4.0 COST COMPARISON

Different levels of IKONOS image accuracy are available at varying prices. The more precision required in an image, the higher the cost.

The IKONOS pricing for this pilot project was US$12/Km^2 ($0.12 per hectare) for panchromatic and the same for the 4m multispectral imagery, at the single-agency price scale. However, both the panchromatic and MSS together were available at a cost of US$18/km^2. The minimum order size at the time of acquisition was US$1000, which equated to a coverage of 55 km^2. A multi-agency cost estimate (single-agency cost x 1.4) for an area equivalent to a 1:20,000 map sheet is approximately $4,389 (G.Weir, pers. Comm). This equates to approximately $0.27/hectare prior to any image processing.

One cannot assume that both image formats will be perfectly co-registered in areas of significant terrain relief, hence some additional costs may be incurred in image processing to correct the imagery. The more mountainous the terrain, the more fine tuning of the co-registering and geocoding will be required.

Costs for processing the data would include time for a remote sensing analyst. For the IKONOS orthorectified product the pricing was US$66/km^2, and the precision product was priced from US$66 to $76 per km^2. Up-to-date pricing for Canadian imagery is available from the following web sites: Space Imaging at http://www.spaceimaging.com; RSI at http://www.rsi.ca/storefront/high_res_usd.htm#top, and Pacific Geomatics Ltd. at http://www.orthosat.com. There are also licensing issues (single-agency versus multi-agency), data sharing, and multiple use issues that would need to be addressed for more widespread use of this data. Cost estimates will vary depending on specific project factors such as time, size of data order, and amount of data to be processed.

There was a standing-order arrangement in place through the Government of BC for the purchase of RADARSAT-1 images at the time of this pilot project, and the price was $650 per scene.

As a comparison, another option available to forest managers is that orthophotographs are available for some areas; for example, a forest licensee has orthophotographs available for the east coast of Vancouver Island at approximately $400 per mapsheet. A BCGS 1:20,000 mapsheet covers about 16,000 hectares, thus the cost is about $0.025 per hectare. Unfortunately, the rest of the district is not covered the same way. In the Queen Charlotte Islands, a set of black-and-white ortho-photos with a 1m resolution was acquired in the late 1990s at a cost of approximately $0.069 per hectare. However, costs are also dependant on the coverage area being surveyed.

GPS typically costs $100 to $200 per linear kilometer. A typical 40 hectare opening could have an external boundary of about 3 km, thus costing about $300 to $600 to accurately locate and measure with GPS, or about $7.50 to $15.00 per hectare. If GPS data collection is not subcontracted, then the cost factors for in-house collection would include purchase of the GPS unit(s), post-processing software, and a GPS specialist to do the processing.

From a cost-benefit analysis perspective the costs of mobilizing a crew by helicopter, fixed wing or boat to a remote site can be substantial. So too can the cost of acquiring aerial photographs or traditional ortho-photos of an area where the resulting product does not contain the range of multispectral information of satellite imagery (e.g., NIR). IKONOS imagery in addition has 11 bits of information per channel, while photogrammetric software works with eight bits of information per channel. Satellite digital imagery also provides the image analyst with more flexibility in enhancing the differences within an image (e.g., through the use of Principal Component Analysis or simple contrast stretching), and the ability to merge images from multiple dates (e.g., for change detection) or multiple sensors. Delivery times for satellite imagery may also be faster than those for aerial photographs, but both are weather dependent.

The software used for this project included PCI®, which is available in modules at a cost of approximately $25,000 to $30,000. ERMapper® is available at a cost of approximately $5000, but there is a free ERMapper® viewer available for download from the company's website at http://www.ERMapper.com. Among the viewer's capabilities are tools to enable the processed images to be viewed and individual features to be measured.

5.0 CONCLUSIONS

Remote sensing technology offers a number of options for the ability to view areas for the purposes of sustainable forest management. The challenge for forest resource managers is how to effectively use these tools for maximum benefit at minimum cost to meet forest management application needs. This pilot-project tested the benefits of using IKONOS data for such applications, and also tested the utility of RADARSAT-1 data fusion for use as a monitoring tool during the winter or cloud-covered periods.

While RADARSAT-1 imagery has the advantage of being weather-independent, the 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. RADARSAT-1 stereo pairs are available with a minimum of 60% overlap in coverage area. In this study, the RADARSAT-1 imagery was not able to provide us with more information than what we could derive from the IKONOS imagery. It was hoped that landslides, the VR block, and geological structures (e.g., faults) could be identified in the RADARSAT-1 imagery. But it was very difficult to identify these features without aid of the IKONOS imagery. Varying the incidence angle for the RADARSAT images also did not appear to provide us with additional ground details.

Remote sensing using IKONOS high spatial resolution optical data is an important and cost-effective tool in assessing and managing forest resources. Most forest management activities involve the production of detailed maps, which usually require significant amounts of data compiled from on-ground observations. Multispectral satellite imagery is becoming more important in the mapping process and has particular benefits in remote and inaccessible areas. IKONOS satellite imagery provides excellent input for mapping, inventorying, monitoring and surveying forest resources.

Some of the advantages of the IKONOS satellite imagery include the capability of providing greater information content than traditional aerial photographs, and information is automatically captured in digital format versus conversion to format for photography. Acquiring high spatial resolution imagery provides panchromatic, natural colour, and NIR spectral information in digital format at the same time. This makes it unique and potentially very useful compared with orthophotography. It allows digital processing such as orthorectification, enhancement, classification, and direct transfer to GIS databases. IKONOS products are available as 11-bit black-and-white and 11-bit colour providing 2,048 shades of gray/colour compared with the traditional 8-bit data used in orthophotographs, which provides 256 shades. The 11-bit data is useful for viewing details in shadowed areas or areas that are very bright. In addition, there is no problem with colour matching across photos, or worrying about the state of the different chemicals for the development of the film, as is the case with aerial photography. Digital images can be used to create an archive of co-registered data, which can be used to monitor changes over time.

It should also be noted that remote sensing imagery such as IKONOS could provide ancillary benefits such as information about adjacent areas, whereas ground-based methods generally only provide information about the specific areas of interest. IKONOS imagery could also be a potentially excellent tool for updating orthophotography images, via a "cut and paste" methodology. Having a visual backdrop to conventional polygon linework on maps (e.g., see the actual tree cover behind the proposed wildlife tree patch) has made the use of ortho-imagery extremely popular for land use planning purposes, particularly where referral to the public and non-forest industry stakeholders is involved. Rather than having to regularly reacquire expensive orthophotography, IKONOS could be used to keep the orthophotos "current" for a considerably longer period of time.

Based on these preliminary assessments, 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. The use of IKONOS satellite imagery is a cost-effective method for detecting changed conditions over large areas, which should reduce management costs.

From the current trend in types of satellites being designed and launched, it appears that satellites with more spectral channels (e.g., hyperspectral sensors with 256 channels) and greater spatial resolution (e.g., sub-metre) will become available over the next few years. The ASTER sensor from NASA is one hyperspectral sensor that is currently providing images for research purposes. The addition of stereo capability will greatly enhance the application of this type of data to forest resource management. One such satellite with stereo capability, Quickbird owned by Earthwatch, was launched in November 2000. However, it failed to reach orbit after launch. A duplicate satellite is scheduled for launch later in 2001.

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APPENDIX A: GLOSSARY OF TERMS

Active Sensor: a type of sensor which provides its own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor.

Automated Gain Control: an image processing technique for auto-correcting for water/land differences in RADAR backscatter.

Backscatter: The antenna receives a portion of the transmitted energy reflected (or backscattered) from various objects within the illuminated beam.

Brightness: Image brightness is influenced by terrain properties (local incidence angles) and parameters of the RADAR system. Brightness is directly proportional to the amount of radiation reflected back to the RADAR system. Rough surfaces and small local incidence angles appear bright in SAR imagery because more microwave energy is reflected to the satellite. Smooth surfaces and larger local incidence angles appear dark because microwave energy is reflected away from the satellite.

Correlation Eigenvector Matrix: a matrix containing factor loadings produced through Principal Component Analysis. This matrix is used to rotate the axes of the input satellite imagery to form new PCA images.

Digital Elevation Model (DEM) provides a digital representation of continuous relief variation over space.

Foreshortening: an effect which commonly occurs when viewing mountainous slopes orthogonal to the RADAR beam. This results in the slope image being compressed in length and is represented by a bright RADAR response. The mountain slopes on the back side are darker and longer. This gives the appearance that the mountains are leaning over.

Geometric rectification: a process by which the geometry of the image area is made planimetric.

Ground Control Point (GCP): a point on the earth's surface where both the image coordinates and map coordinates can be rectified.

Incidence angle: the primary parameter for slant range to ground range conversion.

Layover: the extreme form of foreshortening where the top of the mountain is imaged before its base. The result is an image with the peak "laid over" its base.

Moisture content increases the dielectric constant, which in turn affects the reflectivity of the surface. A wet rough surface has a brighter appearance than the same surface when dry.

Orthorectification: an image processing technique that removes distortions from the collection geometry and resamples the image to a uniform ground distance and user-specified map datum.

Passive Sensor: This type of sensor can only be used to detect energy when naturally occurring energy (such as sunlight) is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth.

Pixel: the smallest digital element which comprises the image data set.

Polarization: the orientation of the electric field.

Principal Component Analysis: a digital image enhancement technique that uses a multivariate analysis method to reduce the number of variables in a data set.

RADAR: acronym for "RAdio Detection And Ranging." This instrument is used to transmit microwave or radio signals, receive backscatter, and measure the intensity and time delay of the return signals.

Resolution: when used in reference to a sensor, refers to the size of the smallest possible feature that can be detected.

Shadow: the area not illuminated by the RADAR beam. Shadow is normally not a factor in RADAR images using steep incidence angles.

Slant range: the line of sight between the RADAR and each reflecting feature on the surface.

Speckle: a type of interference, or noise, which is intrinsic to Synthetic Aperture Radar (SAR) images, and is a significant issue with respect to data analysis. Speckle noise is manifest on an image as a grainy surface which decreases the resolution of the underlying data.

Swath: the width of the area of ground coverage of the satellite.

Synthetic Aperture Radar (SAR): a microwave instrument that sends pulsed signals to Earth and processes the received reflected pulses. SAR uses advanced signal processing techniques to simulate the effect of a long antenna. RADARSAT 's SAR-based technology provides its own microwave illumination and thus operates day or night, regardless of weather conditions.

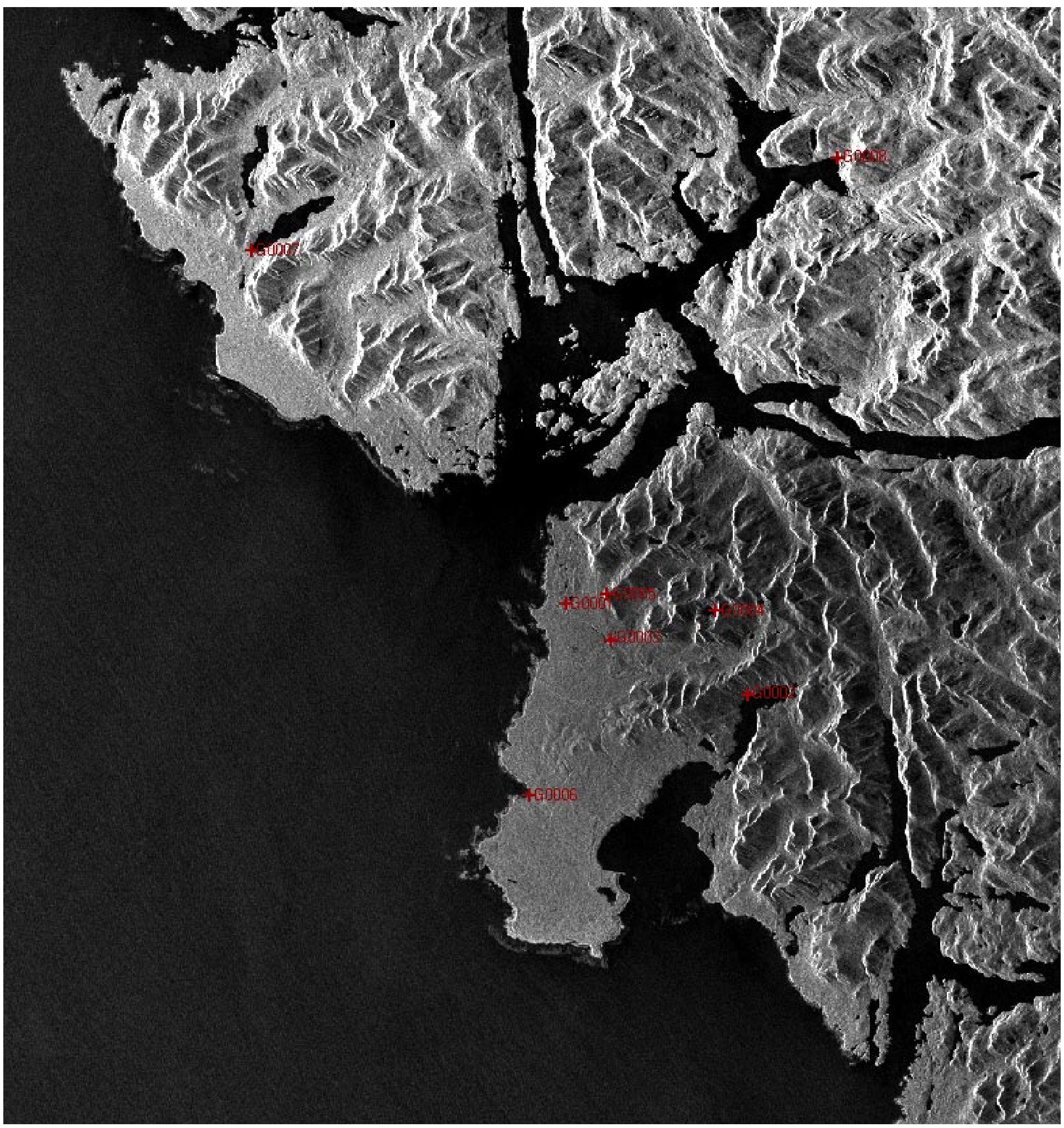
APPENDIX B: RADARSAT GCP LOCATIONS AND RMS RESIDUAL ERROR REPORTS

F1 Residual Error Report

Residual Units: Image Pixels

GCPs: 8 X RMS
1.71 Y RMS
1.16 OVERALL RMS

Point ID	Residual	Residual X	Residual Y	Photo X	Photo Y	Computed X	Computed Y
G0003	3.7	3.5	1.21	5205.5	5405.5	5209	5406.7
G0001	2.6	-1.51	-2.11	4814.5	5122.5	4813	5120.4
G0004	2.47	2.15	1.23	6107.5	5177.5	6109.6	5178.7
G0002	1.54	-0.92	-1.23	6370.5	5886.5	6369.6	5885.3
G0005	0.84	-0.65	0.54	5178.5	5038.5	5177.9	5039
G0006	0.38	-0.16	0.35	4506.5	6757.5	4506.3	6757.8
G0007	0.1	0.04	0.09	2129.5	2109.5	2129.5	2109.6
G0008	0.08	0.02	-0.07	7141.5	1309.5	7141.5	1309.4



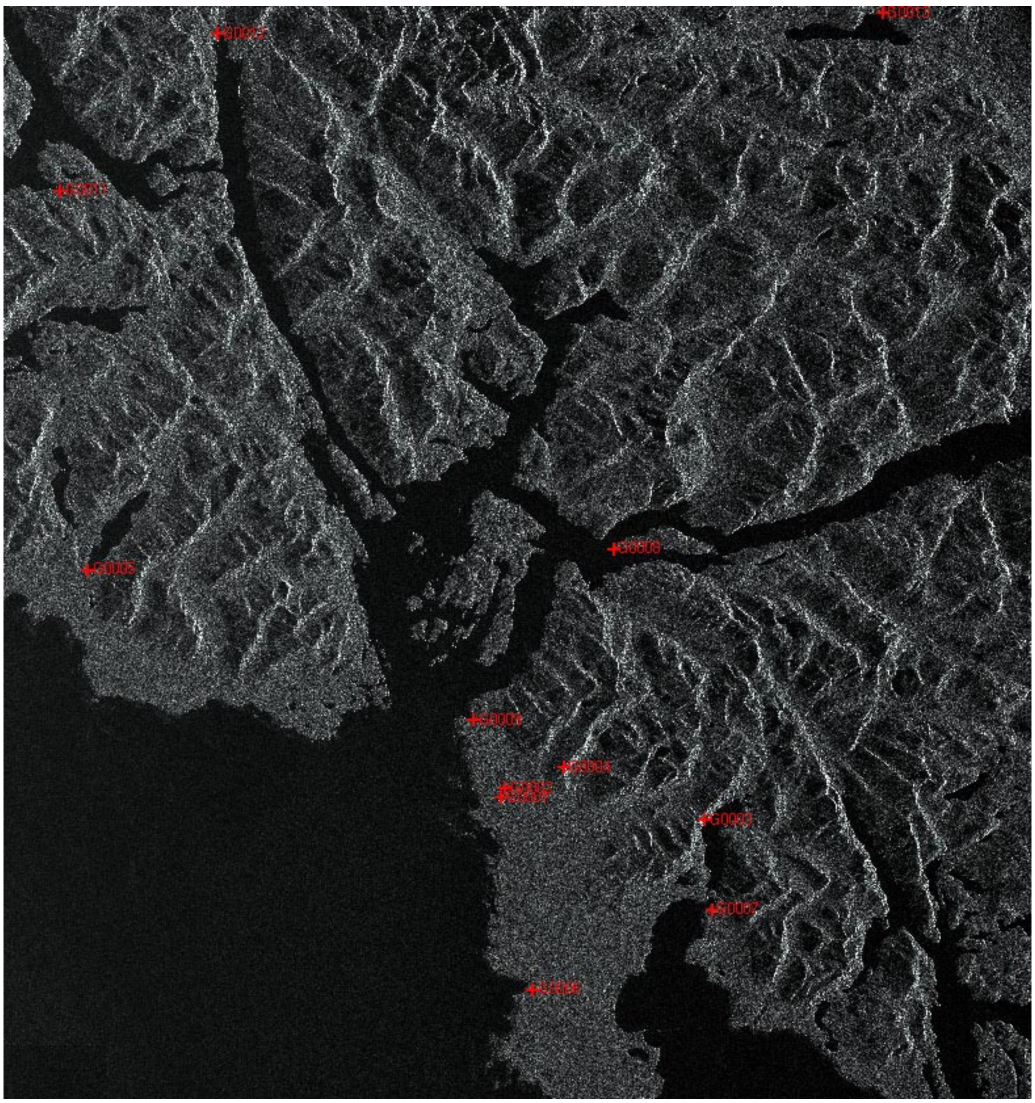
F1 GCP Locations

F2 Residual Error Report (Appendix B continued)

Residual Units: Image Pixels

GCPs: 12 X RMS
2.56 Y RMS
3.03 OVERALL RMS

Point ID	Residual	Residual X	Residual Y	Photo X	Photo Y	Computed X	Computed Y
G0004	7.89	-2.79	7.38	4824.5	6538.5	4821.7	6545.9
G0001	5.15	-1.33	-4.97	4300.3	6790.3	4298.9	6785.3
G0003	5.1	3.82	-3.38	6033.5	6988.5	6037.3	6985.1
G0007	3.87	-3.37	1.9	6089.5	7748.5	6086.1	7750.4
G0009	3.52	-3.34	-1.11	4056.5	6128.5	4053.2	6127.4
G0008	3.48	3.39	0.81	5244.5	4653.5	5247.9	4654.3
G0006	2.83	2.77	0.58	4562.5	8432.5	4565.3	8433.1
G0005	1.78	1.51	0.94	759.5	4837.5	761	4838.4
G0002	1.78	0.68	-1.64	4329.5	6713.5	4330.2	6711.9
G0011	1.68	-1.51	-0.74	518.5	1586.5	517	1585.8
G0012	1.09	1.03	0.35	1874.5	257.5	1875.5	257.9
G0013	0.59	-0.58	-0.12	7549.5	70.5	7548.9	70.4



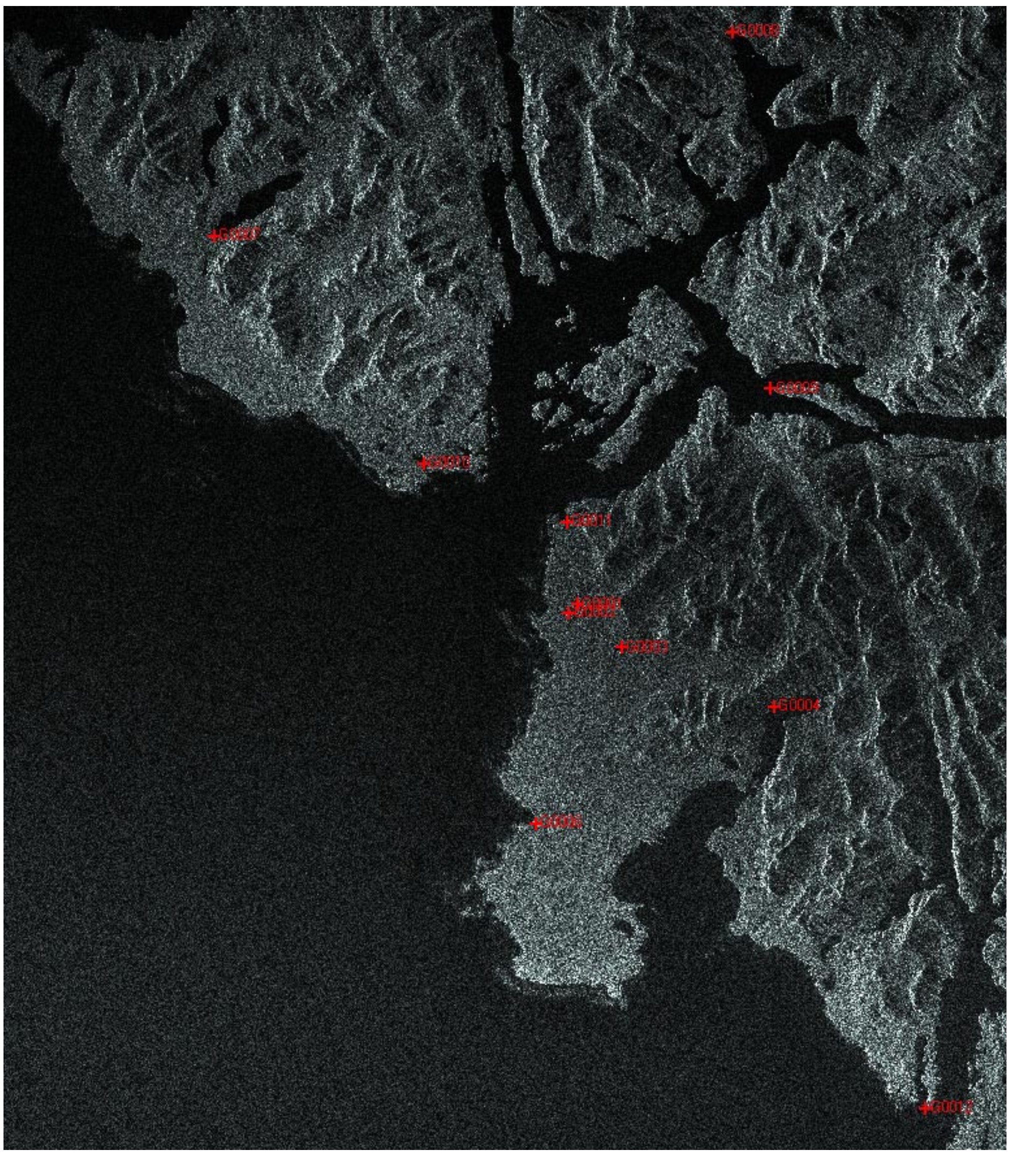
F2 GCP locations

F5 Residual Error Report (Appendix B continued)

Residual Units: Image Pixels

GCPs: 11 X RMS
2.29 Y RMS
2.06 OVERALL RMS

Point ID	Residual	Residual X	Residual Y	Photo X	Photo Y	Computed X	Computed Y
G0004	5.94	-5.43	2.42	6015.5	5470.5	6010.1	5472.9
G0002	4.54	1.59	-4.25	4432.5	4746.5	4434.1	4742.2
G0011	3.64	-0.72	3.57	4409.5	4039.5	4408.8	4043.1
G0009	3.61	3.42	-1.17	6002.5	3000.5	6005.9	2999.3
G0003	3	2.42	-1.77	4831.5	5018.5	4833.9	5016.7
G0012	1.04	0.97	-0.36	7200.5	8600.5	7201.5	8600.1
G0006	1.02	-0.34	0.96	4169.5	6387.5	4169.2	6388.5
G0008	0.99	-0.97	0.19	5693.5	217.5	5692.5	217.7
G0010	0.75	-0.53	0.53	3292.5	3575.5	3292	3576
G0001	0.31	-0.31	0.04	4487.5	4683.5	4487.2	4683.5
G0007	0.17	-0.07	-0.15	1667.5	1802.5	1667.4	1802.3



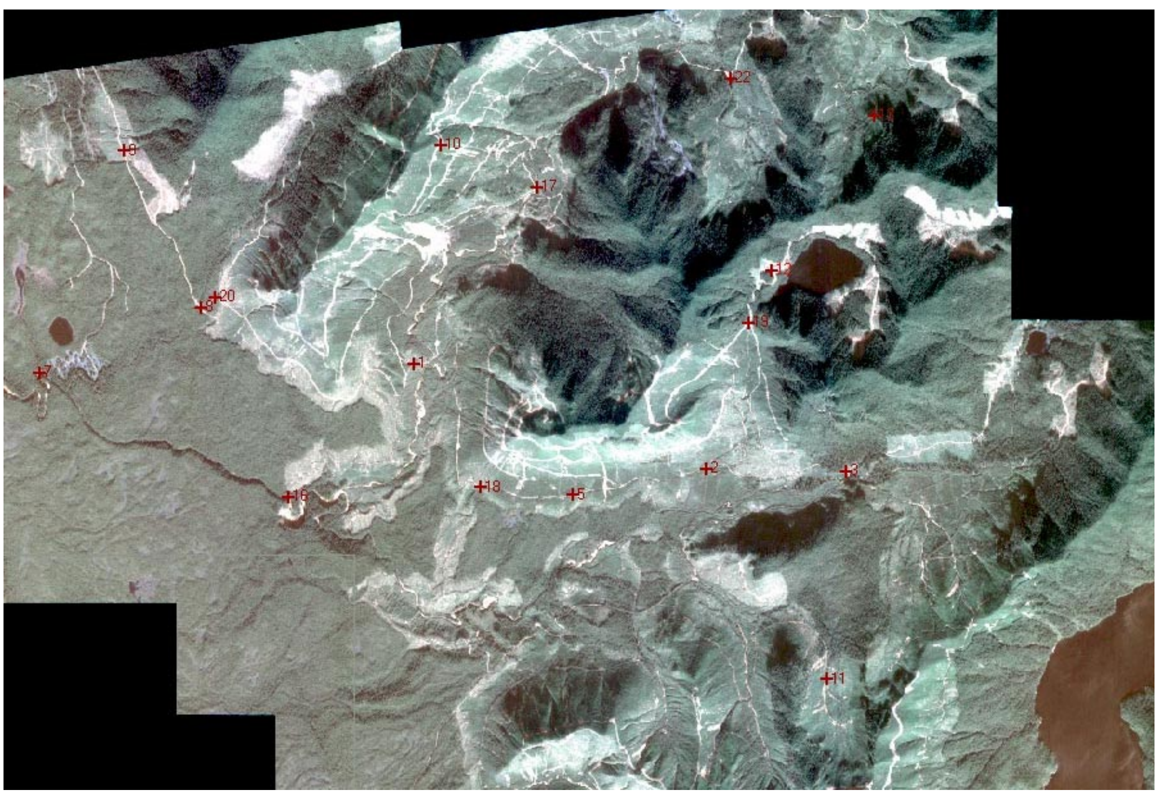
F5 GCP Locations

APPENDIX C: IKONOS GCP LOCATIONS AND RMS RESIDUAL ERROR REPORTS

Residual Units: Image Pixels

GCPs: 17 X RMS
0.49 Y RMS
1.04 OVERALL RMS

Point ID	Residual	Residual X	Residual Y	Photo X	Photo Y	Computed X	Computed Y
10	2.43	0.11	2.42	1127.9	353.6	1128	356
8	1.83	-0.86	-1.62	510.8	771.3	510	769.7
12	1.76	-0.18	-1.75	1974.9	678.1	1974.7	676.4
19	1.41	0.41	-1.35	1915.7	813.6	1916.1	812.2
9	1.12	0.22	-1.09	313.1	370.1	313.3	369
3	1.12	-0.26	1.09	2167.3	1194.3	2167	1195.3
1	0.99	0.6	0.78	1056.9	917.9	1057.5	918.7
5	0.94	0.89	0.31	1465.9	1256.1	1466.8	1256.4
22	0.74	0.58	0.47	1872.6	184.1	1873.2	184.6
20	0.71	0.36	0.61	549.4	746.4	549.7	747
13	0.58	-0.54	-0.23	2241.1	278.9	2240.6	278.6
2	0.56	-0.5	0.25	1808.2	1187.4	1807.7	1187.7
18	0.49	0.47	-0.14	1228.8	1237.6	1229.3	1237.4
17	0.48	-0.46	0.12	1374.1	463.8	1373.6	463.9
7	0.45	-0.4	0.2	96.2	939.7	95.8	939.9
11	0.29	-0.22	-0.19	2117.4	1733.4	2117.2	1733.2
16	0.26	-0.22	0.13	736.6	1261.4	736.4	1261.5



IKONOS GCP Locations

APPENDIX D: SCENE STATISTICS FOR IKONOS IMAGERY

Band 1 = Near Infrared
Band 2 = Red
Band 3 = Green
Band 4 = Blue
Band 5 = Panchromatic

	Band1	Band2	Band3	Band4	Band5
Null Cells	36642500	36526100	36458500	36478500	24615300
Non-Null Cells	86323600	86440000	86507600	86487600	98350800
Minimum	-63.1887	-13.7298	-15.8771	-18.3541	1
Maximum	1028.058	491.0062	537.942	424.2976	770
Mean	282.3613	82.89619	134.3102	149.3473	147.7477
Median	256.5124	76.96494	129.0677	145.9112	142.1836
Std. Dev.	155.7354	35.77183	34.52504	20.44728	95.10369
Std. Dev. (n-1)	155.7354	35.77183	34.52504	20.44728	95.10369
Corr. Eigenvalue	3.79772	0.83484	0.31292	0.04498	0.00954

Correlation Matrix	Band1	Band2	Band3	Band4	Band5
Band1	1	0.6197	0.64344	0.4679	0.69247
Band2	0.6197	1	0.98784	0.94003	0.55408
Band3	0.64344	0.98784	1	0.95006	0.5697
Band4	0.4679	0.94003	0.95006	1	0.46869
Band5	0.69247	0.55408	0.5697	0.46869	1
Determinant	0.00043				

Corr. Eigenvectors	PC1	PC2	PC3	PC4	PC5
Band1	0.39367	0.55264	0.70291	0.20109	0.07137
Band2	0.49269	-0.26405	0.04532	-0.5998	0.57072
Band3	0.49793	-0.24158	0.05986	-0.23757	-0.79604
Band4	0.46312	-0.42871	-0.15227	0.73691	0.18841
Band5	0.37399	0.61864	-0.69072	-0.01775	-0.00045