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DIGITAL MAPPING IN POLAR REGIONS FROM LANDSAT PHOTOGRAPHIC PRODUCTS: A CASE STUDY

by

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ABSTRACT

Landsat photographic products on the Space Oblique Mercator (SOM) projection are used to construct a map of Nordaustlandet (Svalbard), of known accuracy. The map includes ice divides. Accurately enlarged Landsat images were digitized. Combined digitizer and operator errors were 64 m, at the enlargement scale. Fifteen ground control points fixed the two scenes. RMS errors in control point identification were <123 m. Geographical coordinates were extracted by: 1) converting digitizer coordinates to SOM cartesian coordinates and 2) transforming these coordinates to latitude and longitude. This map production method is applicable to any imagery of known projection. The digitally stored map may be plotted on a variety of map projections and scales. Two problems in image interpretation were: 1) shadows obscuring detail on NNE-facing coasts and 2) summer snow cover obscuring parts of the terrestrial ice cap margins. The map is similar to an east coast map produced from Landsat computer compatible tapes. Differences between the Landsat map and a 1:50 000-scale aerial photograph were <100 m.

INTRODUCTION

Since 1972, Landsat multispectral scanner (MSS) photographic products and computer compatible tapes (CCTs) have been applied to both cartographical and glaciological problems in the often inaccessible polar regions (e.g. Krimmel and Meier, 1975; MacDonald, 1976). In general, Landsat photographic products have been used in reconnaissance mapping and glaciological studies (e.g. Swithinbank and Lane, 1977), whereas digital data, stored on CCTs, have provided the basis for detailed analysis and more rigorous mapping (e.g. Ødegaard and Helle, 1982; Lucchitta and others, 1985). Landsat photographic products are inexpensive, relative to their digital counterparts, and can be inspected and interpreted without requiring digital image analysis facilities. Landsat CCTs, however, provide the more flexible and detailed medium of storage, in that computer methods can be used both to transform scene geometry and to enhance the radiometric information in the scene. In this paper, we show that Landsat photographic products can also be used to produce digital maps of the polar regions, which are of known accuracy. Landsat MSS imagery of Nordaustlandet, Svalbard, is used to illustrate this method (Fig.1).

METHOD OF MAP CONSTRUCTION

Three 1978 Landsat scenes of Nordaustlandet, with <20% cloud cover (Fig.1), were obtained from EROS Data Center, where they were corrected to "system level" to compensate for spacecraft attitude variations.

Two summer images (solar elevation angles 22 and 23°) were most useful in defining boundaries between bare ground and ice cover and were used in producing the digital map. Ice cap topography is best viewed on Landsat scenes with relatively low sun elevations (Thorarinsson and others, 1974), and an April 1978 scene (16° solar elevation angle) was used to map these features on Nordaustlandet (Fig.1). Saturation of MSS detectors over snow-covered ice, at the latitude of Nordaustlandet, is only a problem between

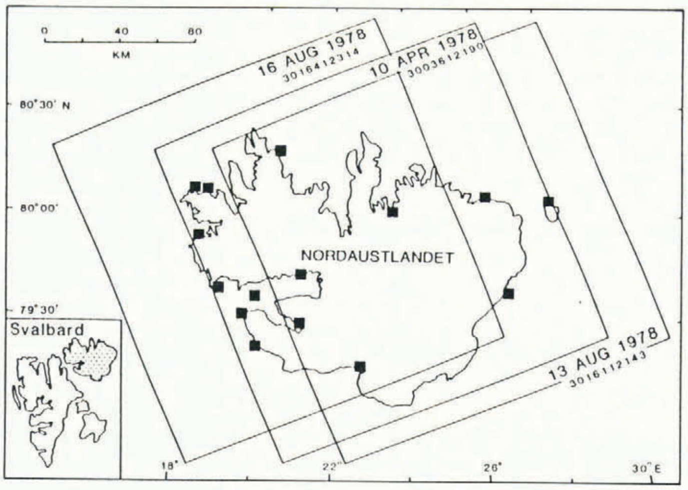

Fig.1. Position of Nordaustlandet (shaded) within Svalbard, and areas imaged in the three Landsat scenes used in mapping. Ground control points are also located.

May and July (Dowdeswell and McIntyre, 1986). MSS band 7 (0.8-1.1 μm) was used for all enlargements employed in mapping, but false colour images incorporating MSS bands 4 (0.5-0.6 μm), 5 (0.6-0.7 μm) and 7 were also used for identifying the bare ground-glacier ice interface in the August 1978 scenes.

Landsat 185 mm negatives of each scene were enlarged to a scale of approximately 1:320 000, using a Wild EA rectifying enlarger with a Wild 6-inch Reprogon lens. Distortion introduced during enlargement was minimal (a few microns at worst). Printing was on very stable 'Veribrom' paper, which was air dried without heating.

The coastline, inland ice margins, ice divides and islands surrounding Nordaustlandet were digitized from the enlarged Landsat images. The digitizer used had an intrinsic error of ± 0.1 mm, and operator error increases the total error to approximately ± 0.2 mm (i.e. 64 m at the enlargement scale).

Surveyed ground control points are required to convert digitizer coordinates to latitudes and longitudes. Norsk Polarinstitutt (NP) provided data on the position of 15 trigonometric points from geodetic field surveys on Nordaustlandet, each located with an accuracy of ±2 m. 1:50 000-scale aerial photographs, with each control point marked (Fig.1), were obtained from NP. Only points around the coast of Nordaustlandet were used, because it was easier to match detail between aerial photographs and Landsat imagery in these areas than at mountain summits.

The following method of extracting latitude and longitude from imagery was used. It is suitable for any scene of known projection. The Landsat images used to compile the map of Nordaustlandet are on the SOM projection (Colvocoresses, 1974; Snyder, 1978). Extraction of geographical coordinates of imaged features proceeds in two stages. First, digitizer coordinates are converted to SOM cartesian coordinates. Secondly, SOM cartesian coordinates are transformed to latitudes and longitudes. To calculate the first transform, four points at the corners of the image are digitized to define the digitizer coordinates of the scene centre. Then a minimum of three control points of known latitude and longitude are digitized.

The method of transformation is as follows:

(1) Using an assumed centre latitude and longitude, calculate the SOM cartesian coordinates of the digitized control points.
(2) Calculate the transformation matrix for the conversion between digitizer coordinates and SOM cartesian coordinates, using a least squares fitting method.
(3) Calculate the latitude and longitude of the centre of the image.
(4) If there is no change in the centre latitude and longitude, proceed to (5), otherwise go to (1), replacing the assumed centre latitude and longitude with those calculated.
(5) Calculate errors for the location of each control point.
(6) Transform the digitized outline of features to latitude and longitude.

In addition to digitizer errors and those associated with the field survey of ground control points, the main error in the method is control point identification on the Landsat images. Radial errors for each control point were calculated and points mislocated by more than 200 m were rejected. Surveyed points were identified and digitized twice on each August 1978 scene to test the repeatability of identification.

A further limitation on mapping accuracy, using this method, is imposed by the size of the picture elements (pixels) in each image. For the Landsat MSS, scene pixels are 79 m by 56 m, after re-sampling during image processing by a Landsat receiving station. The RMS error in control point location varied between 91 and 122 m and almost all individual control points were located within two pixels (approximately 160 m) of their true position. The methods used to map Nordaustlandet therefore involve small, known errors.

RESULTS

These methods enable production of a digital map of Nordaustlandet (Fig.2). Data points are stored in the form of latitude and longitude and may be plotted on a variety of projections and scales. Storage of map coordinates in this form thus gives considerable flexibility in the choice of final product, which is drawn using a digital plotter.

Two principal problems in image interpretation were: 1) shadows obscuring detail on north-east-facing coastline; (2) the presence of snow cover, making the identification of terrestrial ice cap margins difficult. Similar problems will apply to much satellite imagery of the Polar regions.

Relatively long shadows are present in the Landsat scene for 10 April 1978 (Fig.3), which has a sun elevation above the horizon of 16°. Sun azimuth is 208° and, therefore, areas approximately NNE of obstructions, such as mountain summits, or cliffs, will have the longest shadows. All Landsat scenes of Nordaustlandet have sun azimuths between 202 and 208° and the problem cannot therefore be circumvented by acquiring additional imagery, except that higher summer sun elevations (reaching a maximum of 30° in Nordaustlandet) lessen the area affected by shadows.

Shaded areas important in map making were coastal regions immediately north and east of mountains; for example, the coastline abutting the south side of

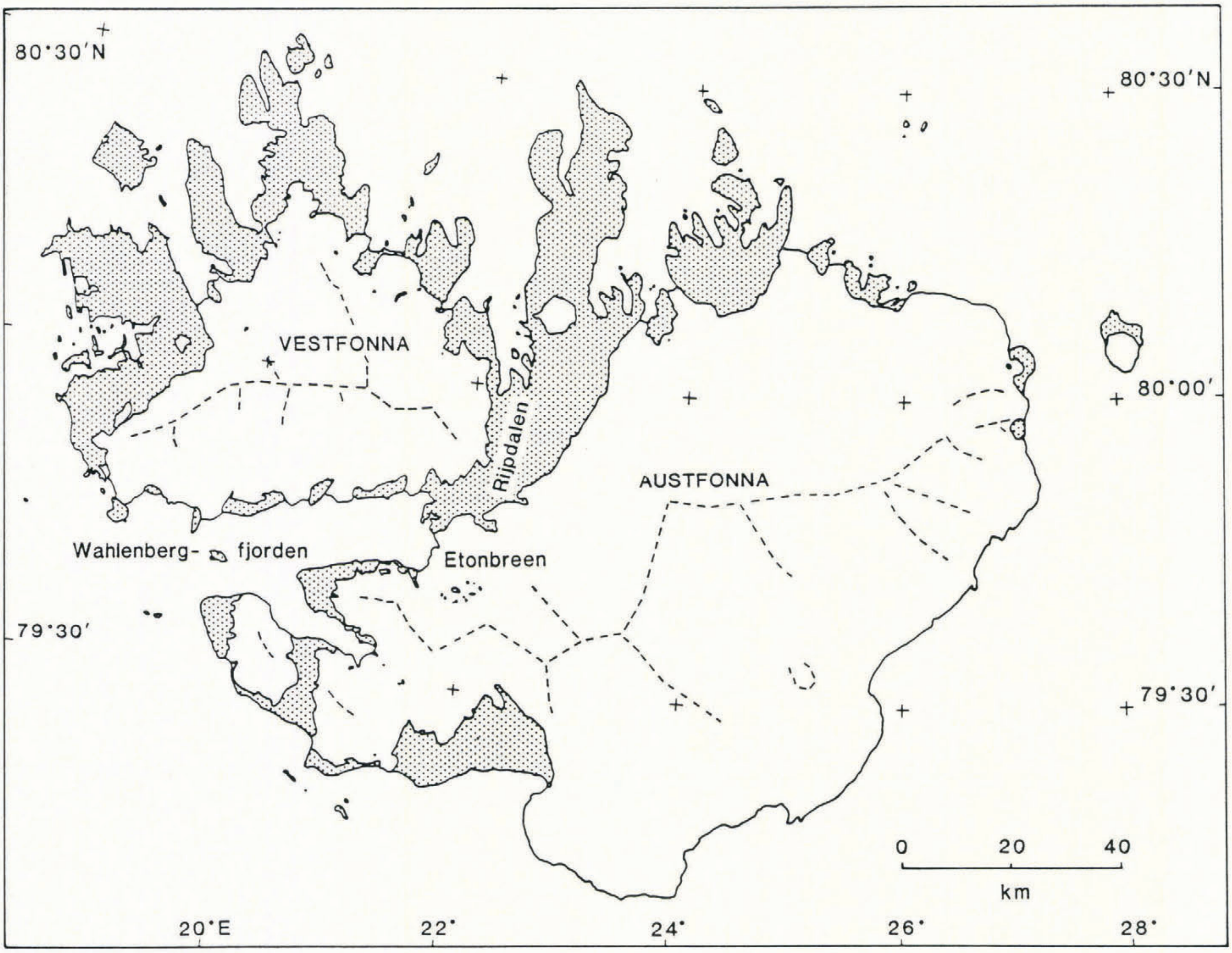

Fig.2. Map of Nordaustlandet, from Landsat MSS photographic products (UTM projection). Shaded areas are ice-free ground. Dashed lines on the ice caps represent ice divides and domes.

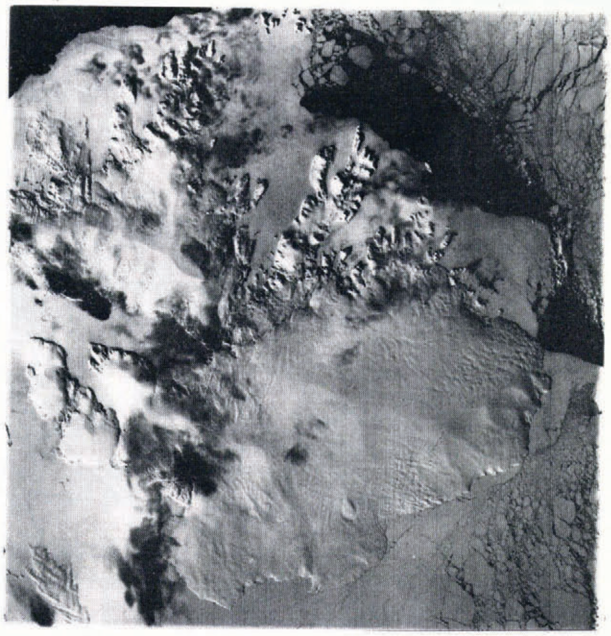

Fig.3. Landsat-3 MSS band 7 scene of Nordaustlandet (10 April 1978; 3003612190). Note the ice divides and long shadows along north-east facing coasts. Sun elevation and azimuth are 16° and 208°, respectively.

Wahlenbergfjorden (Fig.3). Maximum shadow-induced errors are estimated from Figure 4. In the August images, maximum errors of approximately 500 m (0.5 mm at 1:1 000 000-scale) are introduced in the mapping of NNE-facing coastal areas around Duvefjorden (Fig.3), due to the presence of land more than 200 m in elevation very close to the coast (Fig.4). These inaccuracies, however, decrease rapidly away from NNE-facing regions and in NNE-facing areas of lower relief.

Summer snow cover precluded the mapping of several small (<4 km long) glaciers on the northern peninsulas of Nordaustlandet, with significant cover remaining on both August 1978 images. The eastern boundary of Vestfonna, in the ice-free Rijpdalen, also retained significant areas of summer snow and mapping was difficult, despite the use of false-colour-composite images. Fast ice also obscured the Frostøyane, a group of small islands to the east of Nordaustlandet. In most areas, however, ice margins were identified satisfactorily.

Divides on the ice caps of Nordaustlandet are also mapped in Figure 2, and are plotted from the apparent ridges on Landsat imagery (Fig.3) (Dowdeswell and Drewry,

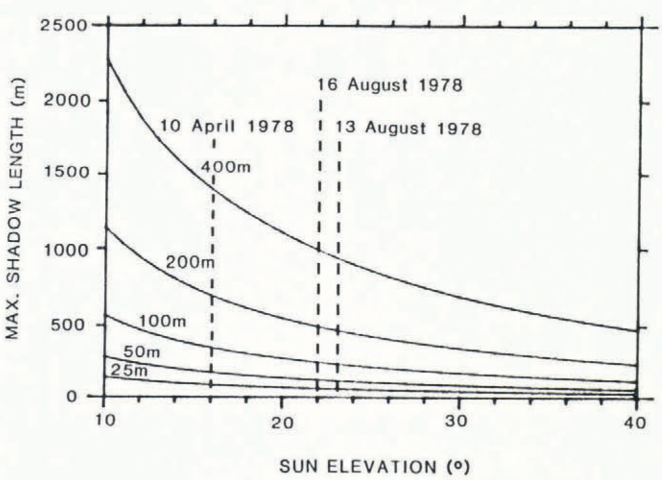

Fig.4. Graph showing shadow length against sun elevation (above the horizontal), for cliffs of various heights (25-400 m), running perpendicular to sun azimuth.

1985). Martin and Sanderson (1980) demonstrated that apparent ridges, imaged by Landsat, coincide with ice divides on the ground. The lack of observed divides in the northern part of Austfonna may be due to ridges being orientated sub-parallel to sun azimuth (i.e. SSW-NNE), thus minimizing apparent shadowing. While Landsat imagery does not provide data on absolute ice cap altitudes, apparent ridges may be used to correct existing maps in terms of relative elevation.

COMPARISON WITH AERIAL PHOTOGRAPHS AND CCT-DERIVED MAPS

A significant advantage of mapping from Landsat imagery, as opposed to aerial photographs, is that, for areas the size of Nordaustlandet, mosaicing is largely unnecessary. In this paper the island is mapped from two 185 by 185 km scenes, whereas more than 800 1:50 000-scale aerial photographs would be required to cover the same area. Two problems associated with aerial photographic surveying and mapping in Polar regions are: 1) the logistical effort required to assemble a complete set of cloud-free photographs; and 2) distortion introduced through mosaicing, without a relatively dense network of ground control points. Both difficulties are avoided in mapping from Landsat imagery. In particular, each Landsat scene has minimal internal distortion, making the main source of error that of control point identification and location.

Comparison between 1:50 000-scale aerial photographs and Landsat derived data was made at the east end of Wahlenbergfjorden and illustrates the relative accuracy of the map derived from Landsat photographic products (Fig.5). Differences between the two sources are generally less than 100 m, and often much less (Fig.5).

Fig.5. Comparison between an aerial photograph (courtesy of NP) and the map produced from Landsat photographic products.

Note that the retreat of the edge of Etonbreen, between the 1969 aerial photograph and 1978 satellite imagery, can be quantified. Different parts of the terminus of Etonbreen have retreated by between 1.15 and 2.65 km in 9 years, a rate of 130-290 m a^{-1}. Conventional maps are compiled and updated from surveys and aerial photographs, acquired over a period of many years. A further useful attribute of the Landsat map of Nordaustlandet (Fig.2) is that ice margins represent the extent of all ice masses at a known time (Williams and others, 1982).

Comparison is also made between our map (Fig.2) and a study of the east coast of Nordaustlandet using Landsat CCTs (Ødegaard and Helle, 1982). The latter work used four ground control points to position the digital scene geographically and image enhancement and enlargement

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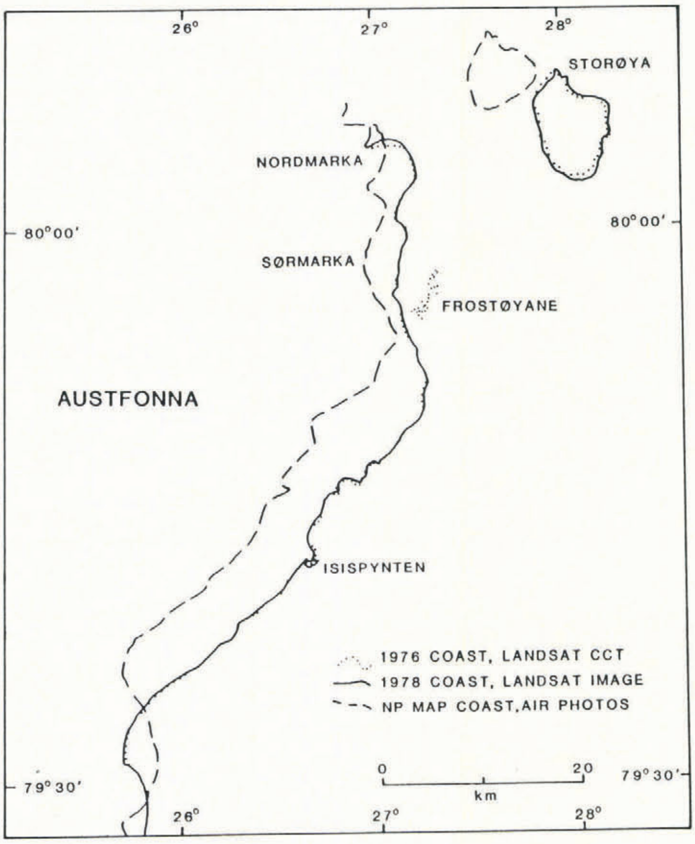

Fig.6. East coast of Nordaustlandet, mapped from: (A) 1978 Landsat photographic products (solid line) (Fig.2), (B) 1:500 000-scale map, compiled from Norsk Polarinstitutt aerial photographs (dashed line), and (C) 1976 Landsat CCT (dotted line) (Ødegaard and Helle, 1982).

assisted in control point identification. A comparison of the two coastal outlines indicates almost equal amounts of eastward displacement, relative to previous maps of the region, which were based on poorly positioned aerial photographs (Fig.6). Note that displacement of up to 8 km includes both ice and rock outcrop. This comparison suggests that photographic enlargements of Landsat images can provide cartographic data of comparable accuracy to that from CCTs. Errors in ground control point location also indicate that the two methods are of similar accuracy. This finding is important, because Landsat negatives are considerably less expensive than CCTs and do not require access to sophisticated image analysis facilities. High quality photographic enlargement is, however, a prerequisite for the method used here.

CONCLUSIONS

The map of Nordaustlandet, produced using Landsat photographic products, is internally consistent, because Landsat scenes contain minimal distortion and high quality photographic enlargement introduced insignificant further errors. Its absolute accuracy is known and is dependent largely on the precise identification of ground control points. The map is stored digitally and can be plotted at a variety of scales and projections. This method of map construction is also applicable to any remotely-sensed imagery of known projection. The map provides glaciological information on the position of ice margins in 1978 and the location of ice divides.

The technique is considerably less expensive than mapping from Landsat CCTs, because the latter require purchase of digital tapes and access to digital image analysis facilities. Mapping from digitized and transformed Landsat photographic products has advantages over mapping from aerial photographs, because of the logistical effort required in obtaining numerous photographs and the necessary ground control points in inaccessible Polar areas. Comparison with the results of mapping from CCTs shows that maps derived from Landsat photographic products are of similar accuracy, although, as maps become more detailed, the ability to enhance and enlarge CCT pixels will lead to progressively better resolution using the latter medium.

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