Production of Landsat 7 Orthoimages
Covering the Canadian Landmass

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Abstract

Despite the significant among of geospatial data around the country, spatially integrating them can prove difficult due to the range of accuracies. Currently, there is no single source that offers accurate, consistent data for Canada as a whole. A project is now underway, however, that could give elements of solution for the integration issue. In fact, production of Landsat 7 orthoimages got started in fall 2000 and is expected to yield complete coverage of the country by 2004.

The Centre for Topographic Information in Sherbrooke (CTIS), part of Natural Resources Canada, is responsible for management, development, and production of the project. In order to reduce costs and use the most accurate control points possible, CTIS entered into a number of partnerships with various public-sector agencies in the field of geomatics. In order to obtain the highest image accuracy, a rigorous mathematical model and uniform methodology in selecting the control points are used. Contracts for delimiting entities to serve as control points for the images were awarded to geomatics firms.

Once the images have been orthorectified, each of the partners can create their own products derived from the Landsat 7 orthoimages. Since many images have been orthorectified to date, Geomatics Canada already has several products derived from orthoimages. The creation of Landsat 7 orthoimage coverage for all of Canada therefore represents an important step for our partners and users of geospatial data.

Keywords: DEM, Landsat 7 satellite, orthoimage, projection, geospatial data, aerotriangulation, partnership, ground control points

1. Introduction

Sources for updating and acquiring new topographic data have always been very expensive and hard to find. Moreover, the broad diversity of geospatial data in the country and the concomitant differences in accuracy, vertical integration of such data has always created headaches for users. The launching of the Landsat 7 satellite in 1999 has given CTIS an opportunity to remedy these problems in a consistent, economical manner.

Image resolution (15 m for the panchromatic band), cost, and flexibility with respect to user and distribution rights make Landsat 7 a very attractive data source for a number of producers and users of geospatial data. As a result, CTIS signed partnership agreements with the main stakeholders in the field of geomatics in Canada (federal, provincial, and territorial levels) to produce Landsat 7 orthoimage coverage of the entire Canadian landmass.

Production of the orthoimages started in fall 2000 and is scheduled to run for a period of three to four years, depending on the weather, since the images used must have the least amount of cloud coverage possible. This article describes the responsibilities of the partners in the project, the process developed to implement national production of orthoimages, the accuracy achieved for the images already produced, and the Geomatics Canada products derived from the orthoimages.

2. Partners in a Win-Win Project

In 1999, a cooperation agreement between the various departments of the federal and provincial governments was signed in order to produce Canadian Landsat 7 orthoimage coverage that is accurate and reasonable in cost. This agreement provides access to the country's most accurate topographic data that can be used to carry out geometric correction of the images.

Most partners contribute financially in acquiring and orthorectifying the images. To date, 14 federal-government organisations as well as all the provinces and territories of the Canada have joined in this partnership agreement.

As a result of this agreement, it was agreed that accurate provincial and/or federal data (National Topographic Data Base (NTBD) and road network GPS) would serve as ground control points for the south of the country, while federal-government aerotriangulation blocks would be used for the north. The digital elevation model (DEM) used in correcting the images can comprise a combination of provincial data (depending on availability) completed with Canadian Digital Elevation Data (CDED, digital elevation data derived from 50K and 250K contours).

While the Canada Centre for Remote Sensing provides management for the stations receiving the raw images, the responsibility for development, production management, and even product delivery has been given to CTIS.

The GeoConnections program, through its framework data component, contributes to project funding. Indeed, one of the program objectives is to fund part of the projects making it possible to establish a national infrastructure, which would facilitate data integration. This integration will provide for better analysis of the information and simplify development of new products. Since the orthoimages produced will cover all of Canada, they could be used as a common base for many partners, which would facilitate integration of geospatial data.

The orthoimages produced in partnership comprise 9 spectral bands: a panchromatic band with a pixel size of 15 metres, 6 multispectral bands with a pixel size of 30 metres, and 2 thermal bands with a pixel size of 60 metres. The orthoimages are based on the NAD83 coordinate reference system and are provided in several projections depending on partner needs. The projections include the universal transverse Mercator (UTM), the Lambert conformal conic projection (LCC), and the Albers equal area map projection. Images produced with the UTM projection that overlap two 6-degree UTM zones are generated in both zones.

3. A National Context for Producing Orthoimages

Accuracy is one of the unavoidable criteria for this production project. In order to obtain the highest image accuracy, a rigorous mathematical model and uniform methodology in selecting the control points are used, in addition to accurate control data. Given the number of images involved (700) and the length of the project (5 years), several steps must be automated in order to reduce quality-control costs. This section discusses the main features of the process put in place by CTIS to ensure the highest accuracy for the national orthoimages. It presents, among other things, the sources used, the mathematical model, the methodology underlying the selection of control points, outsourcing, the quality-control process, and the orthoimage generation process.

3.1 Sources of Control Data

A variety of sources are used for image correction; the most accurate are given priority. The usual priority ranking is: GPS source for the National Road Network, provincial vector data, accurate NTDB data (10 m to 90 %), federal-government aerotriangulation data, and other sources.

3.2 Mathematical Model

The mathematical model used to orthorectify Landsat 7 images was developed by Dr. Thierry Toutin with the Canada Centre for Remote Sensing. It was implemented and marketed by PCI Geomatics. The decision to use this mathematical model was based on the fact that it provides a rigorous geometric correction method that takes into account all distortions. The model is based on principles such as orbitography, photogrammetry, geodetics, and cartography (Cheng et al., 2000).

3.3 Methodology for Selecting Ground Control Points

Giving the national scope of this project and Canada's geographic situation, a rigorous methodology that could be used for the entire country had to be developed. Consequently, tests were carried out on images taken of different types of relief before work began on developing the inspection and image correction processes. Analysis of the entity types visible in the image and available in the sources was made possible by establishing uniform selection criteria for the entire country. Indeed, these tests made it possible to assess the number of control sectors per image, the number of ground control points required per sector, the accuracy of the types of entities selected, and the impact of the ground control points located in the sectors of minimum and maximum elevation. The rules needed to ensure good accuracy when creating image mosaics were also verified.

Among other things, testing confirmed that ground control points evenly distributed in the six base sectors around the perimeter of the image as well as in the sectors of minimum and maximum elevation yielded the highest accuracy when correcting the full satellite scene (Toutin et al., 1996). A sector covers approximately one National Topographic System (NTS) tile at the 1:50 000 scale or a photogrammetric model when the source is federal-government aerotriangulation data. Since the various Landsat 7 satellite scenes are superimposed (30% to 80% in Canada), the theoretical superimposition of adjacent images is taken into consideration. Therefore, when an image is processed, the base sectors of adjacent images located in the superimposition zone are added. These additional sectors do not improve accuracy but ensure that the same ground control points are used in the overlapped areas. This makes it possible to maintain coherency in correcting adjacent images and improves the quality when creating image mosaics. The method requires three points per sector in order to ensure an excess of points for final selection.

Testing also demonstrated that the centres of mass of lakes/islands and road intersections are the two types of control points that yield the best results. In order to prevent inaccuracies, these ground control points must comply with certain well-defined rules. For example, entities corresponding to lakes and islands must not be selected if the expanse of water is not stable. Indeed, these entities must not be selected if a dam is located nearby or if there are adjacent wetlands or sand. Since the water level can vary over time, these situations can affect the quality of control point accuracy. The entities are selected for stability over time so that they can be reused for geometric correction of images in the future.

Outcome of these test made it possible to establish criteria about ground control point selection. These criteria served as the basis for outsourcing specifications and for developing a uniform methodology for producing orthoimages for the entire country.

3.4 Awarding of Contracts to Geomatics Firms

The work for delimiting the entities used for image orthorectification is carried out to Canadian geomatics firms. Approximately 700 Landsat 7 images are needed to provide coverage of Canada. Blocks of 20 to 40 images are contracted out through requests for proposals (RFP). Bidders must demonstrate that their processes are able to meet the technical specifications developed and issued by CTIS. Planning the areas for collecting control entities; selecting or capturing control entities and image entities, such as lakes or road intersections; collecting metadata; and selecting the most accurate sources are examples of what is required.

Two types of contracts are open to firms depending on whether the control-data source is vector or federal-government aerotriangulation data. When vector data sources are used, it is only necessary to capture the control points on the raw image. On the other hand, when federal-government aerotriangulation data is used, the contractor must extract the same entities from both the raw image and, using the photogrammetric process, from the aerial photographs used in producing the federal-government aerotriangulation data.

CTIS, for its part, is responsible for controlling data capture quality, calculating road intersections and the centres of mass of lakes and islands, final selection of ground control points, and geometric correction of the images.

3.5 Quality Control

In order to minimise the time and resources associated with quality control, CTIS has put in place a computerised quality-control process that consists of automated and semiautomated data processing (see Figure 1). The automatic quality-control process verifies the structure of the entities provided and its compliance with the related metadata. Contractors deliver the data directly to an FTP site. During delivery, automated inspection is carried out, including computation of a mathematical correction model. The process sends an acceptance or rejection report to the contractor by e-mail with no manual intervention. A bonus/penalty system provides incentive to contractors to strive for quality. Once the structure has been accepted, the semiautomated process is initiated. This process verifies if the choice of entities and if the data capture quality with respect to the source, complies with specifications. A 3-person team participate to the quality control of 250 orthoimages/years. Given the excess of points required in each area, bad points can be eliminated, reducing returns to the contractor.
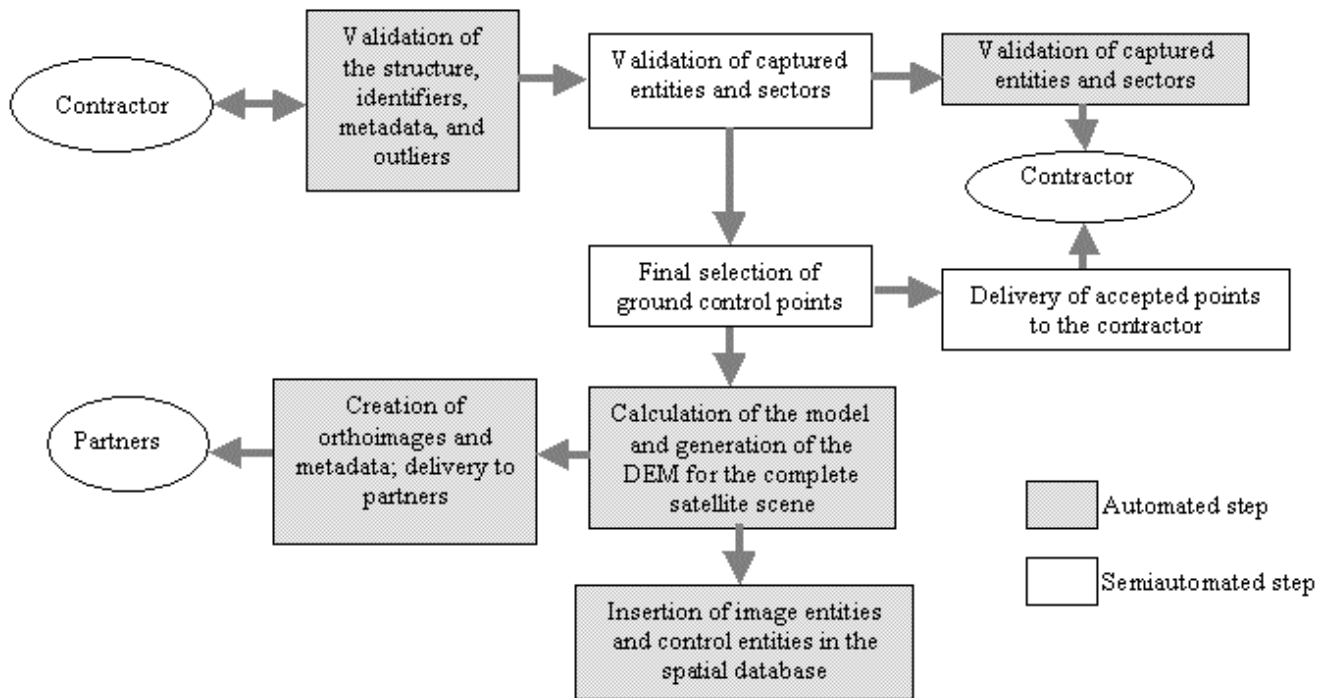
Figure 1 Quality-control and production system for Landsat 7 orthoimages. This figure illustrates the main steps involved in correcting Landsat 7 images. The gray rectangles represent steps that have been automated.

3.6 Generating Orthoimages

After quality control, another completely automated process is executed. This process calculates the final mathematical model for geometric correction, generates a digital elevation model (merge of various DEMs) for the complete satellite scene, generates the orthoimage metadata, and produces the orthoimages in the projections requested by partners (see Figure 1). The burning of CDs is after produced by contract. The control entities and image entities used to correct the images are stored in a spatial database (Oracle). This database makes it possible to reuse the entities for correcting more recent images from the same area.

Many images from across Canada have already been processed in this way and delivered to partners (see Figure 2). In addition, many contracts are now underway. We hope to have complete coverage of Canada with Landsat 7 orthoimages by 2004.
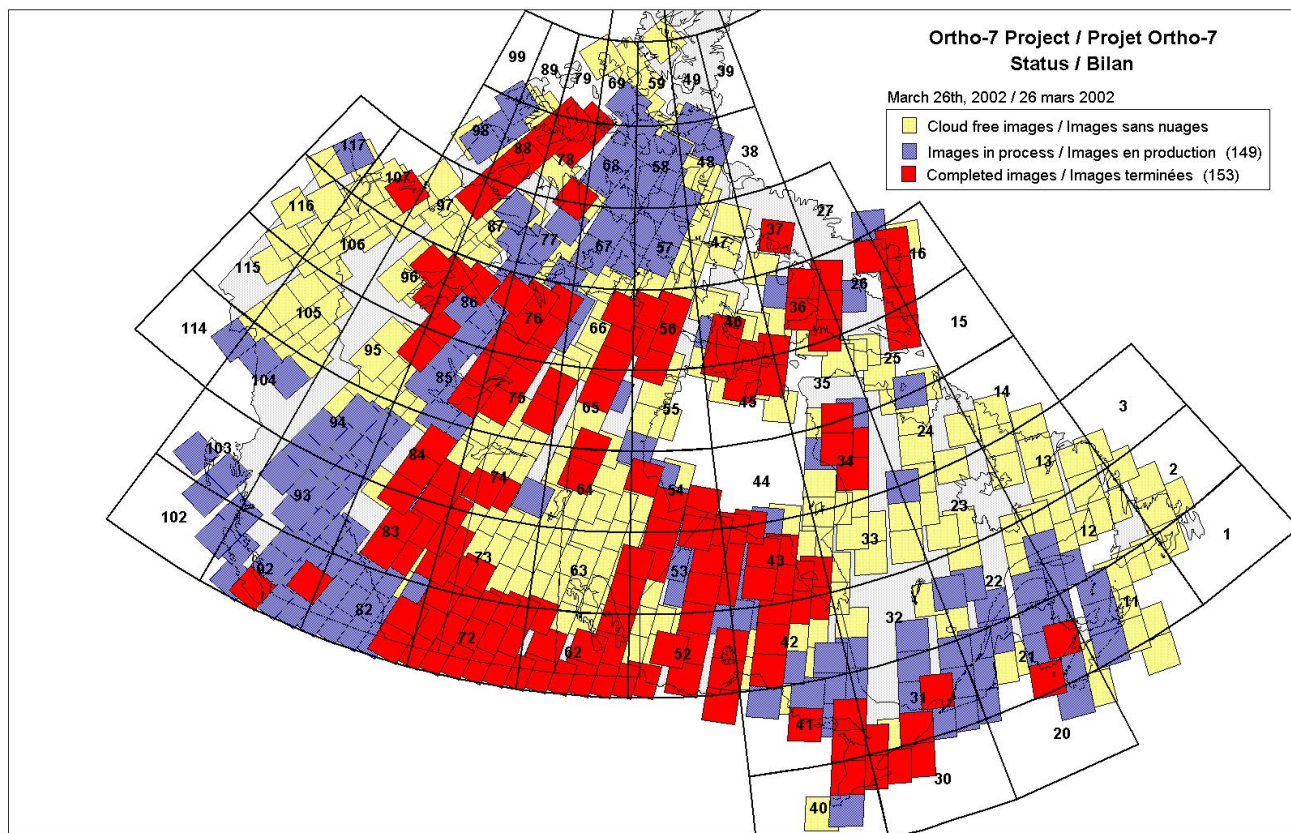

Figure 2 Summary of the production of Landsat 7 orthoimages in Canada as of March 26, 2002. This figure shows the images that have been orthorectified (completed images), those being processed by contractors (in process), and those that have been selected because they have little or no cloud coverage (cloud-free). The latter are considered as potential images for upcoming contracts.

4. Orthoimage Accuracy

A number of parameters are analysed in order to obtain orthoimage accuracy with an acceptable level of confidence. These parameters include the mean square error (MSE) along the x-axis and y-axis of the ground control points after the correction model has been generated, the accuracy of the image control data, and the altimetric and planimetric accuracy of the digital elevation model (DEMs) covering the satellites scene. In order to determine the impact of the DEM on orthoimage accuracy, a slope analysis is carried out for the entire satellite scene using Canadian Digital Elevation Data (CDED) at the 1:250 000 scale. The assessment of this impact takes into account the maximum slope of the terrain and the maximum angle of incidence of the sensor. Once all the errors have been combined, the accuracy is calculated to a level of confidence of 90% (Circular Map Accuracy Standard (CMAS) (CCSM, 1984)).

More than 93% of the orthoimages generated to date have an accuracy of less than 20 m (see Figure 3 and Table 1) with a level of confidence of 90% (Circular Map Accuracy Standard (CMAS)). The production of Landsat 7 orthoimages will make it possible to have the most accurate and consistent source for complete coverage of the country.
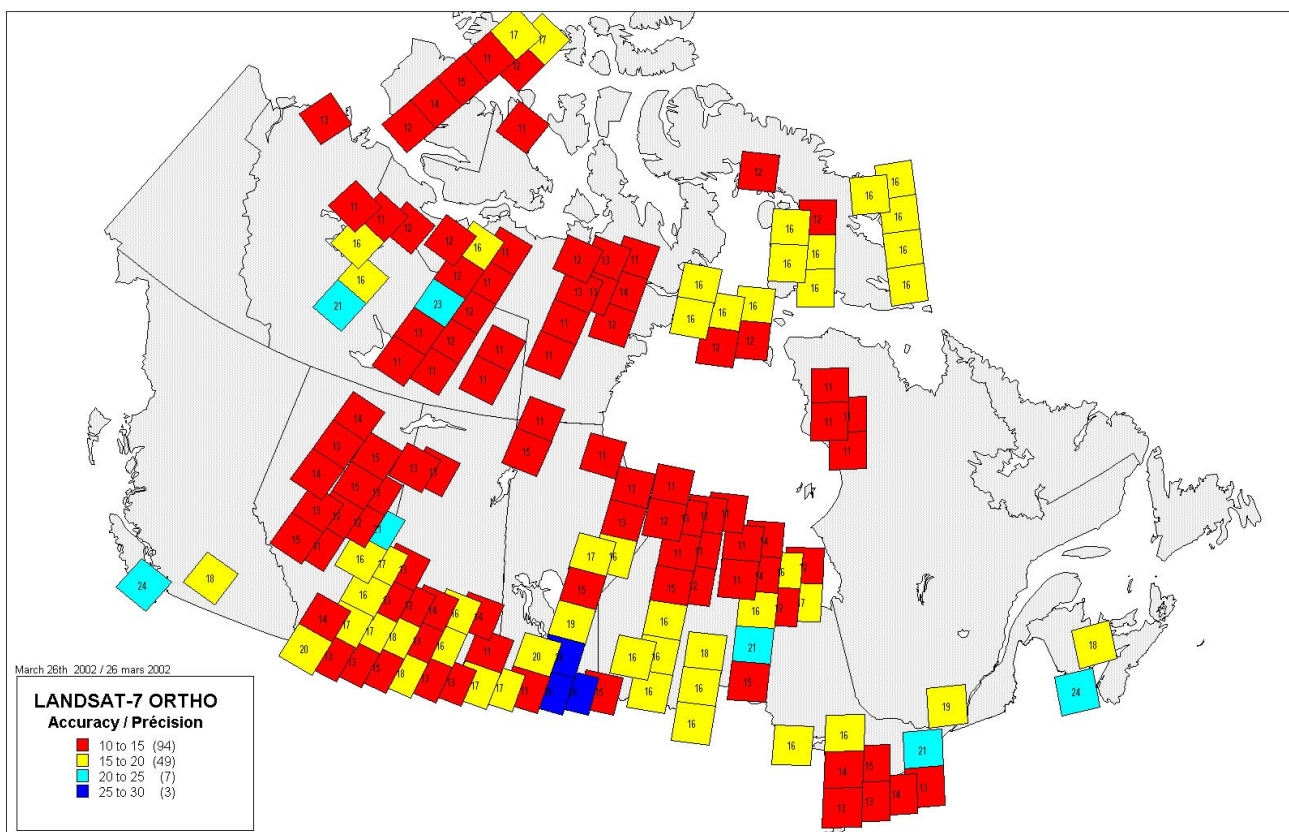
Figure 3 Position and accuracy (to 90%) of images orthorectified as of March 26, 2002. Figure 3 illustrates the accuracy of corrected images with an interval of 5 m, each corresponding to a different color (hue).

Table 1

Accuracy to the nearest metre of orthoimages by province or territory according to level of confidence as of March 26, 2002.

Province or Territory	Number of Images	Average MSE (metres)	Average CMAS (metres)
Newfoundland	0	---	---
Nova Scotia	1	12	18
Prince Edward Island	1	12	18
New Brunswick	2	14	21
Quebec	5	9	13
Ontario	41	10	15
Manitoba	22	11	16
Saskatchewan	26	10	15
Alberta	25	10	15
British Columbia	3	14	21
Yukon	0	---	---
Northwest Territories	22	9	14
Nunavut	43	9	14

Mean square error (MSE) combined in X and Y corresponds to accuracy with a level of confidence of 63.21%. The CMAS is more used in cartography. It corresponds to the MSE circular multiplied by a factor of 1.5174 (CCSM, 1984). This

represents a circular accuracy with a level of confidence of 90% and is used in assessing the orthoimage accuracy. An image may be located in more than one province or territory.

5. New Products from Orthoimages

Each of the partners can create their own products derived from the Landsat 7 orthoimages. Geomatics Canada intends to use orthoimages for many different applications; a number of products have already been developed.

5.1 Geospatial Database

CTIS uses the Landsat 7 orthoimages for updating vector data themes such as the hydrographic network, built-up areas, vegetation, and designated areas. Other themes that cannot be updated by the Landsat 7 source can come from partners (e.g. rail network, airport) or by contracting out (e.g. GPS road network). These will enable CTIS to offer customers a new range of digital topographic products, which will be more accurate and up-to-date than the existing National Topographic Data Base (NTDB).

5.2 CanImage

A new Landsat 7 orthoimage product based on National Topographic System (NTS) divisions at the 1:50 000 scale, called CanImage, has been made available from CTIS since March 2002 for just $25.00. It will be distributed through the CTIS online purchasing and subscription site at http://www.ctis.nrcan.gc.ca. CanImage, offered in the GeoTIFF (RGB) format, will enable users to select a combination of three bands, enhancement, and coordinate system (UTM or geographic) for the orthoimage. The product is also available without enhancement for more specific needs. Since each band represents 8-bit radiometry (values from 0 to 255), the combination of the three bands yields 24-bit RGB (or red, green, and blue) color composition.

All spectral bands available for CanImage have a pixel size of 15 metres. In fact, the high-resolution panchromatic band (15 metres) can be merged with Landsat 7's seven multispectral bands (originally 30 metres). As the result of this technique integrated into PCI Geomatics software, the resolution for multispectral bands 1, 2, 3, 4, 5, and 7 will change from 30 metres to 15 metres. This technique makes it possible to enhance image details when viewing with very little modification of the distinctive spectral characteristics of each band. When it is impossible to entirely cover a data set with a single orthoimage, a mosaic of orthoimages is produced by adjusting the frequency histogram.

CanImage GeoTIFF files can be opened in different applications in response to specific needs: geographic information systems (GIS) for land-management applications, mapping software to visually represent a region, remote-sensing and digital image processing software, and many others.

5.3 Toporama

Toporama, in existence since 1999, is an Internet window on different types of topographic information (products) available from CTIS. It offers free data as raster images (GIF files). It gives a multitude of users from across the world-- from computer novices to experts in the fields of geomatics and cartography--access to the site and its images. A Toporama orthoimage is therefore a low-resolution raster representation of the CanImage product. Orthoimages will be made available by NTS number on the Toporama site according to the CTIS production program. Toporama orthoimages are a combination of three spectral bands in the visible wavelength (red, green, blue) forming a composition of 256 colors (GIF file). This combination of spectral bands makes it possible to view features on the images in colors similar to what the human eye sees (vegetation in green, water in dark blue…). Anyone who wants to consult topographic information for Canada can visit Toporama at: http://toporama.cits.nrcan.gc.ca.

5.4 GeoConnections Discovery Portal

Landsat 7 orthoimages are available at no charge from the GeoConnections discovery portal. The site offers orthoimages based on the following specifications: UTM projection or LCC, complete scenes by band, color composite of bands 7, 4, and 3 in GeoTIFF format, and half or quarter image. To find out more about this portal, visit the Web site at: http://geoconnections.org

6.0 Conclusion

It is certain that this project for producing Canadian coverage with Landsat 7 orthoimages stands out as a distinctive example of partnerships between different public-sector organisations and the various levels of government. Through its agreements, this project has brought together the resources and data from 27 partners in the federal, provincial, and territorial governments.

Orthoimages represent a major source of data for all stakeholders in geomatics because they provide complete coverage of the country (south of the 81st parallel) at an accuracy that is better than acceptable. The creation of national coverage with Landsat 7 orthoimages makes it possible to implement an infrastructure shared by many partners and users of geospatial data. In addition to being a very valuable source of raster information, this orthoimage coverage also provides for integrating data from different sources, updating existing data, and creating new geospatial data in order to respond to user needs.

References

CCSM (1984) National standards for the exchange of digital topographic data, Data Classification, Quality Evaluation and EDP File Format, Volume 1, E.M.R. Canada: 153,157

Cheng P, Toutin Th, Tom V (2000) Unlocking the Potential for Landsat 7 Data, EOM, 28-31.

Natural Resources (1996) Standards and Specifications of the National Topographics Data Base, Minister of Supply and Services Canada, Catalogue No. M52-70/1996E.

Savopol F, Leclerc A, Toutin Th, Carbonneau Y (1994) La correction géométrique d´images satellitaires pour la base nationale de données topographiques, Geomatica 48:193-207.

Toutin Th, Carbonneau Y (1992) La création d´ortho-images avec MNA : description d´un nouveau système, Journal canadien de télédétection, 18 : 136-141.

Toutin Th (1995) Intégration de données multi-sources :comparaison de méthodes géométriques et radiométriques, International Journal of Remote Sensing, 16 :2795-2811.

Toutin Th (1996) La correction géométrique rigoureuse: un mal nécessaire pour la santé de vos résultats, Journal canadien de télédétection, 22 : 184-189.