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Citation for published version:
Spencer, M, Essery, R, Chambers, L & Hogg, S 2014, 'The Historical Snow Survey of Great Britain: Digitised Data for Scotland', *Scottish Geographical Journal*, pp. 1-14.
https://doi.org/10.1080/14702541.2014.900184

Digital Object Identifier (DOI):
10.1080/14702541.2014.900184

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Scottish Geographical Journal

Scottish Geographical Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rsgj20

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Published online: 07 Apr 2014.

To cite this article: Michael Spencer, Richard Essery, Lynne Chambers & Shona Hogg (2014): The Historical Snow Survey of Great Britain: Digitised Data for Scotland, Scottish Geographical Journal, DOI: 10.1080/14702541.2014.900184

To link to this article: http://dx.doi.org/10.1080/14702541.2014.900184

Scottish Geographical Journal, 2014
http://dx.doi.org/10.1080/14702541.2014.900184

The Historical Snow Survey of Great Britain: Digitised Data for Scotland

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(*Received 16 October 2013; accepted 27 February 2014*)

ABSTRACT *Mountain snowline is important as it is an easily observable measure of the phase state of water in the landscape. Changes in seasonal snowline elevation can indicate long-term trends in temperature or other climate variables. Snow-cover influences local flora and fauna, and knowledge of snowline can inform management of water and associated risks. Between 1945 and 2007 voluntary observers collected a subjective record of snow cover across Great Britain called the Snow Survey of Great Britain (SSGB). The original paper copy SSGB data is held by the Met Office. This article details the digitisation of the Scottish SSGB data, its spatial and temporal extents, and a brief example comparison of Met Office snow-lying gridded data. The digitised SSGB data are available from the Met Office authors.*

KEY WORDS: snow survey, snowline, Scotland, mountain, hydrology

1. Introduction

Snowline is the visual boundary between snow cover and no snow on a hillside. Records of snowline over time are important as they can provide an indication of climate, ecological and habitat change (Harrison *et al*. 2001; Trivedi *et al*. 2007), help understand large hydrological events (Black & Anderson 1993) and justify winter sports potential (Harrison *et al*. 2001). While undertaking a modelling exercise on snow, Dunn *et al*. (2000) discussed the accumulation, redistribution and ablation of snow in Scotland. The salient points are the high variability and often temporary nature of snow in Scotland. This is caused by colder periods often interspersed with warmer spells, alternating accumulation and melt. It is often windy in Scotland, which can enhance ablation or redistribute snow during cold periods. Therefore, precipitation occurring at higher elevations as snow can melt or be redistributed according to topography and wind direction, resulting in non-uniform snow-cover distribution. From this we can infer that Scottish snow is often ephemeral in time and space, leading to variations between different hill slope aspects, elevations and

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areas. These local conditions create uncertainty when interpolating snow cover from low-lying, discrete observations to mountain environments.

There are already digital snow-lying data sets available for Great Britain. These fall into two categories: point observations and gridded data. The former includes data collated by the Met Office from their network of automated gauges and observers, which record when snow lies on the ground each day. The Met Office also issued a data set as part of the UKCP09 (United Kingdom Climate Projections 2009) assessment that detailed snow lying between 1971 and 2006 on a 5 km grid covering the UK.

The Met Office station observations are discrete and, as discussed later, only available for lower elevations. They were collected at manual Met Office weather sites by observers who noted if snow was lying at the station, and if so with what depth. These observations were interpolated to form the Met Office gridded snow-lying data set by Perry and Hollis (2005). Perry and Hollis (2005) used multiple regressions with geographic factors like elevation and percentage of each grid cell covered with open water as variables to develop the gridded data. The data set provides the number of days with snow lying per month on a grid of 5 km resolution.

Data from satellite instruments are used to derive global snow-cover products, available from 1966 onwards (Matson 1991). Visible satellite remote sensing methods are not ideal for measuring snow cover in Scotland because snow cannot be viewed through the frequent cloud cover. Windows of opportunity for sampling may occur less than once a week (Slater *et al*. 1999). Working in North America, Tang and Lettenmaier (2010) found that MODIS (Moderate-resolution Imaging Spectroradiometer, Hall *et al*. 2002) had the greatest uncertainty measuring snow covered area during the autumn and spring months, when snow was accumulating or ablating. Dong and Peters-Lidard (2010) investigated the relationship between air temperature and MODIS snow covered area error; as expected from the findings of Tang and Lettenmaier (2010), error increased with temperature. This error was quantified to be 80% for temperatures above 15°C reducing to 10% for temperatures below 0°C or −5°C, location dependent. This is of particular note for remote sensing of snow in Scotland where temperatures do not often stay far below freezing. Snow in Scotland is often wet, which also provides a challenge to microwave satellite observation. Rees and Steel (2001) found that for some types of vegetation cover, notably that without trees, they were able to use remote sensing to detect wet snow by considering a reduction in backscatter attributable to the snow.

The subject of this paper, The Snow Survey of Great Britain (SSGB), is a volunteer observer collected data set that offers snow cover data. It was used to produce the annual publication ‘Report on the Snow Survey of Great Britain’ between 1947 and 1992. The title of this varied through time but the content was consistent, an example is Hawke and Champion (1949). The annual SSGB reports from autumn 1953 until spring 1992 are available from the Met Office (Met Office SSGB). Until now, most of the SSGB data have existed only in paper form and little use had been made of them. Jackson (1978) used the SSGB to discuss the frequency and extent of snow cover in Great Britain. Jackson (1977) also used these SSGB data to help complete a snow index of years from 1875/1876 to 1974/1975. Trivedi *et al.* (2007) digitised data for the Ardtalnaig station on Loch Tay for use in vegetation analysis, undertaking data quality assurance by checking other meteorological stations within the station vicinity. Trivedi *et al.* (2007) found that further use of the SSGB would be warranted as it gave a deeper insight into climate change.

This paper covers the history of the SSGB, the area observed in Scotland, the digitisation process and digital data availability, a limited comparison to another snow cover data set to demonstrate the strengths and weaknesses, and a discussion on the application of the SSGB.

2. History

The Snow Survey of the British Isles began in 1937 (Jackson 1978) and was directed by Mr. Gordon Manley (Anon. 1947). After a hiatus during World War II, the snow survey was resumed in autumn 1946 by the British Glaciological Society. The principle aim was to 'secure representative data relating to the occurrence of snow cover at different altitudes in the various upland districts over the period October to June' (Anon. 1947). The reorganisation of the survey was undertaken by Mr. E.L. Hawke, Honorary Secretary of the Royal Meteorological Society and a member of the British Glaciological Society.

In 1953 the collation of data by the British Glaciological Society ceased and was thereafter undertaken by the British Climatology Branch of the Meteorological Office (Met Office 1954). Hawke and Champion (1954) report in their final snow survey summary that the number of participants had increased from 120 to nearly 400, including land stations, lighthouses and light-vessels.

Between 1946/1947 and 1991/1992, an annual report was produced summarising the data returns for the season. Until 1954 this report was issued by the British Glaciological Society. From 1954 onwards, the Met Office produced the annual SSGB report. The survey was administered by the Met Office from the Scottish Weather Observations Centre in Edinburgh, where data were also collated. In 1992, due to the dwindling interest and lack of funding, the annual publication was withdrawn.

Despite the withdrawal of the annual summary publication, data continued to be collected until 2007. In 1994 there was a review of the 77 participating stations and those deemed not to view high ground or those that duplicated other stations were withdrawn from the survey. Thirty-two stations in Great Britain remained after the review. The observer instructions were also updated following the 1994 review; the most important change was that volunteers were no longer required to note when an observation was obscured by cloud or fog or the observer was absent, although some continued to do so.

Scottish data between Autumn 1945 and Summer 2007 are stored in the Met Office archives in Edinburgh. This pre-dates the beginning of the survey as noted by (Anon. 1947). A likely reason for this is that stations continued reporting snow cover during the Second World War. Some earlier records have been located in the Gordon Manley papers archive (Manley, see references), but these have not been viewed or digitised. The Met Office archive in Exeter holds records for English and Welsh stations between 1946 and 1992.

3. Coverage

The SSGB was collected across Great Britain, but digitisation has only been undertaken for Scottish records, as few English and Welsh records are kept in the Edinburgh archives. Records for 145 sites in Scotland were found within the Met Office archive; the most southerly is Kirkbean near Dumfries and the most northerly is Collafirth Hill on the Shetland Isles. The elevation range from which observations were made is from sea level to 724 m ASL (above sea level), at Lowther Hill near Wanlockhead. Figure 1 shows the

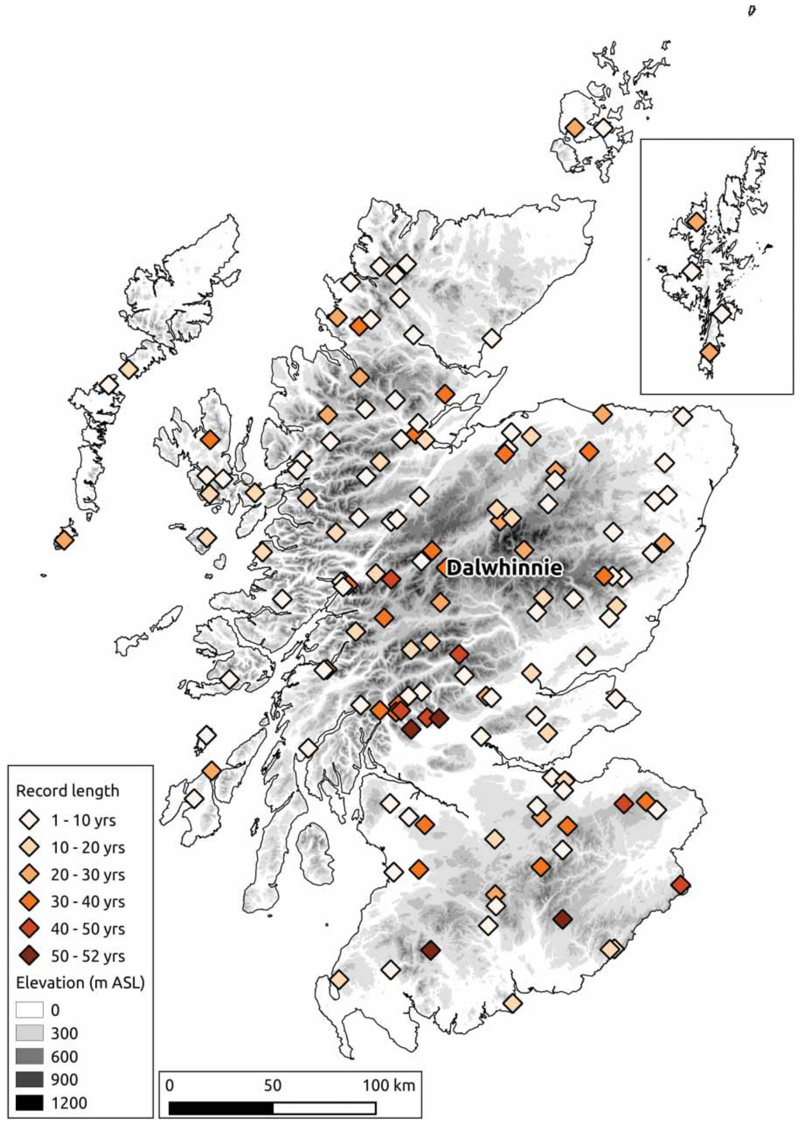


Figure 1 Location of Scottish SSGB stations graded by record length in years. Contains Ordnance Survey and Met Office data © Crown copyright and database right 2014.

distribution of the recording stations, with each station colour graded to indicate its record length. Table 1 details the 10 stations with the longest records.

The observers looked out on the hills that surrounded their location and noted at what level snow was lying. Elevations were grouped into 150 m bands from 0 to 1200 m ASL or 500 feet increments earlier in the record, with most stations supplying metric returns by the early 1980s. The observers were asked (taken from January 1992 instructions) to record at 0900 'or thereabouts' when snow or sleet was falling at station level and if snow was lying at station level, with depth. Lying snow was to be recorded at visible elevations when it covered greater

Table 1 Ten longest operating SSGB stations

name	visible hills	record length (years)	beginning	ending
Couligarten	Ben Lomond	52	1954	2006
Eskdalemuir	Ettrick Pen	51	1954	2005
Forrest Lodge	Corserine, Galloway	51	1954	2005
Loch Venachar	Ben Ledi	50	1954	2004
Ardtalnaig	Ben Lawers	50	1954	2004
Sourhope	Cheviot	49	1954	2003
Fersit	Creag Meagaidh	48	1954	2002
Cassley power station	Ben More (Assynt)	46	1960	2006
Hopes Reservoir	Pentlands	45	1957	2002
Stronachlachar	Stob Choin	43	1954	1997

than half the ground at a given elevation. Finally they were asked to record when fog or cloud obscured observation. The results of this process can be seen in Figure 2, an example return card from Dalwhinnie; note the visible hills listed.

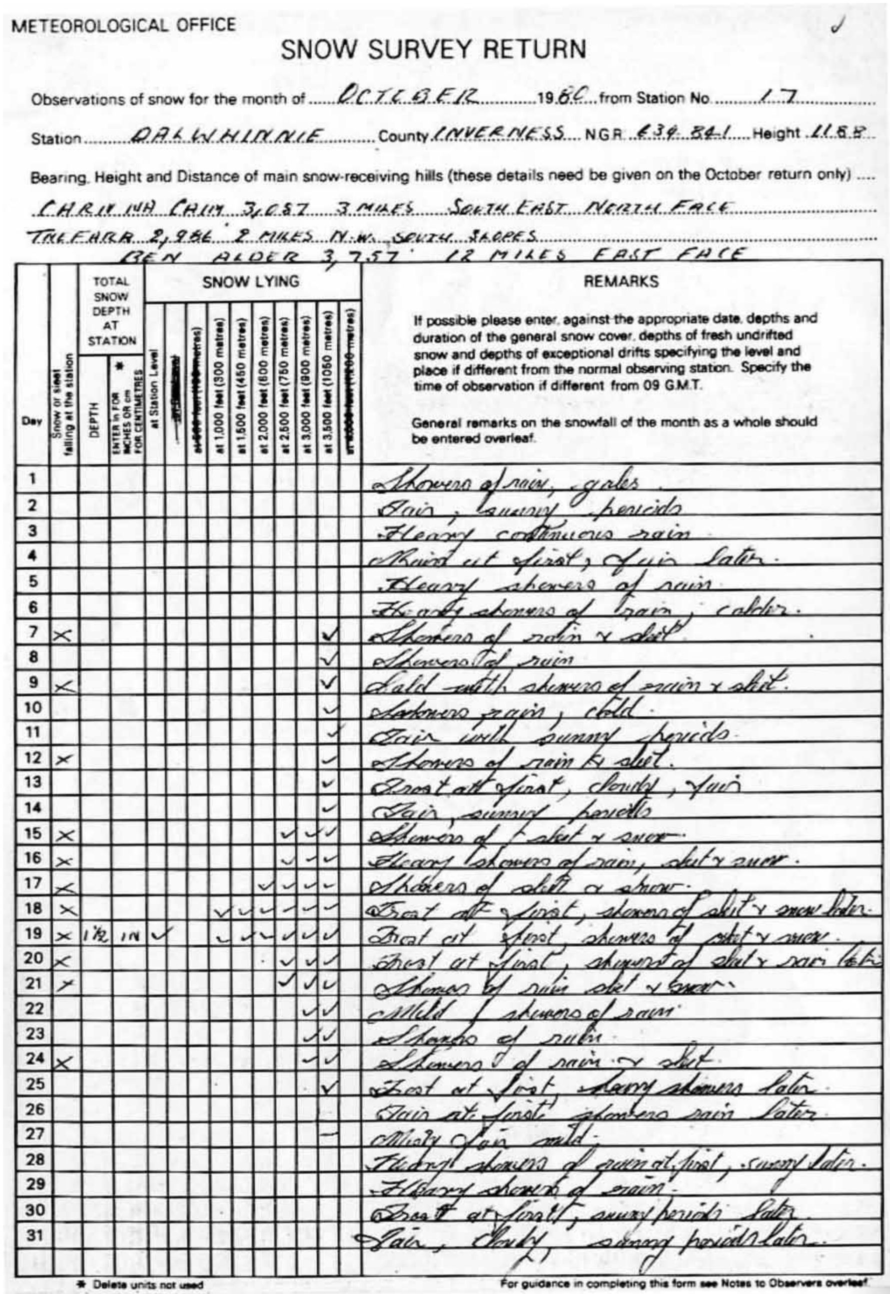
We have assessed the area visible from each SSGB site using line of sight analysis in the GIS software GRASS (GRASS Development Team 2013). Using the Panorama digital terrain model (Ordnance Survey), an area was calculated which shows the land visible from each SSGB station based on grid reference and a viewing elevation of 10 m. The visible areas were combined for the 145 sites and split into SSGB elevation bands. Each SSGB visible area band was then divided by the area of Scotland in that elevation band, giving percentages of each elevation band visible. These are compared in Table 2 to the number of Met Office stations reporting snow lying in each elevation band. The SSGB covers a greater proportion of higher than lower elevations and the Met Office stations are the inverse of this, in-line with the 1946 aims of the survey (Anon. 1947).

From studying the returns and the annual reports, it appears that some hard copy data are missing. While disappointing, it is unsurprising as the paper records have changed hands and locations through the years. Figure 3 shows the number of stations in Scotland for which paper copies exist, by year. Data are missing from 1994 as only three station records were found for that year. This coincided with the station review and perhaps there was confusion over which stations were still to submit reports. Annual SSGB summary reports before 1955 indicate nearly 400 stations across Great Britain, but fewer than 30 were found in the archives. According to Jackson (1978), there are data from 1937 onwards; some of this is in the Manley archives (Manley, see references).

4. Digitisation

For each station encountered, metadata from the SSGB return sheets were noted. This information was: site name; elevation (m ASL); Easting; Northing; hills visible; comments. These data are useful for identifying sites and establishing what was visible from each location. The comments section was used to record notes on data quality. For example, Brig-O-Turk recorded lowest lying isolated snow patch, not level of snow cover greater than 50%. Brig-O-Turk also noted where continuous snow lay in the comments; this value was used in the digitisation.

Where noted, missing values when observation was obscured by poor visibility or the observer was absent were digitised. However, these cannot always be distinguished from



METEOROLOGICAL OFFICE

SNOW SURVEY RETURN

Observations of snow for the month of OCTOBER 1980 from Station No. 17

Station DALWHINNIE County INVERNESS N.G.R. 634 841 Height 1158

Bearing, Height and Distance of main snow-receiving hills (these details need be given on the October return only) ....

CHRIN NA CAIM 3,057 3 MILES SOUTH EAST NORTH FACE

TALEFARR 2,986 2 MILES N.W. SOUTH SLOPES

BEN ALDER 3,757 12 MILES EAST FACE

REMARKS: If possible please enter, against the appropriate date, depths and duration of the general snow cover, depths of fresh undrifted snow and depths of exceptional drifts specifying the level and place if different from the normal observing station. Specify the time of observation if different from 09 G.M.T.

General remarks on the snowfall of the month as a whole should be entered overleaf.

Day	Snow or sleet falling at the station	Total snow depth at station: Depth	Remarks
1			Showers of rain, gales.
2			Fair, sunny periods
3			Heavy continuous rain
4			Rain at first, fair later.
5			Heavy showers of rain
6			Heavy showers of rain, colder.
7	×		Showers of rain & sleet.
8			Showers of rain
9	×		Cold with showers of rain & sleet.
10			Showers rain, cold.
11			Fair with sunny periods.
12	×		Showers of rain & sleet.
13			Frost at first, cloudy, fair
14			Fair, sunny periods
15	×		Showers of sleet & snow
16	×		Heavy showers of rain, sleet & snow.
17	×		Showers of sleet & snow.
18	×		Frost at first, showers of sleet & snow later.
19	×	1½ IN	Frost at first, showers of sleet & snow.
20	×		Frost at first, showers of sleet & rain later
21	×		Showers of rain sleet & snow.
22			Mild / showers of rain
23			Showers of rain
24	×		Showers of rain & sleet
25			Frost at first, heavy showers later
26			Fair at first, showers rain later
27			Misty, fair, mild.
28			Heavy showers of rain at first, sunny later.
29			Heavy showers of rain.
30			Frost at first, sunny periods later
31			Fair, cloudy, sunny periods later.

* Delete units not used

For guidance in completing this form see Notes to Observers overleaf.

Figure 2 Example SSGB return from Dalwhinnie in October 1980. Contains Met Office data ©Crown copyright and database right 2014.

Table 2 Percentage of each elevation band in Scotland, percentage of each elevation band visible from SSGB stations, compared to percentage of Met Office Stations (total 281) sited in each elevation band

elevation (m ASL)	Scotland (%)	SSGB visible (%)	Met Office stations (%)
0–150	41	12	75
150–300	28	10	21
300–450	17	9.9	3.2
450–600	8	11	0.36
600–750	4.1	11	0.36
750–900	1.6	13	0
900–1050	0.36	17	0
1050–1200	0.073	22	0
1200 and above	0.0079	37	0

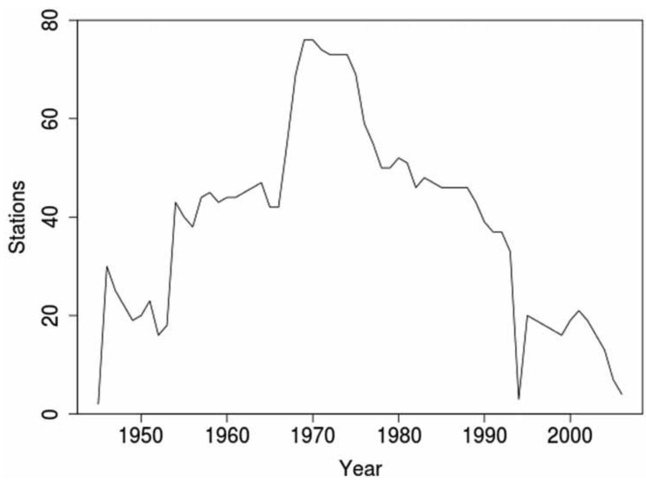


Figure 3 Number of Scottish SSGB stations found within the Scottish Met Office archives with data available by year.

when there was no snow. Quality assurance was undertaken to check for typographical errors, but no further data checks were carried out.

Following digitisation, data were uploaded to the Met Office database MIDAS (Met Office Integrated Data Archive System) and is now managed by the Met Office and is available through the Met Office authors (shona.hogg@metoffice.gov.uk or lynne.chambers@-metoffice.gov.uk). The SSGB data set will eventually be available through the British Atmospheric Data Centre (BADC).

5. Data Comparison

5.1. Method

A data comparison was made between the Met Office snow-lying grid and the SSGB as both cover a large range of elevations, these data were compared for the Dalwhinnie station. Dalwhinnie was chosen as it has a long record (39 years from winters 1967/1968 to 2006/2007, missing 1994) that overlapped the Met Office grid record, and it has a good range of visible elevations from the Spey valley at 350 m ASL to Ben Alder at 1148 m ASL. Visible elevations were established from the SSGB return and verified by a GIS line of sight analysis, using the Ordnance Survey Panorama data (Ordnance Survey), shown in Figure 4.

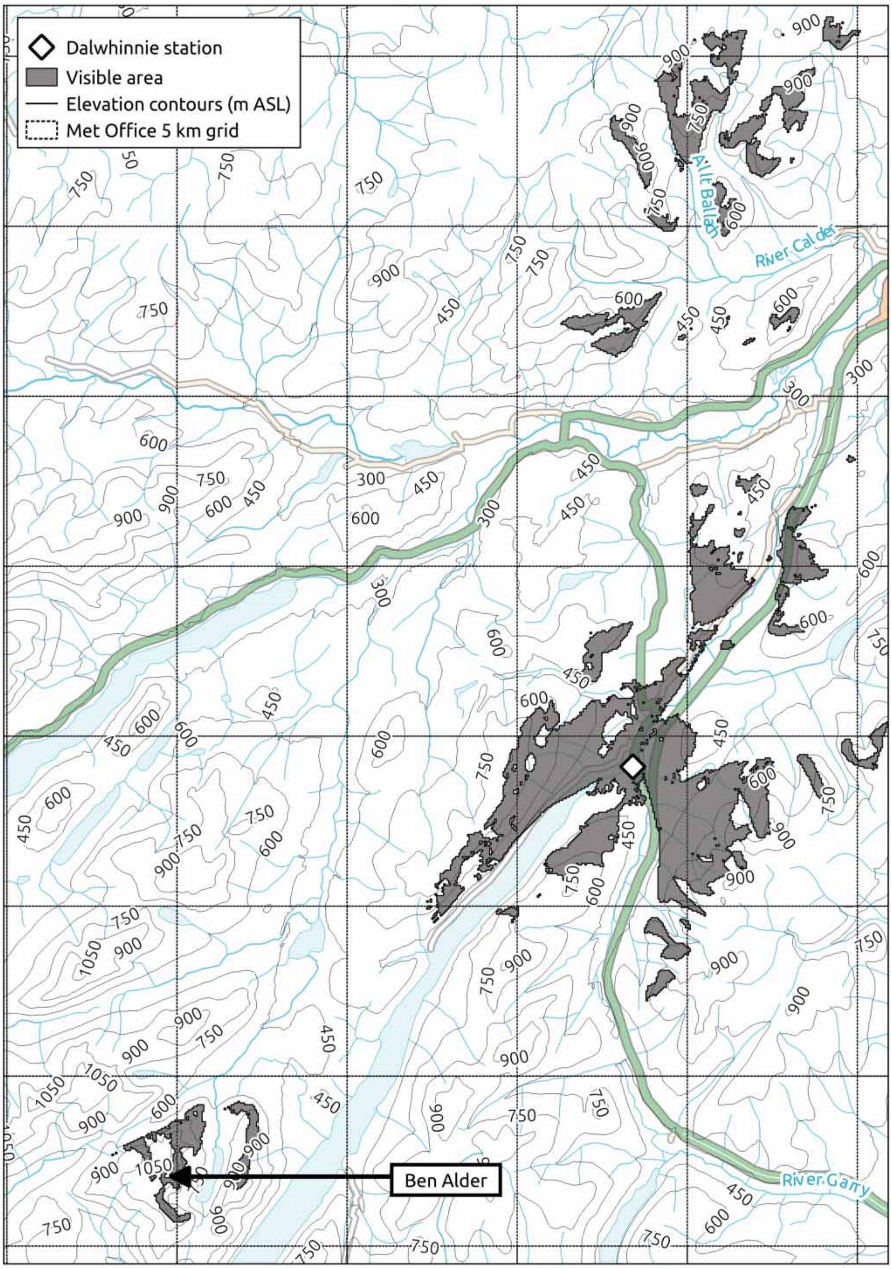


Figure 4 Line of site analysis for Dalwhinnie SSGB station, showing Ben Alder. Contains Ordnance Survey and Met Office data ©Crown copyright and database right 2014.

The Met Office grid data use, amongst others, Dalwhinnie station data. Data collection began on 1 September 1973 and ended on 31 January 2007. There were whole months missing of October and November 1973, January 1978 and also missing data from May 1995 until November 1996. The Met Office grid was interpolated from other reporting stations outside the observed time periods. The closest with snow-lying data for the 95/96 winter is Dall Rannoch School, approximately 30 km to the south.

The monthly Met Office grid data were extracted for the grid cells covering Dalwhinnie and Ben Alder. These were converted to snow years defined, for the purposes of this comparison, as from the beginning of September until the end of August. The mean elevation for these two grid cells were calculated from the Ordnance Survey Panorama as 485 m ASL for the Dalwhinnie cell and 821 m ASL for the Ben Alder cell. The altitude of Dalwhinnie station is 362 m ASL.

The SSGB Dalwhinnie data were then lumped into two groups with snow line of 450 m ASL and below and a snowline of 900 m ASL and below, to correspond with snow lying at the elevations of the Dalwhinnie and Ben Alder grid cells.

A summary of the Met Office grid and SSGB data sets for the Dalwhinnie and Ben Alder grid cells is shown in Table 3. In order to fill gaps in the SSGB due to missing returns the days with snow lying at the Dalwhinnie station were added to the SSGB record for Ben Alder and Dalwhinnie. Days of snow lying per year in the Met Office grid were subtracted from those in the revised SSGB for both Dalwhinnie and Ben Alder. These differences were plotted as time series with box and whisker plots to show data spread (Figure 5). For comparison, the number of missing observations per year was also plotted. Missing values comprise two types: those when no monthly return was submitted or has been lost, and when observation was not possible due to observer absence or reduced visibility. The revised SSGB values were compared to the Met Office grid for Dalwhinnie and Ben Alder (Figure 6) as scatter plots.

5.2. *Results*

Table 3 compares Ben Alder and Dalwhinnie average grid cell elevations using the SSGB and Met Office grid. Of note is the similarity in days snow lying between Ben Alder and Dalwhinnie according to the Met Office grid, this appears unrealistic as snow often falls more frequently and lies for greater periods at higher elevations. The SSGB values have a greater spread, with the mean value for Ben Alder within 7% of the Met Office grid maximum.

Figure 5 shows the difference between the SSGB and Met Office grid for each cell. It was expected that the Dalwhinnie difference would be above zero for winters in which data from

Table 3 Comparison between days of snow lying per winter at Ben Alder and Dalwhinnie, elevation averaged for 5 km grid cell, using SSGB and Met Office grid

	Met Office grid		SSGB	
	Dalwhinnie	Ben Alder	Dalwhinnie	Ben Alder
Minimum	10	25	23	36
Maximum	114	120	126	172
Mean	47	60	63	112
Standard deviation	23	21	27	40

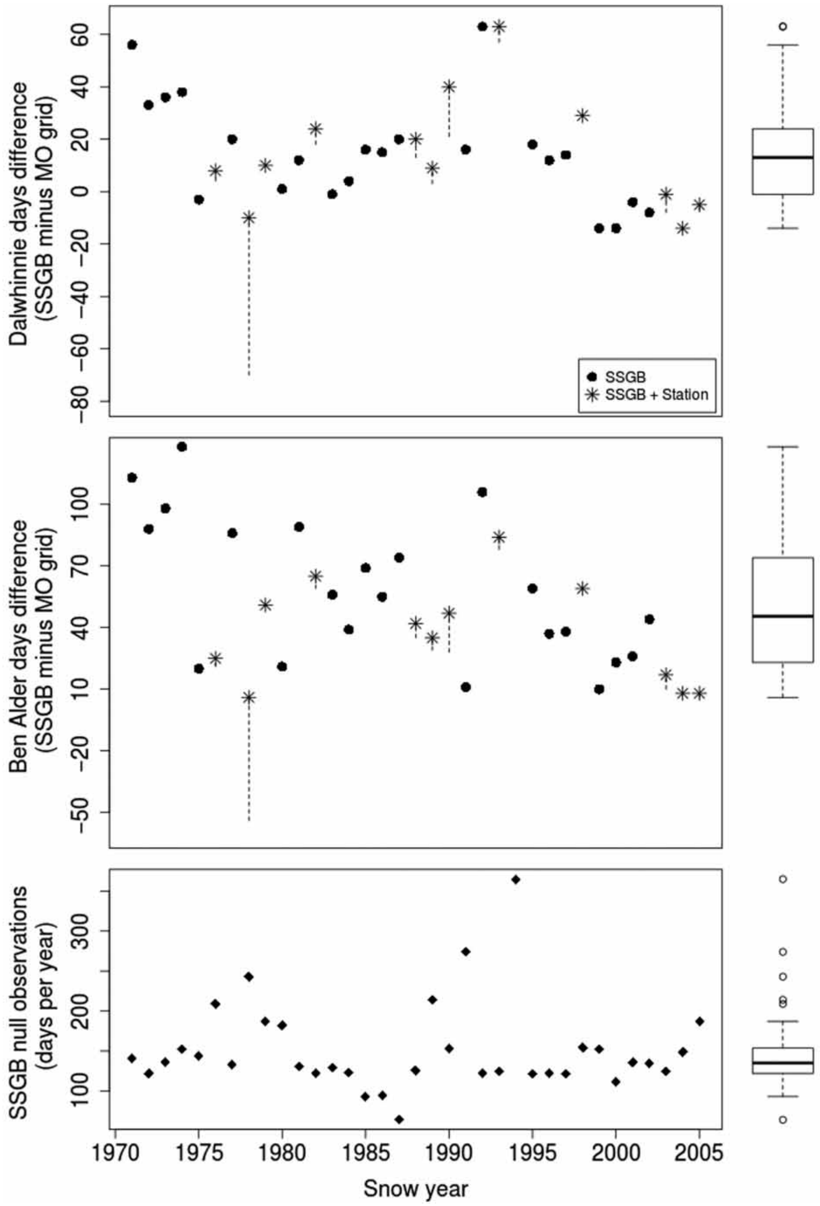


Figure 5 Difference between SSGB and Met Office grid data at Dalwhinnie and Ben Alder, including median and quartiles. The SSGB data was selected to match the average elevation of each Met Office grid square. Where SSGB returns were missing, Met Office station snow-lying data have been added to SSGB records, adjustment is indicated by dashed line from the original SSGB position to the revised value, marked by an asterisk. Numbers of missing values for the SSGB are also shown.

the station were used in deriving the gridded product because the altitude of Dalwhinnie station is 362 m ASL while the grid square average is 485 m ASL. The data distribution for Dalwhinnie is not symmetrical around zero, but have a mean of 14 days and a standard

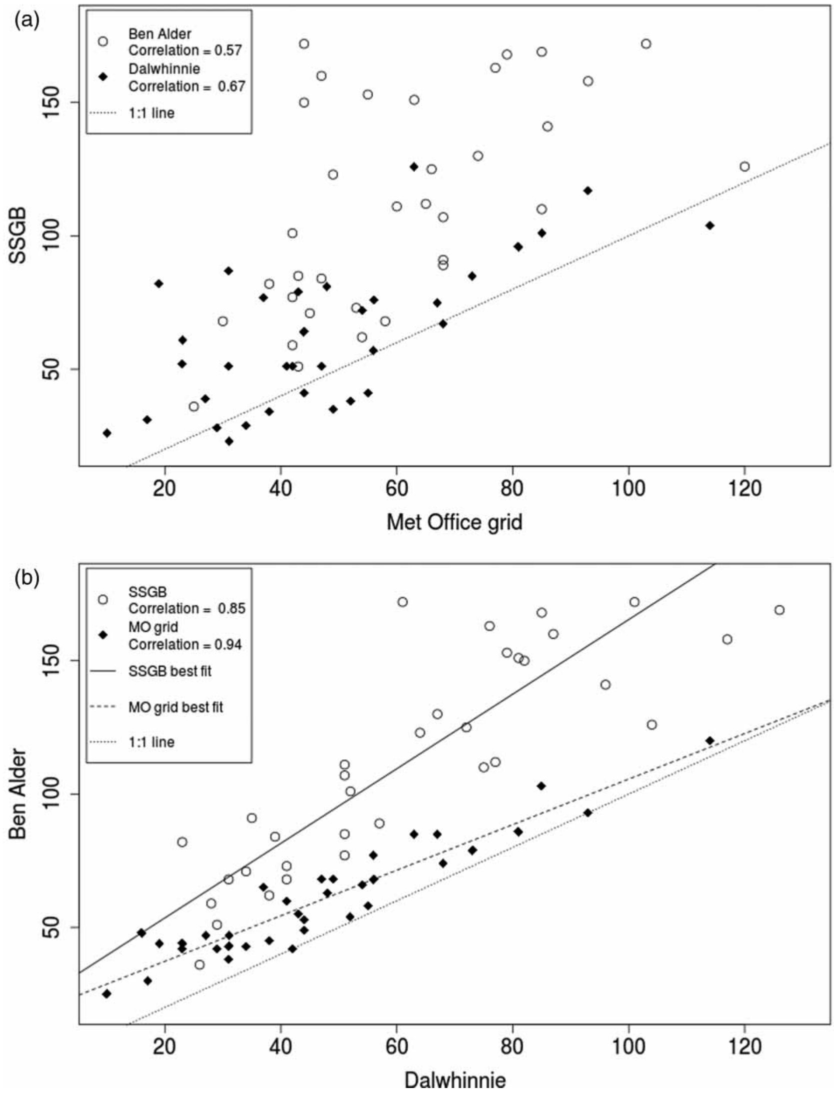


Figure 6 (a) Comparison between Met Office grid and SSGB numbers of days of snow lying per snow year for each site. (b) Comparison between sites for Met Office grid and SSGB numbers of days of snow lying per snow year.

deviation of 21 days. There is a greater variation in data than expected, as it is reasonable to suppose the SSGB was collected by the same observer who recorded the Met Office station lying data used to interpolate the Met Office grid. Some of the higher values coincide with time periods when no snow-lying observation was being made at Dalwhinnie, notably 1971 and 1972. However, some other high values do not match. The greater difference lies with the Ben Alder grid cell data. The mean of these differences is 48 days with a standard deviation of 36 days, indicating that the Met Office grid underestimates the days of snow cover at higher elevations. An outlier was the 1978/1979 winter, during which the SSGB recorded

54 fewer days with snow than the Met Office grid estimated at Ben Alder. This does not coincide with a year of high missing observations, but the SSGB returns for December, February and March were missing. The 1979 snow survey report (Met Office 1979) describes the season as having frequent snow cover with over twice the 1941–1970 average. The anomaly is caused by the three months of missing returns during the peak snow-lying season: the Met Office Dalwhinnie station data recorded snow lying for nearly all of February and March. In total 58 days with snow lying at the Dalwhinnie station were recorded during December, February and March over the 1978/1979 winter. With these added to the SSGB, the outlier is reduced. This process was repeated for other months with missing SSGB returns, shown in Figure 5 using a dashed line and asterisk.

The two scatter plots comparing sites and data sets in Figure 6 show broadly positive correlation. The Met Office grid are most strongly related, correlation 0.94, Figure 6(b), as both sites are compiled from the same data and extrapolated to the higher elevation. The SSGB correlation for Figure 6(b) is 0.85. Figure 6(a) shows a weaker correlation between the data sets at each site than each data set shows with itself in Figure 6(b), correlation of 0.67 for Dalwhinnie and 0.57 for Ben Alder.

6. Discussion

The Met Office gridded snow-lying data set has value for national assessments. However, there are two key limitations for use at a local scale: the spatial resolution of the grid is coarse and the underlying observations used to create the grid have been extrapolated horizontally and vertically. The 5 km cell covering Dalwhinnie, for example, varies in elevation from 350 to 858 m with a mean of 485 m. It is challenging in environmental analysis to work with a single elevation value for a large area, as variation occurs over small vertical and horizontal distances. With nearly all Met Office snow-lying observations recorded at low level and interpolated into mountainous areas, there is uncertainty in a data set when the grid cell covers an area with a large elevation range. This is re-enforced by the small difference in number of days with snow lying between Ben Alder and Dalwhinnie as given by the Met Office grid.

The SSGB is not without its limitations, prominent on this list is the observer error. For example, the observer for Blair Castle Gardens stated an early submission that they did not have access to a 'local' map giving exact elevations. While this is unfortunate, there is still great value in these Blair Castle data as they are relative to themselves and the observer would have known the surrounding area well. In contrast, Crathes Castle station was staffed by Adam Watson, who would have had an excellent understanding of the lie of land and the snow conditions on it, as evidenced by his snow patch work (Watson & Cameron 2010; Watson *et al*. 2011).

Known missing data caused by cloud cover, observer absence or a missing return marks time periods of data uncertainty. What is more challenging is the unknown missing data when an observer submitted a return but did not indicate cloud, fog or absence: this would be interpreted as no snow. When working with a small number of sites or a data period, this should be verifiable by correlating general weather observations, particularly cloud cover, visibility and temperature, with gaps in the SSGB record. For the latter part of the record, the observations can be checked against satellite data, although this may not be straightforward: when cloud cover obscured the SSGB observations, it could also have obscured visible satellite observations; this would not be the case with a cloud inversion below the snowline. Known missing values could be infilled using machine learning like self-organising maps (Mwale *et al*. 2012), although this relies on the SSGB observations and their inherent uncertainty.

7. Conclusion

A newly digitised data set of snow cover in Scotland from 1945 until 2006 snow years is presented. It is taken from 145 sites covering mainland Scotland and a number of islands. The longest station record is 52 years in length at Couligarten observing Ben Lomond.

The digitised data are stored in the Met Office MIDAS database and is available from the Met Office authors and eventually through BADC. Before use, it is suggested that some quality assurance should be undertaken to ensure that these data are fit for the purpose. This could include comparing the SSGB snow cover to nearby Met Office station snow lying, temperature and precipitation data, satellite snow-cover observations or avalanche survey records.

The SSGB advantages and disadvantages are largely governed by the study scale. The main advantages are a long, 60 year, daily record of snow-cover observations across Scotland as recorded by knowledgeable and experienced local weather observers. The disadvantages are that the SSGB covers discreet locations, observed by recorders working in isolation, with missing and lost records due to observer absence or reduced visibility. These lend the SSGB to be used at a mountain or catchment scale, or to provide spot checks for satellite and Met Office grid data when making national assessments. Hence, using a mixture of data sets to reduce uncertainty is potentially the best way forward. The SSGB offers a detailed daily record of snow cover from the station level up to the highest mountains in Scotland; no other snow cover data product contains this resolution of information for Scotland.

Acknowledgement

We acknowledge there is not any financial interest or benefit arising from direct applications of this research.

Funding

This work was supported by the Natural Environment Research Council under [Grant NE/J500021/1].

References

Anon. (1947) Snow survey of the British Isles, *Journal of Glaciology*, vol. 1, p. 32.

BADC. British Atmospheric Data Centre [Online]. Available at: http://badc.nerc.ac.uk/home/index.html (accessed 13 May 2013).

Black, A. & Anderson, J. (1993) The great Tay flood of January 1993, *Hydrological Data*, pp. 25–34.

Dong, J. & Peters-Lidard, C. (2010) On the relationship between temperature and MODIS snow cover retrieval errors in the western U.S. selected topics in applied earth observations and remote sensing, *IEEE Journal of Selected Topics in Applied Earth Observation and Remote Sensing*, vol. 3, no. 1, pp. 132–140.

Dunn, S., Langan, S. & Colohan, R. (2000) The impact of variable snow pack accumulation on a major Scottish water resource, *Science of the Total Environment*, vol. 265, pp. 181–194.

GRASS Development Team. Geographic Resources Analysis Support System (GRASS) software [Online]. Available at: http://grass.osgeo.org, 2013

Hall, D., Riggs, G., Salomonson, V., DiGirolamo, N. & Bayr, K. (2002) MODIS snow-cover products, *Remote Sensing of Environment*, vol. 83, no. 12, pp. 181–194.

Harrison, S., Winterbottom, S. & Johnson, R. (2001) A preliminary assessment of the socio-economic and environmental impacts of recent changes in winter snow cover in Scotland, *Scottish Geographical Journal*, vol. 117, no. 4, pp. 297–312.

Hawke, E. L. & Champion, D. L. (1949) Report on the snow survey of Great Britain for the season 1948–49, *Journal of Glaciology*, vol. 7, pp. 362–370.

Hawke, E. L. & Champion, D. L. (1954) Report on the snow survey of Great Britain for the season 1952–53, *Journal of Glaciology*, vol. 2, pp. 356–362.

Jackson, M. C. (1977) A classification of the snowiness of 100 winters–a tribute to the late L. C. W. Bonacina, *Weather*, vol. 32, no. 3, pp. 91–98.

Jackson, M. C. (1978) Snow cover in Great Britain, *Weather*, vol. 33, no. 8, pp. 298–309.

Manley, G. Catalogue of the Gordon Manley papers held at Durham University [Online]. Available at: http://endure.dur.ac.uk:8080/fedora/get/UkDhU: EADCatalogue.0534

Matson, M. (1991) NOAA satellite snow cover data, *Global and Planetary Change*, vol. 4, pp. 213–218.

Met Office. (1954) Snow survey of Great Britain, season 1953–54, *Meteorological Magazine*, vol. 83, pp. 353–359.

Met Office. (December, 1979) Snow survey of Great Britain, season 1978/79. Climatological Services.

Met Office SSGB. Met Office SSGB reports [Online]. Available at: http://www.metoffice.gov.uk/archive/snow-survey (accessed 10 May 2013).

Mwale, F. D., Adeloye, A. J. & Rustum, R. (2012) 'Infilling of missing rainfall and streamflow data: a self organising map approach', *British Hydrological Society Eleventh National Hydrology Symposium*, Dundee.

Ordnance Survey. Land-Form Panorama digital terrain model [Online]. Available at: http://www.ordnancesurvey.co.uk/business-and-government/products/land-form-panorama.html (accessed 13 May 2013x).

Perry, M. & Hollis, D. (2005) The generation of monthly gridded datasets for a range of climatic variables over the UK, *International Journal of Climatology*, vol. 25, no. 8, pp. 1041–1054.

Rees, W. & Steel, A. (2001) Radar backscatter coefficients and snow detectability for upland terrain in Scotland, *International Journal of Remote Sensing*, vol. 22, no. 15, pp. 3015–3026.

Slater, M., Sloggett, D., Rees, W. & Steel, A. (1999) Potential operational multi-satellite sensor mapping of snow cover in maritime sub-polar regions, *International Journal of Remote Sensing*, vol. 20, no. 15–16, pp. 3019–3030.

Tang, Q. & Lettenmaier, D. P. (2010) Use of satellite snow-cover data for streamflow prediction in the Feather River Basin, California, *International Journal of Remote Sensing*, vol. 31, no. 14, pp. 3745–3762.

Trivedi, M., Browne, M., Berry, P., Dawson, T. & Morecroft, M. (2007) Projecting climate change impacts on mountain snow cover in central Scotland from historical patterns, *Arctic Antarctic and Alpine Research*, vol. 39, no. 3, pp. 488–499.

Watson, A. & Cameron, I. (2010) *Cool Britannia*. (Rothersthorpe, UK: Paragon Publishing).

Watson, A., Cameron, I., Duncan, D. & Pottie, J. (2011) Six Scottish snow patches survive until winter 2010/2011, *Weather*, vol. 66, no. 8, pp. 223–225.