Contemporary (2001) and 'Little Ice Age' glacier extents in the Buordakh Massif, Cherskiy Range, north east Siberia

Contemporary (2001) and 'Little Ice Age' glacier extents in the Buordakh Massif, Cherskiy Range, north east Siberia

STEPHEN D. GURNEY

Department of Geography, University of Reading, PO Box 227, Whiteknights, Reading, RG6 6AB, UK; s.d.gurney@reading.ac.uk.

Abstract

The Buordakh Massif of the Cherskiy Range of sub-arctic north east Siberia, Russia has a cold continental climate and supports over 80 glaciers. Despite previous research in the region, a georeferenced map of the glaciers has only recently been completed and an enhanced version of it is reproduced in colour here. The mountains of this region reach heights in excess of 3,000 m and the glaciers on their slopes range in size from 0.1 to 10.4 km^2. The mapping has been compiled through the interpretation of Landsat 7 ETM+ satellite imagery from August 2001 which has been augmented by data from a field campaign undertaken at the same time. The glaciers of the region are of the cold, 'firn-less' continental type and their mass balance relies heavily on the formation of superimposed ice. Moraines which lie in front of the glaciers by up to a few kilometres are believed to date from the Little Ice Age (ca. 1550-1850 AD). Over half of the glaciers mapped have shown marked retreat from these moraines.

(Received 10^{th} November 2009; Revised 11^{th} March 2010; Accepted 18^{th} March 2010)

ISSN 1744-5647
doi:10.4113/jom.2010.1113

1. Introduction

There are a few regions of the Earth for which there is little information concerning the distribution of glaciers, such a region is the Buordakh Massif of the Cherskiy Range, north east Siberia, Russia. This mountain range was first documented following an expedition led by Obruchev in 1926, but Nekrasov and Sheinkman (1981) were the first to publish on the glaciers in this region. The maps accompanying this work were generalized and without a scale, however, and hence were of limited use. Their work was based upon aerial photographs from 1970 which was supplemented by fieldwork conducted between 1971 and 1976 by the Institute for Permafrost Research of the Russian Academy of Science. These investigations represented all the scientific work conducted in the region until 2001 when fieldwork was undertaken by the author within the framework of a joint Russian/British expedition. Resulting from this work was the first georeferenced map of the glaciers in this area. A glacier inventory based on the mapping has recently been published (Gurney et al., 2008).

2. Method

The mapping available for the area is extremely limited. 1:300,000 topographic maps were obtained (dated 1955), but these do not show all of the glaciers and the sketch maps of Nekrasov and Sheinkman (1981) provided little more than approximate dimensions and names for a few of the glaciers. In order to conduct the mapping, therefore, two Landsat 7 ETM+ scenes (from 7 August 2000 and 25 July 2001) were obtained. These were purchased in a geocoded format, since the necessary data for geocoding and orthorectification was not available to the authors, specifically, there was no sufficiently detailed Digital Elevation Model available for the area.

Image processing (using ERDAS Imagine) of the August 2000 scene was conducted prior to the fieldwork. A 'resolution merge' image of the study area was created which combined the 30 m ground resolution multi-spectral information from 3 bands (Bands 7 (2.09-2.35 μm), 5 (1.55-1.75 μm) and 3 (0.63-0.69 μm)) with the 15 m ground resolution band (Band 8, 0.52-0.90 μm). This process creates an excellent product for identifying geomorphological features, such as glacier margins, glacial moraines etc. Further image processing enabled the removal of areas obscured by cloud on the image so that it would not be confused with snow. The thermal band (Band 6, 10.4-12.5 μm) was utilized to differentiate cloud from snow cover (the tops of clouds being much colder than snow on the ground) and this technique proved highly effective. During the initial field period the accuracy of the imagery geocoding was assessed using a number of Ground Control Points (GCPs), whereby specific locations which could be clearly resolved on the imagery were visited on the ground to obtain a reference (in degrees, minutes and decimal seconds) through the use of a handheld Garmin GPS (Global Positioning System) receiver. These references were then compared to the location report provided by the 'Inquire Cursor' function in ERDAS Imagine revealing that, in the area under direct investigation, the geocoding was accurate to within 1 or 2 pixels (i.e. 30-60 m).

Following the fieldwork, the glacier inventory was produced from the 25 July, 2001 scene (the satellite overpass took place during the fieldwork). Once again image processing enabled a 'resolution merge' image to be created and cloud to be accurately identified, although it should be noted that the 2001 imagery had very little cloud and that present did not hinder the mapping process. Field data obtained at the GCPs (noted above) was also used to validate the image interpretation and ground based photographs from known locations were also employed. The contemporary (i.e. 2001) glacier outlines and their most recent limits were delimited (mapped) manually through the creation of vector file overlays on top of the ETM+ imagery using ERDAS Imagine. Attempts to use a classification scheme for the mapping (supervised or unsupervised) proved unsatisfactory. The authors' experience of using Landsat ETM+ scenes for glacier mapping elsewhere (Gurney and White, 2005; Stokes et al., 2006), as well as that of others (e.g. Heiskanen et al., 2002; Paul et al., 2002) informed the whole procedure. The discrimination between areas occupied by ice at the most recent glacier maxima and those outside this limit is greatest in band 5 of the Landsat ETM+ imagery (cf. Eckardt and Milton, 1999) and this property permitted the recently glaciated areas to be readily determined and mapped.

Eight of the glaciers mapped were investigated in the field, five of them in some detail. These were: Tsaregradskiy, Obruchev, Sumgin, Melnikov and a glacier without a name which was numbered '48' in the original Russian inventory. Ground data was collected at over 50 sites in order to verify interpretations of the satellite imagery as previously mentioned. At each site an accurate location ($\pm$7 m in the x and y) was obtained using a handheld Garmin GPS receiver. Ground data collection sites included moraine junctions, inactive moraines, glacial trim-lines and glacier margins associated with the five glaciers mentioned above and other features that could be used to provide geomorphological context.

3. Glacier characteristics and distribution

There are some 80 glaciers in the core region of the Buordakh Massif (an area of some 1,550 km^2). This does not, however, include those ice aprons, glacierets and very steep cliff or niche glaciers which occur in the higher parts of the mountain basins above 2000 m. Glacier length ranges from a few hundred metres to over 7 km. Areal extents vary from 0.1 to 10.4 km^2, whilst total glacierized area is approximately 70 km^2 as determined by the present mapping. The glaciers which have been mapped are predominantly cirque and small valley glaciers and occur in most valleys above 1650 m. The larger glaciers terminate at elevations of around 1550 m (see accompanying map).

The four largest glaciers in the region are Tsaregradskiy, Obruchev, Sumgin and Melnikov (see map). These have multiple-cirque origins and the cirque backwalls are covered with hanging ice nearly up to the ridge-crests. These glaciers have much supraglacial debris which supply moraines on the glacier snouts and which, in turn, have led to the deposition of moraines in the proglacial area. In addition to the largest glaciers there are numerous cirque glaciers and very steep niche or cliff glaciers. Due to the paucity of precipitation, no mountain ice cap has developed (Serebryanny and Solomina, 1996; Solomina, 1999).

In general, the five glaciers that were studied in detail were characterized by debris covered snouts, large medial moraines, well developed supraglacial streams (some flowing in deeply incised channels), narrow crevasses (at least in summer), extensive 'dead ice' in the immediate glacier foreland and well defined trim-lines above the current glacier surface in their lowermost parts. The surface of Sumgin Glacier displayed slush pools (also referred to as 'snow swamps', e.g. Hambrey and Alean, 2004) which generated slush flows that were observed directly.

4. Discussion

It is likely that most glaciers in the study area achieved their maximum Holocene extents during the Little Ice Age (LIA, ca. 1550-1850 AD, see Matthews and Briffa, 2005; Solomina, 2000). The moraines are unvegetated and only small lichens have colonized boulders in the glacier forelands. Lichen thalli diameters obtained from the foreland of Melnikov Glacier by the author yielded an average size of 15.5 mm inside the most recent glacial limit compared with 86.1 mm just outside the glacial limit. The lack of absolute dating or a locally derived lichen growth curve, however, prevents more precise age estimates of the moraines of this study. Nevertheless, we suggest that the most recent glacier maximum discussed here relates to the LIA.

The glaciers lost about 14.8 km^2 between the LIA and 2001 which represents a reduction in glaciated area of 17%, corresponding to a mean annual rate of just 0.11% per annum. The magnitude of loss is not uniform throughout the Buordakh Massif; with 62% of the glaciers displaying a measurable retreat from their most recent maximum extent and 38% appearing to be stable, although a proportion of these may, of course, have lost mass through thinning.

Ice in the form of icings (also known as aufeis or naled, cf. Åkerman, 1982) can also be seen on the satellite imagery, for example, in the river valleys in the north-east and south west of the region (these have also been mapped). Icings are created when perennial groundwater discharge reaches the surface in winter and freezes to build up layers or sheets of ice, usually in valley bottom locations (Pollard, 2005). They are often a characteristic of permafrost regions. A small example of such an icing was investigated downstream of the terminus of Melnikov Glacier. This investigation revealed that the icing was not created in one winter, but that a portion of it had survived from a previous winter or winters, that is, it had survived at least one summer melting season.

5. Conclusion

Using Landsat ETM+ imagery, the first georeferenced glacier map for the Buordakh Massif, Cherskiy Range, north east Siberia has been produced. Eighty glaciers have been mapped and combined they account for ca. 70 km^2. The glaciers are predominantly cirque and small valley glaciers of the alpine type and occur in most valleys above 1650 m. The extreme continental climate of the Cherskiy Range, with very low winter temperatures (-70°C) and precipitation (208 mm p.a.) and relatively high summer temperatures (+30°C), results in cold glaciers without firn where superimposed ice formation is important. Although the date of the most recent glacial maximum is poorly constrained, it is likely that it relates to the Little Ice Age maximum (cf. Solomina, 2000). The glacier recession identified suggests that the areal extent of the glaciers in the Buordakh Massif have reduced by around 17% since this time. This reduction is somewhat lower than that reported for other mountainous areas in NE Siberia (e.g. Ananicheva et al., 2005).

Software

ERDAS Imagine 9.0 was used for the image processing and the creation of the shapefile overlays of the glacier margins. ESRI ArcGIS 9.3 was used for the creation of the map.

Data

The PDF file of the map is 'layered' so that layers can be turned on and off as the viewer wishes. Each layer can also be interrogated using the 'Object Data Tool' in Adobe Reader. The feature attributes of the '2001 glacier extents' layer provide data on the individual glaciers (polygons), their number and their history including: maximum extent (km^2), minimum extent (km^2), areal difference - area deglaciated (km^2), length (km) and retreat of the margin (km). The feature attributes of the 'LIA glacier extents' includes the polygon data and the glacier numbers.

This PDF has a ZIP archive embedded within it (stored as a .ZI file extension) containing the data (as ESRI Shapefiles) used in the production of the accompanying map and can be accessed by right-clicking on the "paperclip" icon at the beginning of this section (you will need to save the file and edit the file extension to .ZIP). Whilst the contents of the ZIP file are the sole responsiblity of the author, the journal has screened them for appropriateness.

Acknowledgements

The Siberian fieldwork was organized by the Russian Ministry for Emergencies (EMERCOM) and the Royal Logistic Corps of the British Army. Field assistance was provided by Fraser Coleman, Vladimir Donin, Chris Emerton, Phil Kirby, Tim Mayers, Sam Pambakian, Tim Smith, Graeme Stanbridge and John Starling. Funding was obtained from the Ministry of Defence and the Foreign and Commonwealth Office (UK), EMERCOM (Russia) and the expedition received the WEXAS International Award from the Expedition Research Grants Programme of the Royal Geographical Society (with Institute of British Geographers). Geoff Griffiths, Kevin White and Ioannis Vogiatzakis helped with the image processing/GIS and Judith Fox provided useful comments on the map design. Comments from five referees were also extremely useful.

References

ANANICHEVA, M. D., KOREISHA, M. M. and TAKAHASHI, S. (2005) Assessment of glacier shrinkage from the maximum in the Little Ice Age in the Suntar Khayata Range, North-East Siberia, Bulletin of Glaciological Research, 22, 9–17.

ECKARDT, F. D. and MILTON, E. J. (1999) The relationship between time since deglaciation and the reflectance of glacial forelands, Remote Sensing of Environment, 67, 244–247.

GURNEY, S. D., POPOVNIN, V. V., SHAHGEDANOVA, M. V. and STOKES, C. R. (2008) A glacier inventory for the Buordakh Massif, Cherskiy Range, northeast Siberia, and evidence for recent glacier recession, Arctic, Antarctic and Alpine Research, 40, 81–88.

GURNEY, S. D. and WHITE, K. (2005) Sediment magnetic properties of glacial till deposited since the Little Ice Age maximum for selected glaciers at Svartisen and Okstindan, northern Norway, Boreas, 34, 75–83.

HAMBREY, M. and ALEAN, J. (2004) Glaciers, Cambridge University Press, Cambridge.

HEISKANEN, J., KAJUUTTI, K., JACKSON, M., ELVEHŒY, H. and PELLIKKA, P. (2002) Landsat satellite data in Svartisen, northern Norway, EARSeL Proceedings, 2, 34–42.

MATTHEWS, J. A. and BRIFFA, K. R. (2005) The Little Ice Age: Re-evaluation of an evolving concept, Geografiska Annaler, 27A, 17–36.

NEKRASOV, I. A. and SHEINKMAN, V. S. (1981) Katalog lednikov SSSR (Glacier catalogue of the USSR), 17 (7, parts 2,4), 19 (part 4)., Leningrad, Gidrometeoizdat, 88 pp., [In Russian].

PAUL, F., HUGGEL, C., KÄÄB, A., KELLENBERGER, T. and MAISCH, M. (2002) Comparison of TM-derived glacier areas with higher resolution data sets, EARSeL Proceedings, 2, 15–21.

POLLARD, W. H. (2005) Icing processes associated with high arctic perennial springs, Axel Heiberg Island, Nunavut, Canada, Permafrost and Periglacial Processes, 16, 51–68.

ÅKERMAN, H. J. (1982) Studies on naledi (icings) in west Spitsbergen, In Proceedings of the 4th Canadian Conference on Permafrost, National Research Council of Canada, Ottawa, pp. 189–202.

SEREBRYANNY, L. R. and SOLOMINA, O. N. (1996) Glaciers and climate of the mountains of the former USSR during the Neoglacial, Mountain Research and Development, 16, 157–166.

SOLOMINA, O. N. (1999) Gornoe oledneie Evrazii v golotsene (Montane glaciation in Northern Eurasia in the Holocene), Moscow, Nauchny Mir Publishers, 263 pp., [In Russian].

SOLOMINA, O. N. (2000) Retreat of mountain glaciers of northern Eurasia since the Little Ice Age maximum, Annals of Glaciology, 31, 26–30.

STOKES, C. R., GURNEY, S. D., SHAHGEDANOVA, M. V. and POPOVNIN, V. V. (2006) Late-20th-century changes in glacier extent in the Caucasus Mountains, Russia, Journal of Glaciology, 52, 99–109.