Preliminary assessment of the application of IKONOS satellite imagery and its fusion with RADARSAT-1 data for forest resource management

by

Denis Collins, Karl Kliparchuk, Mike Connor, and Warren Warttig
Coverage photo: Digital elevation model using IKONOS imagery and overview RADARSAT-1 image of study area.

Funding for this extension product was provided by Forest Renewal BC—a partnership of forest companies, workers, environmental groups, First Nations, communities, and government. Forest Renewal BC funding—from stumpage fees and royalties that forest companies pay for the right to harvest timber on Crown lands—is re-invested in the forests, forest workers, and forest communities. Funding assistance by Forest Renewal BC does not imply endorsement of any statements or information contained herein.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>2</td>
</tr>
<tr>
<td>Keywords</td>
<td>2</td>
</tr>
<tr>
<td>Author Information</td>
<td>2</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>2</td>
</tr>
<tr>
<td>1 Introduction</td>
<td>3</td>
</tr>
<tr>
<td>2 Methodology</td>
<td>3</td>
</tr>
<tr>
<td>2.1 Study Area</td>
<td>3</td>
</tr>
<tr>
<td>2.2 IKONOS Satellite</td>
<td>4</td>
</tr>
<tr>
<td>2.3 RADARSAT-1 Satellite</td>
<td>5</td>
</tr>
<tr>
<td>2.4 Data Acquisition</td>
<td>5</td>
</tr>
<tr>
<td>2.4.1 RADARSAT-1 Data Acquisition</td>
<td>6</td>
</tr>
<tr>
<td>2.4.2 IKONOS Data Acquisition</td>
<td>7</td>
</tr>
<tr>
<td>2.5 Digital Image Processing Methodology</td>
<td>7</td>
</tr>
<tr>
<td>2.5.1 IKONOS Image Processing</td>
<td>7</td>
</tr>
<tr>
<td>2.5.2 RADARSAT-1 Image Processing</td>
<td>8</td>
</tr>
<tr>
<td>2.6 Image Interpretation and Assessment</td>
<td>8</td>
</tr>
<tr>
<td>2.6.1 Introduction</td>
<td>8</td>
</tr>
<tr>
<td>2.6.2 Manual Interpretation</td>
<td>8</td>
</tr>
<tr>
<td>2.6.3 Accuracy</td>
<td>9</td>
</tr>
<tr>
<td>2.6.4 Digital Image Interpretation</td>
<td>9</td>
</tr>
<tr>
<td>2.6.4.1 RADARSAT-1 Images</td>
<td>9</td>
</tr>
<tr>
<td>2.6.4.2 IKONOS Images</td>
<td>11</td>
</tr>
<tr>
<td>2.6.4.3 Natural Colour and Near-Infrared Composites</td>
<td>12</td>
</tr>
<tr>
<td>2.6.4.4 IKONOS and RADARSAT-1 Imagery Fusion</td>
<td>12</td>
</tr>
<tr>
<td>2.6.4.5 IKONOS Panachromatic and RADARSAT-1 Imagery Fusion</td>
<td>12</td>
</tr>
<tr>
<td>3 Forest Resource Management Applications</td>
<td>14</td>
</tr>
<tr>
<td>3.1 IKONOS</td>
<td>14</td>
</tr>
<tr>
<td>3.1.1 Landslides</td>
<td>14</td>
</tr>
<tr>
<td>3.1.2 Inception Slide and Erosion Zone Identification Using PCA and NIR Imaging</td>
<td>15</td>
</tr>
<tr>
<td>3.1.3 Landslide Recovery</td>
<td>16</td>
</tr>
<tr>
<td>3.2 Road Infrastructure</td>
<td>17</td>
</tr>
<tr>
<td>3.3 Watershed Restoration Monitoring</td>
<td>17</td>
</tr>
<tr>
<td>3.4 Compliance and Enforcement Applications</td>
<td>17</td>
</tr>
<tr>
<td>3.5 Vegetation Type</td>
<td>18</td>
</tr>
<tr>
<td>3.6 Windthrow</td>
<td>18</td>
</tr>
<tr>
<td>3.7 Coastal Watershed Assessment Procedure (CWAP)</td>
<td>19</td>
</tr>
<tr>
<td>3.8 Channel Morphology</td>
<td>19</td>
</tr>
<tr>
<td>3.9 Coarse Woody Debris</td>
<td>19</td>
</tr>
<tr>
<td>3.10 Tenure Mapping</td>
<td>20</td>
</tr>
<tr>
<td>3.11 Digital Elevation Models</td>
<td>22</td>
</tr>
<tr>
<td>3.12 Inventory Update</td>
<td>22</td>
</tr>
<tr>
<td>3.13 Land Use Planning</td>
<td>22</td>
</tr>
<tr>
<td>3.14 Operational Planning</td>
<td>22</td>
</tr>
<tr>
<td>3.15 Future Uses</td>
<td>22</td>
</tr>
<tr>
<td>4 Cost Comparison</td>
<td>23</td>
</tr>
<tr>
<td>5 Conclusions</td>
<td>23</td>
</tr>
<tr>
<td>6 References</td>
<td>24</td>
</tr>
<tr>
<td>Appendix A: Glossary of Terms</td>
<td>25</td>
</tr>
<tr>
<td>Appendix B: RADARSAT GCP Locations and RMS Residual Error Reports</td>
<td>26</td>
</tr>
<tr>
<td>Appendix C: IKONOS GCP Locations and RMS Residual Error Reports</td>
<td>29</td>
</tr>
<tr>
<td>Appendix D: Scene Statistics for IKONOS Imagery</td>
<td>30</td>
</tr>
</tbody>
</table>
Remote sensing technology offers numerous options for the ability to view areas for the purposes of sustainable forest management. Aerial photography, either black-and-white or colour, and of variable scale, is one remote sensing technology that most forest resource managers are currently familiar with. More recently, satellite imagery has begun to offer remote sensing options that can be added to the toolbox of the forest resource manager. For example, active RADARSAT-1 imagery may be obtained regardless of cloud cover and solar illumination, which is an important feature during the winter months. However, the resolution is not optimal for forest resource management. On the other hand, passive IKONOS imagery relies on solar illumination and cloud-free coverage and has high spatial resolution.

The primary objective of this pilot project was to determine the suitability of using IKONOS high spatial resolution optical satellite imagery for forest resource management applications and monitoring in variable terrain. A secondary objective was to determine whether RADARSAT-1 imagery could be utilized in conjunction with the optical imagery to provide enhanced definition of regional scale geological features. Such a capability can be important for terrain mapping, and also to enable environmental monitoring during winter months when there could be increased sediment input into stream systems.

The imagery was analysed for the purpose of classifying resource features associated with forestry operations in an area adjacent to Clayoquot Sound on the west coast of Vancouver Island. These features include conventional clearcut harvesting, variable retention harvesting, roads, landslides, coarse woody debris, riparian areas, windthrow, and watershed restoration activities. Accuracy comparisons were made in relation to GPS ground control points. The relative costs and benefits of remote sensing and ground-based resource feature identification and mapping options were given a preliminary assessment, relative to the primary management objectives at hand. Recommendations for future related work are also presented in this report.

While RADARSAT-1 imagery has the advantage of being weather independent, its utility for routine forest resource management at an operational level requires expertise that is available only to a limited number of specialists. The use of stereo pairs could be of more use in operational forestry and terrain analysis applications than is shown in this pilot project.

This work demonstrates the capabilities of high spatial resolution IKONOS satellite imagery to discriminate and map forest resource features. The high spatial resolution IKONOS imagery is an important tool in the assessment, characterization and documentation of the main forest resource features in a watershed, and provides a new and valuable source of detailed information for environmental monitoring and development planning. Further work is required to demonstrate the application of this type of imagery to vegetation inventories. However, this type of imagery should form an integral part of the toolkit available to forest resource managers.

Figures:
1. Study area location..........................................................4
2. IKONOS satellite specifications........................................4
3. RADARSAT-1 and IKONOS coverage area......................6
4. Results of fine beam mode image database archive search...6
5. Comparison of RADARSAT-1 orthorectified images........10
6. Digitized overlay of VR block and landslides on RADARSAT-1 images..........................................................11
7. RADARSAT-1 RGB with the IKONOS NIR image of the same area for reference..................................................11
8. IKONOS natural colour image alone and with panchromatic image merged..........................................................12
9. IKONOS, RADARSAT-1, and RADARSAT-1 RGB composite images..................................................................13
10a. NIR colour composite merged with RADARSAT-1 image..13
10b. IKONOS NIR colour composite of VR block & landslides..13
11. IKONOS panchromatic images of VR block and large landslide area, with multiplied and RGB images..............14
12. Road fill failure, rockfall, and open slope failure, from IKONOS images..............................................................15
13. Digitized landslide area........................................................16
14. Landslide as PCA colour composite from IKONOS..16
15. NIR and RGB comparison with Figure 14......................16
16. Revegetation example from natural colour IKONOS composite image..................................................................17
17. Example of road in IKONOS imagery.................................17
18. Examples of road ravel.......................................................17
19. Cross ditches on deactivated road......................................18
20. Canopy gap.......................................................................18
21. Examples of alder growth on inactive riparian road..18
22. Leave strips and windthrow................................................19
23. Channel monitoring example............................................19
24. Presence of CWD can be enhanced by manipulating image..19
25. CWD burn pile footprints adjacent to road......................19
26. Variable retention block Z10G...........................................20
27a. DEM overview of area of interest......................................21
27b. DEM of north fork of Escalante River..........................21
27c. DEM of Emy Lake area showing fully recontoured deactivated roads.................................................................21

Tables:
1. IKONOS specifications.....................................................5
2. RADARSAT-1 scene description.........................................7
3. IKONOS order details.......................................................7
4. Accuracy deviations.......................................................9
5. Area of landslides calculated using IKONOS.................16

ABSTRACT

Research Disciplines: Ecology ~ Geology ~ Geomorphology ~ Hydrology ~ Pedology ~ Silviculture ~ Wildlife
1.0 INTRODUCTION

The sustainable management of forest resources requires current and accurate information regarding the extent and nature of many resource features. Conventional information gathering relies heavily on ground-based methods of measuring and monitoring forestry operations. This is difficult in many remote or relatively inaccessible areas along the coast of BC.

The primary goal of this pilot project was to determine the feasibility and effectiveness of locating and mapping forest resource management features on the west coast of Vancouver Island using a recently launched high-resolution optical spaceborne sensor. A secondary objective was to determine the utility of merging this data with RADAR\(^1\) data for environmental monitoring purposes during periods of cloudy weather.

The two types of images used were a) IKONOS satellite imagery and b) RADARSAT-1 imagery. The imagery from the IKONOS satellite was used to determine whether forest resource features could be accurately discerned. In addition, the IKONOS data was fused with the RADARSAT-1 data to determine whether the latter could be of benefit for environmental monitoring during cloud cover periods. The premise was that the optical data would provide detailed spectral information useful for discriminating between surface features, while the RADAR imagery would highlight the regional geologic structure and enable any new significant mass wasting events to be detected during periods of cloud cover. In addition, three different RADARSAT-1 images with varying beam mode incidence angles (positions) were acquired to determine which incidence angle provides the clearest delineation of resource features. Other ancillary data such as Global Positioning System (GPS) data was combined with the imagery to provide additional ground control data points for accuracy comparisons.

The resource features of interest from an operational forest management perspective include, but are not necessarily limited to, the following:

- Topography
- Landforms
- Landslides
- Roads
- Cutblocks, both clearcut and partial harvesting
- Vegetation types
- Stream channels and other aquatic and riparian features
- Wildlife habitats
- Coarse woody debris
- Windthrow

Regarding these resource features, remote sensing imagery has the potential to enable measurement and monitoring of changes, both temporal and spatial, in distribution, condition, and extent. Measurements may include linear distances and bearings (e.g., road and cutblock boundaries), area determination, and derived volume calculations (e.g., for timber harvesting). Monitoring may include presence or absence of indicators (e.g., habitat condition), progress and results of resource management activities (e.g., road deactivation), and compliance with conditions of resource management planning (e.g., harvesting in accordance with an approved Silviculture Prescription).

2.0 METHODOLOGY

2.1 STUDY AREA

This preliminary assessment of the IKONOS and RADARSAT-1 data was conducted on the Hesquiat/Escalante areas, located within and adjacent to Clayoquot Sound on the west coast of Vancouver Island (Figure 1). The area is within the South Island Forest District of the Vancouver Forest Region\(^2\).

The area was chosen due to the significant amount of pre-existing digital and on-ground data available for this area as a legacy of the Forest Renewal BC programs in the area. The topography in the area ranges from flat to steep sided terrain, with elevations ranging from sea level along the coastal plain north of the Estevan Peninsula to approximately 1000 m elevation inland. The flats, known as the Estevan Coastal Plain, extend in-land for approximately 6 km from the Escalante River mouth and encompass the Hesquiat peninsula. Much of the area was

---

\(^1\) Words in bold are defined in the Glossary in Appendix A.

---

KEY WORDS

remote sensing, IKONOS, RADARSAT-1, forest resource management, variable retention mapping, forest inventory update.

AUTHOR INFORMATION

- Karl Kliparchuk, M.Sc., McElhanney Consulting Services Ltd., Vancouver, BC;
- Mike Connor, RPF, Land Information Management Manager, Vancouver Forest Region, BCMOF, Nanaimo, BC;
- Warren Warttig, R.P.Bio., International Forest Products Ltd. (Interfor), Campbell River, BC.

ACKNOWLEDGMENTS

Funding for this project was provided by base funding from the Vancouver Forest Region Research and Land Information sections and International Forest Products (Interfor). Jim Brown, Dale McNeil, Dr. Xiaoping Yuan and Graeme Weir of the Ministry of Forests and Dr. G. Tomlins of Pacific Geomatics Ltd. provided review comments. Thanks also go to Dr. Tomlins and Roger Balser, Ministry of Forests, for assistance with ordering the imagery. Dave Gilbert, Resources Inventory Branch and Dave Cruickshank and Doug Erickson of the South Island Forest district also provided support for this project. Greg Keel from Parallel Geo-Services Inc. assisted with the GPS files. Andrew Durnin of McElhanney provided technical support. Thank you all for your help.

---

\(^2\) The Vancouver Forest Region is one of six administrative areas in the province of BC, as designated by the BC Ministry of Forests. It is located in the southwestern portion of the province, and comprises the South Coast, the Mid Coast, Queen Charlotte Islands, and Vancouver Island.
logged in the 1960s and into the 1980s but some recent variable retention logging is being conducted. There are numerous pre-Forest Practices Code (FPC) and some natural landslides in the area (Lewis and Liard, 1983), many of which were initiated during an intense storm cycle in January 1996.

The area is predominantly underlain by granitoid rocks of the Island Intrusions and Westcoast Complex (Muller, 1977). conglomerates and sandstone of the early Tertiary Escalante Group underlie part of the area, and similar lithologies of the Carmanah Group outcrop in the Hesquiat Lake area. In the North Fork of the Escalante watershed are outcrops of Karmutsen Volcanics, and the bedrock is metamorphosed and intensely sheared. This in conjunction with high rainfall and freeze-thaw processes produces a highly fractured and friable bedrock. This surficial material has resulted in the formation of deep colluvial blankets on many of the steep hillsides. Structurally controlled valleys have been glacially deepened and widened, a legacy of Quaternary glaciation. Preferential erosion along faults and other structural lineaments have eroded tributary valleys and deeply incised gully systems. Deep silty to gravelly tills, stratified gravelly glaciofluvial deposits, and laminated silts are present in the lower valley slopes.

The weather of west coast Vancouver Island is dominated by Pacific cyclones that cause significant cloud cover and precipitation. The area is situated within the transition between the very humid and very wet maritime Coastal Western Hemlock biogeoclimatic zones (CWHvh and CWHvm). Predominant conifer species consist of western redcedar \( (Thuja plicata) \), western hemlock \( (Tsuga heterophylla) \) and amabilis fir \( (Abies amabilis) \). Many of the older landslides are revegetated by red alder \( (Alnus rubra) \).

2.2 IKONOS SATELLITE

The IKONOS satellite was successfully launched on September 24, 1999. This is the first in a new generation of satellites collecting very high spatial resolution optical image data (Figure 2). The IKONOS satellite has a 1m resolution panchromatic sensor and a 4m resolution multispectral sensor (MSS). The multi-

![Figure 1. Study area location.](image1)

![Figure 2. IKONOS satellite specifications.](image2)
spectral sensor provides the capability to view spectral information in the visible and near-infrared portions of the electromagnetic spectrum. The satellite orbits at an altitude of 680 km and has an orbit repeat cycle (temporal resolution) which ranges from one to three days. The technical specifications are outlined in Table 1.

Space Imaging, the operator of the satellite, supplies CARTERRA Geo products based on IKONOS imagery. Through a combination of different multispectral image channels, the IKONOS imagery provides a natural colour image, and a false colour infrared image that can be interpreted visually. The images are available as 1m resolution black-and-white and 4m resolution colour images. Both types of image are in 11-bit format, giving users 2,048 shades of grey or colour compared with the traditional 8-bit data, which provides only 256 shades of grey or colour. CARTERRA Geo products are sold by the square kilometer according to customer requirements. During this project, prices ranged from US $29/sq km to US $66/sq km for 1m black-and-white and 4m colour images, based on the level of geometric correction and the location of the world being mapped. The swath width for IKONOS images is 11 km (from http://www.spaceimaging.com).

### 2.3 RADARSAT-1 SATELLITE

RADAR instruments are used to transmit microwave signals and to receive the backscatter signal. They also measure the intensity and time delay of the return signals. The RADARSAT-1 satellite was launched on November 4, 1995, and is equipped with Synthetic Aperture Radar (SAR) which uses advanced signal processing techniques to simulate the effect of a long antenna. The satellite's orbit repeats every 24 days and the RADARSAT-1 fine beam mode image covers a swath area of 50 x 50 km.

The RADARSAT-1 SAR has the following characteristics:
- **C-band synthetic aperture RADAR (SAR).**
- **Cloud-free images.**
- **Seven beam modes offering a wide range of:**
  - * Resolutions (8 - 100 metres);
  - * Swath widths (50 - 500 km);
  - * Incidence angles (10 - 59 degrees).

A new satellite, RADARSAT-2, is being built by MacDonald Dettwiler of Richmond, BC, for a launch planned for 2003. Comprehensive reference material regarding RADARSAT-1 is available from the Radarsat International web site (http://www.rsi.ca/classroom).

A RADAR sensor does not look straight down, but rather down and to one side of the orbital plane. Known as oblique perspective, this is necessary so that the transmitted microwave pulse interacts with the terrain at increasing distances from the RADAR antenna, and thus provides the range dimension of the image. On an ascending pass from the South Pole the sensor looks to the east, and on a descending pass from the North Pole, it looks to the west.

One benefit of RADAR images is that the sensor receives in the microwave part of the electromagnetic spectrum, allowing it to work day or night. In addition, the sensor can penetrate clouds and rain, so the premise for this pilot project was that one can acquire an image as soon as possible for areas affected, for example, by a landslide. Some of the advantages of RADAR imagery are:
- **Active** remote sensing system generates its own scene illumination and records phase and polarization of reflected microwave energy;
- Not dependent on solar illumination;
- Penetrates clouds, rain, partially penetrates vegetation and soil;
- Produces different information than that available in the visible or infrared region of the spectrum.

However, RADAR is sensitive to:
- Surface roughness and aspect to the sensor which determines the brightness of the image;
- Moisture;
- Electrical properties;
- Motion.

Some disadvantages of RADAR are:
- Distortions inherent to RADAR imaging geometry;
- Speckle;
- Requires user familiarization and expertise for reliable interpretation.

The RADARSAT-1 Fine Beam mode is intended for applications which require the best spatial resolution available from the RADARSAT-1 system. The azimuth resolution is 8.4 m, with range resolution 9.1 m to 7.8 m from F1 to F5. Each Fine Beam position can be shifted either closer to or further away from nadir. The resulting positions are denoted by either an N (near) or F (far). For example, F1 is now complemented by F1N and F1F, which provides variations in the slant range and incidence angles across the swath.

### 2.4 DATA ACQUISITION

The first part of the project was to map the area of Hesquiat and Escalante watersheds using the data from both the IKONOS and RADARSAT-1 satellites. The IKONOS imagery consisted of both panchromatic and multispectral imagery, and three different beam modes (F1, F2, F5) were acquired from the RADARSAT-1 sensor.

The coverage area for both satellites is shown in Figure 3. The area in red denotes the IKONOS coverage overlain on the RADARSAT-1 coverage.

#### Table 1. IKONOS specifications

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Spatial Resolution</th>
<th>Spectral Bands (Micrometers)</th>
<th>Dynamic Range</th>
</tr>
</thead>
</table>
| IKONOS 4 meter Multispectral | 4 meter            | Band 1: 0.45 - 0.53 (Blue)  
Band 2: 0.52 - 0.61 (Green)  
Band 3: 0.64 - 0.72 (Red)  
Band 4: 0.77 - 0.88 (Near Infrared) | 11 Bit (2048 levels)     |
| IKONOS 1 meter Panchromatic | 1 meter            | Pan Band: 0.45 - 0.90                      | 11 Bit (2048 levels)     |
2.4.1 RADARSAT-1 DATA ACQUISITION

The RADARSAT-1 images were acquired through the Satellite Acquisition Services (SAS) department of the Canadian Centre for Remote Sensing (CCRS) in Ottawa. Some difficulties occurred during acquisition of the imagery. Some of the missions were abandoned by the Canadian Space Agency (CSA) which operates the satellite and these then had to be replanned. Other images were acquired but were rejected by the CSA due to quality control parameters. For all images, the CSA was asked to try to minimize the automated gain control (AGC) effects (autocorrecting for water/land differences in backscatter) as much as technically possible during image processing. Swath planning was done with the help of SAS Quicklook images that were initially supplied through the CEONet web site (http://ceonet.ccrs.nrcan.gc.ca) for verification that the image footprint coincided with the actual area of interest on the ground. One image was acquired as a Ghost image (free “thumbnail” image) such that it could be reviewed to verify the ground conditions prior to the decision to purchase. A disadvantage of the Ghost image orders is that they are always a low priority and can easily be abandoned by the CSA if there is a conflict with a regular order.

The SAS desk also performed an archive search for all fine beams covering the area of interest since the start of the year 2000. This produced three potential images (Figure 4). Two of these were F5 beams and one was an F4 beam mode.

Three RADARSAT-1 fine beam images using different incidence angles taken one month apart were procured. An attempt was made to get the dates of the three RADARSAT-1 scenes as close together as possible in order to avoid differences caused by the change in season, e.g., no-snow vs snow. The original plan was also to acquire images with the same orbit. Due to technical difficulties at CSA, the third scene was not acquired as requested and a new request had to be input to their system. Due to time constraints, a Descending orbit image was accepted as there were no Ascending orbit images that could be acquired (Table 2).
A Look-Up Table (LUT), which is intended to improve the appearance of the image, can be applied to the imagery at the ground station. The options were Land, Sea and Mixed. The Land LUT was chosen to be applied to the imagery; however, it may have been more appropriate to apply a Mixed LUT due to the areas of high relief in the images.

### 2.4.2 IKONOS DATA ACQUISITION

To order the IKONOS imagery, an ArcView shape file and corner coordinates of the area of interest were provided to Space Imaging. The initial 30-day search schedule was to acquire an image during August 2000, but the acquisition schedule had to be replanned due to 60% cloud cover in the area of interest at that time. Each search schedule expired after 30 days if the scene could not be acquired and the order had to be reconfirmed.

The IKONOS imagery was ordered in July 2000, and the cloud-free image was acquired in September 2000 (Table 3).

A Quicklook image was provided to verify the coverage, and it appeared that the entire area of interest was imaged. However, when the final image was delivered a discrepancy in coverage was noted. Through discussions with Pacific Geomatics Ltd. and Space Imaging, it was determined that the discrepancy was due to the type of map projection provided to the supplier. The final image consisted of a northern image and a southern image, for both the multispectral and the panchromatic channels. Therefore, while the actual area of interest covers 55 km², Space Imaging provided additional imagery coverage for the purpose of this pilot project.

These two images were mosaicked together by McElhanney Consulting Services Ltd. before geocoding the images. To geocode the images, McElhanney used the PCI® software (http://www.pci.on.ca), as that vendor had recently introduced an IKONOS orthocorrection module. For evaluation purposes, this module along with traditional geocoding with a Digital Elevation Model (DEM) was applied to the imagery. There was no difference in the accuracy of the geocoding. It was expected that the IKONOS orthocorrection module would produce better results, but this was not the case. Difficulties with applying the orthocorrection module to mosaicked IKONOS images were the subject of discussions between McElhanney and PCI®.

### 2.5 DIGITAL IMAGE PROCESSING METHODOLOGY

#### 2.5.1 IKONOS IMAGE PROCESSING

The first step in the image processing was to orthorectify the satellite images, followed by the production of composite images for interpretation. All images were orthorectified to UTM Zone 10, NAD83 datum.

Orthorectification of the IKONOS imagery followed these steps:

1. The IKONOS panchromatic and multispectral images were ingested into PCI®;
2. The two halves of the panchromatic image were mosaicked together, as were the two halves of the multispectral images;
3. Ground Control Points (GCPs) were identified in the IKONOS image which matched known features in the vector linework. An attempt was made to evenly distribute the locations of the ground control points across the imagery, as much as possible, so that the entire image could be rectified. The same GCPs were applied to the panchromatic and multispectral images. Appendix C shows the distribution of the GCPs and the Root Mean Square (RMS) error for each GCP in the image;
4. The DEM and vector linework which coincided with the area of interest was imported into PCI®. The DEM and some of the vector linework were provided from Terrain Resource Inventory Mapping (TRIM) data. The remainder of the vector linework came from GPS survey data collected and provided by Interfor;
5. The image was then orthocorrected using the DEM. An output pixel size of 1m was produced for the panchromatic imagery, and 4m pixel size was produced for the multispectral imagery;
6. The images were then imported into ER Mapper® for producing composite images and for merging with the RADARSAT images;

One of the digital processing techniques used for this project was Principal Component Analysis (PCA), which is a form of data merging or data compression. The PCA reduces the dimensionality or number of bands that the interpreter has to analyse to produce results. PCA is a statistical technique for compressing the spectral variance in multiple image bands into a subset of principal component (PC) bands, where each of the PC bands are uncorrelated with each other. This means that each PC band provides unique information not contained in the other bands.
other PC bands. The first PC band (PC1) is the average of the input bands. The second PC band (PC2) contains the second highest amount of scene variance that is not taken into account by the first PC band. This process continues until the last PC band, which contains the least amount of unique scene variance information. The last PC band usually contains scene noise.

As a result of the concentration of scene variance in the first few PC bands, this reduces the number of image bands that need to be analysed to produce results. One of the drawbacks of this type of analysis is that it is very scene dependent. All multispectral channels plus the panchromatic channel were analyzed together for the PCA. The factor loadings were then reviewed and chosen based on having an inverse relationship between the visible and near infrared channels. The bands that have very large positive and very large negative values were also checked as these could be viewed as pseudo ratios.

### 2.5.2 RADARSAT-1 IMAGE PROCESSING

Image rectification of RADARSAT-1 images followed these steps:

1. The images were ingested into PCI®.
2. The DEM and vector linework which coincided with the area of interest was imported into PCI®. The DEM and some of the vector linework were provided via TRIM. The remainder of the vector linework came from GPS survey data collected and provided by Interfor;
3. An Antenna Path Correction (APC) was applied to the raw images. APC performs a radiometric balancing of RADAR data to compensate for non-uniform illumination in the range direction caused by the antenna pattern. Antenna pattern effects usually appear as a gradual increase then decrease in mean column grey levels as the RADAR backscatter is received by the sensor in the range direction (PCI® online help). Additive function, first order, was applied to the F1 and F2 images. As the southern part of the F5 image was very dark, the file was rotated 90 degrees, then the APC was applied in a multiplicative mode, second order, then re-rotated back –90 degrees. A number of runs were applied to the image in order to select the correct mode and order;
4. GCPs were identified in the RADARSAT image which matched known features in the vector linework (both from survey and from TRIM). An attempt was made to evenly distribute the locations of the ground control points across the imagery, as much as possible, so that the entire image could be rectified. Appendix B shows the distribution of the GCPs and the RMS error for each GCP in each image;
5. The images were then orthorectified using the SRORTHO module. A 7x7 Kuan filter was applied to the image to reduce speckling in the image during the SRORTHO process. The Kuan filter smoothes the speckle in the image data without removing edges or sharp features in the images. More information about the Kuan filter is available through the PCI® online help or user documentation. The output pixel size for all three RADARSAT-1 images was 12.5 x 12.5 m;
6. The orthorectified images were overlain with the vector linework in order to ensure the positional accuracy of images;
7. The images were then imported into ER Mapper® software for producing composite images and for merging with the IKONOS images.

### 2.6 IMAGE INTERPRETATION AND ASSESSMENT

#### 2.6.1 INTRODUCTION

The following images were used for interpretative purposes:

1. Geocoded IKONOS pan and multispectral images in ER Mapper® and TIFF formats;
2. Geocoded RADARSAT-1 Fine beam mode images (three images) in ER Mapper® and TIFF formats;

In addition, ER Mapper® algorithms with the fusion and image enhancements for the following image combinations were examined:

3. IKONOS red, green and blue channels with best RADARSAT-1 image;
4. IKONOS near-infrared, red, green channels with best RADARSAT-1 image;
5. IKONOS panchromatic with best RADARSAT-1 image;
6. Principal Component composite using Correlation Eigenvectors (PC2, PC4, PC5 of IKONOS image).

#### 2.6.2 MANUAL INTERPRETATION

Manual interpretation of the imagery involves a systematic visual examination of the imagery with the objectives of a) identification, b) interpretation, and c) determining the significance of the resource features. The main elements used in the visual interpretation of images are differences in:

- **tone/colour** – objects have different light reflectance properties and also backscatter properties;
- **texture** – this is a measure of the smoothness or coarseness displayed;
- **pattern** – there may be a spatial arrangement of features evident;
- **shape** – features may have different shapes;
- **size** – mainlines versus deactivated roads;
- **association** – relationships of objects such as landslides and connectivity to streams;
- **shadow** – may cause problems by obscuring ground, e.g., canopy may cast shadow on mainstem.

It must be noted that orthorectification of any imagery causes distortion, as the process either stretches or compresses portions of the image as dictated by topography and the orthorectification algorithms. To various degrees, the distortion affects all the above visual interpretation elements, and the user must learn to adapt and allow for this. Referral to the raw image can assist with resource feature identification, although positional accuracy will be lost.

Because the scenes are acquired in a digital format, they can be

---

Research Disciplines: Ecology ~ Geology ~ Geomorphology ~ Hydrology ~ Pedology ~ Silviculture ~ Wildlife
manipulated using digital processing software in a variety of ways to extract information pertinent to the user. There is still a need to use manual interpretation techniques, but the digital processing enables the process to be repeatable. Image enhancements can be used to improve the visual appearance of the image for interpretive requirements or for highlighting the features most important for the task at hand. The actual enhancement selection is dependant on the nature of the data and the elements in the scene. It should be noted, however, that stretching changes the value of the original pixels and is therefore not advisable, for example, in computer assisted classifications or change detections. One useful technique in resource infrastructure management is edge enhancement, which delineates edges or sharp changes in the brightness values between two contiguous pixels, thereby making sharp details easier to see and analyse.

2.6.3 ACCURACY

The use of the same DEM for rectification of the imagery made it possible to compare the positional accuracy of the imagery with the GPS survey points. The orthocorrected IKONOS image was overlain with GPS survey points to determine relative accuracy. The GPS data used as a baseline for the assessment was collected using a local corrected base station and is considered to be of sub-metre accuracy. Analysis of the orthocorrected IKONOS imagery with the GPS survey points demonstrates that the image generally has high spatial accuracy. An accuracy table (Table 4) shows the deviation in meters in the x and y dimension between a selection of GPS survey points and these locations in the IKONOS image. From the table, the y dimension error distance is almost always larger than the x dimension error distance. It is not known whether this discrepancy in error between the x and y dimensions is caused by the orthorectification algorithm, the DEM, our control point marking and distribution, or some other factor(s).

However, there are some places where the fit is not as good. An example is on the right side of the image where there is a cutblock trending east-west and above it, two cutblocks trending north-south. From measurements on the image, the east-west trending cutblock varies between 30 to 50m in positional accuracy. The positional inaccuracies for the cutblocks occur along the edges of the image. In addition, there is some smearing of the image between the two north-south cutblocks. This smearing is caused by the orthorectification software. It may be speculated that the positional inaccuracy and the smearing is caused by a combination of the location of the GCPs and the elevations in the DEM used for the orthorectification. In general, the edges of a satellite image tend to be not as accurately orthorectified as the middle of the satellite image, due to the mathematics of the rectification algorithm. Areas surrounded by GCPs can have their position accurately mapped, while areas that are not surrounded by GCPs only get an approximation of their position.

Absolute positional accuracy across the RADARSAT-1 images is difficult to ascertain, as many surveyed features are not visible in the RADARSAT images. The closest estimate for positional accuracy comes from a review of the RMS error report derived from the orthocorrection (this estimate describes the fit of the orthorectified data to the ortho model being used by PCI®). From these reports the positional accuracy was the best for the F1 image at 1.71 pixels in the x direction and 1.16 pixels in the y direction. The F2 and F5 images had lower positional accuracies in the 2 pixel range. This could be due in part to the fact that the sensor is pointing further from nadir for the F2 and F5 images, so the effects of foreshortening and layover are greater than for the more vertical F1 image.

2.6.4 DIGITAL IMAGE INTERPRETATION

2.6.4.1 RADARSAT-1 IMAGES

An overview of the use of RADAR digital imagery for mapping clearcuts has been documented by Leblon (1999). In addition, several studies have demonstrated that SAR imagery is a useful tool for geological mapping (Saint-Jean et al., 2000). After orthocorrecting the RADARSAT-1 images and importing them into ER Mapper®, the three orthorectified images were individually viewed and assessed for the suitability to detect features of interest in the image. A comparison of the three RADARSAT-1 beam modes is shown in Figure 5.

The descending F2 scene is visually different from the F1 and F5 ascending scenes and appears much smoother than the other images. In addition, the descending scene is significantly brighter

![Table 4: Accuracy deviations](https://example.com/table4.png)

<table>
<thead>
<tr>
<th>Survey Point ID</th>
<th>Distance (m)</th>
<th>Distance X (m)</th>
<th>Distance Y (m)</th>
<th>Surveyed Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>2.91</td>
<td>1.9</td>
<td>2.2</td>
<td>Spur - Semi</td>
</tr>
<tr>
<td>363</td>
<td>15.02</td>
<td>9.3</td>
<td>11.8</td>
<td>Spur - Full</td>
</tr>
<tr>
<td>402</td>
<td>8.57</td>
<td>1.7</td>
<td>8.4</td>
<td>Mainline</td>
</tr>
<tr>
<td>276</td>
<td>5.3</td>
<td>2.8</td>
<td>4.5</td>
<td>Mainline</td>
</tr>
<tr>
<td>109</td>
<td>2.96</td>
<td>2.9</td>
<td>0.6</td>
<td>Mainline / Spur - Semi Intersection</td>
</tr>
<tr>
<td>207</td>
<td>1.36</td>
<td>1.1</td>
<td>0.8</td>
<td>Mainline / Stream Intersection</td>
</tr>
<tr>
<td>222</td>
<td>14.45</td>
<td>5.4</td>
<td>13.4</td>
<td>Mainline</td>
</tr>
<tr>
<td>599</td>
<td>18.76</td>
<td>5.6</td>
<td>17.9</td>
<td>Spur - Semi</td>
</tr>
<tr>
<td>521</td>
<td>16.48</td>
<td>11.5</td>
<td>11.8</td>
<td>Spur Semi / Spur Full Intersection</td>
</tr>
<tr>
<td>394</td>
<td>21.68</td>
<td>2.8</td>
<td>21.5</td>
<td>Mainline / Spur Semi Intersection</td>
</tr>
</tbody>
</table>
and more uniform across the entire image. The ascending scenes appear to show more changes in brightness and tone. One of the issues concerning acquisition of RADAR images is if the weather conditions are dry or rainy. If there was rain shortly before a RADAR image of an area was acquired, e.g. everything is still wet, the image will tend to be darker and more homogenous in tone. This may be the case with the descending F2 scene, since it was acquired in November 2000. The F2 scene may appear brighter, but this is just the effect of contrast stretching the image. However, the overall tone of the F2 image is smooth.

Two areas of interest are a variable retention (VR) block on the Escalante flats and an area of large landslides in the north fork of the Escalante River. Additional analysis was done on the VR block and the main landslide area to determine whether these features could be defined in the imagery. The digitized outline of the VR block and the landslides was incorporated for reference purposes (Figure 6).

The F5 image appears to show slightly more detail than the F1 and F2 images. This may be a result of the F5 incidence angle being more perpendicular to the slopes of the mountains in the image. Research by CCRS has indicated that geological detail is enhanced the more perpendicular the incidence angle is in relation to the terrain surface (Singhroy and Saint-Jean 1999). Singhroy and Mattar (2000) found that high resolution fine mode RADARSAT-1 imagery, although not as useful as the airborne InSAR images, can be used to identify some landslide features. From the individual images, it was not possible to visually delineate the large landslide areas in this pilot project. There has been significant pre-FPC logging in the area, so the terrain surface would be very similar (e.g., early seral stage regeneration, shrubs, grasses), therefore it is likely that a very similar amount of reflection would be provided by the RADAR data to the sensor. It is possible that the slides may be detectable under circumstances where they are bounded by large trees, since one could expect that varying seral stage would present backscatter values that are distinctive and associated with the physical and scattering characteristics.

The VR block could not be identified in all the RADARSAT images. This is surprising since the boundary between the roads and the trees forms corner reflectors which should provide a strong reflection back to the sensor. From a regional geologic perspective, the F5 image did appear to show two parallel NW - SE trending lineaments. The southern lineament, as it follows a river, was visible in all three RADARSAT images. The northern lineament was only identifiable in the F5 image.

The three orthorectified RADARSAT images were combined into an RGB colour composite (F1 being displayed in Red, F2 in Green and F5 in Blue) to determine if a colour composite could better define the landslides, VR block, other cutblocks, and geological features in the area (Figure 7). Together, the RADARSAT images did not provide any additional details to allow easy mapping of these features. Again, this would be a result of the fact that these features were not visible in the individual images. In the landslide area, roads were not visible, nor were the landslides. There is a colour shift in this RGB composite, as the slope with the landslide is coloured green (Figure 7). This is because F2 is displayed as green, and the F2 image was descending while the F1 and F5 are ascending. The F2 image appears as a mirror image in brightness compared with the F1 and F5 images. In the F2 image, the slope is facing the sensor and appears in bright tones. In the F1 and F5 images, the slope is facing away from the sensor and appears in dark tones.
2.6.4.2 IKONOS IMAGES

The PCA of the IKONOS images was produced with PC2 displayed as red, PC4 displayed as green, and PC5 displayed as blue. PC2 was selected as it shows an inverse relationship between the visible light channels (RGB) and the near-infrared (NIR) plus panchromatic channels. PC4 showed an inverse relationship between the blue and red light channels. The PCA colour composite shows differences between bare rock/soil areas in the image. For example, as will be discussed in Section 3.0, in the landslide area the landslides are shown in red and blue colours, while the roads in the area appear as a purple colour. In the near-infrared colour composite, the landslides and roads are both in bluish hues.

In the VR block, the particular combination of PC images did not provide any additional visual details compared with the NIR image for the area. It is possible, though, that changing the combination of PC images for the colour composite could show additional differentiation. Changing the PC colour combination may also be used to try to enhance differences in forest cover type and/or forest vigour.

Appendix D provides the scene statistics for the IKONOS imagery along with the correlation matrix, correlation eigenvector matrix, and the factor loadings for the PCs.
2.6.4.3 NATURAL COLOUR AND NEAR-INFRARED COMPOSITES

The natural colour images (4m pixel) without the merged panchromatic image (1m pixel) are visually more blurry than the same images with the panchromatic image (Figure 8). The natural colour and near-infrared colour composites provided very useful images when fused with the panchromatic image to enhance spatial detail. Individual tree crowns, decked logs, coarse woody debris, landslides, roads, and many other features could be easily seen and digitized in these colour composites. The shape of the shadows cast by the trees could be clearly seen, which may, in the absence of stereo imagery, help identification of tree type in an area.

Since the images are in digital format, the use of edge enhancement filters and various contrast stretching techniques can enhance the image so that small details are easier to differentiate and map compared with a hardcopy photographic print.

2.6.4.4 IKONOS AND RADARSAT-1 IMAGERY FUSION

A secondary objective of this pilot project was to determine whether RADARSAT-1 imagery could be utilized in conjunction with optical IKONOS imagery to provide enhanced definition of regional scale geological features, which could be important from a terrain mapping perspective, and also to enable environmental monitoring during winter months. The premise is that if landslides could be differentiated on the RADARSAT-1 imagery, then this could be utilized for monitoring purposes following storm periods along the west coast. The IKONOS imagery would form the base map for the imagery.

Previous forestry studies using RADARSAT-1 imagery have largely concentrated on mapping clearcuts and riparian leave strips. Many studies have demonstrated that environmental conditions have a significant influence on the SAR backscatter from vegetation, and thereby alter the contrast between seral stages in individual images (e.g., Yatabe & Leckie, 1995). In addition, clearcut mapping is more accurate using multi-date images acquired during contrasting seasons (Leblon, 1999).

Figure 9 shows overview images of the north fork of the Escalante watershed: a) an IKONOS image, b) a RADARSAT-1 image, and c) a RADARSAT RGB composite. The F5 image was selected as providing the best discrimination of features of interest. The F5 image was combined with the IKONOS imagery to see whether the RADARSAT image could help enhance structural features in the IKONOS imagery. As will be discussed in Section 3.0, the near-infrared colour composite provided additional information that was not visible in the natural colour composite. The addition of the RADARSAT-1 F5 image did not appear to enhance details in the IKONOS red, green and blue (RGB) channels image. The roads in the VR block appear as brown coloured features. The standing trees within the VR block are still green in appearance, but the boundaries of these trees are rendered diffuse. The addition of the RADARSAT image does appear to enhance the differences between forest cover types around the VR block. The trees to the south of the VR block are brighter and have a more distinct boundary in the combined image compared with the IKONOS image. Therefore, for road details it appears that IKONOS is better, but for mapping the boundary between different forest cover types the combination of IKONOS and RADARSAT may provide some benefit.

The next images show the NIR colour composite merged with RADARSAT imagery (Figure 10a) and the IKONOS NIR colour composite image of the same areas (Figure 10b).

In the north fork of the Escalante River area, a major fault plane outcrops and forms the headscarp of a large natural wedge failure rockslide (the landslide to the east in Figure 10). It has been demonstrated that RADARSAT-1 imagery enhances geologic features (Singhroy and Saint-Jean, 1997) and it was speculated that it would also enhance the traceability of this structure. Unfortunately the fault trace could not be delineated along geologic strike. Within the landslide area, the details from the IKONOS image were lost when combined with the RADARSAT image. Standing trees along the headscarp of the eastern landslide are easy to differentiate in the IKONOS image, but are diffuse in the merged image.

2.6.4.5 IKONOS PANCHROMATIC AND RADARSAT-1 IMAGERY FUSION

Two methods of merging the IKONOS panchromatic image with the RADARSAT-1 F5 image were tested. The first method
was to multiply the IKONOS panchromatic image with the RADARSAT-1 F5 image. The second method was to display the IKONOS panchromatic image as an RGB image, then, using an intensity transform (RGBI), integrate the RADARSAT F5 image as an intensity channel. Other approaches were also tested where the RADARSAT was used as the RGB image and IKONOS as the intensity image, but the resultant image looked

Figure 9. a) IKONOS (top left), b) RADARSAT-1 (top right), c) RADARSAT-1 RGB composite images.

Figure 10a. NIR colour composite merged with RADARSAT imagery

Figure 10b. IKONOS NIR colour composite image of VR block and landslides.
just like the IKONOS image, and the RADARSAT image could not be distinguished. Square rooting the two images and then summing them together also did not result in a useful image.

Figure 11 shows the IKONOS panchromatic images for the VR block and the large landslide areas, followed by the multiplied images and finally by the RGBI image.

The RGBI image tends to show less spatial detail than the multiply image. In the VR block, some of the spatial detail can be recognized in the multiply image when compared with the IKONOS image for reference. However, the addition of the RADARSAT data does not appear to highlight any features that are not easily recognized in the IKONOS image. The forested area to the north of the VR block has more variation in the multiply merge compared with the IKONOS image. All the variability from very dark to very bright is a direct result of the RADARSAT image. Edges in this part of the image – as identified by the road leading to the VR block and the stream to the south of the VR block – are still recognizable in the multiply image. Smaller edges, such as those within the VR block, are not easily identifiable. The RADARSAT image overpowers the IKONOS image in the RGBI merge. No more features are recognizable than are in the RADARSAT image alone.

In the landslide area, the multiply image again shows more detail than the RGBI image. The RGBI image has a smoother overall tone compared with the multiply image. The landslides are displayed as dark linear features within both images. Without knowing that this is a landslide area, one could easily misinterpret these dark features as steep sided gullies. The large block of standing timber to the northeast of the natural landslide is shown as a dark speckled area. Again, this area could not be easily identified as forest without prior knowledge of the area or having other images of the area.

Therefore, it is possible to differentiate large landslides using the multiply image fusion of IKONOS and RADARSAT-1 F5 imagery, but it is likely that smaller events would be difficult to delineate. In an emergency situation there may be some benefit to acquiring RADARSAT-1 imagery following storm periods, but it is not recommended to merge together RADARSAT F5 imagery with IKONOS panchromatic imagery on a routine operational basis.

3.0 FOREST RESOURCE MANAGEMENT APPLICATIONS

3.1 IKONOS APPLICATIONS

A comparison of the high spatial resolution optical data and RADAR data for this pilot project demonstrated that the IKONOS was most user-friendly for operational forestry applications. Therefore, the focus of this section is on the potential forestry applications of the IKONOS imagery.

3.1.1 LANDSLIDES

Mapping of terrain stability and landslide hazards is a requirement for many forest development plans in BC, especially on the coast and in community watersheds. Landslides and other major sediment sources may be classified from the IKONOS imagery. The types of disturbance, origins or initiation points, area of disturbance and runout zones, connectivity to streams, and degree of revegetation are all identifiable. The landslides