the '+' symbol and reaches magnitudes of greater than 20 metres. The profile represented on the right axis by solid circles is the ratio between the residual error and the true change in the surface. From this profile we can see that there are instances when the error is significant, reaching levels over 40% of the actual change and being above 10% for most of the profile.

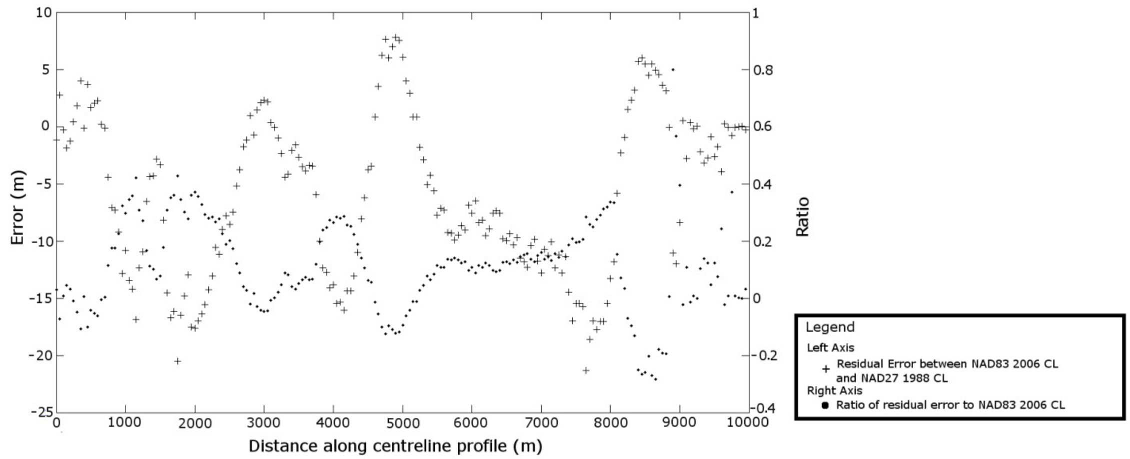

Fig 3 Profile lines showing the error that occurs when the 1988 dataset is referenced to NAD27 and the 2006 dataset is referenced to NAD83. Profile shown with '+' (left axis) is the residual error between the correctly performed change profile and the incorrectly performed changed profile. Profile shown with the solid circle (right axis) is the ratio between the residual error and the correctly performed change profile.

CONCLUSION

This analysis shows that the quantification of glacial change over a period between 1988 and 2006 over a glacier surface is sensitive to horizontal datum shifts. Incorrectly referencing historical profiles to outdated datums can cause errors in observed downwasting (or growth) in the glacier that are up to 40% of the true change. When observing only the surface profiles of the glacier surface it is difficult to identify errors of this magnitude because of the scale of the elevation change relative to the range of elevations typically experienced, thus allowing this error to easily go unnoticed. The error can manifest as erratic change along the profile which is typically characterized by consistent decline from areas of high elevation to areas of low elevation. The errors introduced can have significant impact on mass balance estimates, the interpretation of glacier – climate interactions and for future water resource availability assessment. Future work in this area will include analyzing the effect of changes to the vertical datum, including cross-sectional profiles of the glacial system and inclusion of several additional study sites within different geological and climatic contexts.

REFERENCES

Barry, R.G. (2006) The status of research on glaciers and global glacier recession: a review. *Progress in Physical Geography*, **30,** 285-306.

Hopkinson, C., Demuth, M.N. & Sitar, M.R. (2010) Hydrological implications of periglacial expansion in the Peyto Glacier catchment, Canadian Rockies. *Remote Sensing and Hydrology 2010.* Proceedings of a symposium held at Jackson Hole, Wyoming, USA, September 2010 (IAHS Publ. 3XX, 2011).

Mark, B. G. and G. O. Seltzer. (2005) Tropical glacial meltwater contribution to stream discharge: a case study in the Cordillera Blanca, Perú. *Journal of Glaciology* **49** (165), 271-281.

Oerlemans, J. (1994) Quantifying global warming from the retreat of glaciers. *Science,* **264 (5156)**, 243-245.