DYNAMICS OF ICELANDIC ICE CAPS AND OUTLET GLACIERS

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ABSTRACT. Since late 1972, when the first Landsat images of Iceland became available, the ice caps of Iceland and their outlet glaciers have been under intensive study with Landsat images. The original emphasis of the Landsat research of Icelandic ice caps was to record and quantitatively measure dynamic change of glaciers and phenomena related to glaciers. A comparison of Landsat images with the best available topographic maps revealed a number of discrepancies in the planimetric shape and size of Icelandic ice caps and in the mapping of prominent surface features. Some of the surface features recorded on Landsat images turned out to be the subdued morphological expression of subglacial topography and geologic structure or the surficial response to subglacial volcanic and geothermal activity. Of particular interest was a winter image of Vatnajökull, acquired at a solar elevation angle of 7°, which revealed a number of surficial features not recorded before, including a large volcanic caldera in the Kverkfjöll area. A computer-enhanced early fall image of Vatnajökull revealed similar phenomena, and computer-enhancement techniques have also been applied to summer images of Hofsjökull, Langjökull, Mýrdalsjökull, and Eyjafjallajökull. In the case of Hofsjökull a subglacial volcanic edifice with the approximate dimensions of the Dyngjufjöll massif in north-central Iceland, and possibly with a caldera, may exist. Radio echo-sounding surveys have been carried out over some parts of Vatnajökull and Mýrdalsjökull to determine the precise nature of the subglacial topography, and it is of great interest to compare the results of these surveys of glacier bed topography with the surface features recorded on Landsat and other imagery. Landsat images are also being used to plan the optimum location of field traverses and as a navigational tool (map substitute) during field work.

Two experimental Landsat image maps, at a scale of 1 : 500 000, were published by the U.S. Geological Survey, in association with the Icelandic Geodetic Survey and the Icelandic National Research Council, in 1976 and 1977. A black and white image map delineates surface features on Vatnajökull in late January 1973; a false-color infrared-image map portrays Vatnajökull in late September 1973, when snow cover was at a minimum and maximum retreat of the firn limit had occurred. Two other experimental Landsat image maps, at scales of 1 : 250 000, are under preparation by the U.S. Geological Survey. An unusual 1 : 250 000-scale image resulted from a trimodal (three-part) linear contrast stretch, by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology, of the September 1973 Landsat image of Vatnajökull. Separate contrast stretch enhancement of snow, vegetation, and water of MSS bands 4, 5, and 7, when combined in false color, produced a unique image of Vatnajökull. Of particular interest is the portrayal of the ablation facies of the ice cap and enhancement of surface morphology. The other 1 : 250 000-scale image was produced by the EROS Data Centers EDIES (EROS digital image enhancement system)

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and IDIMS (Interactive digital image manipulation system) equipment, in which the September 1973 Landsat image of Vatnajökull is portrayed in conventional false color. Edge enhancement, destriping, triple piecewise linear contrast stretch (similar to the JPL technique), and other computer-enhancement techniques have resulted in another unique image of Vatnajökull, in which enhancement of surface morphology and detailed delineation of glaciological features are evident. There is no question that, in the specific case of large ice masses, computer enhancement of Landsat images can produce considerably more information about the dynamics of such ice masses than is possible with conventionally processed (electron-beam recorder) Landsat imagery.

A comparison of the areas of Icelandic ice caps, as recorded on Landsat imagery, with previously published maps shows significant differences. These are the result of the combination of original-map inaccuracies and true change in area encompassed by the ice caps and the various outlet glaciers. In certain cases comparison of the Landsat images with available aerial photographs is also necessary. This is particularly true for the monitoring of change in those glaciological features (e.g. medial moraines, proglacial lakes, etc.) which were either not shown on topographic maps or have changed since the topographic maps were published.

The variety of types of glaciological phenomena observable on Landsat images of Iceland is quite extensive. The movement of two surging outlet glaciers (Eyjabakkajökull and Hagafellsjökull eystri), the velocity of glacier flow (Skeiðarárjökull) over a period of several years, and variation in areal size and position of proglacial lakes have been measured from Landsat images. Changes in surface morphology due to subglacial volcanic and geothermal activity and to the effect of jökulhlaups have also been recorded.

DISCUSSION

F. Pessl: Do you have any data on *rates* of recession along the margin of Hofsjökull in the vicinity of the striking series of recessional moraines you showed in the oblique aerial photo?

R. S. Williams, Jr: No, not off the top of my head. Systematic measurements of some of the Icelandic outlet glaciers were begun by Eiríksson in 1930 and by Eythórsson in 1932. In 1951, in the first issue (Ár. 1) of *Jökull*, Eythórsson began to publish an annual compilation of variations of Icelandic glaciers. After Eythórsson's death in the mid-1960s this very important field measurement programme has been continued by Sigurjón Rist. I do not recall when Múlajökull, the outlet glacier of Hofsjökull which you note in your question, was first monitored in the field. The available field data may then shed some light on the rate of recession of Múlajökull.

S. F. Ackley: Have you looked at NOAA infrared imagery to get a comparison of the "true" temperature with the inferred melting temperatures you have from the Landsat reflectivities?

Williams: Yes, we have looked at the NOAA weather-satellite images, but those available have too coarse a resolution (*c.* 4 km for the scanning radiometer) to reveal much thermal data of any use to our studies. NOAA does produce VHRR (very high resolution radiometer) data in both the visible and near-infrared and thermal-infrared wavelengths, at a resolution of *c.* 1 km, but it had to have been acquired by tape recorder in 1973, something that did not take place.

The heat capacity mapping mission (HCMM) spacecraft, which was launched in 1978 would be ideal, but a ground receiving station is needed to acquire data for the Iceland area. NASA would also have to agree to process the data because HCMM is very experimental.

Finally, we are not really inferring melting temperatures. We are mapping, by means of reflectivity differences, variations in water content of surficial snow cover within the accumulation zone and bare glacial ice and superimposed ice in the ablation zone. In short, there is a strong possibility that we are actually able to delineate some of the facies (e.g. bare glacial ice zone, the exposed part of superimposed ice zone, soaked and percolation zones, and dry snow zone) by tonal variations on the various multispectral scanner (MSS) bands (4, 5, 6, and 7) of Landsat images of Icelandic ice caps.

LONGITUDINAL STRESS GRADIENTS AND BASAL SHEAR STRESS OF A TEMPERATE VALLEY GLACIER

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Abstract. For the first time field data from a temperate valley glacier, the Variegated Glacier, are used to investigate the behavior of longitudinal stress gradients predicted by the relation

$$\tau_{xy}(y_b) = -f\rho g H \sin \alpha - 2G + T, \qquad (1)$$

where

$$G = \int_{y_s}^{y_b} \frac{\partial \tau_{xx}'}{\partial x}\, dy,$$

$$T = \int_{y_s}^{y_b} \int_{y_s}^{y'} \frac{\partial^2 \tau_{xy}}{\partial x^2}\, dy''\, dy',$$

H is the local depth, and y_s and y_b are the surface and bed elevations respectively. This equation is similar to one derived by Budd (1970) for plane strain-rate, to evaluate the importance of longitudinal stress gradients, but a shape factor f is included to account approximately for lateral strain-rate gradients. Predictive numerical models of valley glaciers require the local base shear stress to be known as accurately as possible. It has been argued on theoretical grounds that when T is averaged over distances of more than five to ten times the depth, this term is negligible. At larger averaging scales, $2G$ can then be considered a correction to the simple geometric expression of base stress due to the presence of longitudinal stress gradients. Field data of velocity and geometry are used to evaluate the terms of Equation (1), where τ_b and $2G$ are estimated as

$$\tau_b = \tau_{xy}(y_b) = \left[\frac{(n+1)\, U_s}{2A(f\rho g \sin \alpha)^n\, H^{n+1}}\right]^{1/n},$$

and

$$2G = 2H \frac{\partial}{\partial x}\left[\frac{\dot{\epsilon}_{xx}}{A}\right]^{1/n},$$

at intervals of 100 m, U_s is the measured surface center-line velocity, A and n are the flow-law parameters, and $\dot{\epsilon}_{xx}$ is the surface longitudinal strain-rate. The expression for $2G$ is an approximation proposed by Budd (1970).

The precise method of distance averaging is investigated carefully. Two methods are considered: a running arithmetic mean and a digital low-pass filter. By Fourier analysis the

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