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Satellite Remote Sensing of Glaciers and Ice Caps in Svalbard, Eurasian High Arctic

Gordon S. Hamilton
Principal Investigator; University of Maine, Orono, gordon.hamilton@maine.edu

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Principal Investigator: Hamilton, Gordon S. **Award ID:** 0221292

Organization: University of Maine

Title:

Satellite Remote Sensing of Glaciers and Ice Caps in Svalbard, Eurasian High Arctic

Project Participants

Senior Personnel

Name: Hamilton, Gordon

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr Hamilton was project lead. He specified experimental procedures, guided data processing and analyses activities, and liaised with project collaborators. He advised Bill Sneed, who used project data as the major component of his MS thesis.

Post-doc

Graduate Student

Name: Stearns, Leigh

Worked for more than 160 Hours: Yes

Contribution to Project:

Leigh Stearns was involved in satellite image processing and analysis, and was especially involved in the generation of digital elevation models from stereo satellite data.

Name: Sneed, William

Worked for more than 160 Hours: Yes

Contribution to Project:

Bill Sneed conducted the majority of the image processing and data analysis tasks of this project. He searched for and obtained relevant image products, performed geocoding and orthorectification, developed band arithmetic algorithms for determining snow facies types, and initiated a study of melt lake volume mapping using satellite imagery. He collaborated closely with our colleagues at the Norwegian Polar Institute. His involvement in this project formed the central component of his MS dissertation.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Norsk Polarinstitutt

This research was a collaborative effort with Jack Kohler and Elisabeth Isaksson at the Norwegian Polar Institute. We conducted personnel exchanges, research visits, and data sharing during the project lifetime. The key Norwegian contribution was provision of digital geographic and geodetic data for Svalbard, as well as access to historical image archives.

USGS EROS Data Center

USGS EDC was the principal data provider for this project. We interacted with John Dwyer at Sioux Falls.

University of Colorado at Boulder

We collaborated with Bruce Raup at the National Snow and Ice Data Center, especially in algorithm and database development.

University of Arizona

Our principal collaborator at UArizona is Jeff Kargel, who is project scientist for GLIMS (Global Ice Measurements from Space), of which this project is a component part.

Other Collaborators or Contacts

We had many informal discussions with Prof. Jon Ove Hagen, University of Oslo, regarding Svalbard glaciology, especially his field observations of melt pond evolution on Austfonna in northeast Svalbard.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Project personnel were able to develop new skills in remote sensing data analysis, and to develop international collaborative partnerships. Bill Sneed used project data as the central component of his MS thesis research.

Outreach Activities:

Our outreach activities have mainly been in the form of hosting visiting school groups in our remote sensing laboratory. A typical visit involves the students working with real satellite image data at one of our computer workstations to map glacier changes and other attributes. We introduce topics such as space remote sensing of the Earth system, climate change, and glacier behavior in the Arctic. Most of the groups we have hosted were middle school level or above.

Journal Publications

Kargel, J.S., M.J. Abrams, M.P. Bishop, G.S. Hamilton, A. Kaeaeb, H.H. Kieffer, F. Paul, F. Rau, B. Raup & L.A. Stearns, "ASTER imaging contributions to Global Land Ice Measurements from Space", Remote Sensing of the Environment, p. 197, vol. 99(1-2), (2005). Published

Raup, B., F. Rau, F. Paul, A. Kaeaeb, M. Bishop, G.S. Hamilton, W. Sneed, "Remote Sensing and GIS technology in the Global Land Ice Measurements from Space (GLIMS) Project", Computers and Geoscience, p. 104, vol. 33(1), (2007). Published

Sneed, W. and G.S. Hamilton, "Evolution of melt pond volumes on ice cap surfaces from multispectral satellite imagery", Geophysical Research Letter, p. , vol. , ( ). Submitted

Books or Other One-time Publications

Sneed, W. & G.S. Hamilton, "Data fusion and band ratioing using ASTER satellite imagery to map snow and ice facies distributions on Svalbard", (2004). Book, Published
Editor(s): Hagen, J.0. & H. Oerlemans
Collection: International Symposium on Arctic Glaciology, Geilo, Norway, August 2004.
Bibliography: International Glaciological Society, Cambridge, UK

Hamilton, G.S. & W. Sneed, "Ice cap change on Storoya, Svalbard, as an indicator of recent High Arctic climate conditions", (2004). Book, Published
Editor(s): Hagen, J.O. & H. Oerlemans

Collection: International Symposium on Arctic Glaciology, Geilo, Norway, August 2004.
Bibliography: International Glaciological Society, Cambridge, UK

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

This project has resulted in the development of several new algorithms for discriminating geophysical information from optical satellite imagery. The results of the project are also useful for determining recent glacier changes on Svalbard, and their role in Arctic climate change.

Contributions to Other Disciplines:

The algorithms developed as part of this project are useful across a wide range in geophysical sciences, such as ocean optics, optical limnology, pattern recognition and other spatial sciences. We have borrowed liberally from medical imaging fields, and applied these techniques to geophysical topics.

Contributions to Human Resource Development:

This project has provided the PI with experience in experimental design, guidance of graduate students, and interacting with international collaborators. The graduate students engaged as part of this project developed new skills in data analysis, image processing, and computer mapping.

Contributions to Resources for Research and Education:

Two graduate students were employed as part of this project. One student, Bill Sneed, is completing his MS thesis based on data and products developed by this project. Both students had the opportunity for international exchange visits with our Norwegian collaborators.

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Any Web/Internet Site

Any Product

Contributions: To Any Beyond Science and Engineering

Major Findings

The advantage of using satellite imagery to map changes in glacier extent is that, compared to fieldwork, extensive areas can be mapped repeatedly at relatively low cost. In Svalbard, this allows us to extend the analysis of glacier changes to parts of the archipelago not usually studied. Most studies of glacier mass balance to date have been restricted to a few small glaciers close to the northwest coast of the island of Spitsbergen. Because of the large range in glacier sizes and climate regimes in Svalbard, there are obvious limitations to applying results from a limited sample to the whole archipelago.

We selected several ‘benchmark’ glaciers throughout the archipelago, representing a variety of sizes, types, and climate regimes. In collaboration with our project partners at the Norwegian Polar Institute, we digitized glacier boundaries from their extensive collection of geodetic aerial photographs. This allows us to construct multi-decadal records of terminus position change (e.g., Figure 1) for each of the study glaciers. The results show that (1) glacier retreat is occurring everywhere on the archipelago, with the exception of the ice caps and outlet glaciers on Nordaustlandet; (2) the rate of retreat is fastest in the southeastern quandrant of the archipelago; and, (3) retreat rates appear to be slightly faster in the last ~5 years, relative to mean conditions over the period 1950-2000.

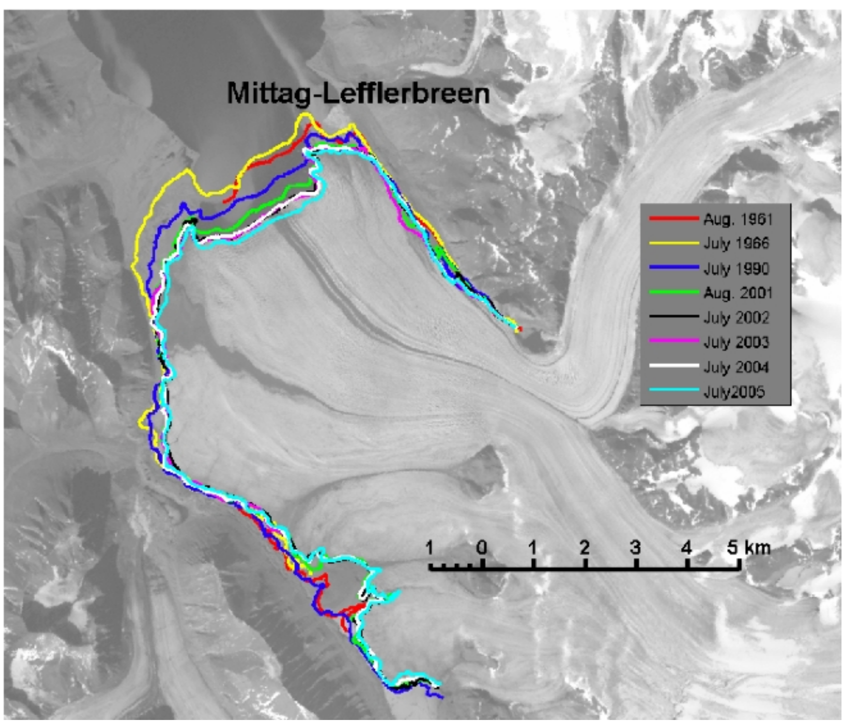

Figure 1. Front position changes, 1961-2005, for Mittag-Lefflerbreen, central Spitsbergen.

We are currently analyzing possible causes for the spatial pattern in retreat behavior. The situation can be complicated in Svalbard because (i) many glaciers are of surge-type and their fluctuations are driven by non-climate related effects, and (ii) the Little Ice Age occurred relatively late in Svalbard, ending only around 1900, meaning that many glaciers are still responding to that event. We account for the first complication by selecting benchmark glaciers that have not exhibited any evidence of surge-type activity. The second complication is taken into account by analyzing rates of change, with the assumption that recent variations in the rates of change most likely represent responses to recent climate forcings. The recent accelerations in rate of frontal retreat since 2000 are probably due an overall warming trend in Svalbard over the same period. Conversely, the glacier expansions noted in Nordaustlandet are probably also related to the regional warming trend which has reduced sea ice cover in the adjacent Barents Sea and provided a ready source of available moisture, thus increasing annual net balances on these glaciers and ice caps. This effect might be shortlived – many small ice caps analyzed with satellite imagery are fully below the summer snowline, and only receive input in the form of superimposed ice. As summer warming increases, more of this runoff will leave the glacier instead of being refrozen in situ.

An additional way of studying the interaction between glaciers and ice caps is to look at the distribution of surface melt features. On the ice caps of Nordaustlandet, melt ponds and small lakes form each summer in topographic depressions in the ice surface. Changes in the distribution of these ponds with time would represent a change in the climate conditions causing them to form. There is also some concern that the availability of large volumes of ponded water opens the possibility of its sudden drainage to the bed, a change in basal lubrication, and a rapid increase in ice speed (the so-called "Zwally effect"). While the problem of calculating the areal extent of meltwater ponds using satellite imagery is fairly straightfoward, determining the depth and thus the volume is not. We developed a powerful new technique for estimating melt pond depth using multispectral satellite imagery acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The method relies on reasonable assumptions about the albedo of the bottom surface of the ponds and the optical attenuation characteristics of the ponded meltwater. Derived depths of surface are consistent with water-filled surface depressions comprised of an annulus of shallow water and rapidly deepening water towards the center (Figure 2A). The profile in Figure 2B shows the maximum water depths along the profile line but not necessarily the maximum depth of the ponds. Pond depths of 5 m or more are not uncommon.

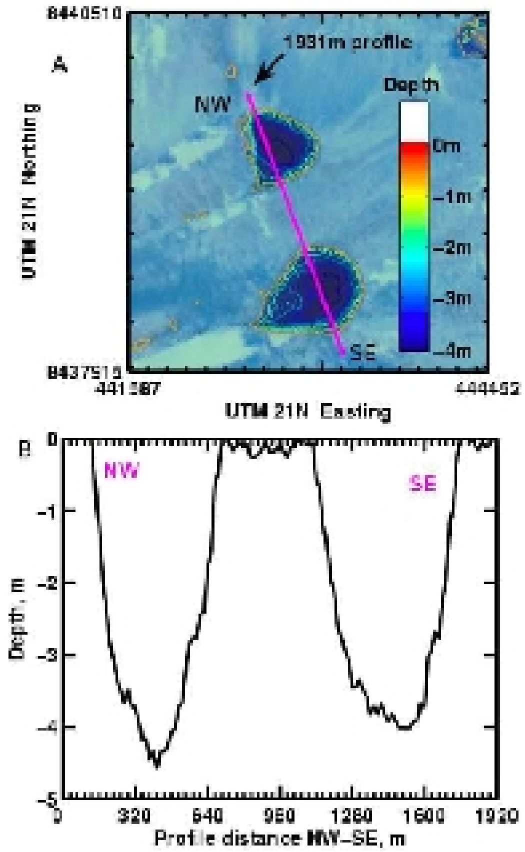

Figure 2. (A) Top. Contoured depths of two surface melt ponds on Nordaustlandet, Svalbard, produced with our depth-finding algorithm. (B) Bottom. Cross-profile of depth versus distance along the pink line in Panel A.

Melt ponds on the surface of Austfonna, a large ice cap in northeastern Svalbard, undergo a rapid seasonal evolution according to our analyses of two ASTER images collected 6 d apart in the summer of 2004 (Figure 3). Wetted surface area increases by a factor of five and water volume increases by a factor of three. The formation of new ponds, rather than the deepening of existing ponds, is the primary cause for the increase in stored water volume. In some cases, existing ponds become shallower as their margins extend (e.g., the pond in the upper right corner of Figure 3 upper panel). In another case (lower right corner of Figure 3 lower panel), an entirely new pond forms during the short observation period, reaching a maximum depth of ~3 m.

The algorithm yields promising results, and has numerous applications in Arctic glaciology. Our next steps are move towards operational implementation, and at the same time incorporate field data that our Norwegian colleagues will collect in late-spring 2007.

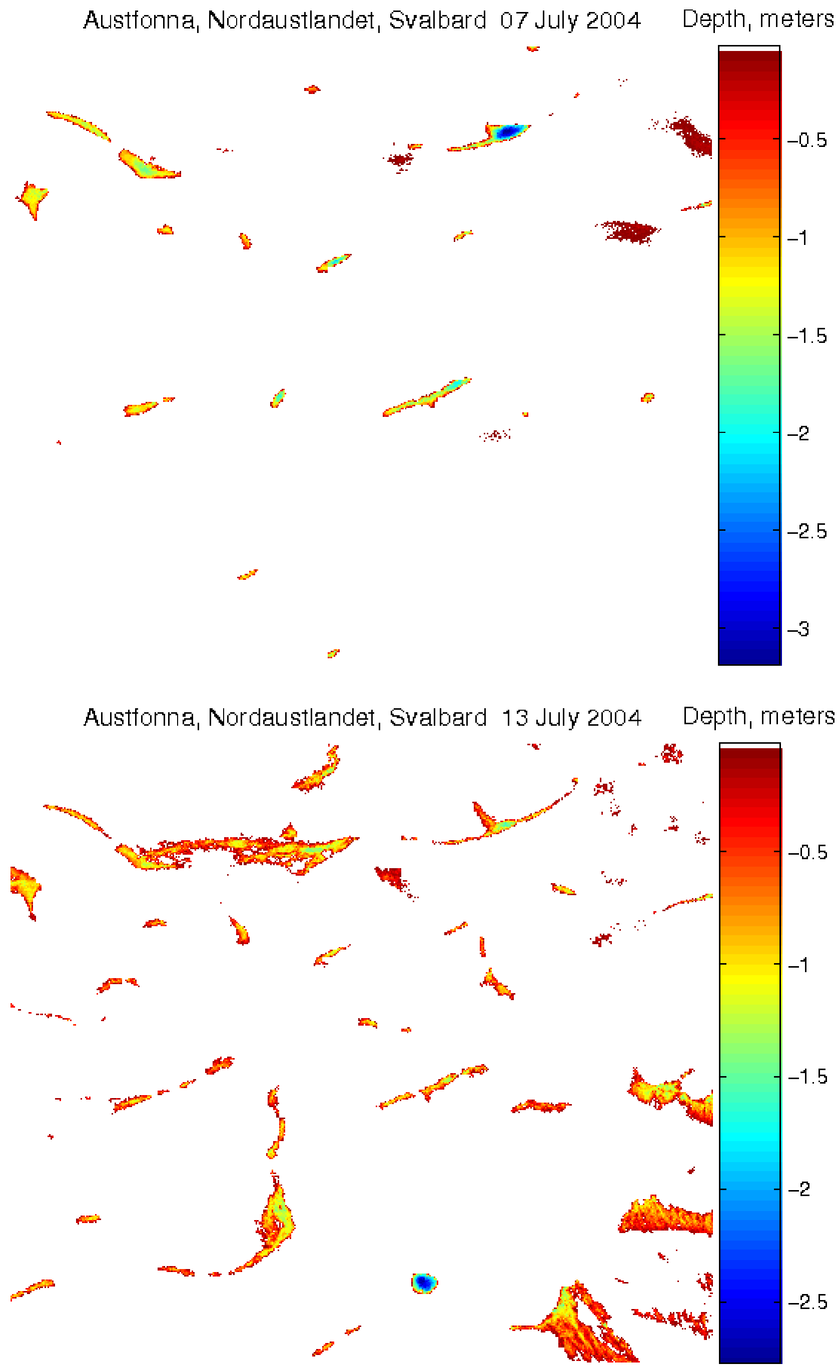

Figure 3. Melt pond evolution on the Austfonna ice cap, Nordaustlandet, Svalbard. The two ASTER images were acquired 7 days apart in July 2004. Not the rapid evolution of the melt pond network.

Major Research and Education Activities

This project included the following major activities:

- satellite image analysis of glacier changes in the Norwegian Arctic archipelago of Svalbard
- development of algorithms to derive geophysical information about glacier behavior from optical satellite images
- integration of modern satellite imagery and archival mapping information to map historical changes in glacier geometry
- training of an MS student
- outreach activities.

Our principal data source was imagery collected by the Advanced Spaceborne Thermal Emissions and Reflection Radiometer (ASTER) flying on board NASA's Terra satellite. ASTER imagery is particularly well-suited to polar glacier studies because of its fine spatial resolution (~15 m in the visible bands) and good radiometric range (14 bands) and its ability to image to 85°N/S. The sensor has been collecting data since spring 2000. In order to understand glaciers as indicators of climate change it is necessary to look at multidecadal records of glacier behavior. We do this by merging modern data with historical mapping information, mostly in the form of topographic maps and aerial photographs archived by our project partners at the Norwegian Polar Institute.

Our principal algorithm development activities have been concerned with three principal tasks: improved spatial resolution of thermal band imagery; extraction of surface topographic data from stereo imagery; and mapping of melt pond depths and volumes using visible band data.

Improved spatial resolution in the thermal bands is helpful for a number of studies. Band-ratioing for image classification purposes, such as discriminating different snow and ice facies, often requires a combination of 30 m resolution thermal and 15 m resolution VNIR bands. A decision needs to be made as whether to upsample the thermal bands to the higher resolution 15 m pixel size, or downsample the high-resolution VNIR bands to 30 m. Quite often, the loss of spatial resolution caused by downsampling leads to a real loss of scientific information. A case example is mapping a fine-scale feature such as the transient snowline on a glacier; delimiting its position to 30 m, as opposed to 15 m, can lead to large uncertainties in its mapped elevation (due to steep slopes on glaciers), reducing the utility of the result for climate reconstruction. We have implemented a Smoothing Filter-based Intensity Modulation (SFIM) algorithm to ASTER images of snowfields and glacier in Svalbard. The technique resamples the 30 m thermal data with 15 m VNIR data in a computationally efficient manner to yield a product that enables precise mapping of various snow types.

One of the unique attributes of the ASTER sensor is its along-track stereo imaging capability. This allows us to extract topographic information from stereo scenes. For many glaciers in remote regions such as Svalbard, the resulting digital elevation models are the first reliable measurements of their surface topography. From these products, we can derive useful glaciological characteristics, for example surface slopes necessary for understanding flow dynamics. By combining repeat digital elevation models of the same area taken at different times, we can examine changes in surface topography, and hence ice volume, with time. This is an extremely promising technique which is already yielding interesting results for Arctic glaciers.

Ponded surface meltwater on ice caps and ice sheets is an important glaciological and climatological characteristic. Changes in the distribution and amount of ponds with time represent changes in the surface climate conditions controlling melting. The availability of large volumes of ponded surface water raises the possibility of sudden drainage to the bed, a change in basal lubrication, and a rapid increase in ice velocity. While the problem of calculating the areal extent of meltwater ponds using satellite imagery is fairly straightforward, determining their depth (and thus their volume) is not. We have developed a technique for deriving the depth of meltwater using the 15 m VNIR imagery from ASTER. The method involves making some reasonable assumptions about the albedo, or reflectance, of the bottom surface of the ponds and the optical attenuation characteristics of the relevant ASTER bands through the meltwater. Results of the development to date suggest great promise.