The Cryosphere Discuss., 7, C7–C20, 2013
www.the-cryosphere-discuss.net/7/C7/2013/


The Cryosphere
Discussions

# *Interactive comment on* "Spatial and temporal variations of glacier extent across the Southern Patagonian Icefield since the 1970s" *by* A. White and L. Copland

**B. Davies**

bdd@aber.ac.uk

Received and published: 17 January 2013

By Bethan Davies and Neil Glasser

## 1 General comments

Copland and White (2012, TCD) present an analysis of the shrinkage of glaciers of the Southern Patagonian Icefield from 1976 to 2010. The analysis is divided into two temporal segments; 1976-1984 and 1984-2010, in order to investigate the changing



rates of glacier shrinkage more closely. The study also investigates the relationship and interaction between glaciers and climate, and provides some initial analysis of atmospheric temperatures since the 1950s.

This is an interesting manuscript on an important topic, but we would like to take this opportunity to point out what we believe are some shortcomings.

### 1.1 Originality and novelty

The most obvious problem to be addressed is the fact that the manuscript repeats a lot of the work and detailed analysis published recently by Davies and Glasser (Davies, B.J., and Glasser, N.F., 2012. Accelerating shrinkage of Patagonian glaciers from the Little Ice Age ( AD 1870) to 2011. Journal of Glaciology 58 (212), 1063-1084). If the Copland and White article is to be published in TC, the authors need to read and cite this paper, and write a section of text explaining how the findings of their research differ from those already published.

The authors should consider how the study by Davies and Glasser (2012) could be built upon or extended and should focus on novel and new findings. Areas that this could cover could include ELA and mass-balance estimates of the glaciers (subject to the provisos below), analysis of ELA change, debris cover, accumulation area ratio change or structural glaciology, or further analysis of precipitation and temperature records. Alternatively, the authors could draw out changes in the glaciers prior to the 1980s (the Davies and Glasser 2012 paper averages change from 1870-1986 for the SPI), perhaps focussing on change from the 1940s onwards, using satellite images or published maps (e.g., Gordon et al., 2008; Berthier et al., 2010). This would highlight interesting glacier dynamical behaviour over a decadal timescale. However, this is all subject to the authors being able to address the methodological comments below, and the gathering of additional data.

We are aware that all of these things require substantial amounts of work, but the paper is not suitable for publication without substantial additional original data, analysis and discussion.

### 1.2 Methodological issues

The most important methodological difficulty is the analysis of glacier area and glacier area change. All the change rates are given in absolute rates (km2 per year), rather than relative measures (

Related to the above point is the assessment of annual rates of change. How have the authors accounted for the different lengths of time between inventories, related to the availability of cloud-free satellite images (cf. Abermann et al., 2009)?

The methods used need more clarification. It is difficult upon reading to ascertain exactly how area changes were measured, and whether length changes were measured. The method for defining the ablation area is not clear. The area change measurements do not apparently conform to GLIMS guidelines, which are also not cited (Kargel et al., 2005; Rau et al., 2005; Raup et al., 2007a; Raup et al., 2007b; Racoviteanu et al., 2009; Raup and Khalsa, 2010). The authors should reference the GLIMS literature and explain their methodology in more detail, stating why it deviates from established methods.

Standard glacier names and IDs are available in the GLIMS database - why were these not used? There is no need to assign new and confusing names or numbers.

How are east-west and north-south gradients accounted for in the analysis of climate data? GLIMS also uses glacier designations (glacieret, valley glacier, etc) to define glaciers, and this may also influence its behaviour. This data is all available within the GLIMS database, but it is not referred to or used.

The error analysis needs further work. Uncertainty in glacier inventories comes from



many sources (Davies et al., 2012), not just from orthorectification and georeferencing of satellite images (cf. Granshaw and Fountain, 2006), but also from human error, slope (Jiskoot et al., 2009) and the quantification of change of debris-covered snouts (Bolch, 2007; Davies and Glasser, 2012). One method of quantifying mapping accuracy is to blind-map the same glacier 5-10 times and assess differences in area mapped (Stokes et al., 2007). In any case, further discussion of the mitigation of these uncertainties is required.

How can the authors assess if the observed annual rates of change are significant? Ideally, measurements of change should have uncertainties attached.

Finally, the terminology is incorrect. It is difficult to know throughout the manuscript whether length or area changes are being dealt with. Glacier inventories should use "shrinkage" when dealing with glacier area change, as glacier area can change in all regions, including around nunataks in the accumulation zone. For clarity, "recession" should be used only when discussing length changes (Bolch et al., 2010; Davies et al., 2012; Davies and Glasser, 2012).

### 1.3 Glacier dynamics and climate change

Perhaps one of the most fundamental issues that the authors need to address is the relationship between climate and glaciers. The climate analysis is very brief and does not refer to other regional records (e.g., Giese et al., 2002; Bown and Rivera, 2007; Aravena and Luckman, 2009), or include important data on precipitation (Bolch, 2007), which may well influence the glaciers on the SPI, where there is a strong east-west precipitation gradient (Masiokas et al., 2008). Furthermore, the authors categorically state in their conclusions that more precipitation is falling as snow, but this is only inferred and implied in the discussion. The authors provide no clear evidence for declining precipitation.

It is very dangerous to make sweeping statements about glacier response to climate change without establishing clear mass-balance records (Bolch, 2007; Hoelzle et al., 2007) or without taking into account response times (see Bamber and Rivera, 2007; Möller et al., 2007; Oerlemans, 2007; Möller and Schneider, 2008).

Important factors concerning glacier dynamics are not considered. Glacier change is rarely a linear and simplistic response to changing atmospheric conditions, as is implied in this study. Glacier response time is controlled strongly not only by precipitation, but also whether it is calving, floating, or on land; its hypsometry, size, altitude and steepness; and its orientation or aspect, and amount of debris cover (Granshaw and Fountain, 2006; Bolch, 2007; Paul et al., 2007; Gordon et al., 2008; Jiskoot et al., 2009; Paul and Svoboda, 2009; Raper and Braithwaite, 2009; Jiskoot, 2011). Glacier recession directly as a result of changing precipitation and temperature can generally only be inferred from small, land-terminating glaciers (Oerlemans, 2005). Most of the glaciers in this study area are calving, and therefore react non-linearly to climate and are driven primarily by internal factors (Warren and Aniya, 1999; Benn et al., 2007a; Benn et al., 2007b). Glacier recession of calving glaciers can therefore not be simplistically related to changing atmospheric temperatures.

The authors should consider showing scatter plots of normalised annual rates of recession versus glacier size, altitude, hypsometry and other variables.

Although much of this information is readily available in the GLIMS database or through simple analysis of a DEM (Frey and Paul, 2012), none of these factors are considered in this study, and we strongly recommend analysing as a minimum the effect of calving, size and orientation when investigating recent glacier change. Overall, the analysis of the variation in recession rates across the SPI is only weakly analysed, does not use all the available data, and is not considered acceptably in the manuscript. In general, it is not justifiable to simply and simplistically argue for reduced precipitation and its effects on the glaciers of the SPI without showing this and providing convincing evidence. If more robust evidence is not available, this section should be omitted.



### 1.4 Summary

This study repeats much of what has gone before and does not utilise much of the freely existing available data from GLIMS. Before it is publishable, the authors should highlight and draw out where their work is original and new, and consider undertaking new and original data collection and analysis.

The authors should also use relative area change to compare different glaciers of different sizes in different areas, and they should consider in detail the causes of asynchronicity and variance in glacier behaviour. They should investigate the influence of basic topographic factors, such as glacier size and terminal environment (calving or not) at the very least, in order to better understand glacier recession across the Southern Patagonian Icefield.

The manuscript fails to cite numerous key papers on the glaciation of the SPI and on general Patagonian climate as well as glacier inventory methods. We have included a list of numerous references below, which should be considered for citation. We are aware that our comments suggest that the authors undertake a substantial amount of work and reanalysis of the data, but we hope that ultimately this will result in a more robust, interesting and novel publication.

## 2 Specific comments

Below we have highlighted some further specific suggestions:

P3 L23: What is a 'highest' advance?

P4 L3-4: define abbreviations

P5 L4: an inventory of the SPI has been completed (Davies and Glasser, 2012)

P5 L15-20: Clarify. Were length changes measured? This section is confusing.

P6 L3: Give GLIMS weblink and abbreviation, and cite key GLIMS papers (see references below)

P6 L24: How was the ablation area defined? Explain in more detail the measurements across the ablation area and why this varies from standard GLIMS procedures. Why were existing GLIMS outlines not used?

P7: again methods are confusing; clarify. Was length or area measured?

P7 L25: Why not use existing glacier names in GLIMS? There is no need to introduce new and confusing glacier names/numbers.

P8. How do you quantify human interpretation errors? This needs discussion at least.

P9 L1. How about also using/discussing longitudinal surface structures (Glasser and Gudmundsson, 2012)?

P10 L1: Be clear. Recession - change in glacier length. Shrinkage - change in glacier area.

P10 L14. Glaciers are all of different sizes. To compare rates of shrinkage for glaciers of different sizes, use

P10. L15: Is this change significant? Difficult to assess without knowing more about the uncertainty.

P11 L1. Are these differences related to size?

P12 L3. How is this difference defined? Why is it based on square blocks rather than on the ice divide? There are large differences in size, precipitation, aspect, steepness, etc, on either side of the ice divide, which is not discussed.

P13. Discussion is very descriptive and needs more analysis and depth. Results from this work need to be better integrated with previous analyses. The structure is confused



and unclear. There is no detailed analysis on the impact of climate / temperature on glaciers; that which exists is very vague.

P14 L11: citation needed for surging looped moraines.

P14 L25. It is very difficult to attribute glacier change to warming directly without detailed mass balance studies, analysis of precipitation or response times, particularly when one is discussing calving glaciers.

P15 L2: Declining snow precipitation is not rigorously documented in this study; this is better omitted.

P16 L2: Compare with Davies and Glasser's (2012) and Glasser et al.'s (2011) study of the NPI and SPI

P16 L9: "97

P17 L1. "reduction in the proportion of total precipitation falling as snow". There is no evidence for this in this study. Remove or substantiate. This is not well justified. Discuss what causes variation in recession rates. Calving glaciers should be analysed separately.

P18 L21: What is the status of this paper now?

Table 1: How do you account for the different length of time between analyses when calculating annual recession rates? There are not GCPs associated with every image. how does this affect overall error assessment? It is more where there are no GCPs? On steeper ground?

Table 2: N/D not applicable.

Table 3: Consider showing area change as a Far-reaching conclusions are drawn from 1976-1984 with few data points.

Figure 1: Too small, cannot read. Simplify.

Figure 2: Is East or West changing more? Why?

Figure 4: A prime example of how glacier dynamics can influence recession rates. Perito Moreno Glacier is strongly influenced by grounding against land on the far side of the lake (Stuefer et al., 2007)

Figure 6: Is this a graph of aspect / orientation or location? Unclear. Putting the years on the individual graphs would make it a lot easier to read.

Figure 7: It is clear from this figure that larger glaciers have lost more absolute area, but this is not surprising. Consider showing it as a

## 3 References

Abermann, J., Lambrecht, A., Fischer, A. and Kuhn, M., 2009. Quantifying changes and trends in glacier area and volume in the Austrian Ötztal Alps (1969-1997-2006). The Cryosphere, 3: 205-215.

Aravena, J.C. and Luckman, B.H., 2009. Spatio-temporal rainfall patterns in Southern South America. International Journal of Climatology, 29 (14): 2106-2120.

Bamber, J.L. and Rivera, A., 2007. A review of remote sensing methods for glacier mass balance determination. Global and Planetary Change, 59 (1-4): 138-148.

Benn, D.I., Hulton, N.R.J. and Mottram, R.H., 2007a. 'Calving laws', 'sliding laws' and the stability of tidewater glaciers. In: M. Sharp (Editor), Annals of Glaciology, Vol 46, 2007. Annals of Glaciology. Int Glaciological Soc, Cambridge, pp. 123-130.

Benn, D.I., Warren, C.R. and Mottram, R.H., 2007b. Calving processes and the dynamics of calving glaciers. Earth-Science Reviews, 82 (3-4): 143-179.

Berthier, E., Schiefer, E., Clarke, G.K.C., Menounos, B. and Remy, F., 2010. Con-



tribution of Alaskan glaciers to sea-level rise derived from satellite imagery. Nature Geoscience, 3: 92-95.

Bolch, T., 2007. Climate Change and glacier retreat in northern Tien Shan (Kazakhstan/Kyrgyzstan) using remote sensing data. Global and Planetary Change, 56: 1-12.

Bolch, T., Kulkarni, A., Kääb, A., Huggel, C., Paul, F., Cogley, J.G., Frey, H., Kargel, J.S., Fujita, K., Scheele, M.P., Bajracharya, S. and Stoffel, M., 2012. The state and fate of Himalayan Glaciers. Science, 336: 310-314.

Bolch, T., Menounos, B. and Wheate, R., 2010. Landsat-based inventory of glaciers in western Canada, 1985-2005. Remote Sensing of Environment, 114 (1): 127-137.

Bown, F. and Rivera, A.s., 2007. Climate changes and recent glacier behaviour in the Chilean Lake District. Global and Planetary Change, 59 (1â€̀4): 79-86.

Davies, B.J., Carrivick, J.L., Glasser, N.F., Hambrey, M.J. and Smellie, J.L., 2012. Variable glacier response to atmospheric warming, northern Antarctic Peninsula, 1988–2009. The Cryosphere, 6: 1031-1048.

Davies, B.J. and Glasser, N.F., 2012. Accelerating recession in Patagonian glaciers from the "Little Ice Age" (c. AD 1870) to 2011. Journal of Glaciology, 58 (212): 1063-1084.

Frey, H. and Paul, F., 2012. On the suitability of the SRTM DEM and ASTER GDEM for the compilation of topographic parameters in glacier inventories. International Journal of Applied Earth Observation and Geoinformation, 18 (0): 480-490.

Giese, B.S., Urizar, S.C., Fu and kar, N.S., 2002. Southern Hemisphere Origins of the 1976 Climate Shift. Geophys. Res. Lett., 29 (2): 1014.

Glasser, N.F. and Gudmundsson, G.H., 2012. Longitudinal surface structures (flowstripes) on Antarctic glaciers. The Cryosphere, 6: 383-391.

Glasser, N.F., Harrison, S., Jansson, K.N., Anderson, K. and Cowley, A., 2011. Global sea-level contribution from the Patagonian Icefields since the Little Ice Age maximum. Nature Geoscience, 4 (5): 303-307.

Gordon, J.E., Haynes, V.M. and Hubbard, A., 2008. Recent glacier changes and climate trends on South Georgia. Global and Planetary Change, 60 (1-2): 72-84.

Granshaw, F.D. and Fountain, A.G., 2006. Glacier change (1958-1998) in the North Cascades National Park Complex, Washington, USA. Journal of Glaciology, 52 (177): 251-256.

Hoelzle, M., Chinn, T., Stumm, D., Paul, F., Zemp, M. and Haeberli, W., 2007. The application of glacier inventory data for estimating past climate change effects on mountain glaciers: A comparison between the European Alps and the Southern Alps of New Zealand. Global and Planetary Change, 56 (1-2): 69-82.

Jiskoot, H., 2011. Dynamics of Glaciers. In: V.P. Singh, P. Singh and U.K. Haritashya (Editors), Encyclopedia of snow, ice and glaciers. Springer, Dordrecht, The Netherlands, pp. 245-256.

Jiskoot, H., Curran, C.J., Tessler, D.L. and Shenton, L.R., 2009. Changes in Clemenceau Icefield and Chaba Group glaciers, Canada, related to hypsometry, tributary detachment, length-slope and area-aspect relations. Annals of Glaciology, 50 (53): 133-143.

Kargel, J.S., Abrams, M.J., Bishop, M.P., Bush, A., Hamilton, G., Jiskoot, H., Kääb, A., Kieffer, H.H., Lee, E.M., Paul, F., Rau, F., Raup, B., Shroder, J.F., Soltesz, D., Stainforth, D., Stearns, L. and Wessels, R., 2005. Multispectral imaging contributions to global land ice measurements from space. Remote Sensing of Environment, 99 (1-2): 187-219.

Masiokas, M.H., Villalba, R., Luckman, B.H., Lascano, M.E., Delgado, S. and Stepanek, P., 2008. 20th-century glacier recession and regional hydroclimatic changes



in northwestern Patagonia. Global and Planetary Change, 60 (1-2): 85-100.

Möller, M. and Schneider, C., 2008. Climate sensitivity and mass-balance evolution of Gran Campo Nevado ice cap, southwest Patagonia. Annals of Glaciology, 48 (1): 32-42.

Möller, M., Schneider, C. and Kilian, R., 2007. Glacier change and climate forcing in recent decades at Gran Campo Nevado, southernmost Patagonia. Annals of Glaciology, 46 (1): 136-144.

Oerlemans, J., 2005. Extracting a climate signal from 169 glacier records. Science, 308: 675-677.

Oerlemans, J., 2007. Estimating response times of Vadret da Morteratsch, Vadret da Palu, Briksdalsbreen and Nigardsbreen from their length records. Journal of Glaciology, 53 (182): 357-362.

Paul, F., Kääb, A. and Haeberli, W., 2007. Recent glacier changes in the Alps observed by satellite: Consequences for future monitoring strategies. Global and Planetary Change, 56 (1-2): 111-122.

Paul, F., Kääb, A., Maisch, M., Kellenberger, T. and Haeberli, W., 2002. The new remote-sensing-derived Swiss glacier inventory: I. Methods. Annals of Glaciology, 34: 355-361.

Paul, F. and Svoboda, F., 2009. A new glacier inventory on southern Baffin Island, Canada, from ASTER data: II. Data analysis, glacier change and applications. Annals of Glaciology, 50 (53): 22-31.

Racoviteanu, A.E., Paul, F., Raup, B., Khalsa, S.J.S. and Armstrong, R., 2009. Challenges and recommendations in mapping of glacier parameters from space: results of the 2008 Global Land Ice Measurements from Space (GLIMS) workshop, Boulder, Colorado, USA. Annals of Glaciology, 50 (53): 53-69.

Raper, S.C.B. and Braithwaite, R.J., 2009. Glacier volume response time and its links to climate and topography based on a conceptual model of glacier hypsometry. The Cryosphere, 3 (2): 183-194.

Rau, F., Mauz, F., Vogt, S., Khalsa, S.J.S. and Raup, B., 2005. Illustrated GLIMS Glacier Classification Manual, Version 1.0. GLIMS (Global Land Ice Measurement from Space), NSIDC, GLIMS Regional Centre, 'Antarctic Peninsula', 36 pp.

Raup, B., Kääb, A., Kargel, J.S., Bishop, M.P., Hamilton, G., Lee, E., Paul, F., Rau, F., Soltesz, D., Khalsa, S.J.S., Beedle, M. and Helm, C., 2007a. Remote sensing and GIS technology in the Global Land Ice Measurements from Space (GLIMS) Project. Computers Geosciences, 33 (1): 104-125.

Raup, B. and Khalsa, S.J.S., 2010. GLIMS Analysis Tutorial. GLIMS, Global Land Ice Measurements from Space, NSIDC, www.GLIMS.org, 15 pp.

Raup, B., Racoviteanu, A., Khalsa, S.J.S., Helm, C., Armstrong, R. and Arnaud, Y., 2007b. The GLIMS geospatial glacier database: A new tool for studying glacier change. Global and Planetary Change, 56 (1-2): 101-110.

Schneider, C., Schnirch, M., Acuña, C., Casassa, G. and Kilian, R., 2007. Glacier inventory of the Gran Campo Nevado Ice Cap in the Southern Andes and glacier changes observed during recent decades. Global and Planetary Change, 59 (1-4): 87-100.

Stokes, C.R., Popovin, V., Aleynikov, A., Gurney, S.D. and Shahgedanova, M., 2007. Recent glacier retreat in the Caucasus Mountains, Russia, and associated increase in supraglacial debris cover and supra-/proglacial lake development. . Annals of Glaciology, 46: 195-203.

Stuefer, M., Rott, H. and Skvarca, P., 2007. Glaciar Perito Moreno, Patagonia: climate sensitivities and glacier characteristics preceding the 2003/04 and 2005/06 damming events. Journal of Glaciology, 53 (180): 3-16.



Warren, C. and Aniya, M., 1999. The calving glaciers of southern South America. Global and Planetary Change, 22 (1-4): 59-77.

---

Interactive comment on The Cryosphere Discuss., 7, 1, 2013.