EVALUATION OF STEREOSCOPIC GEOEYE-1 SATELLITE IMAGERY TO ASSESS LANDSCAPE AND STAND LEVEL CHARACTERISTICS

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ABSTRACT:

An ongoing remote sensing project has been underway within the Coast Forest Region since 2000. The initial parts of the project investigated the application of commercially available high-resolution satellite imagery to resource feature mapping and compliance and enforcement surveillance. In the current project, stereo imagery from the new GeoEye-1 satellite was acquired. This system provides 0.5m panchromatic and 1.65m colour imagery, which is approximately a four time increase in spatial resolution compared to IKONOS imagery. Stereo imagery at this resolution enables the delineation of single trees, coarse woody debris measurement and the generation of Digital Elevation Models and estimation of volumes of material displaced by landslides. Change detection and identification of high priority zones for Compliance & Enforcement investigation is greatly enhanced. Results of this research are presented and discussed.

1. INTRODUCTION

1.1 Introduction

The initial focus of the project was to investigate the application of commercially available high-resolution satellite imagery to resource feature mapping and compliance and enforcement surveillance. A previous published study by the authors in 2008 extended the use of high resolution IKONOS imagery through the acquisition of reference stereo IKONOS imagery and analysis of the imagery using KLT softcopy photogrammetry for forest cover, topographic, and landslide mapping

Using GeoEye-1 imagery, our goals were to:

- assess the increase in detail of topographic mapping of a watershed using GeoEye-1 imagery compared with the same areas compiled from the IKONOS imagery;
- assess the change within a major landslide between the 2007 IKONOS and the 2009 GeoEye-1 imagery.

1.2 Study Areas

Two areas were selected for this analysis. The Hesquiat area (Figure 1a), is located in and around Clayoquot Sound on the west coast of Vancouver Island. The area's topography ranges from flat to steep-sided terrain, with elevations ranging from sea level along the coastal plain north of the Estevan Peninsula, to approximately 1,000 m elevation inland. Much of the area was logged in the 1960s and into the 1980s, but some recent variable retention logging has been conducted. There are numerous pre-Forest Practices Code landslides and some natural landslides in the area, many of which were initiated during an intense storm cycle in January 1996.

Figure 1. Study area locations (shown in red rectangles). a) Hesquiat Inlet (left), b) Moses Inlet (right).

The weather on the west coast of 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).

The Moses Inlet area (Figure 1b) is within the hypermaritime, Coastal Western Hemlock, Submontane and Montane Very Wet Hypermaritime (CWHvm1 or vm2), which occurs along the windward slopes of the Coast Mountains. (Coast Forest Region, BEC WEB http:// www.for.gov.bc.ca/rco/research/eco/bec_web/dni.htm).

2. METHODOLOGY

2.1 GeoEye-1 Satellite and Data Acquisition

GeoEye-1 was launched on September 6, 2008, and orbits at an altitude of approximately 684 km. The satellite is one of the latest generation of satellites, collecting very high spatial resolution optical image data with a 0.41 meter resolution panchromatic sensor and a 1.64 meter resolution multispectral sensor. The 0.41 meter panchromatic imagery is resampled and delivered at 0.5meter resolution for non-military users. For this project, 0.5m pan-fused colour GeoStereo imagery was ordered. The sensor for both satellites can be pointed up to 60 degrees off nadir in order to generate stereo image pairs. Two sets of in-track stereo images were acquired in the fall of 2009 (Figures 2 and 3). All GeoEye-1 images shown are copyright GeoEye Corp.

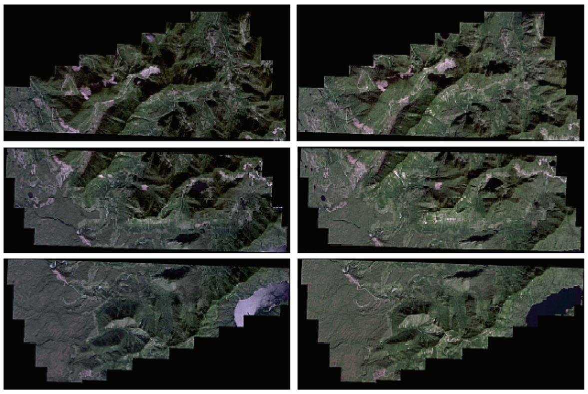

Figure 2. September 27, 2009 GeoEye-1 natural colour image coverage of Hesquiat / Mooyah area. (Left image on left, right image on right)

2.2 Creation of Colour Composite Images

Colour composite image combinations were produced from the GeoStereo GeoEye-1 images using the ER Mapper and PCI image processing systems: 1) red, green and blue channels fused with panchromatic image; 2) near infrared, red, green channels fused with panchromatic image. The image combinations were enhanced using manual contrast stretching. These composite stereo pair images were loaded into a KLT softcopy photogrammetric workstation for stereo visual analysis using polarized goggles.

2.3 Photogrammetric Data Input

The KLT softcopy photogrammetric software (www.kltassoc.com) was used for stereo setup and viewing. The stereo GeoEye-1 imagery is supplied with Rational Polynomial Coefficients (RPC) files, which contain a series of coefficients used to describe the relationship between the image as it existed when captured and the Earth's surface. The RPC files contain

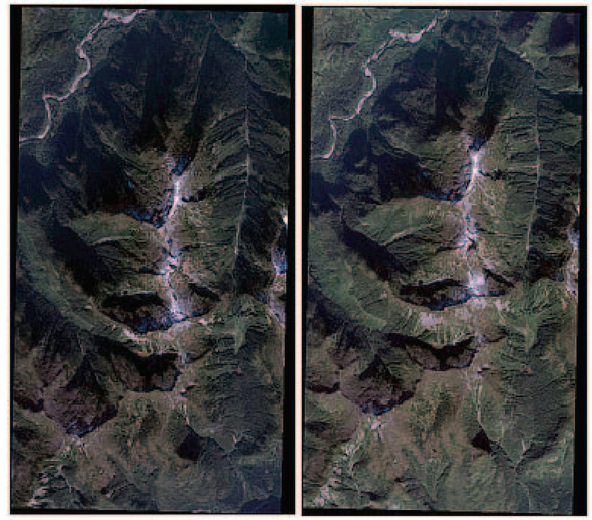

Figure 3. October 8, 2009 GeoEye-1 natural colour image of Moses Inlet area (Left image on left, right image on right)

information that is needed to determine "interior" and "exterior" orientation, as well as supplemental information such as the geographic coordinates associated with the coordinates of the imagery. Individual stereo model setups were created for Hesquiat Inlet and for Moses Inlet.

GeoStereo GeoEye-1 imagery, without supplemental ground control points, has a published positional accuracy of:

- 4m horizontal accuracy CE90, and
- 6m vertical accuracy at a 90% Confidence Level (CL).

At this level of positional accuracy, GeoEye Corp. Indicates that 0.5m GeoStereo imagery can be used for topographic mapping up to 1:5,000 without additional ground control points (GCP). Fraser and Ravanbakhsh. (2009) noted geopositioning accuracy of 0.1m (0.2 pixels) in planimetry and 0.25m (0.5 pixel) in height can be attained with a single additional GCP. When the GeoEye-1image was overlaid on the IKONOS image from 2007, the two datasets coincided approximately +/- 3m for most areas.

2.4 Analysis of Images for Forest Cover and Landscape

From the stereo imagery, the following types of information products were generated:

- Coarse Woody Debris Measurements (CWD)
- Digital Elevation Model (DEM) compilation
- Forest Cover Mapping
- Land Cover Change Detection
- Landslide Volume Measurement

3. RESULTS

3.1 Coarse Woody Debris

One key potential application for the sub-metre satellite imagery could be to measure the amount of CWD left within cutblocks. A cutblock within the Hesquiat Inlet area that is visible on both the 2007 and the 2009 satellite imagery was selected to measure CWD. Figure 4 shows the two dates of imagery over the cutblock.

The measurements were undertaken using heads-up digitizing on the monoscopic orthorectified images. Table 2 provides information on the CWD measured for each image. Three times more logs could be measured and digitized in the 0.5m GeoEye-1 imagery than in the earlier IKONOS imagery. This directly impacts the total length of logs reported as CWD.

	Number of Logs Marked	Min Log Length	Max Log Length	Mean Log Length	Total Log Length
2007	54	4.50m	20.42m	9.37m	505.74m
2009	159	2.55m	25.60m	8.27m	1315.14m

Table 2. Log measurements of CWD analysis from 2007 and 2009 images.

3.2 Digital Elevation Model

A DEM was previously produced by photogrammetrically using the natural colour IKONOS imagery acquired in 2007. With the higher spatial resolution GeoEye-1 satellite image from 2009, this area was recompiled to produce a new DEM for comparison.

The spot heights and break lines were saved as 3D AutoCAD files and imported into ArcGIS. A Triangulated Irregular Network (TIN) model function was used to convert the points into a DEM with 10x10m grid cells. This process was applied to both the 2007 and the 2009 data. The two DEMs (Figures 5 and 6) were subtracted (2007 minus 2009) to produce a differenced grid (Figure 7). Statistics were calculated on the minimum, maximum, mean, median and standard deviation values for the grid difference values, in order to make an estimate of repeatability of compilation (Table 3).

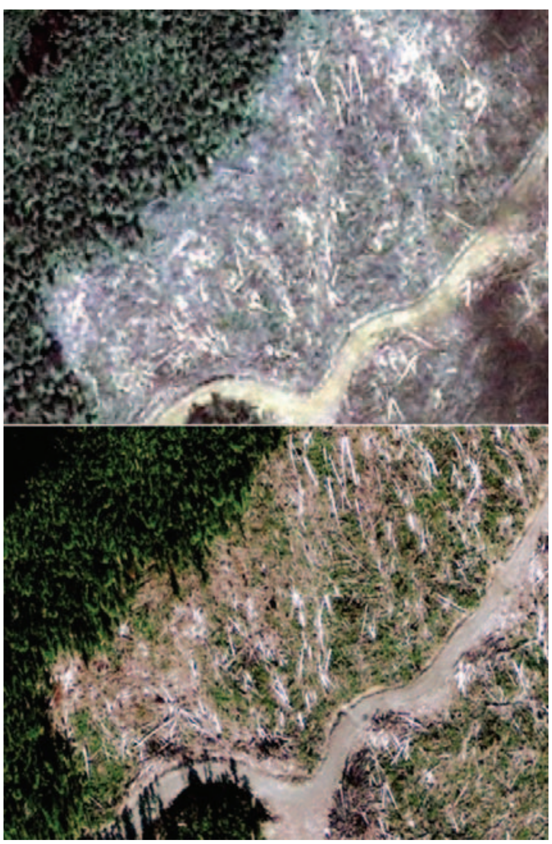

Figure 4. CWD images. 2007 top image from IKONOS, 2009 bottom image from GeoEye-1.

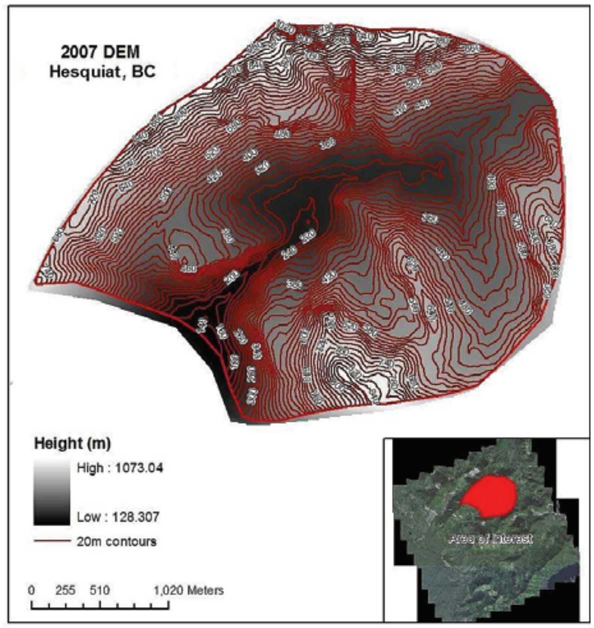

Figure 5. DEM compiled from 2007 IKONOS image.

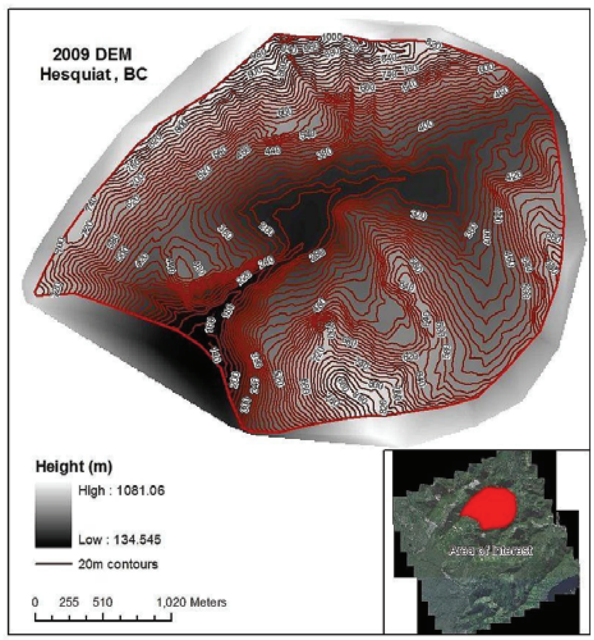

Figure 6. DEM compiled from 2009 GeoEye-1 image.

Most of the differenced grid is “grey”, indicating minimal difference between grids. The largest differences are in the negative values, which represent 2009 height values larger than 2007 values (2007 – 2009 = difference grid). The large negative values occur both on the north and south sides of the drainage area. These areas have both flat valleys and steep-sided slopes. It is possible that the 2009 GeoEye-1 image height values are slightly more accurate due to the smaller pixel size, allowing a more accurate elevation point to be captured on the ground surface, however this assumption needs to be validated.

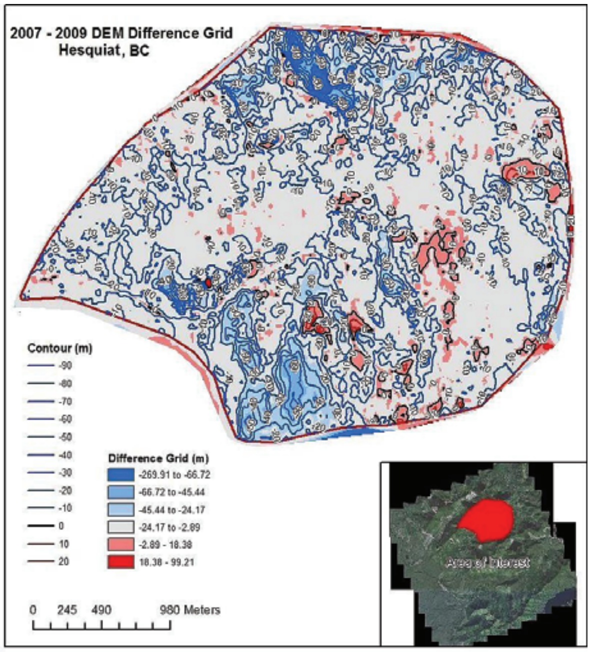

Figure 7. Differenced DEM (2007 – 2009).

GeoEye-1 2009 stereo pair	
Minimum	137.774m
Maximum	1081.06m
Mean	502.501m
Standard Deviation	180.136m
IKONOS 2007 stereo pair	
Minimum	128.336m
Maximum	1073.04m
Mean	490.858m
Standard Deviation	178.983m
Differenced grid	
Minimum	-94.650m
Maximum	28.851m
Mean	-11.739m
Standard Deviation	10.850m

Table 3. DEM statistics for GeoEye-1 2009 and IKONOS 2007 stereo pairs.

Overall, the statistics between the two DEMs are quite similar, which indicates repeatability of DEM generation and possibly minimal differences in accuracy of height collection regardless of pixel size. The longer and deeper shadows in the GeoEye-1 image could be contributing to errors in surface elevation in the middle values, e.g., 2.89 to -24.17m.

3.3 Forest Cover Mapping

A Registered Professional Forester (RPF) undertook forest cover interpretation of the Hesquiat Inlet stereo pairs in 3D using the natural colour RGB composite and the false colour near infrared (NIR) composite. One area of interest from a forest inventory perspective is to determine how consistent the forest cover polygons interpreted by the RPF from the GeoStereo GeoEye-1 images are when compared with the conventional base forest cover map (FC1) derived from aerial photography.

A total of 32 polygons were interpreted from the false colour near infrared (NIR) image (Figure 8) and 15 polygons were interpreted from the RGB image (Figure 9). Table 4 indicates which forest polygons were interpreted from which image, and the number of FC1 polygons per interpreted polygon. The CW_HW and HW_CW classes appear to be the easiest to interpret from either the RGB or the NIR image.

Forest Cover Type	RGB Number of Polygons	NIR Number of Polygons
CW_HW	6	18
HW_CW	1	10
DR_HW	0	0
CW	0	1
HW_BA	3	1

Table 4. Forest cover types identified from GeoEye-1 imagery.

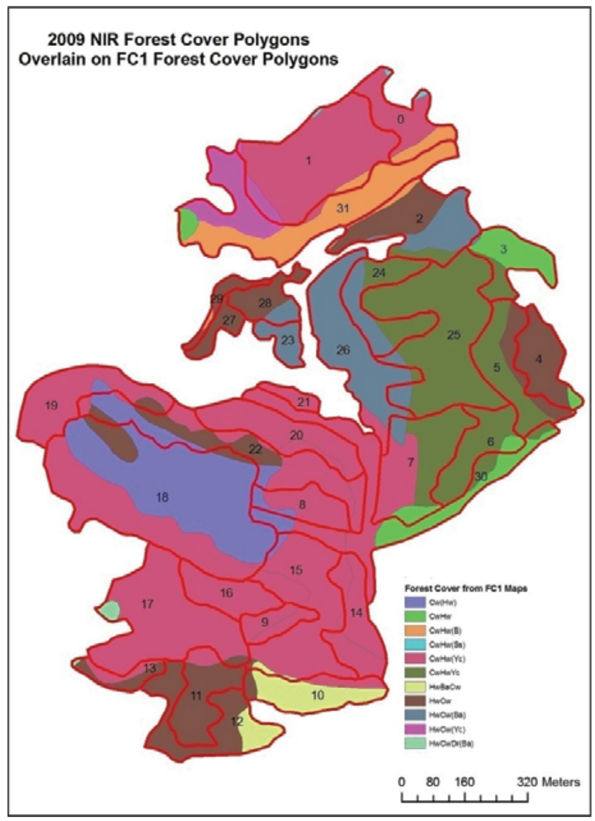

Figure 8. NIR derived forest cover polygons overlain on FC1 Forest Cover polygons, Hesquiat Inlet.

3.4 Land Cover Change Detection

As part of the monitoring component to this project, the 2007 and 2009 Hesquiat Inlet images were combined into a single dataset, to which guided Principal Components Analysis (PCA) was applied. The images in this study are separated in anniversary date by almost three months – the 2007 image was acquired in early July and the 2009 image was acquired in late September. Summer versus fall vegetation changes have an effect, as do differences in length of shadows between the two

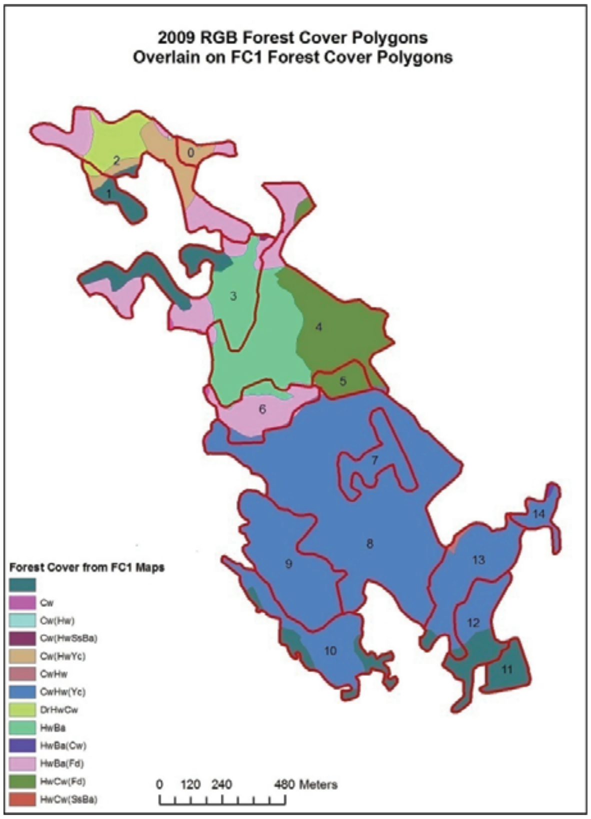

Figure 9. Natural colour derived forest cover polygons overlain on FC1 Forest Cover polygons, Hesquiat Inlet.

images. The Principal Component channels were generated using only the red and near infrared channels from both 2007 and 2009. In general, vegetation changes are detected through differences between the red and near infrared reflectance. The factor loadings (eigenvectors) for the principal components, using the covariance matrix as input to the analysis, are shown in Table 5.

Cov. Eigen-vectors	PC1 66.71%	PC2 23.93%	PC3 6.79%	PC4 2.56%
2007-red	0.149	0.152	-0.433	-0.876
2007-NIR	0.743	0.608	-0.076	0.270
2009-red	0.170	-0.461	-0.800	0.345
2009-NIR	-0.630	-0.629	0.408	-0.204

Table 5. Factor loadings (eigenvectors) for the four principal component channels using the covariance matrix.

PC1 is usually weighted average of the input channels, but in this case it is more a difference between the NIR values from the two imaging dates. PC2 is the difference between 2007 and 2009 dates. PC3 is a difference between the red and near infrared channels from 2009 with some contribution from the red channel from2007. This may represent vegetation vigour both within 2009 and between years. PC4 is a weaker version of PC2. A PCA colour composite image was produced by combining the first 3 PCA channels as RGB (Figure 10).

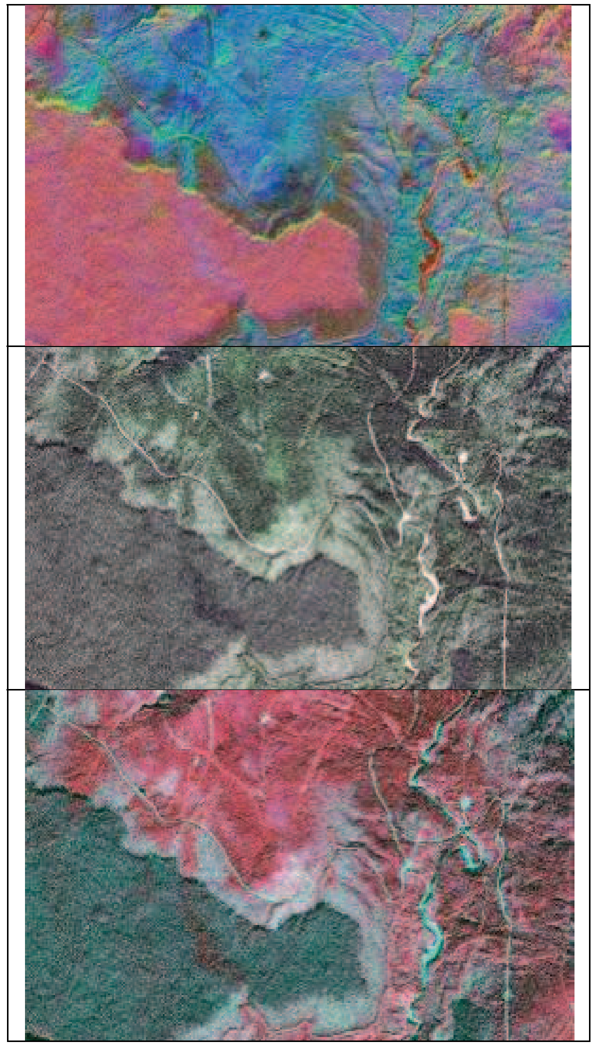
Figure 10. PCA image of 2007/2009 images (top), 2009 Natural colour image (middle), 2009 NIR image (bottom).

The above images show conifer stands with no change (dark grey area on left side of image in the Natural Colour image) between the two dates, plus deactivated roads with alder regrowth (visible in the reddish coloured vegetation in the NIR image). At the edge of the forest cover in the centre of the image, there is a brownish coloured area in the top right PCA image. In the natural colour images it appears as a grassy area. The 2009 NIR image appears to show more vegetation growth in the harvested area compared to the 2007 image so the brownish colour in the top right PCA image could be representing small increases in vegetation vigour.

3.5 Landslide Volume Measurements

In the author's previous study (Kliparchuk and Collins, 2008), a DEM was produced from the 2006 and 2007 stereo IKONOS natural colour imagery for a large landslide in the Hesquiat area. Using the 2009 GeoEye-1 stereo imagery, the landslide area was recompiled to produce a new DEM to compare against the 2007 IKONOS-derived DEM. The spot heights and break lines were sampled between 4-9m within the slide area and 15m around the slide area margins. A TIN model algorithm was used to convert the points into a DEM with 3x3m grid cells.

The 2009 DEM was subtracted from the 2007 DEM. Statistics were generated from the differenced grid within the red polygon boundary (Table 6 and Figure 11).

Minimum	-18.506m
Maximum	6.448m
Mean	-4.476m
Standard Deviation	3.451m

Table 6. Descriptive statistics for differenced grid in the landslide area.

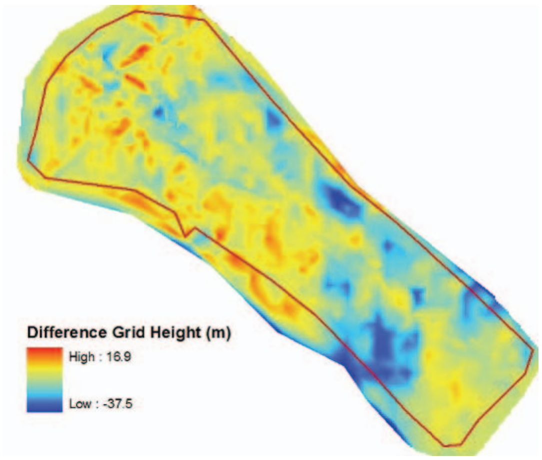

Figure 11. Differenced grid for landslide area (2007 – 2009)

Positive values in the differenced grid represent areas that had more soil in 2007 than in the 2009 measurement. Negative values represent areas that had less soil in 2007 compared to the 2009 measurement. We noted that there is some variation in the stereo setups between the two dates of images. From the setups, we determined that there was approximately a 3m variation in height throughout the images. The mean value for the differenced grid is -4.4775m, which is very near to the 3m variation that we observed. It could be argued that the mean variation in the differenced grid +/- 3m, could represent areas of no change between the two dates.

Visually, it appears from the differenced grid colouring, that there has been a loss of soil from the western and northern edges of the landslide, with an accumulation of soil primarily at the bottom (southern) end of the landslide.

4. CONCLUSIONS

4.1 DEM Comparison

The DEM from 2009 GeoEye-1 imagery was compared with the DEM previously created from the 2007 IKONOS imagery. From descriptive statistics generated from both DEMs, no large discrepancies could be identified between the two DEMs. The DEMs were also differenced to determine if there was any spatial pattern in the differenced grid. No specific area or pattern of significant elevation discrepancy between the two DEMs was identified, indicating that either 0.5m or 0.81m stereo imagery may be suitable for DEM creation in forested, mountainous areas.

4.2 Landslide Feature

A landslide feature in the Hesquiat stereo image was digitized from the GeoEye-1 image to produce a DEM. This same landslide feature was previously digitized from the 2007 IKONOS imagery. A comparison was made between the two landslide DEMs to determine if there have been significant changes within the slide area. By subtracting the 2009 landslide feature DEM from the 2007 landslide feature DEM, it was determined that there has been a loss of soil from the western and northern edges of the landslide, with an accumulation of soil primarily at the bottom end of the landslide.

4.3 Forest Cover Interpretation

Forest cover interpretation was undertaken for the Hesquiat Inlet stereo pairs in 3D using the natural colour RGB composite and the false colour near infrared (NIR) composite by a RPF. The RFP noted a preference for viewing and interpreting the natural colour image, as the near infrared image did not appear as sharp as the natural colour image. The CW_HW and HW_CW classes appear to be the easiest to interpret from either the RGB or the NIR image for the Hesquiat area.

4.4 Change Detection

The 2007 and 2009 Hesquiat Inlet images were combined into a single dataset, and guided PCA was applied to the dataset. Deactivated roads with alder regrowth were detected along with an increase in vegetation vigour between 2007 and 2009.

4.5 Recommendations

1. Commercially available satellite imagery is now at a resolution that is sufficient to conduct detailed feature-specific mapping and analysis for resource management.
2. Change detection within a forest may be monitored on an operational basis using Principal Component Analysis.
3. High resolution stereo satellite imagery can be used for mapping topography and calculation of landscape elements
4. GeoEye-1 satellite imagery is suitable to be considered for the following applications:
   - capturing conifer timber volumes in the understory of deciduous stands during leaf-off, using NIR imagery;
   - reconnaissance-level mapping of areas affected by pests and other defoliators;
   - visual quality assessments for new development proposals;
   - quantifying CWD left in cutblocks, for both carbon accounting and bio-energy utilization.

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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