Economical Maintenance of a National Topographic Data Base Using Landsat Images*

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ABSTRACT: Under a series of contracts from the Surveys and Mapping Branch of the Canadian Department of Energy, Mines and Resources, Gregory Geoscience Limited has developed and implemented an operational program to detect changes for 1:50,000 mapping and to provide information for the revision of 1:250,000 maps. A specialized projection-compositor (PROCOM-2) is used to register a recent Landsat MSS image onto a 1:50,000 topographic map. Experience to date indicates that the average relative error in positioning of linear features is about 30 m at a scale of 1:50,000. A recent program of 2700 maps, representing an area of about 2 million km², was completed in 9 months including selected field verification. The average cost for this combined program of change detection and map revision was 15¢ (U.S.) per km² or $150 (U.S.) per 1:50,000 map. Relevant experience suggests that these techniques can be transferred with minimal training and capital cost for use in other parts of the world; some modification may be required for arid areas and rainforest.

INTRODUCTION

Cartographic and other applications of satellites were first considered by the United Nations and its member states over 15 years ago (U.N., 1970; Gregory, 1971). At that time, meterological satellites were operational and the potential utility of space data for completing and updating national topographic data bases had been recognized. Now, in 1985, geodetic positioning satellites are a global fact of life, although cartographic applications of space data have grown more slowly.

Within that time frame, Canadian development of practical applications of space data was left largely to a diverse group of potential users, both public and private. Geodetic and topographic applications receive strong technical and administrative support from the Surveys and Mapping Branch of the Department of Energy, Mines and Resources. On the other hand, a variety of organizations were involved with research into thematic mapping from space data, primarily from Landsat data produced by the Canada Centre for Remote Sensing. The principal geometric control for such mapping is the Canadian national topographic data base.

While the need for continued revision and maintenance of national data bases is well known, there has been little progress until recently toward this essential, but seemingly mundane, task. For example, at an international symposium in 1978, R.E. Moore (1978, p. 4) re-emphasized the need to develop and implement a simple, economic system for detecting areas of change and for updating maps with acceptable accuracy. This present paper reports on one system that has been operating successfully in Canada since 1980 and which might be adapted to other areas of the world with minor expense.

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THE CANADIAN CONTEXT

Diversity in Terrain and Density of Population

As the second largest country in the world, Canada faces monumental economic and technical challenges in completing and maintaining a national topographic data base. The lands and freshwaters that are represented in this data base cover 10 million square kilometres. The Canadian terrain is extremely varied and ranges from temperate rain forest on the Pacific coast through rugged mountains, semiarid steppes, fertile prairies, and vast boreal forests to the woodlands and farmlands of eastern Canada and the treeless expanses of the Arctic tundra. Much of the land is rocky or mountainous and is exposed to a harsh, cold climate. About 8 percent of the land is covered by permanent waterbodies, ranging from the Great Lakes to small ponds; but, in addition, there are large areas of marsh, wooded swamps, and intermittent lakes.

Canada has a relatively small population, just over

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25 million, of which 90 percent live in a zone about 300-km wide along the boundary with the United States of America. Over half of these people are concentrated in the towns and cities of southern Ontario and southern Quebec. North of the populated zone, the country is uninhabited or sparsely inhabited, except near scattered small resource developments and centers of government.

The Technical Challenges of Maintenance

The National Topographic series of 918 maps at a scale of 1:250,000 is currently the most detailed data base containing topographic information for *all* of Canada. These maps, which were published over a 23-year period ending in 1970, provide the only information for much of northern Canada. Traditional methods of photointerpetive revision were based on arbitrary cycles that reflected anticipated change. Almost three-quarters of these maps are in a "remote" class with a revision cycle of 30 years. In areas of resource development, changes take place much more rapidly; for example, within a few years, hundreds of kilometres of road may be built, millions of tons of soil and rock may be removed, and millions of hectares of land may be flooded by reservoirs. Thus, by the early 1980's, many of the 1:250,000 maps were out-of-date while some older maps did not meet the most recent cartographic standards.

The technical challenges for 1:250,000 mapping were (1) to identify those maps which required revision and (2) to complete the revision accurately.

The National Topographic Series of over 13,000 maps at a scale of 1:50,000 present more detailed information than the 1:250,000 maps. However, only 76 percent of these maps had been produced by the end of 1984. Much of the completed mapping represents the ecumene, the area of concentrated human activity. These maps are candidates for revision almost as soon as they are published. Such revision is in competition with the primary mapping that is essential for completion of the series.

The technical challenges for 1:50,000 mapping, then, were (1) to identify those areas where primary mapping had highest priority, (2) to identify other areas where revision was required, and (3) to complete either mapping or revision as warranted.

The Economic Challenges of Maintenance

Until recently, revision of maps in Canada was completed at three levels of complexity and cost: (1) overprinting of changes on extant maps, (2) amendment of extant cartographic bases and reprinting, and (3) recompilation to produce a completely new map. Where single maps required minor revision, the most economical approach was overprinting. Amendments and recompilations, as well as primary mapping, were completed by photogrammetric methods using aerial photography. The most economical approach to such revision was based on the completion of large blocks of maps so as to distribute the costs of photography and ground control over many maps. In the past, aerial photography was acquired systematically over large areas of the country. However, this approach has become increasingly expensive, and relevant costs have become a factor that limits the maintenance program.

In view of the continuing climate of economic restraint and of the urgent need to revise many of the published maps, maintenance of the Canadian topographic database faces two economic challenges: (1) to develop funding for maintenance when a direct economic or social benefit is difficult to demonstrate, and (2) to effect a significant reduction in the cost of maintenance so that the program can be accelerated.

A Canadian Response to the Challenges

Over the past 12 years, the authors and their associates at Gregory Geoscience Limited have used Landsat and collateral data to prepare maps for a wide variety of themes at scales ranging from 1:15,000 to 1:2,000,000. In 1974, we began a contract to assess various remote sensing techniques for mapping mine wastes on behalf of the Canada Centre for Mineral and Energy Technology. In 1976, we completed a national inventory of mine wastes using Landsat MSS and RBV images projected onto 1:50,000 topographic maps (Moore, Adams and Gregory, 1977). The experience of that broad program led us to propose to the Surveys and Mapping Branch that the technique should be assessed and developed for the detection of change and revision of topographic maps. At the same time, we started to develop specialized projectors, both multiband and single-band, which eventually became our PROCOM systems (Gregory *et al.*, 1982). The single-band system (PROCOM-2) projects one image to register on a map and has become the basic tool for using Landsat images to maintain the national topographic database.

In 1978, the Surveys and Mapping Branch initiated a sequence of contracts which assisted Gregory Geoscience Limited in assessing digital and cerebral* processing of Landsat data for change detection and map revision. The most accurate and economical method of change detection at scales of 1:250,000 and 1:50,000 was cerebral processing using the PROCOM-2. This was true also for revision of 1:250,000 maps (Moore, 1982). However, Landsat MSS data alone did not provide enough detail for the accurate revision of 1:50,000 maps. These accuracies were assessed independently by the Surveys and Mapping Branch using new 1:80,000 aerial photography (Fleming, 1980, 1981). Proto-operational programs were then implemented with the continuing support

* Using the eyes and brain of an experienced mapper.

of the Surveys and Mapping Branch in order to develop costs for systematic mapping and to assess techniques of verification. All of these techniques are now in use to meet the current requirements for maintenance and, with new types of data in particular, have potential for systematic use at larger scales.

OPERATIONAL MAINTENANCE

GENERAL

To be operational in the Canadian context, any new program of maintenance must, for reasons previously outlined, be accurate, economic, and compatible with the existing data base and mapping system. The following sections outline the current techniques that are used to assist in maintaining the Canadian data base using Landsat MSS images, the PROCOM-2, and experienced interpreters. Further details may be found in the relevant manual (Moore *et al.*, 1982).

SELECTING AND ORDERING IMAGES

The initial selection of Landsat images is a procedure that is critical to the success of the maintenance program. The selection is made from a computer listing by experienced interpreters. They consider such factors as spectral characteristics and temporal variations for features in the map area (Moore *et al.*, 1982) as well as cloud cover and image quality. Because of these variables, one image per map may be inadequate for revision. On the other hand, many images per map will be expensive for large areas. Thus, costs are reduced by selecting only images that are optimal for interpretation in the specific map area. Such optimal data may include seasonal enhancements to delineate features that are not detectable at other times, e.g., snow enhances narrow (3 to 5 m) seismic lines in boreal forest. Where contrasts are low, it may be preferable to request special digital enhancements rather than standard Landsat products.

Further, because of a common lag of four to six weeks between selection of images and delivery, operational programs require that most of the data be selected well in advance of the program; otherwise, serious delays may be experienced.

FEATURE DISCRIMINATION

The detection and identification of a feature represented in a Landsat scene is based on standard photointerpretive procedures, particularly those that emphasize shape, pattern, association, spectral characteristics, and seasonal variations. With respect to the varied geographic regions of Canada, we have compiled interpretive keys (Moore *et al.*, 1982). While initially these keys are important, they are soon replaced by the practical experience that is fundamental to the operational program. In addition, knowledge of many relevant variables must be acquired. Specific to the area are geographical factors (especially climate, topographic relief, vegetation and forests, soils and rocks, erosion, and human activities) and seasonal factors (such as snow cover, haze and cloud, drought, intermittency of water bodies, cropping and harvesting patterns, solar elevation, shadow). Further, image factors (such as dropped pixels, line shifts, dust, scratches) must be recognized under high magnification and excluded from analysis.

OPERATIONAL CHANGE DETECTION AND REVISION

The techniques for change detection and revision are essentially the same except that, in the former case, there is less concern for accuracy in positioning and completeness of identification of the map features. The steps noted below outline the procedure for revision. Steps marked with an asterisk are omitted for change detection. Relevant details may be found in the manual (Moore *et al.*, 1982).

- Organize Landsat images in files representing the specific map areas, with appropriate notation for overlap.
- Superimpose Landsat image on appropriate 1:50,000 topographic map using PROCOM-2; where 1:50,000 maps are not available, enlargements of 1:250,000 maps may be used.
- Register projected image to each sub-area of map (e.g., UTM grid square) with, as warranted, local rescaling and registration to features in or adjacent to the sub-area.
- Conduct systematic grid search for change in each sub-area using map features as internal calibration.
- Delineate all changes on map in pencil, identify from Landsat image where possible, and mark each change with small adhesive labels.
- Verify as many unidentified changes as possible using available documents and publications.*
- Transfer all change information to the 1:250,000 map from the appropriate set of 16 maps at 1:50,000 and plan for airborne field verification.*
- Verify remaining unidentified features using observations and photographs made from light aircraft in the map area.*
- Complete revision information on each 1:50,000 map by incorporating appropriate verifications.
- Complete supplementary listings of changes and images.
- Perform independent quality control on revision using the same Landsat data to find errors of omission, commission, positioning, or classification.
- Complete cartography of change in ink according to specifications of contract.

The first ten steps are usually completed by the interpreter who worked on the specific map area. This is particularly valuable in broadening personal interpretive experience and in confirming that experience with verification.

Revision of 1:250,000 Topographic Maps

The 16 revised large-scale maps (1:50,000) that comprise each 1:250,000 map are delivered to the Surveys and Mapping Branch. The Branch's standard procedures are then followed to reduce those maps to compilation scale and to prepare the final manuscript incorporating other relevant information, e.g., legal boundaries, names, surround, etc. The maps are then published at 1:250,000 by the Branch.

Change Detection for Conventional Revision of 1:50,000 Topographic Maps

The change maps are less complete versions of the revision. They are used by the Surveys and Mapping Branch to assign priorities for revision of 1:50,000 maps. At present, such priorities are used to guide acquisition of aerial photography so that the 1:50,000 maps can be revised by conventional photogrammetry.

Accuracy in Position

Local registration is the key to accurate positioning. Control points are established within a small area on the map by scaling and overlaying the projected Landsat images to select features that have remained constant since the map was made. The Landsat image is then registered to those controlling features, and positions of intermediate changes are plotted directly on the map from the image. As required, the image is moved slightly and re-registered for an adjacent area.

Accuracy of positioning has been verified in two ways: (1) direct comparison between independent revisions by photogrammetry from aerial photographs (Fleming, 1980, 1981) and by Landsat techniques as outlined here; and (2) by comparison of Landsat revision information at 1:50,000 with maps that were revised subsequently by photogrammetric methods at the same scale. Both assessments suggest that the standard for 1:250,000 maps (90 percent of errors less than 125 m) was consistently met.

The latter assessment was completed for linear features (e.g., roads, powerlines, and reservoir shoreline) on two NTS sheets at a scale of 1:50,000. The initial maps prepared by us for detection of change were compared with subsequent photogrammetric revisions prepared by the Surveys and Mapping Branch. The two different maps were precisely registered, and differences in relative position were measured at 1/2-km intervals along the length of the linear features.

The results of this analysis are given in Table 1. The weighted mean differences in relative position are 0.48 mm (24.0 m at scale) for 64A and 0.59 mm (29.5 m at scale) for 92N. These accuracies are close to Class A standards for 1:50,000 mapping, and we believe they can be improved. However, Landsat MSS images do not contain sufficient detail to map all the features that appear on a 1:50,000 map. More detail is presented in Landsat TM images, and preliminary analyses suggested that Class A standards for 1:50,000 maps can be achieved by projecting at 1:10,000. However, the content of TM images in terms of required map information remains to be assessed.

Of course, non-linear features with an area less than one hectare (two Landsat pixels) will not be positioned as accurately and may not be recognized at all.

SOME CONCLUSIONS FROM PRACTICAL EXPERIENCE

This discussion is based on numerous projects, both research and application, that have been completed by Gregory Geoscience Limited using Landsat images and PROCOM systems (or their predecessors). Over the past 12 years, such projects have ranged from mineral exploration through agriculture and forest depletion to land use, including detection of relevant changes. The following examples represent some of the operational-type programs that have been implemented using Landsat images as the principal data:

- Weekly maps of snow and ice cover for northwestern Canada (approximate scale of 1:20,000,000) with forecasts of future cover in two weeks time (about 200 maps, break-up to freeze-up, 1975 to 1977).
- National inventory of mine wastes and revegetation (217 maps at 1:50,000 plus 399 data sheets).
- Forest depletions and access roads (40 maps at 1:15, 840).
- Land cover and land activity (25 maps at 1:50,000).
- Wetlands and peat bogs (40 maps at 1:50,000).
- Geology (100 maps at scales between 1:50,000 and 1:250,000) by integration with geophysical data.

By far the largest operational program is that which provides information on change detection and map revision for the Surveys and Mapping Branch. In total, the work performed for the Branch includes

- revision information for about 2320 maps at 1:50,000 to be compiled into 145 maps at 1:250,000, and
- change detection for another 2682 maps at 1:50,000.

Excluding overlap, these 5000 maps represent an area of about 3.7 million km^2 (over one third of Canada) and required about 2000 Landsat images (color composites primarily, but also single MSS bands and RBV).

CONCLUSIONS

This broad and intensive Canadian experience has resulted in a number of conclusions that may be applicable in other countries also.

Conclusion #1. The systematic analysis of standard Landsat MSS images by an experienced mapper using the PROCOM-2 is an economical method for detecting change on topographic maps at a scale of 1:50,000 and

TABLE 1. DIFFERENCE IN RELATIVE POSITION OF FEATURES MAPPED FROM LANDSAT AND AERIAL PHOTOGRAPHY. SCALE 1:50,000; CLASS A PLOTTING STANDARDS = 0.5 MM; 1 MM = 50 METRES

Feature	Location	Distance	Samples	Mean	Std. Devn.	2× Std. Devn.	% < 0.5 mm
Sheet 64A							
		km		mm	mm	mm	
Powerline 1	Maps 1&2	65	65	0.31	0.33	0.66	75
Powerline 2	Maps 1&2	48	48	0.27	0.31	0.62	63
Powerline 3	Map 1	8	9	0.61	0.47	0.94	0
E Road	Maps 1,2 & 3	72	73	0.58	0.64	1.28	58
Reservoir shoreline	Map 2	20	40	0.78	0.75	1.5	53
			235	0.48[1] (24.0 m)[2]			
Sheet 92N							
D Road	Map 15	6	13	0.31	0.38	0.76	85
E Road	Map 16	6	13	0.23	0.27	0.54	92
E Road	Map 15	12	24	0.52	0.46	0.92	54
F Road	Map 9	15	30	0.72	0.53	1.06	37
F-G Road	Map 9	26	26	0.64	0.55	1.1	53
G Road	Map 15	10.5	21	0.80	1.13	2.26	66
G Road	Map 16	3	7	0.14	0.24	0.48	100
G Road	Map 1	25	5	1.23	1.01	2.02	0
			139	0.59[1] (29.5 m)[2]			

[1]weighted mean
[2]at map scale

for providing accurate information at 1:50,000 for the revision of 1:250,000 maps.

Discussion. For a combined program of change detection and map revision in Canada, the average operational cost in Canadian funds is 21¢ (15¢ U.S.) per km² or about $210 ($150 U.S.) per 1:50,000 map. The cost of providing revision information for 1:250,000 maps varies greatly ($500 to $16,000 Can.) with the amount of change. The average cost for revision information is about $5,000 (Can.) per 1:250,000 map, including field verification but excluding compilation and production of the published map. A significant benefit/cost ratio (at least 10:1) has been achieved for such maintenance relative to previous photogrammetric methods.

Conclusion #2. All significant and major features that appear on Canadian topographic maps at a scale of 1:250,000 can be detected, identified, and plotted with acceptable accuracy for either change detection or map revision using the techniques outlined above.

Discussion. The nominal 80-m "resolution" (IFOV) of Landsat MSS images is not as severe a limitation for maintenance of topographic maps as it might first appear to be. Interpretive keys have been established for numerous point, line, and area features that have land and water associations. Up to six classes of roads are consistently identified with field experience. Features as small as clearings along an aerial cableway or a bridge across a river may be detected, although aerial verification is required to define their precise nature. Very small features, such as isolated cabins in the forest or communication towers on rock outcrops, may be missed unless systematic and more expensive field searches are made.

Conclusion #3. The accuracy of positioning for features plotted from Landsat MSS images that are registered to the topographic map at a scale of 1:50,000 meets the Canadian standards for 1:250,000 maps.

Discussion. Current evidence shows that many linear features are plotted as accurately from Landsat MSS images as from aerial photographs (i.e., relative error = 0) while the average observed relative error is on the order of 30 m when plotted on maps at a scale of 1:50,000. With improvements in technique, class A accuracy for 1:50,000 maps may be attainable; however, it remains to be seen whether all essential features for such maps can be derived from Landsat images.

Conclusion #4. The PROCOM-2 system for maintenance of the topographic database utilizes available mapping skills and experience with minimum requirements for special training, capital investment, and operating costs.

Discussion. Accurate mapping can be completed by a variety of resource specialists (e.g., photointerpreters, geographers, geologists, foresters, etc.) who have become familiar with the principles of Landsat interpretation and who have been selected for their *personal mapping skills*. The initial capital cost for PROCOM-2 is on the order of $10,000 (U.S.), depending upon options, while operating costs are primarily those of periodically replacing lamps and fan belts. Salaries, overhead, and field expenses should not be overlooked. The recent program operated with three PROCOM-2 systems that ran about 11 hours a day for a staff comprising one project director, three team leaders, seven interpreters, and two cartographers.

Conclusion #5. Experience with semi-arid areas and overhanging deciduous trees in Canada suggest that special techniques of image selection, digital processing, and/or field verification may be required to adapt the Canadian experience to countries with deserts or rainforest.

Discussion. Where abundant topographical and cultural detail is lacking (as control for local registration), it may be necessary to obtain geometrically corrected images. For areas of low contrast (e.g., arid conditions), special digital processing such as contrast stretch may be useful. The problem of tree canopies that overhang roads and small features may be overcome by appropriate selection of seasonal data (as in Canada) and/or development of systematic techniques for field verification.

Conclusion #6. Limited experience with aerial photographs (diapositives) and other satellite data and simulations suggests that similar techniques can be used for systematic mapping at other scales than those reported here.

Discussion. The techniques have been tested with aerial photographs enlarged to scales of 1:500 for mapping right-of-way along roads and with TM images and other satellite images that are not yet available for systematic use. We conclude that, where primary control does not have to be developed across the map, these techniques will be a useful adjunct to maintenance of the topographic data base as well as to many types of thematic mapping.

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